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Production and Quality Assurance of Detector Modules for the LHCb Silicon Tracker*

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Abstract

The LHCb experiment, which is currently under construction at the Large Hadron Collider (CERN, Geneva), is designed to study CP violation and find rare decays in the B meson system. To achieve the physics goals the LHCb detector must have excellent tracking performance. An important element of the LHCb tracking system is the Silicon Tracker, which covers a sensitive surface of about 12 m^2 with silicon microstrip detectors and includes about 272k readout channels. It uses up to 132 cm long detector modules with readout strips of up to 38 cm in length and up to 57 cm long Kapton interconnects in between sensors and readout hybrids. The production of detector modules has been completed recently and the detector is currently under installation. A rigorous quality assurance programme has been performed to ensure that the detector modules meet the mechanical and electrical requirements and study their various characteristics. In this paper, the detector design, the module production steps, and the module quality assurance programme are briefly described.

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1 Introduction

Since $b\bar{b}$ hadrons at the LHC will be predominately produced at low polar angles in the same forward cone, the LHCb spectrometer [1] is designed as a single-arm, forward spectrometer with an angular coverage from 10 mrad to 300(250) mrad in the horizontal (vertical) plane. The Silicon Tracker is part of the LHCb tracking system. It comprises two sub-detectors: the Trigger Tracker (TT) and the Inner Tracker (IT). Both use single-sided silicon sensors and a common readout[1] and infrastructure such as high voltage, low voltage and cooling. Around 30 physicists from 5 universities and laboratories from 4 countries are currently involved in the LHCb Silicon Tracker project.

The TT is a 150 cm wide and 130 cm high planar tracking station, which is located just in front of the entrance of the LHCb dipole magnet. Charge particle fluxes of about $5{\times}10^5\mathrm{cm}^{-2}\mathrm{s}^{-1}$ are expected in the innermost region of the TT. The detector consists of four planar detection layers of silicon microstrip sensors that cover the complete LHCb acceptance. The detection layers are arranged according to the x–u–v–x configuration: the first and the last layer have vertical strips, while the second and third have strips which are rotated by an angle of $+5^{\circ}$ and -5°, respectively. The layers are enclosed in a common thermally-insulating box that also provides electrical and optical shielding and mechanical support. A detailed description of the TT detector layout can be found in Ref. [4].

The IT covers a roughly 120 cm wide and 40 cm high cross-shaped area around the beam pipe in the centre of three planar tracking stations downstream of the magnet. Although the IT covers only 1.3% of the sensitive surface of the tracking stations, approximately 25% of all charged particles from the pp interaction point that reach the tracking stations will pass through the IT. Charge particle fluxes of about $1.5{\times}10^5\mathrm{cm}^{-2}\mathrm{s}^{-1}$ are expected in the innermost region of the IT. There are four separate IT boxes in each of the tracking stations: above, below, to the left and to the right of the beam pipe. They provide electrical and thermal shielding for the silicon sensors and readout electronics. Each IT box contains four detection layers of silicon microstrip detectors with a x–u–v–x topology, as in the TT. A detailed description of the Inner Tracker detector layout can be found in Ref. [5].

2 Module design

The basic detector unit of the TT is the half-module. It consists of seven 500 μm thick silicon sensors[2] and a stack of readout hybrids located at one end. To provide mechanical stability two carbon fibre rails are glued along the sensor edges. By bonding the strips on adjacent sensors, the half-module is segmented into two or three readout sec-

[1] Both detectors use the same readout chip (the Beetle [2]) and readout link [3].

[2] TT sensors are 9.64 cm wide and 9.44 cm long, and carry 512 readout strips with a strip pitch of 183 μm.

tors. This allows to limit the hit occupancy and to decrease the total load capacitance at the input of a readout amplifier. There are two different types of half-modules: LMK and LM half-modules. The LMK half-modules are placed in the innermost part of the detector around the beam pipe, where the occupancy is highest. In these half-modules, the seven silicon sensors are electronically divided into three independent readout sectors: an outer four-sensor long readout sector, an intermediate two-sensor long readout sector and an inner readout sector consisting of a single silicon sensor. The LM half-modules are placed outside the beam pipe region. These half-modules are electronically divided into two readout sectors: an outer four-sensor long readout sector and an inner three-sensor long readout sector. Each readout sector is independently read out by a front-end hybrid located at the end of the half-module. This leads to two (three) stacked readout hybrids for the LM (LMK) half-module. The four-sensor long readout sectors are directly connected to their front-end readout hybrids via a short pitch adapter. In order to connect the three-sensor and two-sensor readout sectors of the LM and LMK half-modules to the corresponding readout hybrids, an interconnect Kapton cable[3] with a length of 39.1 cm is used. A similar cable with a length of 58 cm is employed to connect the one-sensor readout sectors of the LMK half-modules to their readout hybrids.

IT detector modules consist of one 320 μm thick or two 410 μm thick silicon sensors[4] that are connected via a short pitch adapter to a single readout hybrid. Silicon sensor(s), pitch adapter and readout hybrid are glued onto a flat backplane that consists of a thin layer of polyetherimide foam sandwiched in between two sheets of carbon fiber of high thermal conductivity. A thin Kapton foil is used to insulate the silicon sensors from the carbon-fibre sheets. To provide a direct heat path between the readout hybrid and a thin aluminium cooling rod onto which the modules will be mounted, a small aluminium insert ("cooling balcony") is embedded into the backplane at the location of the readout hybrid.

3 Module production

The series production of TT modules was launched in September 2005 and was completed in December 2006. Including 15% spares, 149 half-modules have been produced: 119 LM half-modules and 30 LMK half-modules. The production of TT modules proceeded in two or three stages, depending on the module type. During the first production step the seven silicon sensors and the lowest readout hybrid were placed on an assembly template, the two carbon fibre rails were glued along the sensor edges, the bias voltage cable was connected to the sensors, and the readout strips and the ground connections of the four-sensor readout sector were bonded. After this stage, the four-sensor sector was fully operational. At the next production step, the readout hy-

[3] The interconnect Kapton cable has a thickness of 0.010 cm and a width of 6 cm and carries 512 signal lines with a fan-in section which reduces the sensor pitch of 183 μm to the 112 μm pitch of the cable.

[4] IT sensors are 7.8 cm wide and 11 cm long, and carry 384 readout strips with a strip pitch of 198 μm.

brid and a 39.1 cm long interconnect Kapton cable for the three-sensor and two-sensor readout sectors of the LM and LMK half-modules were mounted and the sensors within these sectors were bonded together. After this step, the assembly of a LM half-module was completed. For the LMK half-modules, a third production stage was performed to attach and bond the readout hybrid and a 58 cm long interconnect Kapton cable of the one-sensor readout sector.

The series production of IT modules was launched in January 2006 and was completed in September 2007. In total, about 415 modules have been produced. The production of IT modules proceeded in several steps. At first, the pre-fabricated support backplane was placed on an assembly template and the readout hybrid and pitch adapter were positioned and glued onto the support. Then, a first readout test was performed to assure the functionality of the readout hybrid. Depending on the module type, one or two silicon sensors were further positioned on a second template, transfered to the assembly template using a vacuum transfer jig, and glued onto the support using a silicone-based glue. At the next step, bias voltage and ground connections were bonded and a first HV test was performed. Finally, the readout strips were bonded.

4 Quality assurance

A crucial role in the quality assurance programme for the detector modules was played by the comprehensive "burn-in" test, through which each detector module passed at least once during its assembly. This test allowed to investigate the long-term behaviour of the detector modules at different thermal conditions, to study their electrical characteristics and to search for defective channels. The burn-in setups and programmes for IT and TT differed in details, however their main features were similar. The typical burn-in programme took around 36 hours for TT and 48 hours for IT and included temperature cycling between room temperature and +5°C in case of TT and between +40°C and -5°C in case of IT. During the cycling, the modules were continuously biased at 500V and leakage currents were monitored as a function of temperature and time. Furthermore, the leakage currents were measured as a function of the applied bias voltage at cold and warm temperature. These measurements provided a search for the breakdown voltages of the silicon sensors. In order to investigate the noise performance of the detectors, pedestal runs were repeatedly taken at cold and warm temperatures. Measurements of the signal pulse shapes were performed at both temperatures using an internal test pulse implemented in the Beetle readout chip and, in case of the TT setup, using an array of infra-red laser beams that permitted to generate charges at predefined locations on each readout sector. This allowed to verify the optimal timing settings of the readout electronics and to study pulse shape characteristics as a function of different parameters. In particular, the dependence of the signal amplitude on the applied bias voltage was investigated and the charge-collection efficiency curves were obtained. In case of TT, the burn-in programme was running fully automatically. This was achieved by using the LabView programming language that allowed to control all components of the burn-in test-stand, including readout electronics and data taking. An extensive and uninterrupted measurement programme was running even overnight and over the weekends. The need for operator intervention was limited to searching of defective channels at the beginning and at the end of the test and to exchanging the half-modules.

The overall quality of the modules is very good. The fraction of defective channels (interrupts, shorts, pinholes) is only 0.13% for TT and around 0.1% for IT. Leakage currents per sensor at 500V and at room temperature are typically below 0.4 μA. A small number of modules were graded as spares due to higher or unstable leakage currents at 500V. Around 2 TByte of data have been accumulated in the TT burn-in tests alone.

5 Outlook

The production of detector modules for the LHCb Silicon Tracker has been completed. The results of the quality assurance programme demonstrate that the detectors meet the mechanical and electrical requirements for the LHCb Silicon Tracker. The detector installation has been started and will be completed by the end of 2007.

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