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First spatial alignment of the LHCb VELO and analysis of beam absorber collision data

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ABSTRACT

A first alignment of the LHCb Vertex Locator has been obtained from beam induced tracks at the LHC. A 450 GeV/c protons were collided on a beam absorber during the LHC synchronisation tests of the anti-clockwise beam in August and September 2008. The resulting particle tracks have been reconstructed by the Vertex Locator. This was the first full reconstruction of tracks induced by the LHC beam. The quality of the data obtained is discussed. A total of 2200 tracks were reconstructed from the full data sample, and a first spatial alignment was obtained. The detector is aligned to an accuracy of 5 μm in the sensor plane. The results confirm that all detector modules have not been displaced from their surveyed positions by more than 10 μm.

1. Introduction

The Large Hadron Collider (LHC) at CERN will collide bunches of up to 10^{11} protons (and 7×10^{7} heavy ions) at a centre of mass energy up to 14 TeV (5.5 TeV) and a design luminosity up to $10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$ ($10^{27}\,\mathrm{cm^{-2}\,s^{-1}}$). The four large detectors [1–4] are currently in their commissioning phase. Cosmic ray tracks have been observed in multiple sub-systems of the LHC experiments from 2006 onwards, and regular data taking of cosmic rays in several sub-systems of the experiments took place during 2008 as the final construction of the experiments was completed. The data have been used for the sub-detector calibration and alignment [5–7]. However, as explained below, the layout of the vertex detector is not conducive to being commissioned *in situ* with cosmic rays. This paper reports on data quality checks and spatial alignment of the VELO based on data from LHC injection tests.

The alignment of each detector is crucial in reaching the required tracking performance in all LHC experiments. Typically, the initial alignment is evaluated by survey measurement at different stages of the assembly, and the final alignment procedure is based on track reconstruction [8]. The first evaluation of the track based alignment of the LHCb vertex detector has been performed with data recorded during the beam commissioning.

The LHCb experiment is dedicated to heavy flavour physics and it has been primarily designed to study CP violation and other rare phenomena in b-hadron decays. For a nominal luminosity of

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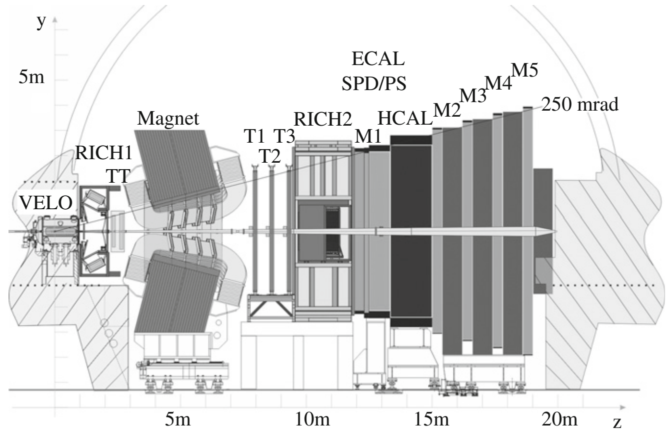

Fig. 1. The LHCb detector setup with the different sub-detectors in the longitudinal plane. The Vertex Locator is shown on the left-hand side of the diagram and the other sub-detectors of the spectrometer are indicated.

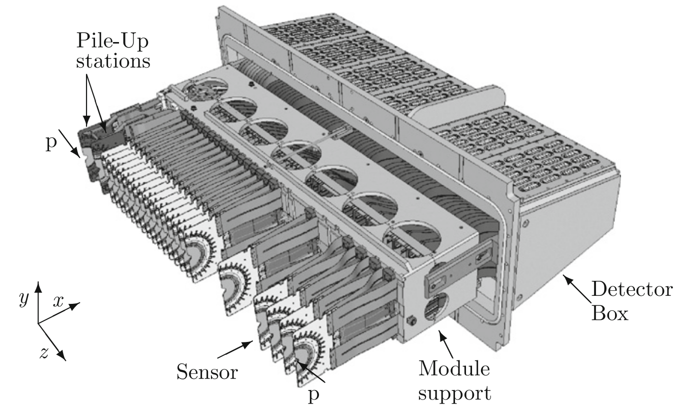

Fig. 2. Overview of the VELO left half. The sensors, module supports and detector box are indicated.

$2\times10^{32}\,cm^{-2}\,s^{-1}$ and for collisions at a centre-of-mass energy of 14 TeV, the expected production yield of $b\overline{b}$ quark pairs is about 10^{12} per year. LHCb (shown in Fig. 1) is a forward-angle spectrometer with an angular coverage of 15–300 mrad. The track reconstruction [10] near the interaction point is performed by the silicon microstrip VErtex LOcator (VELO) [9] which is positioned around the primary impact point. The VELO provides precise tracking coordinates to reconstruct the position of the primary vertex and identify the displaced vertices, which are a distinctive feature of b-hadron decays. The LHCb trigger system uses the collected data to enrich the b-content of the selected events in the high level trigger. The tracking system consists also of a silicon microstrip detector, named the Tracker Turicensis (TT) in front of the spectrometer magnet, and three tracking stations behind the magnet. The tracking system is expected to give a precision on reconstructed B hadron masses of 15–20 MeV/c^2 and a proper time resolution of about 40 fs. The Cherenkov detector system (RICH1 and RICH2) provides excellent π/K separation in the momentum range between 2 and 100 GeV/c: the average efficiency for kaon identification is $\varepsilon(K\rightarrow K)\sim95\%$ with a corresponding average pion misidentification rate $\varepsilon(\pi\rightarrow K)\sim5\%$. The calorimeter system (PS, ECAL, HCAL) and the muon chambers provide electron and muon identification, respectively. The particle identification is essential for signal selection and background rejection in many exclusive B channels as well as for flavour tagging.

Synchronisation tests of the LHC beam were performed in August and September 2008. During the initial phase of each test, a beam containing single bunches of protons was collided with a beam absorber in the transfer line between the CERN Super Proton Synchrotron (SPS) and the LHC. LHCb detectors measured some of the particles produced by the proton interactions in the absorber and by their re-interaction. This test provided the first reconstructed tracks after installation. The data sample has been extensively used for commissioning the detector and the first alignment of the VELO has been obtained with this sample.

The VELO has fully reconstructed about 2200 tracks traversing the detector. This sample provided the first opportunity to optimise the ADC sampling time of the sensors with respect to the SPS/LHC clock. The data reconstruction parameters had also not been optimised before these runs. In this paper the quality of the data sample obtained is discussed, and the improvements obtained by optimising the reconstruction parameters are presented. The results of aligning this detector are then provided.

This paper is structured as follows: a brief description of the VELO and of the commissioning is given in Section 2; the synchronisation test is described in Section 3 and the VELO data taking configuration in Section 4; the calibration of the VELO timing is then discussed in Section 5; the track reconstruction is presented in Section 6; Section 7 illustrates the results obtained by offline reprocessing of the data with the correct parameters for the data acquisition boards; Section 8 describes the module alignment results; the measured spatial resolution of the VELO is shown in Section 9; Section 10 summarises the main conclusions.

2. VELO description and commissioning

The VELO consists of two detector halves. The so-called "A-side" and "C-side" correspond to the positive and negative x halves,[1] respectively (shown in Fig. 2). Radial and azimuthal hit coordinates are provided by 21 modules, each contains R and Φ semi-circular n^+-on-n silicon sensors perpendicular to the beam-axis. In addition, each half contains two Pile-Up veto stations used by the trigger system to reject events with more than one interaction. The detectors are operated in vacuum. The LHC beam vacuum is separated from the detector vacuum by 300 μm thick aluminium foils mounted on each side for RF shielding and protection of the primary LHC vacuum from detector outgassing.

The large flux of secondary particles produced in the collisions constitutes an extreme radiation environment with highly non-uniform particle fluences across the VELO sensors: the maximum fluence at nominal luminosity has been estimated to 1.4×10^{14} MeV neutron equivalents/cm^2 per year. The VELO cooling system is designed to absorb the heat generated in the sensor electronics and to minimise radiation induced effects in the silicon sensors by maintaining them at a temperature below $-5\,^{\circ}$C.

The VELO halves are movable to the aperture required for the operation of the LHC machine. During collisions at 7 TeV, the halves are closed and the sensors overlap by a few millimetres to form complete circles with a radius of 7 mm. However, the required LHC aperture increases during injection and energy ramping, and the detector halves have to be retracted by 30 mm from the beam axis. This is achieved with a precise motion system capable of positioning the VELO in the x- and y -directions with an accuracy of 10 μm. The same system can correct for variations of the beam position from fill to fill. The online imaging of the beams

[1] The coordinate system is shown in Fig. 2. The origin is the nominal interaction point, the x-axis is horizontal, and points from the interaction point towards the outside of the LHC ring. The y-axis is perpendicular to the x-axis and to the beam line and points upwards. The z-axis point from the interaction point towards the LHCb detector and is aligned with the beam direction, to create a right-handed Cartesian coordinate system.