Characterisation and commissioning of the LHCb VELO detector

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2009

Summary

The Large Hadron Collider (LHC) is a 27 km long circular proton accelerator outside Geneva, Switzerland. Protons are injected into the clockwise and anti-clockwise directions of the ring and accelerated to a momentum of 7 TeV/c. When filled, the LHC contains 3×10^{14} circulating protons, equivalent to a beam current of 0.584 A.

At four interaction points along the ring, the protons are brought to collision every 25 ns, i.e. 40 million times per second per interaction point. As the protons are smashed together at energies unprecedented in a laboratory the kinetic energy of the protons transforms into mass, and new particles can emerge that are heavier than the proton. These new particles are highly unstable, and decay within very short time spans.

One of these particles is the b-quark. It is an elementary particle of nature and a heavier type of quark than those that make up protons and neutrons. The b-quark decays within approximately 1.6 ps and during this period it travels about 1 cm from the point of production. By studying the decay products, fundamental questions about matter and antimatter may get an answer.

LHCb is one of the four experiments at the LHC. Its design is optimised for precision studies of the b-quark. One of the detectors of the LHCb experiment is the Vertex Locator (VELO), which measures the trajectories of b-quark decay products with micrometre precision using the technology of silicon strip sensors. The research described in this thesis focuses on the performance characterisation and commissioning of the VELO detector.

Chapter 3 describes a test of the performance of near-final prototype silicon sensors in a beam of charged particles. This was the last beam test in the R&D phase and the results were used as main input for the final design decisions. The Signal-to-Noise (S/N) ratio of the detector was investigated for three different versions of the Beetle front-end readout chip. It was found that the S/N of a 200 μm thick sensor was in the range 16.2 – 17.1. In another study systematic errors in the position measurement were investigated.

Chapter 4 gives a detailed report of a system test in which a quarter of the final detector was placed in a charged particle beam and read out with the final data acquisition system. The test was a first step of the commissioning of the VELO. The performance of the silicon sensors was investigated and the vertex reconstruction capability of the detector was put to test with a fixed target setup specifically designed to emulate a set of conditions present during LHC operation. The S/N of the 300 μm thick sensors was shown to be in the range $21.4 - 23.9$ for R-sensors and $23.9 - 29.5$ for the Φ-sensors. This is in good agreement with measurements of the S/N of prototype VELO sensors, and better than the requirements.

The resolution of the position measurement for particles with 0° incidence angle was shown to be in the range $8.5\,\mu$m$-21.5\,\mu$m for an R-sensor in the pitch range $40\,\mu$m$-90\,\mu$m. The resolution can be expressed as a function of the strip pitch by $8.5 + 0.26 \times (pitch - 40)\,\mu$m.

In the vertex performance study the beam was aimed at a set of lead targets rendering tracks from secondary particles through the detector. These tracks were combined into vertices and used in a detailed analysis. By developing a model for the target distributions, the edges of the targets and the vertex precision could be successfully extracted from the data. The reconstructed edges were shown to agree with the metrology measurements within errors. The resolution, which was expected to be considerably worse than for the LHC conditions, was measured to be in the range $100 - 300\,\mu$m for x and y.

Chapter 5, documents the commissioning of the VELO and its readout system after the detector installation in the experimental area of LHCb. The chapter reviews the software tools that were developed for commissioning and data quality checking and describes the most important steps of the Data Acquisition System commissioning. As part of the commissioning, the performance integrity of the sensors was verified by an examination of their noise characteristics. The results of this analysis yielded an average noise of 2.06 and 1.89 ADC counts[2] for the R- and Φ-sensors respectively. Furthermore, an investigation to determine differences in raw and common mode corrected noise levels between individually and collectively powered modules showed no effects of significance.

The final section briefly describes results from the first injection of a counter-clockwise beam into the LHC. By taking data with 15 consecutive triggers the VELO could be properly time-aligned with respect to the L0-trigger supplied by the SPD, and tracks through the detector were successfully reconstructed for the first time after the VELO was installed.

[2] Corresponding to an equivalent noise charge of approximately 900 and 830 electrons.