Nuclear Instruments and Methods in Physics Research A 628 (2011) 69–72

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Commissioning and performance of the LHCb Silicon Tracker

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On behalf of the LHCb Silicon Tracker Group [1]

ARTICLE INFO

Available online 6 July 2010

Keywords:
LHCb
Silicon Tracker
Performance
Commissioning
Alignment

ABSTRACT

The LHCb Silicon Tracker is a silicon micro-strip detector with a sensitive area of 12 m^2 and a total of 272k readout channels. The Silicon Tracker consists of two parts that use different detector modules. The detector installation was completed by early summer 2008 and the commissioning without beam has reached its final stage, successfully overcoming most of the encountered problems. Currently, the detector has more than 99% of the channels fully functioning. Commissioning with particles has started using beam-induced events from the LHC injection tests in 2008 and 2009. These events allowed initial studies of the detector performance. Especially, the detector modules could be aligned with an accuracy of about 20 μm. Furthermore, with the first beam collisions that took place end of 2009 we could further study the performance and improve the alignment of the detector.

1. Introduction

The Silicon Tracker [2] is part of the tracking system of the LHCb experiment [3]. LHCb is a single-arm, forward spectrometer with excellent tracking and particle identification capabilities, ideally suited to perform high-precision measurements of CP violation and rare decays of B hadrons. The Silicon Tracker (ST) consists of two detectors, both of which use silicon micro-strip detectors with p-on-n type sensors, built from 6 in. wafers.

The first of these detectors, the Tracker Turicensis (TT), is a 150 cm wide and 130 cm high planar tracking station that is placed upstream of the LHCb dipole magnet and covers the whole acceptance of the experiment. It has been constructed using sensors with a pitch of 183 μm and a thickness of 500 μm. It is composed of four layers arranged into two half stations separated 30 cm along the beam (z) axis, and in an orientation of 0°, $+5^\circ$, -5°, and 0° with respect to the vertical (y) axis. The total active area of the TT equals 7.8 m^2. The layers are made out of 14-sensor long modules, except directly above and below the LHC beam pipe where the module is split into two 7-sensor half-modules (see Fig. 1(a)). Up to four sensors are bonded together thereby forming readout sectors of 1-, 2-, 3-, and 4-sensors. This segmentation is indicated by the different shadings in Fig. 1(a) and is motivated by the falling particle density when moving away from the beam axis. There are 280 readout sectors with a total number of readout channels 143k.

The second of the two detectors is the Inner Tracker (IT). It extends over a 120 cm wide and 40 high cross-shaped region in the center of the three planar tracking stations downstream of the magnet. Although the IT covers only 1.2% of the acceptance of these tracking stations, about 30% of the particles from the main interaction point are passing through the first IT station. Each IT station consists of four independent boxes arranged around the LHC beam pipe (see Fig. 1(b)), where each box contains four layers of silicon micro-strips again in an orientation of 0°, $+5^\circ$, -5°, and 0°. The total active area of the IT equals 4.2 m^2. The detector modules placed left and right of the LHC beam pipe are 22 cm long with a thickness of 410 μm, while the modules above and below the beam pipe are 11 cm long with a thickness of 320 μm, in both cases the strip pitch is 198 μm. There are 336 readout sectors with a total number of readout channels 129k.

Both detectors use the same radiation-hard front-end chip [4] and readout electronics [5], operating at a clock frequency of 40 MHz. Clustering and zero-suppression are performed on a common off-detector readout board [6], located in a zone accessible during LHC operation. The TT (IT) has been designed to withstand a radiation dose of $5(8)\times10^{13}$ 1 MeV n/cm^2 equivalent to 10 years of nominal LHC operation. They can be cooled below 5 °C (with the coolant at -15 °C) in order to keep the effect from radiation damage to an acceptable level after 10 years of operation.

2. Commissioning without beam

The installation of the ST was completed by early summer 2008, followed by an extensive commissioning period. Readout channels that are not fully functioning were identified by comparing measured noise levels with the expected ones.

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doi:10.1016/j.nima.2010.06.286

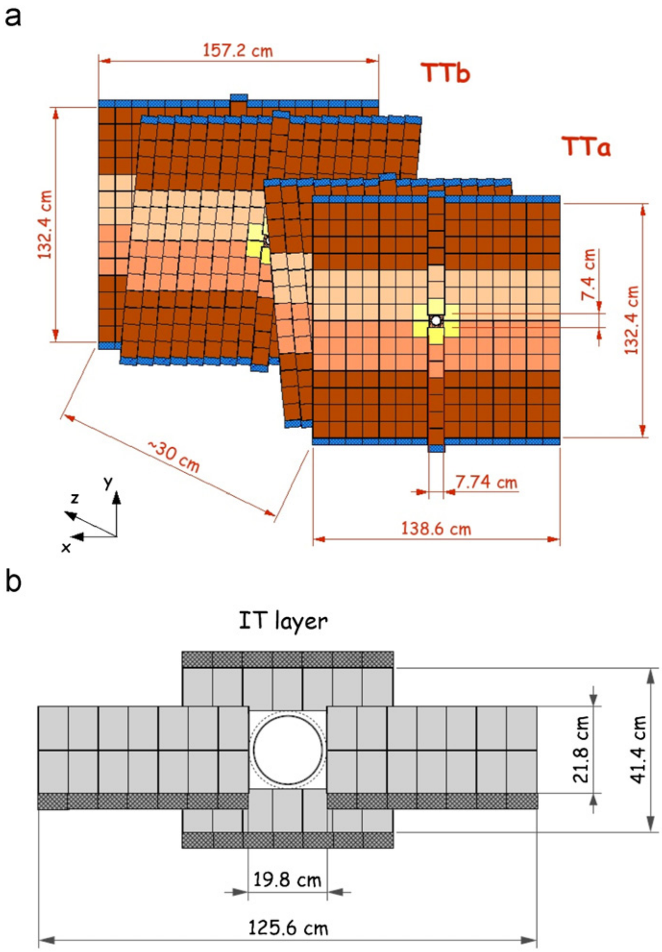

Fig. 1. Layout of the full TT detector (a) and a single IT layer (b).

Problems in the readout chain could be fixed, mostly by replacing the faulty component (e.g. electronics board, patch panel, cable, connector). Currently, the TT has 99.7% and IT has 99.2% of the channels fully functioning. Below we highlight two of the problems encountered during the commissioning without beam.

2.1. Broken bond wires (TT)

Soon after the installation of the first detector modules in the TT in June 2008 it was observed that in a few readout sectors every fourth channel started to show a lower noise than expected. Examining the affected readout hybrids under a microscope showed that this problem was caused by broken bond wires between the readout chip (Beetle) and the pitch adapter that leads to the sensor. These bond wires are staggered in four rows of which only the innermost row of bond wires was broken, thereby explaining the low-noise pattern of every fourth channel. In total 9 out of 280 readout sectors are (partially) affected. Despite many investigations, it was not possible to reproduce the bond wire breaking in the lab. Our current understanding is that material fatigue, induced by stress on the wire, e.g. vibrations and thermal cycling, has probably initiated the process. In addition the low loop height of the innermost bond wires is not ideal and might have accelerated the breaking process. Nevertheless, the total number of broken bond wires is still very low and the number of new broken bond wires has been decreasing over time. There are no new broken bond wires seen since July 2009. Six out of the nine affected sectors have been replaced and currently, the TT has 99.7% of the channels fully functioning.

2.2. Header cross talk

The analog data from the Beetle are sent via four output ports. Each port corresponds to 32 channels (silicon strips). These data are preceded by four header bits, which are encoded as analog signals. The first few data channels are affected by cross talk from these header bits, which effectively gives rise to higher noise in these channels. A small amount of cross talk was indeed expected in the first channel only, due to an internal feature of the Beetle chip. However, the cross talk affects not only the first channel, but the first 4 (2) channels in the TT (IT). The amount of cross talk and the number of affected channels depend mainly on the length of the output cable going from the Beetle to the digitizer board. The effect can be corrected for in the LHCb readout board (TELL1) before the zero-suppression. The correction values can be obtained from a calibration run by calculating the correlation between a high or low header bit and the readout value in the first strips in each port. This correction is then subtracted from the readout values in the FPGA on the TELL1. In the current FPGA implementation the correction can be applied to the first 6 strips in each port. Fig. 2 shows the effect of the header correction on the noise level in a readout port.

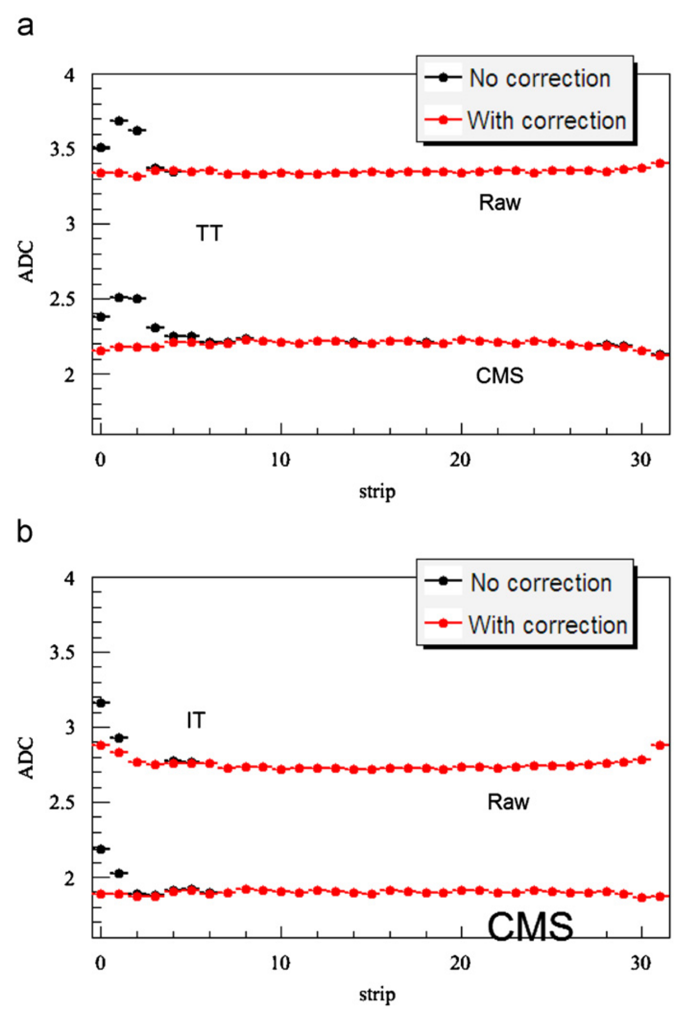

Fig. 2. Raw noise and common-mode-subtracted (CMS) noise in the 32 data channels of a port for TT (a) and IT (b). It shows the effect of the header correction on the noise in the first few data channels.