6 High-precision CP-violation Physics at LHCb

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The full LHCb collaboration consists of 48 institutes from Brazil, China, France, Germany, Italy, The Netherlands, Poland, Romania, Russia, Spain, Switzerland, Ukraine, the United Kingdom, and the United States of America.

(LHCb)

The main goal of the LHCb experiment (1; 2) is to perform high precision measurements of CP violating processes and rare decays in the B meson systems. The comparison of results from many different decay modes will permit to perform consistency tests of the Standard Model explanation of CP violation. Since CP violating asymmetries are generated through processes involving internal loops of virtual particles, they are very sensitive to contributions from possible new particles. Precision measurements of CP violating processes therefore provide a powerful tool to search for physics beyond the Standard Model, which is complementary to direct searches at the high energy frontier. Our group concentrates on the development, construction, operation and data analysis of the LHCb Silicon Tracker and on the preparation of physics analyses.

6.1 LHCb detector

The LHCb detector is currently being installed at the new 14 TeV proton-proton collider LHC at CERN. It is foreseen to receive first beams in autumn this year and to collect first physics-quality data in 2008. A vertical cut through the detector is shown in Fig. 6.1. Since the production of b quarks at the LHC is strongly peaked towards small polar angles with respect to the beam axis, the detector is layed out as a single-arm forward spectrometer.

The LHCb tracking system consists of a silicon-microstrip vertex detector (VELO) and four planar tracking stations (TT upstream of the LHCb dipole magnet and T1-T3 downstream of the magnet). The Silicon Tracker comprises two components of the tracking system: The Trigger Tracker (TT (2; 4)) is a 160 cm wide and 130 cm high four-layer tracking station which covers the full acceptance of

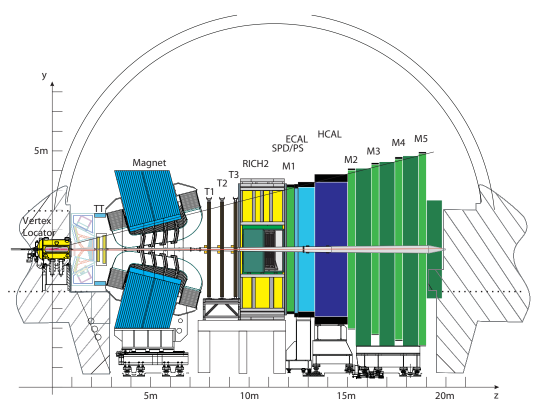

Figure 6.1:
Vertical cross section through the LHCb detector.

the experiment with long silicon micro-strip detectors. The Inner Tracker (IT (3)) also uses silicon micro-strip detectors and covers a 120 cm wide and 40 cm high region in the centre of T1-T3. The outer region of these stations is covered by straw drift-tubes. Other components of the LHCb detector are two ring-imaging Cerenkov (RICH) detectors, calorimeters (SPD,PS,ECAL,HCAL) and muon chambers (M1-M5).

6.2 Silicon tracker

Our group has taken the leading rôle in the development, production, commissioning and operation of the Silicon Tracker. The project is led by O. Steinkamp with U. Straumann as his deputy.

Within this project, the main responsibility of our group is the design and construction of the TT station. A large fraction of our efforts in 2006 was spent on the production and quality assurance (QA) of detector modules and on the assembly, testing and installation of the detector box and support frames. Both activities were completed in the beginning of 2007. Other responsibilities of our group include the design and procurement of the silicon sensors and the design and production of the optical digital readout link for both TT and IT. The last batch of silicon sensors was received and successfully tested early in 2006, whereas the production of the readout system components took place in autumn 2006.

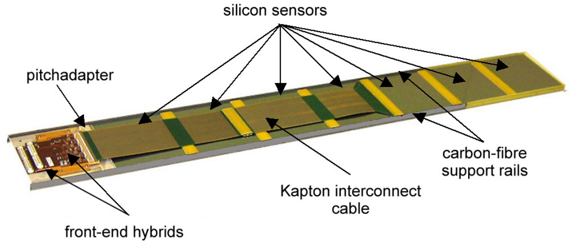

Figure 6.2: TT detector module.

6.3 Trigger tracker

A photograph of a TT detector module is shown in Fig. 6.2. The module consists of seven silicon sensors that are electronically organised into either two or three readout sectors. The front-end readout hybrids for all readout sectors are located at one end of the module, the "inner" readout sectors being connected to their readout electronics via approximately 39 cm, resp. 58 cm, long Kapton interconnect cables. The layout of a TT detection layer is illustrated in Fig. 6.3. Different readout sectors are indicated by different shadings. The areas above and below the beam pipe are each covered by a single detector module, the areas to the left and to the right of the beam pipe are covered by 14-sensor long super-modules that are formed by gluing two detector modules together end-to-end. The advantage of the chosen detector design is that it permits to keep all readout electronics and the associated dead material outside of the acceptance of the experiment.

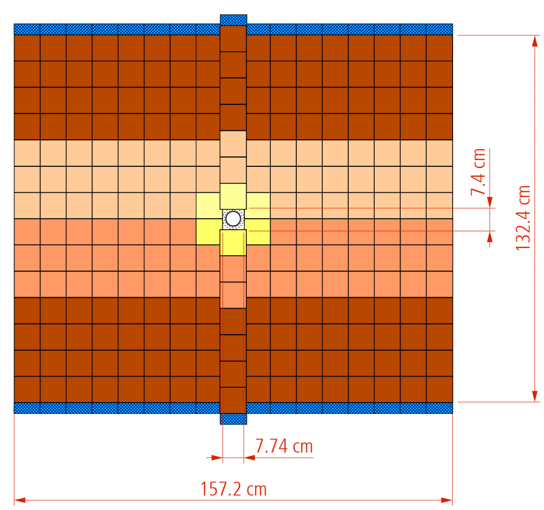

Figure 6.3: Layout of one detection layer of TT.

6.3.1 Module production and quality assurance

The series production of detector modules was launched in September 2005 and completed just before Christmas 2006. Including 15% spares, a total of 148 modules with about 165′000 readout channels has been produced. At all stages of the production, a rigorous QA programme was carried out to ensure that the modules fulfill our strict mechanical and electrical acceptance criteria (5). As part of this QA programme, each module went through at least two "burn-in" tests. These included 36h-long temperature cycling between room temperature and the foreseen operating temperature of 5°C, measurements of leakage currents as a function of temperature and applied bias voltage, of detector noise to identify faulty readout channels and readout chips, of signal pulse-shapes and of the charge collection efficiency. For the latter measurement, charge was generated at pre-defined locations in the silicon sensors using pulsed infra-red laser diodes. A total of 2 TByte of data were accumulated during these burn-in tests. They are stored in a central production data base that was set up for this purpose and permits easy access to the data and the main test results.

Figure 6.4: TT module production.

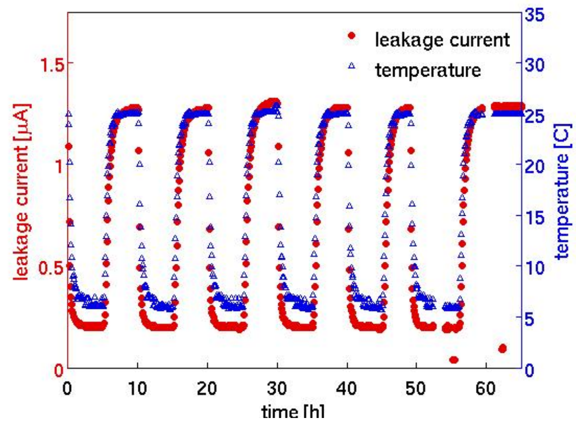

Figure 6.5: Operating temperature and leakage current as a function of time as measured during the burn-in of a TT detector module.

Based on the results of these tests, a quality grading has been established that permits to select the "best" modules for installation in the most important region of the detector close to the beam-pipe, and to assign the least good modules as spares. The module production was run by F. Lehner and T. Sakhelashvili with help from J. Gassner, the quality assurance programme was run by J. Gassner with help from D. Volyanskyy and A. Vollhardt. The production data base was set up by T. Müller and N. Chiapollini and a significant part of the data analysis was done by V. Hangartner. For the latter two, this work was part of their Bachelor theses (6; 7). A photograph from the module production and an example of one of the many measurements performed in the burn-in test are shown in Figs. 6.4 and Figs. 6.5.

6.3.2 Detector box and support rails

All detector modules will be housed in a common light-tight and thermally insulating box, which also provides electrical insulation to the environment (8). This detector box consists of two halves that are mounted onto precision rails and can be retracted from the beam pipe for detector maintenance and for bake-

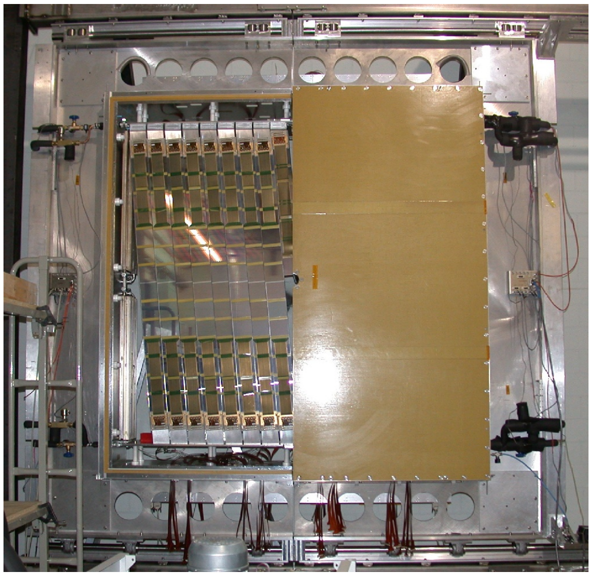

Figure 6.6: The test installation in Zürich.

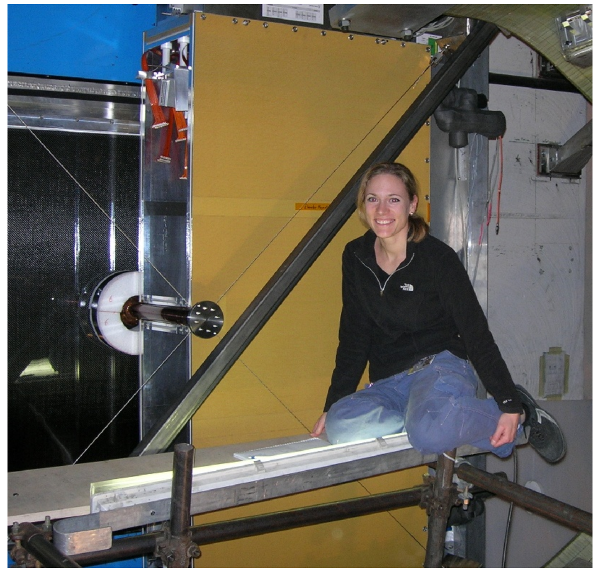

Figure 6.7: The installation in LHCb.

outs of the LHC beam pipe. To remove the heat generated by the front-end electronics and to obtain the desired ambient temperature of around 5°C inside the detector box, the box design incorporates several cooling plates through which C_6F_{14} is circulated as a cooling agent.

In summer 2006, the complete detector box including support rails was set up in our mechanical workshop and various mechanical and thermal tests were performed, including a test installation of several detector modules. The detector box was then disassembled and shipped to CERN where it was installed in the LHCb experiment in December 2006. The design and production of the station mechanics has been the responsibility of S. Steiner. The thermal tests were prepared, performed and documented by A. Büchler as part of her Master thesis (9). J. van Tilburg and S. Steiner played leading rôles in the installation of the detector box at CERN. Photographs from the test installation in Zürich and from the final installation at CERN are shown in Figs. 6.6 and 6.7.

6.4 Readout system

The analog detector signals from TT and IT are transmitted via short copper cables to so-called Service Boxes, where they are digitised, multiplexed and prepared for optical transmission to the LHCb electronics barrack. The Service Box crates and the "digitizer boards" on which the processing of the signals takes place have been produced and are currently being tested in the laboratory in Zürich. Their installation in the experiment is foreseen for spring 2007. The design, production, testing and commissioning of the readout link for TT and IT is the responsibility of A. Vollhardt.

6.5 Detector simulation and reconstruction software

In addition to the hardware activities described above, we continued our involvement in software activities on the Monte-Carlo simulation of the Silicon Tracker and on algorithms for track reconstruction and detector alignment. Main achievements were the implementation of a more robust algorithm for track fitting and an upgrade of the track reconstruction software to be able to cope with mis-aligned detectors. J. van Tilburg has been a main contributor to these LHCb-wide activities.

6.6 Physics studies

Monte-Carlo simulation studies for the decay mode $B_s^0 \rightarrow J/\psi\,\eta'$ have been continued. 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 "new" physics beyond the Standard Model [10].

The goal of our simulation study is to optimize event selection criteria and to estimate the sensitivity of the experiment to the underlying physics parameters. Selection cuts have been further optimised using a multi-variate grid search and larger samples of generated background events. The chosen set of cuts results in an estimated annual signal yield of about 4 k reconstructed events and an upper limit on the background-to-signal ratio of around 0.4 at 90% confidence level. The results of this Monte-Carlo study have then been used to simulate a large number of toy experiments and estimate the expected sensitivity of LHCb to the CKM angle χ. For the statistics corresponding to one nominal year of data taking the sensitivity was found to be 0.04 rad [11]. This physics study has been undertaken by D. Volyanskyy who is currently finishing his Ph.D. thesis under the guidance of J. van Tilburg and U. Straumann.

6.7 Summary and outlook

The series production of detector modules for the Trigger Tracker has been completed. An extensive quality assurance programme has been performed on all modules and the quality of the produced modules has been found to be excellent. The Trigger Tracker detector box has been assembled, tested and installed in the experiment. The readout electronics boards for Trigger Tracker and Inner Tracker have been produced, testing of these boards will be completed soon.

Software developments for detector simulation and reconstruction algorithms are ongoing as well as simulation studies in preparation for physics analyses.

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