CERN-LHCb-2006-027

# The LHCb tracking system

Jeroen J. van Hunen*

*(For the LHCb collaboration)*

*École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland.*

**Abstract**

The LHCb detector is being constructed to measure CP-violation parameters and rare B decays. The LHCb tracking system consists of silicon micro-strip detectors and straw chambers. The system is composed of four major sub-detectors: the Velo (Vertex Locator), TT (Trigger Tracker), IT (Inner Tracker) and OT (Outer Tracker). The Velo uses silicon micro-strip detectors which are placed at 8 mm from the beam, and that can be retracted during injection. The TT is a four-layer silicon strip detector that covers the full acceptance of the experiment at the entrance of the spectrometer dipole magnet. The fringe field of the magnet allows the transverse momentum of tracks to be measured by their deflection between the Velo and TT detectors for use in the trigger. The IT and OT detectors measure the tracks behind the magnet. The IT is a silicon strip detector which covers the region close to the beam pipe, while the OT is a straw tube detector which covers the rest of the acceptance. All of the detectors are currently under construction and will be ready for installation before the end of 2006. The expected performance for the tracking system is as follows; the tracking efficiency is larger than 95% and the ghost rate is smaller than 7%, for tracks with a momentum larger than 12 GeV. The momentum resolution ranges from 0.35% to 0.5% and the IP resolution reaches 14 μm for tracks with a large transverse momentum.

*Keywords:* Solid state;detectors;micro strip;silicon;tracking system;reconstruction

## 1. The LHCb experiment

LHCb [1] is a b-physics experiment that is designed to perform high-precision measurements of CP-violation parameters and to measure rare B decays. Both the CP parameters and the branching ratios of the rare B decays are sensitive to physics beyond the Standard Model. The LHCb detector is a single-arm spectrometer with good tracking and particle identification characteristics. A schematic overview of the LHCb detector is shown in Figure 1.

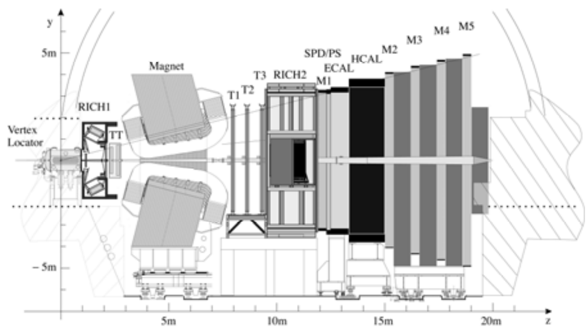



Figure 1. Schematic view of the LHCb detector.

The track reconstruction at LHCb starts by first reconstructing short straight line segments in the Vertex

* Corresponding author. Tel.: +41-21-6930501; fax: +41-21-6930477; e-mail: jeroen.vanhunen@epfl.ch

Locator (Velo tracks). These straight line segments are then extrapolated through the magnetic field, and hits in the three tracking stations behind the magnet (the T-stations, T1, T2, and T3) are added. A second method to reconstruct long tracks is also used. In this case track seeds in the T-stations are extrapolated to the Velo, where they are matched with Velo tracks. The long tracks are of highest quality and have good momentum and impact parameter resolution. Other track types are downstream tracks, which have hits in the TT and the T-stations and are important for efficient $K_S$ finding, Velo tracks (for primary vertex reconstruction), T-tracks (for pattern recognition in the 2nd Ring Imaging Cherenkov detector, RICH2), and upstream tracks (for pattern recognition in RICH1). In the next section the tracking detectors are described in some detail and the status of the detector production is given. In Section 3 the expected performance for the complete tracking system is discussed, while the conclusions follow in Section 4.

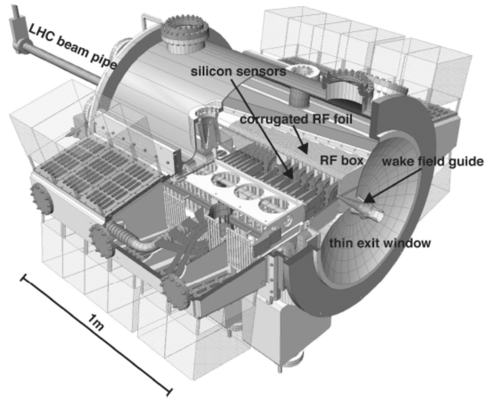



Figure 2. Schematic view of the Velo detector. The corrugated foil separates the beam and detector vacuum, and serves as an RF shield for the detector modules.

## 2. The tracking detectors

The Vertex Locator (Velo) is located in vacuum around the interaction point (see Figure 2). It is a silicon micro-strip detector, where the sensors allow for a measurement of the R and phi coordinates of the particle. The detector consists of two halves which can be retracted from the beam during injection by about 30 mm. An aluminum foil separates the beam and detector vacuum, and also serves as an RF shield. The sensitive area starts at a radius of 8 mm from the beam. The radiation environment is very non uniform. For the inner part of the sensor (at a radius of 8 mm) the expected radiation level equals $1.3\times10^{14}$ neq/cm$^2$/year, while at the outer edge of the sensor (42 mm) this is expected to be $5.0\times10^{12}$ neq/cm$^2$/year. Due to the high level of radiation the detector modules will have to be replaced after three or four years.

The Trigger Tracker (TT) [2] is located in the fringe field, between the Velo and the spectrometer magnet. This detector is used to obtain an estimate of the momentum, and is important for the trigger decision. The TT is a silicon strip detector with a pitch of 183 μm. The layout of this detector is shown in Figure 3, while one of the TT modules is shown in Figure 4. The Trigger Tracker consists of four detection planes with a width of 139 cm. The orientation of the strips for the first plane is vertical, the 2nd plane has strips rotated by $-5^0$ around the beam axis, the 3rd plane by $+5^0$, and for the last plane the strips are again vertical. The modules have up to fourteen sensors each, and up to four sensors are connected to one front-end hybrid. The three sensors which are in the horizontal plane close to the beam line (y=0) are connected to the front-end hybrids by long kapton cables. The total load capacitance for the front-end chips is 57 pF, which requires relatively thick silicon sensors of 500 μm.

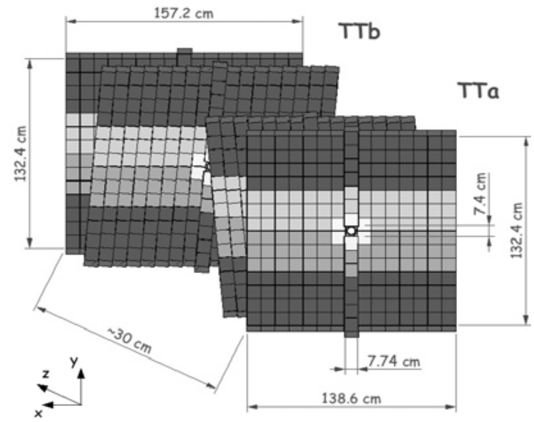



Figure 3. A schematic layout of the Trigger Tracker. The square elements represent the silicon sensors, which have a size of $9.44\times9.64$ cm$^2$.

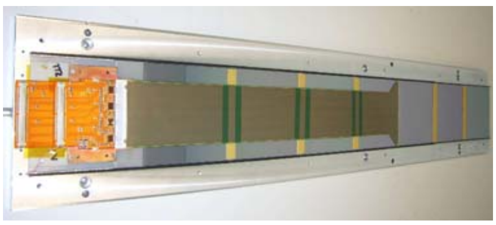


Figure 4. One of the TT modules. There are four sensors connected to one front-end hybrid. The long kapton cable serves to connect the inner three sensors to their readout hybrid, which is located outside the detector acceptance.

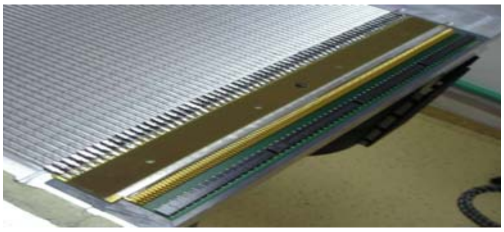


Figure 5. One of the straw tube chambers while it is being assembled. Two layers of straws are visible in the picture.

The tracking stations behind the magnet (T-stations) consist of two detector types. The inner region, close to the beam line is made of silicon strip detectors with a pitch of 198 μm. This detector is referred to as the Inner Tracker (IT). The outer region is covered by straw tube chambers with straw tube diameters of 5 mm (Figure 5). This detector is referred to as the Outer Tracker (OT). In Figure 6 the layout of one of the three T-stations is shown. The Inner Tracker has two different types of modules. The modules which are located at the sides of the beam pipe have two 410 μm thick sensors, while the modules which are located below and above the beam pipe have one 320 μm sensor. A single-sensor module is shown in Figure 7.

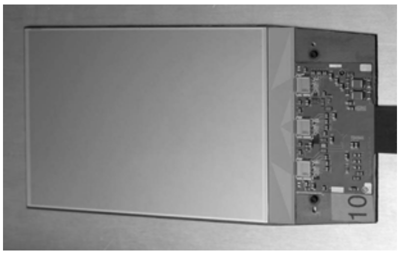
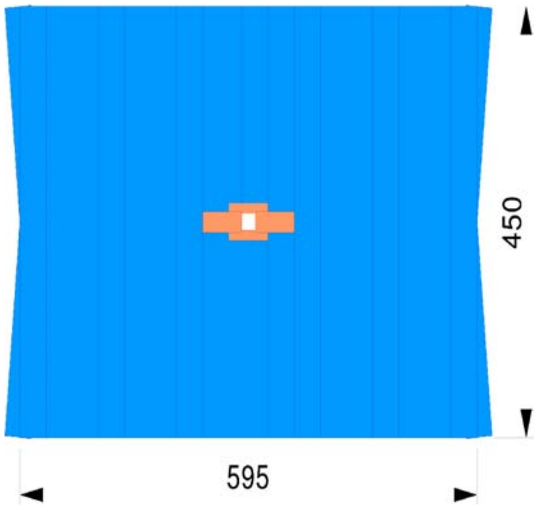


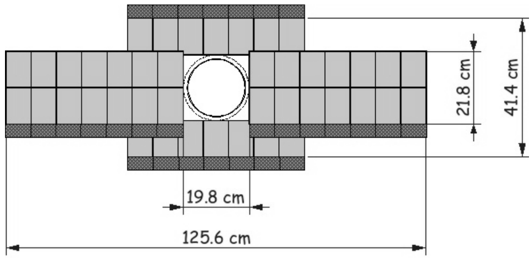
Figure 7. An IT module with one silicon sensor. The silicon sensor is 7.8×11 $cm^2$ in size. The three Beetle front-end chips are glued to the kapton hybrid and wire bonded to an Alumina pitch adapter.

For the Velo, TT and the IT, the Beetle chip [3] is used as front-end. The Beetle chip is made in a 0.25 μm CMOS technology. The front-end that is used for the straw tube detectors is the ASDBLR readout chip [4].

The construction of all the tracking detectors is well underway. For the Velo detector 8 prototype hybrids have been constructed, while in total 84 will be needed to complete the detector. For the TT 80 half modules are under construction, from which 30 are fully completed and tested. In total 128 modules for the TT are required. The straw tube modules for the OT are all constructed and the installation of the OT at the LHCb experimental area will take place during summer 2006. For the IT, 100 out of the 336 required modules have been produced and about 60 are fully tested. The testing procedures include thermal cycling for accelerated aging.




(a)




(b)

Figure 6. The layout of one of the three tracking stations. The center region is covered by a silicon strip detector (b) which is surrounding the beam pipe. The outer region (a) is covered by a straw tube detector (the dimensions are given in cm).

## 3. Expected performance of the LHCb tracking system

A detailed Monte Carlo (MC) simulation was performed for the LHCb detector to study the detector performance concerning the tracking, event selection and physics sensitivity. In this section the results on the tracking performance will be summarized. The performance concerning the event selection and the sensitivity to physics parameters are reported elsewhere [1]. The MC simulation shows that the average number of measurements per long track is 38. In a typical event at LHCb about 100 tracks are reconstructed.

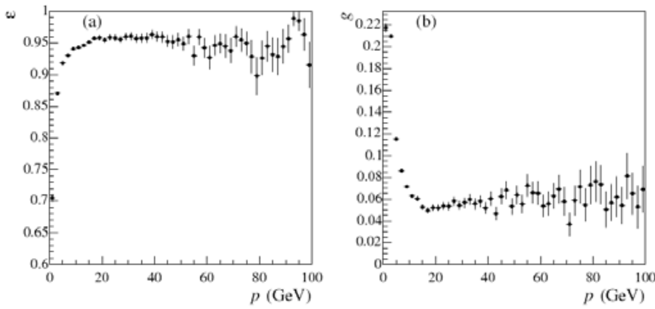



Figure 8. The tracking efficiency and ghost rate for long tracks.

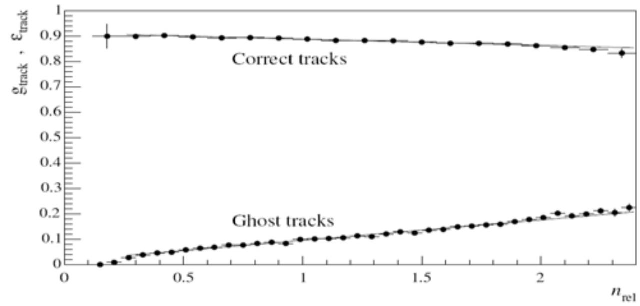



Figure 9. The tracking efficiency and the ghost rate for long tracks as a function of the relative hit multiplicity, i.e. the hit multiplicity of the tracking detectors divided by the average hit multiplicity.

The tracking efficiency and ghost rate for long tracks are shown in Figure 8. It can be seen from the figure that for tracks with energy above 12 GeV the efficiency is higher than 95%, while the ghost rate stays below 7%. The efficiency and ghost rate depend on the hit multiplicity of the events as shown in Figure 9. It can be seen that for a hit multiplicity equal to twice the average hit multiplicity the efficiency drops by 4% while the ghost rate increases by 7%. The momentum and impact parameter (IP) resolutions are shown in Figure 10. The momentum resolution ranges between 0.35% and 0.5%, and is dominated up to 80 GeV by multiple scattering. The IP resolution is 14 μm for the tracks with the highest transverse momentum, and is dominated by multiple scattering in the material before the first measured point.

An important quantity in B physics is the decay time of the B mesons. The proper time resolution is shown in Figure 11 for $B_s \rightarrow D_sK$ decays. The core (54%) resolution is 38 fs.

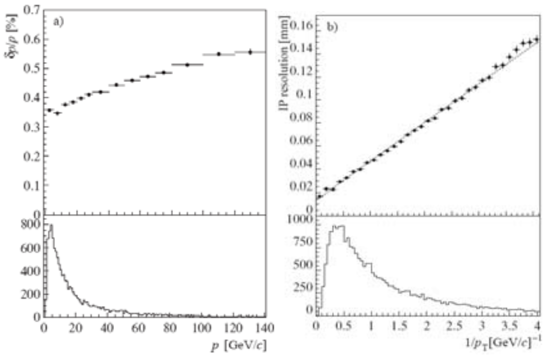



Figure 10. The momentum (a) and impact parameter (b) resolution for B-decay tracks. B-decay tracks are generally long tracks. The histograms at the bottom of the plots show the momentum and IP distribution of B-tracks.

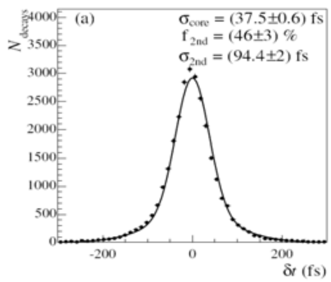



Figure 11. A double Gaussian fit of the decay time resolution for $B_s$-mesons which decay as $B_s \rightarrow D_sK$.

## 4. Conclusions

The construction of the LHCb tracking system is advancing well, and the tracking detectors will be installed at the LHCb experimental area before the end of 2006. For tracks with an energy that is larger than 12 GeV the tracking efficiency is larger than 95% while the ghost rate remains below 7%. The momentum resolution ranges between 0.35% and 0.5%, and the IP resolution is 14 μm for the tracks with the highest transverse momentum. The B-meson decay time resolution is ~38 fs.

## Reference:


[1] LHCb Technical Design Report. CERN- LHCC-2003-030

[2] K. Vervink et al. Design and performance of the LHCb Silicon Tracker. CERN-LHCb-2005-102

[3] N. Bakel et Al., CERN-LHCb 2005-105

[4] N. Dressnandt et al. Implementation of the ASDBLR Straw Tube Readout ASIC in DMILL Technology, IEEE (2000) Trans. on Nucl. Sci. 48 n4, 1239, 2000.