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The LHCb Silicon Tracker[1]

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Abstract

The LHCb Experiment at CERN's Large Hadron Collider LHC is a dedicated B physics experiment that is set up as a single-arm magnetic spectrometer. To fully exploit the physics potential of the experiment, a good tracking performance with high efficiency in the high particle density environment close to the beam pipe is required. Silicon strip detectors with large readout pitch and long strips will therefore be used as part of the LHCb tracking system. We will present the design and the production status of this detector, the LHCb Silicon Tracker.

1 Introduction

The LHCb experiment [1] at the Large Hadron Collider LHC is a dedicated B physics experiment to investigate CP-violating phenomena. The detector is set up as a forward spectrometer with a 4 Tm dipole magnet and covers a polar angle of 300 mrad in the (horizontal) bending plane of the magnet. The experiment comprises a vertex detector system (Velo), a tracking system, two Ring Imaging Cherenkov counters for

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particle (π/K) identification, a calorimeter system consisting of pre-shower detector, electromagnetic and hadronic calorimeters, and a muon system. Tracking of charged particles is provided by the Velo and four planar detector stations: The first station (TT) is located in front of the magnet and consists entirely of silicon strip detectors. Using the magnetic fringe field in between Velo and TT, this detector is used in the Level-1 trigger to select events containing particles with large impact parameter and high p_T. The other three tracking stations are located behind the magnet. Here, only the inner part (IT) is employing silicon strip devices while the outer area is covered with straw tubes. This split solution was optimized to better cope with the high particle densities around the beam pipe and keep the occupancies at an acceptable level. Simulation studies have shown that the track momentum resolution in LHCb is dominated by multiple scattering over a wide range of momenta. This results in a spatial resolution requirement which can be met by silicon strip detectors with a wide pitch of about 200 μm. Large readout pitch and long strips adapted to the expected hit occupancies are used throughout the Silicon Tracker (IT+TT) in order to reduce the number of readout channels and hence the costs. The Silicon Tracker covers a total surface area of 12 m^2 and is segmented in 336 (IT) and 280 (TT) readout units with a total of about 270k channels.

2 Design of the ST Tracker

2.1 The TT Station

The TT station situated in front of the magnet consists of four planar detection layers that cover the entire acceptance between 15 mrad and 300 mrad in the horizontal plane. The four detection planes are arranged in two groups of two layers each. The first two detection layers have a strip orientation of $0°$ and $+5°$ with respect to the vertical axis followed by the second group with two layers of strip orientation of $-5°$ and $0°$. All silicon sensors are kept in a common light tight, dry and thermally insulating detector housing with an ambient temperature of about 5°C provided by cooling plates through which liquid C_6F_{14} circulates. The TT detector box is vertically split into two half stations allowing a retraction from the beam pipe for installation and maintenance. Each detection plane of the TT detector is build out of 150 cm long silicon modules equipped with readout electronics at both ends situated outside the acceptance of the experiment. The modules are mounted vertically or close to vertically on cooling balconies into the detector station frame. Each of the four detector planes consists of 14 or 16 silicon modules of full length and two half-length modules above and below the beam pipe. The basic construction unit during the assembly is a half-length module consisting of seven silicon sensors plus two or three readout hybrids located at one end of the half module. The sensors and readout hybrids are held together by two carbon fiber rails that are glued along the edges of the sensors and the hybrid. The seven sensors of a half module are segmented into either a 4-3 or a 4-2-1 readout grouping with a maximum active strip length of 36 cm. The half modules with the finer grouping of 4-2-1 are situated around the beam pipe. The outer, four-sensor long, readout sectors are directly bonded to the readout electronics. The inner readout sectors for the 4-3 (4-2-1) half modules have one (two) flexible interconnect cables on polyimide basis which route the silicon analogue signal from the sensors to the readout hybrids.

2.2 The IT Stations

Although the IT covers only few percent of the total area of the tracking stations behind the magnet, about 20% of all tracks are passing through the IT. Due to increased particle fluxes the IT has to cover a larger area in the bending plane of the magnet. Each IT station consists of four independent detector boxes, which are arranged in a cross-shaped way around the beam pipe. Each detector box has four detection layers of silicon planes with strips oriented in 0°, ±5° and 0° relative to the vertical axis. The silicon planes are enclosed in a light-tight and thermally insulating housing. As in the TT station liquid C_6F_{14} cooling provides an ambient temperature of 5°C in the IT detector boxes. The sensitive planes in each detector box are assembled in a modular fashion. The basic building units are silicon ladders with an either 11 cm (one sensor) or 22 cm (two sensors) long and 7.8 cm wide active area. The front-end electronics are located on a hybrid at the end of the ladder. A carbon fiber composite sandwich serves as support for sensors and hybrid. The 28 ladders per detector box are mounted via small aluminum balconies to cooling rods, which provide the cooling passage for the liquid coolant.

2.3 Silicon Sensors and front-end electronics

The IT and TT detectors use AC coupled, single-sided silicon microstrip sensors with 384 (IT) and 512 (TT) strips, respectively. In total 896 (504) TT (IT) silicon sensors are necessary to build all detector modules. The TT sensors have a thickness of 500 μm and are identical in their layout to the CMS OB2 sensors [2]. They have a readout pitch of 183 μm and a size of 96×94 mm^2. The IT sensors have a size of 78×110 mm^2 and a strip pitch of 198 μm. They are either 320 μm (one-sensor ladders) or 410 μm (two-sensor ladders) thick. The silicon thickness was adjusted to the different ladder types of IT and TT in order to maintain a signal over noise ratio of at least 12:1. The sensors are presently manufactured by Hamamatsu Photonics, Japan, and about 85% (25%) of the IT (TT) sensors have been delivered so far. It is expected to have all sensors in hand by end of the year. Upon reception, the silicon sensors undergo a quality assurance program. They are visually inspected for scratches and other blemishes. Afterwards, leakage currents and depletion voltages are determined. Moreover, on selected sensor samples an automatic strip testing is performed to detect bad channels. The preliminary results obtained from almost 500 tested sensors indicate an excellent quality of the silicon sensors. The strip of the silicon sensors are read out by integrated circuits, the

Beetle chips [3] that are located on front-end hybrids at the end of the detector modules. Analogue data from the Beetle chips are then further sent via differential lines on up to 5 m long twisted pair cables to so-called service boxes located outside the detector acceptance. In the service boxes, the data are then digitized with 8-bit resolution, multiplexed and converted into an optical signal. The digital-optical signal is further transmitted via fibers of up to 120 m length to the counting house to an optical receiver card, which is located on the Level-1 preprocessing boards. The Beetle chip is a 128-channel ASIC device for 40 MHz sampling and multiplexed deadtimeless readout. It is manufactured in a 0.25 μm CMOS process and was irradiation tested up to 40 MRad. The chip features for each channel a low-noise charge-sensitive preamplifier, an active CR-RC pulse shaper with a minimum rise time (13 ns) well below the LHC requirements and an analogue pipeline with a programmable latency of up to 160 sampling intervals. Upon a L0-trigger the corresponding signals stored in the pipeline are readout within 900 ns. The two main types of hybrid packages that are employed in the Silicon Tracker carry either three chips for the IT detector modules or four chips for the TT detector modules. The Beetle chips are mounted together with passive electronic components on a flexible printed circuit board. Ceramic pitch adapters are necessary to match the silicon sensor pitch to the pitch of the Beetle input pads. The complete package is attached to heat spreader substrates that provide a low thermal impedance path to the cooling plates. The production of the pitch adapters and the assembly of the hybrid packages including the ultrasonic aluminium wire bonding are done by industry. The pre-series consisting of 15% of the total hybrid production quantity has been delivered recently and went successfully through numerous functionality tests including a long-term burn-in.

3 Production and Testing of Detector Modules

The series production of the IT silicon ladders and TT half modules has just started. Production room facilities at CERN/Lausanne for IT and in Zurich for TT are in place and assembly equipment is in operation. In a pre-series phase, which lasted from March to August 2005, many details of the module assembly procedures were improved and refined. A few problems were identified and solved during the pre-series production. For instance, the HV insulation between carbon fiber supports and silicon sensor backplane for IT and TT detectors was significantly improved to prevent sparking. After some optimizations of the production jigs, the achieved mechanical accuracy of assembled silicon devices is now well within the specifications. Although the production is not yet proceeding at full pace, it is expected to be able to ramp up to full production speed within the next months. The anticipated rate will then be 12 ladders/week for the IT and 5 half modules/week for the TT in order to guarantee the completion of all detector devices in time. The schedule calls for the installation of the IT and TT detector boxes into the LHCb experimental hall by June/July 2006. After the assembly, the IT and TT detector modules undergo a burn-in test. For that purpose, several dedicated teststands using the final readout chain electronics have been set up at CERN (IT) and Zurich (TT) and are presently being commissioned. The goals of the burn-in measurement are a thorough characterization and final electrical grading of the detector modules. The two burn-in boxes for the TT half modules have a very similar, albeit downsized, design as the final TT detector box. The TT burn-in stands are further equipped with optical fibers fed by pulsed infrared laser diodes which illuminate the silicon sensors at various points to generate charge in the silicon and to determine the operation voltage of the modules. During burn-in measurements, the detector signals, the leakage currents, the temperatures and relative humidity within the burn-in box are permanently recorded. Moreover, pulse shape scans will verify the optimal timing settings of the Beetle preamplifiers. Finally, the burn-in stands will allow a controlled thermal cycling of the detector modules and all characterization measurements are repeated at pre-defined temperature settings.

4 Summary

In order to cope with the high particle density close to the beam pipe a good portion of the LHCb tracking system is realized with silicon detectors. The single tracking station before (TT) and the inner part of the three tracking stations (IT) behind the LHCb dipole magnet are using silicon microstrip sensors with a large pitch of about 200 μm and readout strips with a length of up to 36 cm. The series assembly of detector grade modules has just started after finalizing a pre-series production, which led to several refinements of the assembly procedure. Even if the LHCb ST detector does not have the scale and dimension of the Atlas or CMS silicon trackers, its series production of all detector modules still represents a formidable production task.

References

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