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THE LHCB SILICON TRACKER

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LHCb is one of the experiments for the Large Hadron Collider, dedicated to B-physics and CP-violation measurements. To fully exploit the physics potential, a good tracking performance with high efficiency in a high particle density environment close to the beam pipe is required. Silicon strip detectors with large readout pitch and long strips will be used for the LHCb Silicon Tracker. The design and test beam results are presented here.

1. Introduction

LHCb is a dedicated B-physics experiment for the LHC[1], a 14 TeV pp-collider which is under construction at CERN. CP-violation and other precision measurements with B-mesons, provide important tests of the Standard Model and may hint to new physics.

The luminosity at the LHCb interaction point of $2 \cdot 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ results in a yearly production of a large number of about 10^{12} $\mathrm{b}\overline{\mathrm{b}}$ pairs. Their angular distribution is strongly peaked towards the incoming beam directions. The LHCb detector is designed as a single arm forward spectrometer, taking advantage of this particular angular distribution. The detector has 300 mrad polar angle coverage in the bending plane of the magnet. The silicon-microstrip vertex detector, the Trigger Tracker (TT)-station before the magnet and the tracking stations T1-T3 behind the magnet are used to reconstruct charged particle trajectories. LHCb consists furthermore of two RICH detectors for particle identification in addition to electro-magnetic and hadronic calorimeters as well as muon detectors at the far end of the spectrometer.

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The LHCb detector has recently been re-optimised[2] and as a result the entire solid angle of the TT-station is coverd by silicon strip detectors. Due to its fast readout and good spatial resolution, this optimises the performance of the second trigger level, where the TT-station is used to add transverse-momentum information to large-impact parameter tracks. The T1-T3 stations are split into the Inner Tracker, consisting of silicon detectors in the region of high particle densities near the beam-pipe, and the Outer Tracker built from straw-tubes. The Silicon Tracker, consisting of the TT-station and Inner Tracker, covers a total area of $12.5\,\mathrm{m}^2$ with 310k readout channels.

2. Inner Tracker design

Each Inner Tracker station[3] consists of four individual detector boxes which are arranged around the beam pipe as shown in Fig.1. The side boxes consist of Si-ladders that are 22 cm long and 7.8 cm wide and are built out of two single-sided AC coupled p^+n silicon strip sensors with a thickness of $320\,\mu$m. The detector boxes above and below the beam-pipe employ shorter ladders of one Si-sensor only. With this geometry, a very modular and simple detector design is achieved that is well adapted to the distribution of particle densities in the experiment. The charged particle density is largest within the horizontal bending plane of the magnet. The Inner Tracker covers this region, ensuring that the occupancy in the adjoining Outer Tracker is kept below the required 10%. Each station has four layers of silicon detectors with the two inner layers placed with a $\pm 5°$ stereo angle. Every quadrant contains 28 silicon ladders enclosed in a box providing electrical and thermal insulation. The operation temperature is foreseen to be $5°$ C in order to keep the noise contribution due to leakage current after irradiation small. Fluences of up to $\times 10^{13}\mathrm{cm}^{-2}$ 1 MeV neutron equivalent are expected at the centre after 10 years of operation.

Because of moderate spatial resolution requirements, with the momentum resolution being limited by multiple scattering, silicon detectors with a large readout pitch of $198\,\mu$m are used. Each ladder is read out via 3 Beetle readout chips. The Beetle is a 128 channel custom made analog readout chip in radiation hard $0.25\,\mu$m CMOS technology, operating at 40 MHz and providing a pipeline for 180 clock cycles. Its shaping time can be varied via an internal programmable register (V_{fs}) which changes the feedback resistance.

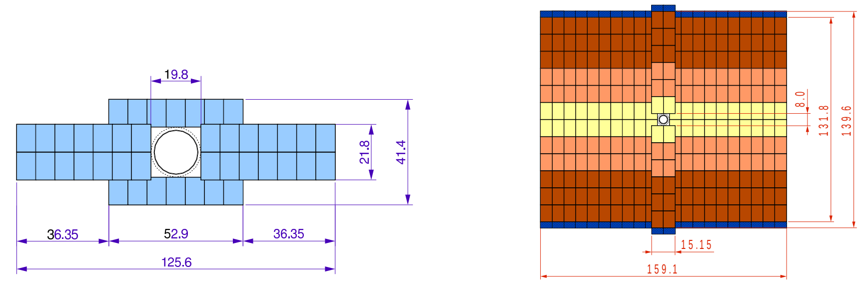

Figure 1. The layout of one Inner Tracker station consisting of four individual detector boxes (left) and the layout of one layer in the TT-station (TTb).

3. TT-Station design

The TT-station consists of a total of 4 layers arranged in two half stations, TTa and TTb, that are separated by 30 cm along the beam axis and are enclosed in a single box providing electrical and thermal shielding. Like in the Inner Tracker, the first and the fourth layer have vertical readout strips, while the second and the third layer have a stereo angle of +5° and -5°, respectively. The Si-sensors have the same geometry as in the Inner Tracker, but 410 μm thickness. As indicated in Fig.1, they are arranged in readout sectors of one sensor in the centre, two sensors in the middle and finally three sensors on the outside, the latter resulting in 33 cm long readout strips. The readout hybrids are the same as used for the Inner Tracker and are located at the outer edge of the detector, outside of the acceptance. The inner sectors are connected to the readout hybrids via 33 cm and 55 cm long Kapton interconnect cables. With a measured and simulated capacitance of < 0.5 pF/cm for such cables, the total load capacitance of each readout sector does not exceed that of the 33 cm long silicon strips.

4. Prototype test results

Several prototype modules with 500 μm-thick CMS-OB2[4], 410 μm-thick GLAST2000[5] and with 320 μm-thick LHCb Inner Tracker sensors have been built and tested. Both CMS and GLAST sensors have a strip implant width over strip pitch ratio (w/p) of 0.25, while the LHCb sensor is a multi-geometry sensor with different w/p values implemented. For the analysis presented here, the region with w/p=0.35 has been used. This study was particularly aimed to determine the necessary thickness of the sensors in order to get sufficient S/N ratio for the 33 cm long silicon strips used in

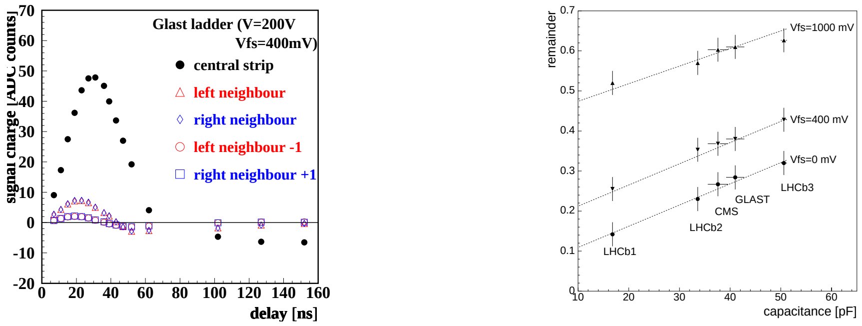

Figure 2. Pulse shape on the central strips, their neighbours and their next neighbours (left) and signal remainder 25 ns after the peak(right).

the TT-design. Tests have been performed with an infrared laser and with 120 GeV pions in a testbeam at CERN. Spatially resolved measurements investigating the charge loss in between two readout strips for 200 μm readout pitch have been performed as well as pulse-shape measurements. The latter reveal the time structure of the signals on the central strip, closest to the incident particle, and on the neighbouring strips. For particles that traverse the detector close to one of the readout strips, charge sharing by diffusion between the strips is negligible. Hence the signal on the adjacent strips is dominated by other mechanisms like induction and capacitive coupling. This results in the time structure illustrated in Fig.2 where the neighbouring strips reach their maximum and the undershoot significantly earlier than the central strip. A similar observation is repeated for the next neighbour strip. The shaping time has been varied by means of the V_{fs} setting in order to adjust the remaining signal 25 ns after the maximum (i.e. one bunch crossing later) to the required 30% and 50% for the Inner Tracker and the TT-station, respectively. The signal width increases with increasing load capacitance as shown in Fig.2. The signal remainders can be kept below 50% even for the 33 cm ladder, which represents the largest load capacitance, if V_{fs} is set to 400 mV. This value is used in the following.

The signal to noise ratio (S/N) distribution obtained for the different ladders has been measured and an example from the GLAST ladder is shown in Fig.3. The most probable value has been determined from fitting a Landau distribution convoluted with a Gaussian. A clear separation of the S/N for noise and signal clusters is obtained for the 500 μm and the 410 μm thick sensors, while the S/N for the 320 μm thick sensors is only

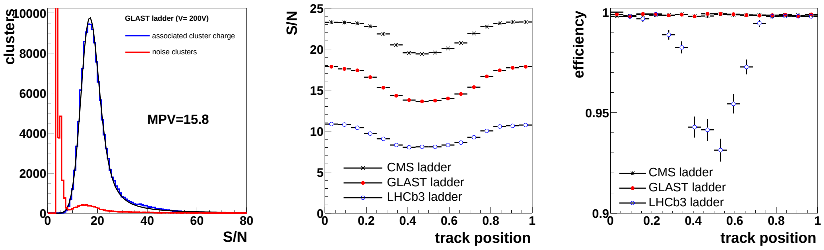

Figure 3. Average S/N ratio for the Glast ladder(left) and a comparison of the S/N (middle) and cluster finding efficiency (right) as a function of on the relative positions of the incident particle w.r.t. the readout strips for the different ladders.

marginal. Fig.3 also shows measurements of the S/N ratio for different relative positions of the incident particle w.r.t. the readout strips. The decrease of the S/N ratio in between the strips is due to a charge loss in this area as it was already observed in previous measurements[3]. The particle detection efficiency has been determined after adjusting the clustering cuts to give less than 0.1% noise clusters per readout strip and event. An average cluster finding efficiency exceeding 99.8% has been found for the CMS and GLAST ladder, while for the thinner LHCb ladder the reduced S/N-ratio in between the readout strips results in a significant efficiency loss, as shown in Fig.3. The average efficiency for this ladder is 96.2%.

5. Summary

The LHCb Silicon Tracker is designed using silicon strip detectors with up to 33 cm long readout strips, a large pitch of ≈200 μm and fast readout electronics adapted to the 40MHz bunch crossing rate at the LHC. Testbeam measurements have shown that sufficiently high S/N ratio under these operating conditions are achieved for 410 μm thick sensors, as they are foreseen in the design.

References

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