8 High-precision CP-violation Physics at LHCb

R. Bernet, A. Büchler, N. Chiapolini, V. Hangartner, C. Salzmann, S. Steiner, O. Steinkamp, U. Straumann, J. van Tilburg, A. Vollhardt, D. Volyanskyy, A. Wenger

in collaboration with: The silicon tracking group of LHCb: University of Lausanne; Max Planck Institute, Heidelberg, Germany; University of Santiago de Compostela, Spain; and Ukrainian Academy of Sciences, Kiev, Ukraine.

The full LHCb collaboration consists of 49 institutes from Brazil, China, France, Germany, Ireland, Italy, Netherlands, Poland, Romania, Russia, Spain, Switzerland, Ukraine, U.K., and U.S.A.

(LHCb)

LHCb (1; 2) is a dedicated B-physics experiment that is currently being set up at the new 14 TeV proton-proton collider LHC at CERN. The installation of the detector is almost completed and its commissioning is in good progress. The experiment is expected to see the first proton-proton collisions from the LHC in summer 2008.

The main goal of LHCb is to perform precision measurements of CP violating processes in the B meson systems and to search for rare B decays. These measurements provide a powerful tool to search for signs of physics beyond the Standard Model. They are complementary to the direct searches at the high energy frontier that will also be performed at the LHC. Since CP violating asymmetries are generated through processes that involve internal loops of virtual particles, they are very sensitive to contributions from the new particles that are predicted in most extentions of the Standard Model.

Figure. 8.1 shows a vertical cross section through the LHCb detector. One of the crucial tasks in LHCb is the efficient and precise reconstruction of the trajectories and momenta of the charged particles that are generated in the decays of the B mesons. The

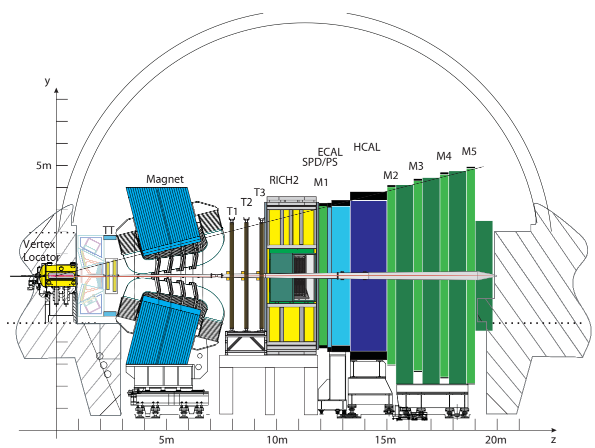

Figure 8.1:
Vertical cross section through the LHCb detector.

tracking system consists of a silicon-microstrip vertex detector (VELO) and four planar tracking stations: TT (Tracker Turicensis[4]) upstream of the LHCb dipole magnet and T1-T3 downstream of the magnet. The TT has an active area that is 160 cm wide and 130 cm high and is covered by four layers of silicon micro-strip detectors. In the much larger stations T1-T3 two detector technologies are employed: A 120 cm wide and 40 cm high region in the centre of the stations is covered with silicon micro-strip detectors (Inner Tracker,

[4]Initially, TT stood for “Trigger Tracker” since this was the only tracking station that was used in the trigger. The name was changed after a revision of the LHCb trigger philosophy, which resulted in all tracking stations being used in the trigger.

IT), whereas the outer part of these stations is covered by straw drift-tube detectors. Other components of the LHCb detector are two ring-imaging cherenkov detectors (RICH1 and RICH2), calorimeters (SPD,PS,ECAL,HCAL) and muon chambers (M1-M5).

8.1 The Zürich Group in LHCb

Our group has a leading rôle in the design, construction and operation of the LHCb Silicon Tracker, which comprises the Tracker Turicensis (2; 4) and the Inner Tracker (3).

The Tracker Turicensis was entirely developed, designed and constructed in Zürich. In addition, we have been responsible for the design specifications, the procurement and the quality control of the silicon sensors and for the design and production of the optical digital readout link for both TT and IT. A large fraction of our efforts in 2007 was spent on the installation and commissioning of the TT detector and the readout electronics in the experiment. These efforts also included the development of the slow-control software for the TT.

In addition to these contributions to the detector, we completed a simulation study in preparation for physics analyses, we continued our participation in the production of the large samples of simulated data that are necessary for these studies, and we further improved the geometry description of the TT in the LHCb simulation software.

8.2 Tracker Turicensis

The TT station (see Fig. 8.2) contains 128 detector modules that are arranged in four detection layers. All modules are housed in a common light-tight and electrically and thermally insulating detector box. During operation, an ambient temperature of around 0°C will have to be maintained in the detector volume to mitigate the effects of radiation damage. In order to avoid condensation on the cold surfaces, the detector volume is continuously flushed with a steady flow of nitrogen gas. To facilitate access for the installation and maintenance of detector modules, the box is constructed from two halves that can be retracted horizontally from the LHC beam pipe.

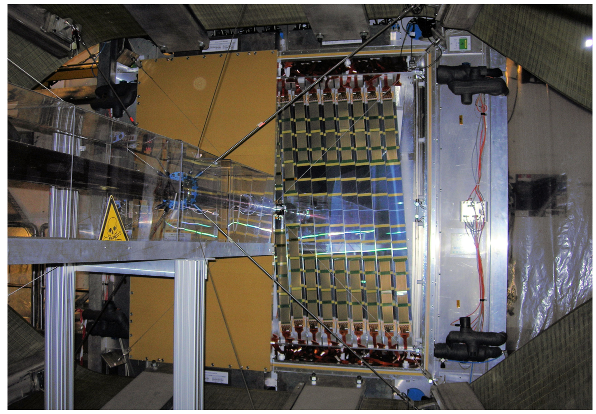

Figure 8.2: Photograph of the TT station viewed through the LHCb dipole magnet. One half of the detector box is open and the modules can be seen.

After extensive mechanical and thermal testing in Zürich, the detector box, without modules, had been shipped to CERN and installed in the experiment at the end of 2006. Throughout 2007, various tests were then performed on the still empty detector box, to commission the cooling system, to demonstrate that the design temperature can be reached everywhere in the detector volume, and to determine the flow of nitrogen necessary to avoid condensation. Automatic safeguards were implemented to protect the sensitive detector modules against potential failures of the cooling system or the nitrogen supplies.

Several geometrical surveys were performed to determine the precise positioning of the detector box in the experiment, both without and with the LHCb dipole magnet being switched on. Without magnetic field, the position of the box was found to agree with its nominal position within the measurement pre-

Figure 8.3: A. Büchler (left) and J. van Tilburg (right) during the installation of detector modules.

cision of $\pm 100\ \mu$m. However, a shift by several hundreds of micro-meters was found when the magnet was switched on, despite the fact that the detector is built from non-magnetic materials. This effect will be investigated further. Photogrammetric measurements were performed to determine and adjust the positions of the so-called balconies, on which the detector modules are mounted inside the detector volume. The results of these surveys are now being implemented in the software description of the detector geometry (see below).

The production and quality assurance of the TT detector modules was completed end of March 2007. Out of the 150 modules that were started, only two had to be rejected because of excessive leakage currents. All other modules are of detector-grade quality, such that we now have 20 spare modules of good quality on top of the 128 modules that are needed to fully equip the detector. The detailed results of the quality assurance tests were used to determine which modules to install at which position in the detector and which modules to keep as spares. Typically, the best modules were installed close to the LHC beam pipe, where particle densities are highest and where an excellent detector performance is most important for the physics goals of the experiment.

The modules were installed in several batches. After each installation campaign, bias-voltage tests and readout tests were performed. This permitted to identify and solve potential problems before the next batch of modules was installed. A few photographs from the module installation are shown in Fig. 8.3. By the end of April 2008, all detector modules were installed and more than 94% of the readout channels were fully debugged and operational.

8.3 Readout electronics

TT detector modules have either two or three readout sectors with 512 readout strips each. In total, the TT has more than 143'000 readout channels, to which 130'000 readout channels from the Inner Tracker have to be added. The analog signals from the detectors are transmitted via short copper cables to custom made electronics crates that are located at a few meters from the detectors. Here, the signals are digitised, multiplexed and prepared for optical transmission to the LHCb electronics barrack. The digitizer boards on which the processing of the signals takes place were produced in industry and then tested in Zürich. Two problems were identified on these boards, which made it necessary to go through a repair cycle at the assembly company. The first problem concerned the ADC chip, which had a much higher input bandwidth than was quoted in the data sheets, leading to an excessive sensitivity to high-frequency noise. This problem could be fixed by adding a simple first-order low-pass filter at the input of each ADC. The second problem was that a significant fraction of the VCSEL diodes was damaged during the assembly of the boards. All effected VCSELs were replaced. The digitizer boards were finally installed in the experiment in the second half of 2007.

8.4 Slow-control software

A general software framework for the slow-control of the detectors is provided by the LHCb collaboration. However, the components of this framework have to be adapted to the specific needs of the individual detectors. For example, so-called data points have to be built, which provide the interfaces to specific hardware components, user interfaces have to be defined, and a detector hierarchy has to be set up. The latter defines the interactions between different detector components and makes it possible to address and control different subsections of the detector. An important aspect of the slow-control is the handling of errors and alarms. The implementation of this software for TT is progressing well.

8.5 Physics studies

A detailed software description of the detector geometry is required for the generation of simulated data as well as for data reconstruction. The geometry description of the TT has been completely revised over the last months to provide an additional level of detail to the description of the active detector elements and to make the code more flexible and easier to maintain. For example, the new detector description makes it possible to correct for a possible mis-alignment of individual silicon sensors, whereas in the old description detector modules, consisting of several sensors, could only be aligned as a whole.

We continued to contribute to the generation of the large samples of simulated data that are required for physics studies. Using computer resources in Zürich and at the CSCS in Manno, about 2.75 Million events were generated. We also participated in the development and maintenance of the GRID software that is used to steer the world-wide data generation and analysis effort.

A Monte-Carlo simulation study of the decay mode $B_s^0 \rightarrow J/\psi\eta'$ was continued, and completed in summer 2007 (6). The time-dependent measurement of the CP asymmetry in this decay can be used to determine the phase of $B_s^0\overline{B^0}_s$ oscillations (i.e. the CKM angle χ). Since this phase is predicted to be very small in the Standard Model, it provides a sensitive probe for contributions from physics beyond the Standard Model (7). The simulation study consisted of an optimisation of the event selection criteria, followed by an estimation of the sensitivity of the experiment to the underlying physics parameters. Selection cuts were optimised using a multi-variate grid search on large samples of signal and background events. The results of this study were used to simulate a large number of toy experiments to estimate the expected sensitivity to the CKM angle χ. A sensitivity of 0.04 rad was found for one nominal year of data taking. The physics studies will be extended to other interesting decay channels, for example the rare decay $B_s^0 \rightarrow \mu^+\mu^-$.

[1] LHCb technical proposal, CERN/LHCC 998-4.

[2] LHCb Reoptimised Detector Technical Design Report, CERN/LHCC 2003-030.

[3] LHCb Inner Tracker Technical Design Report, CERN/LHCC 2002-029.

[4] Layout and expected performance of the LHCb TT station, J. Gassner, M. Needham, O. Steinkamp, LHCb note 2003-140.

[5] The Mechanical Design of the LHCb Silicon Trigger Tracker, J. Gassner, F. Lehner, S. Steiner, LHCb note 2004-110.

[6] The Trigger Tracker and a Monte Carlo Study of the $B_s^0 \rightarrow J/\psi\eta'$ Decay in the LHCb Experiment, D. Volyanskyy, PhD thesis, Universität Zürich (2007).

[7] J.P. Silva and L. Wolfenstein, Phys. Rev. **D 55** (1997) 5331.