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Design and performance of the LHCb Silicon Tracker

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Abstract

The LHCb detector is currently being installed at the Large Hadron Collider at CERN and is foreseen to start operating in 2007. It is designed to perform high-precision measurements of CP violation and rare decays of B hadrons. The Silicon Tracker is part of the LHCb tracking system. It consists of the Trigger Tracker in front of the experiment's dipole magnet and the Inner Tracker downstream of the magnet. Both detectors employ silicon micro-strip technology to cope with the charged particle fluxes of up to 5×10^5 cm^{-2} s^{-1} that are expected in the innermost regions of the detectors. In this note the design and production status of the Trigger Tracker and the Inner Tracker are presented together with an overview of the LHCb tracking strategy.

Key words: silicon detector, LHCb, tracker
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1. Introduction

The LHCb experiment [2], presently under construction, is dedicated to precision measurements of CP violating phenomena and rare b-hadron decays. The layout of the detector is shown in Figure 1.

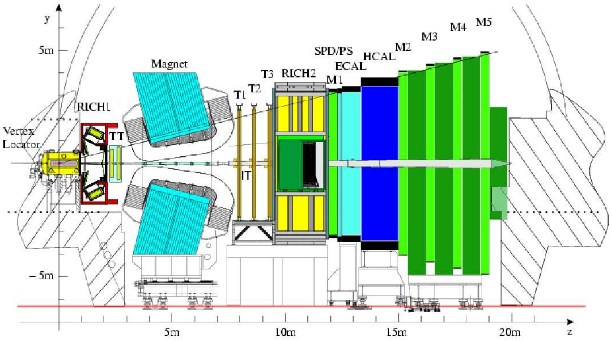
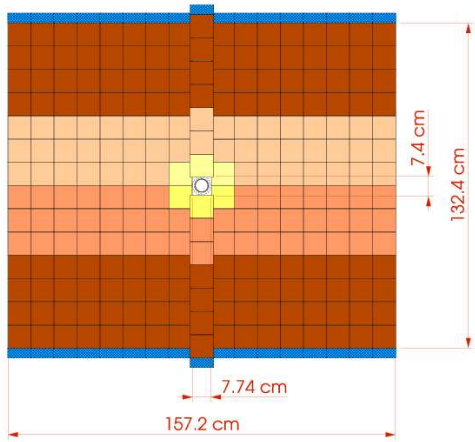


Fig. 1. Side view of the LHCb detector.

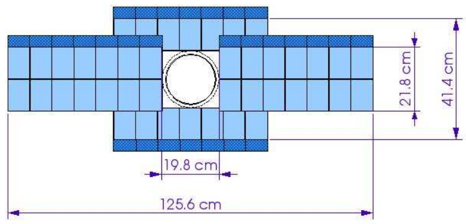
At the LHC, the $b\bar{b}$ production is peaked towards small angles with respect to the beam axis. Therefore, the detector is designed as a single-arm magnetic spectrometer. The tracking system consists of a silicon micro-strip detector located around the interaction point, an all-silicon tracking station located immediately in front of the magnet (Trigger Tracker) [3], a 4 Tm dipole magnet and three tracking stations located after the magnet. The latter, T stations, are sub-divided into an Inner Tracker [4], constructed using silicon micro-strip technology and an Outer Tracker, built using straw tubes. The Inner Tracker(IT) and Trigger Tracker(TT) are being developed in a common Silicon Tracker project which is the subject of this paper together with a discussion of the overall tracking system performance.

2. Silicon Tracker

The Trigger Tracker is positioned just upstream of the LHCb dipole magnet. Figure 2(a) illustrates the layout of one TT detection layer. The detector modules, constructed from seven silicon sensors, cover the area above and below the beam pipe, while the areas to the left and right of the beam pipe are covered by modules consisting of 14 silicon sensors. Electronically, each module is split into several readout sectors indicated by different shadings in the figure. Modules in the outer part of the detector are split into an outer four-sensor long readout sector and an inner three-sensor sector, whereas modules close to the beam pipe have the three innermost sensors segmented into a two-sensor readout sector and a single-sensor readout sector. The inner readout sectors are connected via Kapton interconnect cables to their readout hybrids which are located at the end of the ladder, outside of the detector acceptance.



(a) Trigger Tracker station



(b) Inner Tracker station

Fig. 2. The active area of the (a) Trigger Tracker and the (b) Inner Tracker.

The Inner Tracker covers a cross-shaped area around the beam pipe. Even though the active area represents only 1.3% of the total LHCb angular coverage, the acceptance of the Inner Tracker weighted with the expected track distribution is

20%. The detector boxes above and below the beam pipe contain modules with one sensor while the boxes next to the beam pipe have modules made out of two silicon sensors, which are bonded together and connected to a single readout hybrid. The cooling elements, cables and front-end electronics are located within the detector acceptance. Attention has therefore been paid to minimizing the material in these components.

Each tracking station consists of four silicon layers. The strip orientations of the first and last layers are vertical while the middle ones have $\pm 5^\circ$ stereo angles. In total, 336 IT and 280 TT modules will have to be produced by June 2006. The series production started in August 2005.

The Silicon Tracker covers an area of about $14\,\mathrm{m}^2$. However, the requirements on the spatial resolution are moderate. Therefore, the detector is designed with on one hand, an as many as affordable number of readout channels but on the other hand, as few as acceptable by the physics and reconstruction. This resulted in the choice of silicon sensors with strip pitches of about 200 μm and modules with readout strips of up to 37.6 cm in length. An extensive R&D program was carried out to demonstrate that an acceptable S/N performance above 12:1 could be obtained in spite of the large strip capacitances (from 17 pf for a single IT sensor up to 57 pf for a 4-sensor TT readout sector) and the fast shaping time of (15 ns to 20 ns), which is required for operation at the LHC. The front-end of the Beetle readout chip [5], which is used by TT and IT, was carefully designed to optimize its noise performance for large load capacitances. Sensors of different thicknesses will be employed in different parts of the detector in order to provide sufficiently high signals while keeping the material budget as low as possible: 500 μm thick sensors will be employed in the TT station, 410 μm thick sensors for the two-sensor long IT ladders and 320 μm thick sensors for the one-sensor long IT ladders. A width-over-pitch ratio of 0.25 was chosen as a best compromise between charge loss in the inter-strip region [6] and noise due to inter-strip capacitance. IT sensors have 384 readout strips on a 11 cm by 7.8 cm surface. TT sensors have 512 strips on a 9.64 cm by 9.44 cm surface and are identical to the OB2-type sensors [7] designed for the outer barrel of the CMS silicon tracker. All sensors work on the principle of p+ microstrips on n-type bulk.

The LHCb tracking system is completed by the silicon micro-strip vertex detector(Velo), which consists of 21 stations surrounding the interaction region and distributed over a length of about 1 m along the LHC beam axis, and the straw-tube Outer Tracker that covers the regions outside the IT in tracking stations T1 to T3.

3. Track reconstruction in LHCb

The reconstruction of the trajectories of charged particles in the LHCb environment is challenging as up to 50 primary particles are produced within the LHCb Velo acceptance, in a collision that produces at least one $b\bar{b}$ in the LHCb acceptance. Of these 50 particles around 30 are also seen in the T stations. In addition, the material between the interaction point and the end of the tracking system amounts to 40% of radiation length, which gives rise to secondary particles as well as multiple scattering. Finally, the 40 MHz bunch crossing rate implies that some fraction of the hits from previous crossings will be detected in the crossing of interest, resulting in a small fraction of ghost tracks.

A multi-pass track finding strategy has been developed. In the first pass, so called “long tracks” that traverse the entire detector from the Velo to the T stations are searched for. These tracks have the best momentum resolution and are most important for physics studies. Long tracks are reconstructed using two different methods. The first method, the forward tracking, also used in the High-Level Trigger, starts with a Velo seed which is then linked to a measurement in a T station [8]. With this information and a parametrization of the expected trajectory in the T stations, the track parameters are fully constrained. The other hits in the T stations are then used to confirm that the hypothesis is valid. The used hits are removed so that the subsequent algorithms are only run on the remaining hits.

In a second method, long tracks are searched for starting from the T stations. The seeding algorithm employed in the T stations works in projections starting from the information in the bending plane (x coordinate). The T stations are located in the fringe field of the magnet and see significant field. Therefore, in the bending plane of the magnet it is found to be necessary to parameterize the track trajectory with a parabola. The seeding first searches for triplets of hits that lie on a parabola which is consistent with a particle originating from the primary vertex region. Other x hits are then used to confirm the hypothesis. After this, the stereo information is added. The candidate track is then extrapolated to the Velo and matched with a Velo track using a χ^2 criterion.

The next pass is searched for tracks without hits in the Velo, for example the decay products of long-lived K_S mesons and Λ hyperons. Here the remaining seeds in the T stations are matched with hits in the TT stations. Finally, a search is made for low momentum particles, which are bent out of the acceptance before they reach the T stations, using unused Velo tracks together with unused hits in TT detector. This last method has a moderate efficiency of around 70% and a moderate momentum resolution ($\delta p/p =$ 15%).

The reconstruction performance for long tracks is illustrated in Figure 3, 4 and 5. These results have been maintained using a detailed Monte Carlo simulation which includes Pythia for the event generation and Geant4 for the particle tracking. For the efficiency and ghost rate plots, all particles in the acceptance with a momentum larger then 1 GeV were used. An efficiency of 95% is achieved for particles with momentum above 10 GeV, whilst the ghost rate is below 5% if a loose cut on the track p_t, i.e. $p_t > 300$ MeV, is applied. For tracks with a transverse momentum less than 0.5 GeV/c, the tracking performance degrades significantly, however these tracks are of less importance for physics analysis.

4. Summary

The design and prototyping of LHCb Silicon Tracker have been completed and the production of the detectors has started. A track reconstruction strategy has been implemented and tested on simulated events where it gives a good performance.

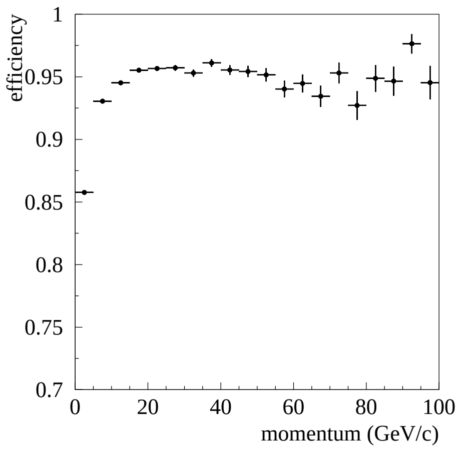


Fig. 3. Tracking efficiency for long tracks.

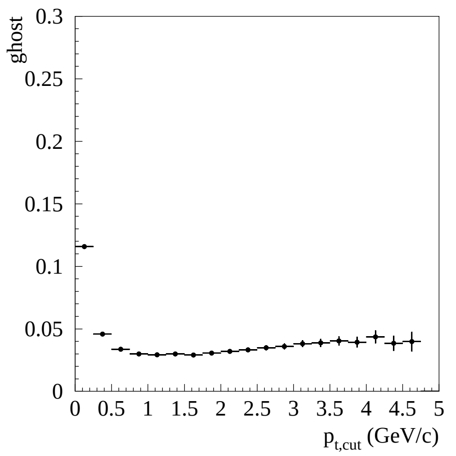


Fig. 4. Ghost rate for long tracks.

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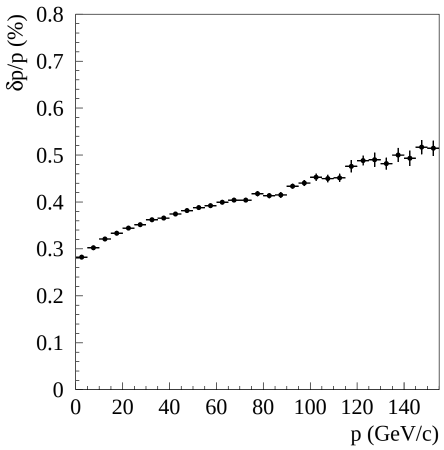

Fig. 5. Momentum resolution for long tracks.

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