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Design and production of detector modules for the LHCb Silicon Tracker

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Abstract

The LHCb Silicon Tracker will cover a sensitive surface of about 12 m^2 with silicon micro-strip detectors. The production of detector modules is currently coming close to its conclusion. In this paper, the design of the detector modules, the main module production steps, and the module quality assurance programme are described. Selected results from the quality assurance are shown and first lessons are drawn from the experience gained during module production.

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1. Introduction

The Silicon Tracker is part of the tracking system of the LHCb experiment [2], which is layed out as a typical forward magnetic spectrometer and covers an acceptance out to 250 mrad × 300 mrad around the LHC beam axis. The Silicon Tracker comprises two detectors, both of which use silicon microstrip detectors with long readout strips and with strip pitches of a little less than 200 μm. The first of these detectors, the Trigger Tracker (TT), is a 150 cm wide and 130 cm high planar tracking station that is located upstream of the LHCb dipole magnet and covers the full acceptance of the experiment. The second of the two detectors is the Inner Tracker (IT). It covers a roughly 120 cm wide and 40 cm high cross-shaped region in the centre of three planar tracking stations downstream of the magnet.[2] Each of the four Silicon Tracker stations comprises four detection layers. In total, the Silicon Tracker covers an active surface of about 12 m^2 with about 272k readout channels.

The two detectors use the same front-end readout chip (the Beetle [4]) and the same readout link [5]. Due to different experimental constraints, however, different designs have been adopted for their detector modules. Including 15% spares, 148 TT modules and 386 IT modules have to be built. At the time of writing of this paper, all TT modules and 80% of the IT modules have been assembled, and more than 90% of these have undergone an extensive quality assurance programme.

The module production and testing is run by two small teams of physicists and technicians in two production sites, one for the TT and one for the IT. Given the available resources and the relatively small number of modules that need to be produced, the production proceeds largely manually. A significant amount of effort was, however, invested to set up automated "burn-in" test stands for module quality assurance measurements. In the remainder of this paper, I will briefly describe the design of the detector modules, followed by a short description of the module production and the quality assurance programmes. For a few key parameters, I will demonstrate the quality of the modules completed so far. Finally, I will try to draw some first lessons from our experience gained during the module production for the Silicon Tracker.

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[2] The outer part of these approximately 450 cm high and 600 cm wide tracking stations is covered by a straw-tube tracker [3].

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2. Module design

The design of the TT modules is illustrated in Fig. 1. A main feature of this design is that most of the "dead material" that is invariably associated with front-end readout hybrids, cooling, mechanical supports, and cables, is kept outside of the acceptance of the experiment. Each detector module consists of a row of seven silicon sensors[3] with a stack of either two or three front-end readout hybrids at one end. Depending on the location of the module in the detector, the seven sensors are organised into two or three readout sectors. For all modules, the first of these is formed by the four sensors closest to the hybrids. They are directly connected to the lower-most readout hybrid, which carries a short pitch adaptor and the front-end readout chips. For the majority of modules ("4-3" type), the remaining three sensors form a single readout sector. It is connected via a 38 cm long flexible Kapton interconnect cable to a second front-end hybrid, which is mounted on top of the first one. For modules that will be installed in the central region of the detector, the remaining three sensors are further split into a two-sensor and a one-sensor readout sector ("4-2-1" type). In this case, each of the two readout sectors has its own Kapton interconnect cable (of 38 cm and 57 cm in length, respectively) and is read out via a separate front-end hybrid. Mechanical stability of the modules is achieved by gluing two thin fibre–glass/carbon-fibre rails along the sides of the sensors and the lower-most readout hybrid. Bias voltage is connected to the sensor backplanes via a thin Kapton cable that runs along the back of the module. Two such detector modules, glued together end-to-end, form a 14-sensor long super-module which spans the full height of the LHCb acceptance. The hybrid stacks at each end of this super-module are located just outside of the acceptance. All (super-)modules are mounted inside one large detector box, in which an ambient temperature of 5 °C is maintained in order to suppress leakage currents and reverse annealing after irradiation. Mechanical support of the detector modules, as well as cooling of the front-end readout chips and the detector volume, is provided by so-called cooling plates that are located at the top and bottom of the detector box and onto which the modules are mounted via individual cooling balconies. As these cooling plates and balconies are located outside of the LHCb acceptance, no special care had to be taken with respect to their material budget.

In the case of the IT, it was impossible to keep the readout hybrids outside of the acceptance. A lot of attention, therefore, had to be payed to minimising the "dead material" from mechanical supports and cooling. The resulting module design is illustrated in Fig. 2. Depending on their location in the detector, modules consist of either one or two silicon sensors[4] that are directly connected to a readout hybrid carrying a short pitch adaptor and the front-end readout chips. Sensor bias voltage is provided to bond pads on the strip-side of the sensors, which are in contact with the sensor backplane via n^+-wells. Sensor(s), pitch adaptor and hybrid are glued onto a common backplane that consists of a thin layer of polyetherimide foam, sandwiched in between two sheets of thermally highly conductive carbon fibre. Electrical insulation between the silicon sensors and the electrically conductive carbon-fibre sheets is ensured by a thin Kapton foil. A small aluminium insert ("cooling balcony") that is embedded into the backplane at the location of the readout hybrid provides a direct heat path between the front-end chips and a thin aluminium cooling rod onto which the modules will be mounted. The carbon fibre sheets are also in thermal contact with the cooling rod through this aluminium insert. Due to their high thermal conductivity, they form large cold surfaces that contribute to cooling the detector volume to the desired ambient temperature of 5 °C.

3. Module production

The production of TT modules is run by a team of three physicists and technicians at Universität Zürich. It proceeds in two or three stages, depending on the module type. After each of these production stages, the module undergoes a two to three day long burn-in test, which will be described in Section 4. The first production step consists in placing the seven sensors and the lower-most hybrid on an assembly template. They are positioned by pushing them against an alignment rail embedded in the template. Vacuum is switched on to fix the sensors and the hybrid in place. Their positions are verified under a precision coordinate measurement machine and corrected if necessary. The first carbon-fibre rail is then glued against the free edge of the sensors and the hybrid. After overnight curing of the glue, the alignment rail is removed from the template and the second carbon-fibre rail is glued against the second edge of the module. The glue is left to cure overnight, before the vacuum is released, the module is removed from the template, and the final sensor positions are measured. The module is then flipped over and the bias voltage cable is glued along its back. The electrical connection of this cable to hybrid and sensors was initially made using silver paint or silver glue. As this turned out to be unreliable (see Section 5), all modules later went through a repair cycle in which these connections were in addition bonded. Once the bias voltage cable is attached,

[3]The TT sensors are 500 μm thick, 9.64 cm wide and 9.44 cm long, and carry 512 readout strips with a strip pitch of 183 μm. They are identical to the OB2 sensors used in the Outer Barrel of the CMS Silicon Tracker [6] and were produced by HPK, Hamamatsu, Japan.

[4]The IT sensors are 7.6 cm wide and 11 cm long and carry 384 readout strips with a strip pitch of 198 μm. They are 320 μm thick for the one-sensor ladders and 410 μm thick for two-sensor ladders. They were designed specifically for the IT and were produced by HPK, Hamamatsu, Japan.