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Observations of sensor bias dependent cluster centroid shifts in a prototype sensor for the LHCb Vertex Locator detector

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Abstract

We present results from a recent beam test of a prototype sensor for the LHCb Vertex Locator detector, read out with the Beetle1.3 front-end chip. We have studied the effect of the sensor bias voltage on the reconstructed cluster positions in a sensor placed in a 120 GeV pion beam at a 10° incidence angle. We find an unexplained systematic shift in the reconstructed cluster centroid when increasing the bias voltage on an already overdepleted sensor. The shift is independent of strip pitch and sensor thickness.

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Keywords: Vertex detector; Silicon micro strip; Ballistic deficit; Beam test; Detector alignment

1. Introduction

The Vertex Locator (VELO) is one of the silicon tracking detectors in the LHCb detector, designed for operation at the Large Hadron Collider (LHC) at CERN. The LHCb detector is a one arm spectrometer designed to measure CP-violation in the B-system and detect rare B-decays. The VELO consists of 84 half circle shaped n-on-n micro strip sensors with R and ϕ geometry. The active region starts at 8.2 mm from the beam and extends to 42 mm. The strip pitch of the R-sensors increases linearly with the radius, from 40 to 101 μm. The VELO and LHCb experiment are described in detail in Refs. [1,2].

The main purpose of the VELO is the reconstruction of primary and secondary vertices. For this, excellent experimental accuracy is needed, which can only be achieved with an accurate alignment of the VELO sensors. In this paper we present results from beam tests of two unirradiated VELO sensors. We observe problems in the sensor alignment that may show up during LHCb running, unless the origin of the problems is understood.

2. Experimental setup

Two unirradiated R-measuring prototype sensors of 200 and 300 μm thickness (hereafter referred to as R200 and R300) were read out with Beetle1.3 front-end (FE) chips [3] set to a peaking time of about 25 ns. The depletion voltage of the 200 μm (300 μm) sensor is measured to be 34 V (55 V). At 100 V bias the average drift time of the electrons is expected to be 4 ns (8 ns), which is well below the peaking time of the FE chip. The sensors were placed in the SPS 120 GeV pion beam in the X7 area at CERN. One quarter of a sensor was read out, covering the full pitch range. A separate beam telescope [4] provided the tracks. The use of a scintillator trigger asynchronous to the Beetle sampling clock enables full pulse shape determination. Each event was stamped with a TDC time value, which can be used offline to select events that were sampled at their peak signal value.

The normals to the sensors were positioned at a 10° angle of incidence relative to the beam. Data were recorded at 100, 200 and 300 V sensor bias, consecutively and without applying any other change to the experimental setup.

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3. Analysis

The analysis is performed within the framework of VeloTB [5], a software package developed for VELO beam tests. It provides tools for track reconstruction, alignment, clustering and histogram generation. The histograms are saved in a Root file [6].

The track algorithms are described in detail in Ref. [7]. Clusters are seeded by strips that pass a Signal-to-Noise (S/N) threshold of 6. Neighbouring strips passing a threshold of 10% of the seeding strip S/N value are added to the cluster. The cluster size is limited to 5 strips but at 10° beam incidence angle the vast majority of the clusters are 1 or 2 strip clusters. The cluster position is calculated using the weighted mean of the strip positions with respect to their charge, taking advantage of charge sharing in the sensor to increase the position resolution. The track residual is defined as the distance between a cluster centre and the track intercept point on the sensor as determined by the telescope. We use the standard deviation of a Gaussian fit to the residuals distribution as a measure of the spatial resolution of our detector.

The alignment is done by minimising a χ^2 built from the residuals between track intercept points and clusters. The χ^2 is minimised using an iterative technique implemented using Minuit [8]. The positions of the telescope and the sensors were kept unchanged during the entire data taking period. We therefore perform the alignment using the 100 V data and use the outcome in the analysis of the 200 and 300 V data. Due to alignment problems, the strips in the fine pitch region (40–50 μm) are not included in the analysis.

The full data sets contain about 310 000, 410 000 and 470 000 events at 100, 200 and 300 V, respectively. To minimise the presence of noise clusters in the analysis only events passing a ±5 ns TDC-cut around the peak of the pulse shape[1] are included. Clusters with or adjacent to dead or noisy strips are excluded. Only events with tracks that point to a fiducial region of the sensors are included. To correct for cross talk in the setup a digital signal filter[2] is applied to the data offline.

4. Results

A Gaussian function is fitted to the track residuals distribution and the fitted mean value is plotted versus the radius of the strips. Figs. 1(a) and (b) show this for the different bias voltages and two sensor thicknesses. The standard deviation of the residuals distribution ranges from 10 to 25 μm, depending on strip pitch region. The fitted mean of a perfectly aligned sensor[3] should be 0. The crucial observation is that the 200 and 300 V points show a shift towards negative values. The shift looks constant in the entire radial range[4] of the sensor. The residuals mean shift relative to the 100 V data is shown in Fig. 2. The average shift at 200 V bias for a R200 (R300) sensor is 3.6 ± 0.1 (3.6 ± 0.1) μm, and at 300 V 8.1 ± 0.1 (8.9 ± 0.1). From first-order polynomial fits to the data points of Fig. 2 no significant pitch dependence can be deduced. Of interest is also the observation that the standard deviation of the residual distributions does not change between the sensor bias settings.

Based on the absence of any time dependence of the residuals mean within each data set, we can exclude the possibility that slow sensor displacement is the source of the apparent shift. We therefore believe that the shift is directly related to the change in sensor bias. The possibility of sensor displacements due to electrostatic forces related to the sensor bias can not be excluded but a more plausible explanation is that the shift is due to a change of conditions in the silicon.

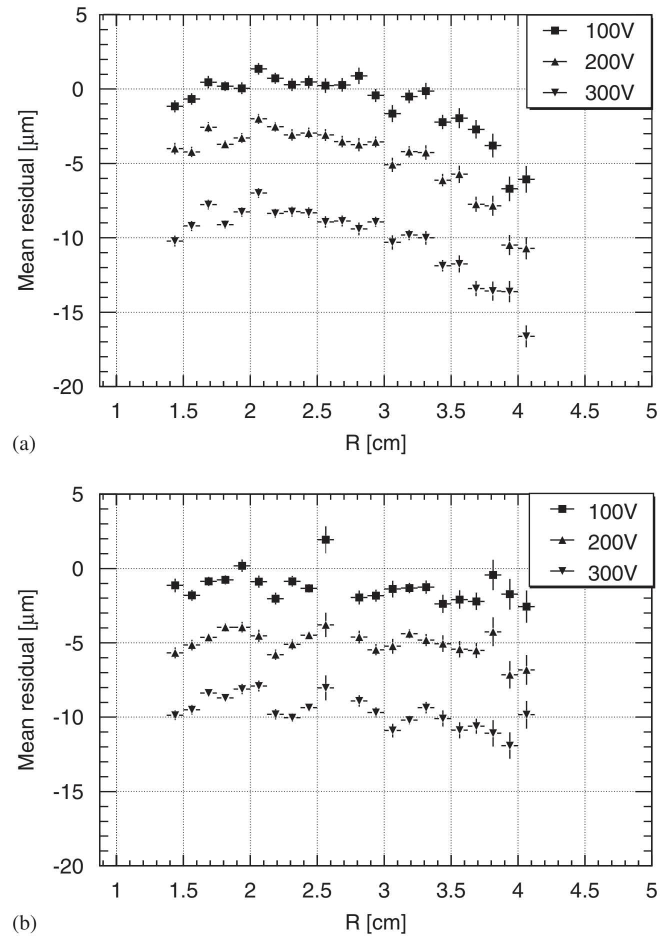

Fig. 1. The residuals mean versus strip radius for the R200 (a) and R300 (b) sensors. The error bars represent the statistical error on the fitted mean. The lack of the data points around 2.7 cm radius in (b) is due to a dead read out chip.

[1] The pulse peaking time is about 25 ns.

[2] The filter is a fifth order Finite Impulse Response filter, the coefficients of which are based on beam measurements.

[3] The reasons behind the "banana" shape of the R200 sensor are not yet fully understood. One hypothesis is that it is due to a warped sensor.

[4] We remind the reader that the strip pitch increases with the radius.