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Performance of the LHCb vertex detector alignment algorithm determined with beam test data

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ABSTRACT

LHCb is the dedicated heavy flavour experiment at the Large Hadron Collider at CERN. The partially assembled silicon vertex locator (VELO) of the LHCb experiment has been tested in a beam test. The data from this beam test have been used to determine the performance of the VELO alignment algorithm. The relative alignment of the two silicon sensors in a module and the relative alignment of the modules has been extracted. This alignment is shown to be accurate at a level of approximately 2 μm and 0.1 mrad for translations and rotations, respectively, in the plane of the sensors. A single hit precision at normal track incidence of about 10 μm is obtained for the sensors. The alignment of the system is shown to be stable at better than the 10 μm level under air to vacuum pressure changes and mechanical movements of the assembled system.

1. Introduction

As part of the LHCb VELO [1] detector commissioning, a beam test experiment with a partially equipped system was conducted. This paper reports on the results obtained when applying the VELO alignment algorithm to the data collected. The alignment of the LHCb VELO is particularly critical due to the high precision required from the VELO for the physics programme of the experiment, the on-line use of the VELO in finding displaced vertices in the trigger system, and the requirement that the detector is retracted and re-inserted between each fill of the LHC machine. The alignment procedure is described in Ref. [2].

An overview of the detector setup used during the beam test is provided in Section 2. The performance of the alignment algorithm is assessed in Section 3 through the analysis of track residuals and a comparison of the results with the metrology survey of the modules. Section 4 reports the impact of the alignment on the detector performance. It covers the diagnosis of a cluster position reconstruction bias due to cable cross-talk, the analysis of the alignment effect on the reconstruction of track vertices, and the determination of the resolution of the sensors. As the detector will be operated in vacuum and will be retracted and re-inserted for each LHC fill [3], the stability of the alignment under pressure variations and mechanical movements is reported in Section 5. Section 6 summarises the main conclusions.

2. Beam test setup

A partially equipped VELO detector half was tested in November 2006 in a 180 GeV/c hadron and muon beam at the CERN SPS. The mechanical suspension, cooling system and vacuum operation were designed to provide a good representation of the conditions expected from the final experiment. Ten of the 21 modules in one half of the detector were installed in their final setup. Each VELO module contains two approximately

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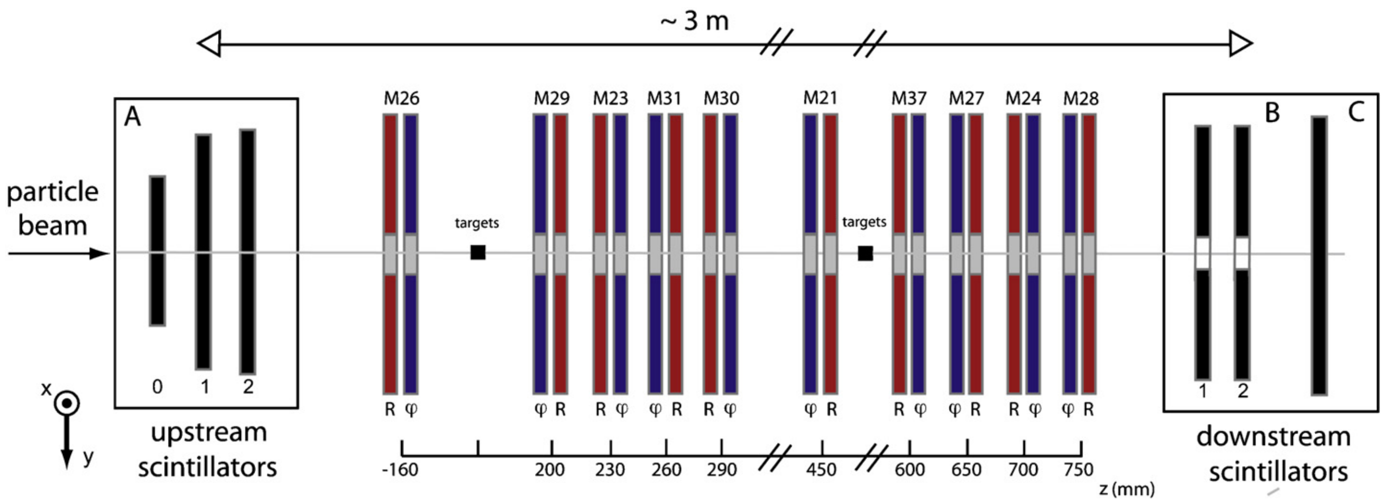

Fig. 1. Schematic top view of the beam test setup. A total of 10 modules were mounted in the detector half. The module numbers are indicated and the location of the *R* and Φ sensors in the modules. The location of the targets is also shown.

semi-circular silicon sensors: one with strips that are sectors of a circle, known as the *R* sensor; and one with pseudo-radial strips, known as the Φ sensor. The strips on the Φ sensor are divided into an inner and outer sector with a positive and negative stereo angle, respectively.

Six out of the 10 installed modules were readout simultaneously. Data were taken with several different cabling configurations for the module readout. Particles were observed directly from the beam or from interactions of the beam with a series of targets. The 1 mm radius 300 μm thick circular lead targets were installed to represent the primary vertex location that will be obtained in the final experiment. Fig. 1 shows a schematic overview of the mounted modules. The coordinate system used, as indicated, is equivalent to that used in the final LHCb detector.

The electronic read-out system and prototype data processing algorithms of the final experiment were applied. Analogue information is obtained from each channel and digitised to 10-bit precision. Pedestal subtraction and common mode suppression algorithms were applied. In addition it was found that it was necessary to remove cable cross-talk effects, see Section 4.1, for which a Finite Impulse Response (FIR) filter was used. A clustering algorithm with a weighted pulse-height centre calculation was applied. In the final experiment these algorithms will be applied in firmware in field programmable gate arrays, here a bit-perfect C-emulation of these algorithms has been used. The detector half was operated under vacuum (10^{-3} mbar) with modules cooled down ($<0\,^{\circ}$C).

3. Alignment quality

3.1. Alignment algorithm

The LHCb VELO alignment algorithm is presented in Ref. [2]. The alignment proceeds in three stages: the relative alignment of the *R* and Φ sensors inside a module; the relative alignment of the modules inside a detector-half; and the relative alignment of the two detector-halves. The results of applying the first two stages of the procedure are reported here.

The relative alignment of the *R* and Φ sensors inside a module is extracted from a fit to the distribution of track residuals as a function of the ϕ co-ordinate, that is from the characteristically curved shapes that are shown in Fig. 2. The relative alignment of the modules inside a detector half is determined by a non-iterative matrix inversion technique. The residuals are expressed as a linear function of both the individual track parameters and the module alignment constants. The alignment constants are extracted through the inversion of only the components of this large matrix that involve these alignment constants.

The results presented here used the data from two read-out cabling configurations and primarily use data in which the beam passed through the targets, as this contained a complimentary set of tracks both perpendicular and at small angles to the sensors.

The relative positions of the *R* and Φ sensors inside the individual modules and the relative position of the modules were initially assumed to be at their nominal design positions. Corresponding alignment constants were applied as the starting point for the alignment procedure. The software algorithms to determine the relative alignment of the *R* and Φ sensors and the relative alignment of the modules were then applied and the results are presented in the following sections.

3.2. Residual distributions

The observed signals on sensor strips are used to determine the best estimate of the hit cluster position. The hits on the sensors (other than those in the module under study) are fitted to produce tracks. These tracks are extrapolated to obtain the track intercept point in the sensor under study. The unbiased residual is then defined as the perpendicular distance between the track intercept point and the line parallel to the strip at the observed cluster position. Consequently, these residuals are sensitive to sensor misalignments perpendicular to the strip direction.

The distribution of the residuals across the sensor surface is sensitive to misalignments. For example, as described in Ref. [2], plotting the Φ and *R* sensor residuals as a function of the ϕ co-ordinate gives direct information on the relative *x*, *y* translations of the sensors. In the case of a perfect alignment these distributions should be flat when plotted against any co-ordinate variable.

Fig. 2 shows the distribution of residuals on the Φ sensor plotted against the ϕ co-ordinate before the alignment procedure has been performed assuming the alignment constants are as in the nominal detector design. The results after applying the alignment procedure are shown in Fig. 3. Equivalent results were obtained for *R* sensors. As expected, applying the alignment information results in reducing the deformations in the distributions (which result primarily from the *x* and *y*