# Performance of the LHCb VELO

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**Abstract**

LHCb is a dedicated experiment to search for new physics in the decays of beauty and charm hadrons at the Large Hadron Collider (LHC) at CERN. Measurement of the flight distance of these hadrons is critical for the physics programme. The Vertex Locator (VELO) is a silicon micro-strip detector which surrounds the LHCb interaction point and provides µm resolution of charged tracks and vertex positions. The VELO has been run successfully for the 2010 and 2011 LHC physics runs. Operational results show a signal to noise ratio of approximately 20 and a best hit resolution of 4 µm.

*Key words:* Tracking detectors, Silicon Micro-Strip, LHCb, VELO, LHC, Vertex
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## 1. Introduction

LHCb is a single arm spectrometer designed to take advantage of the production of $b\bar{b}$ and $c\bar{c}$ pairs at small angles to the beam axis[1]. The main focus of the LHCb physics programme is to study new physics in the decays of beauty and charm hadrons. Analysis of the decays of these particles often requires precise measurement of the decay length, therefore precise determination of the primary vertex (PV) and secondary decay vertex positions are required. The vertex measurement at LHCb is performed by the Vertex Locator (VELO) sub-detector, which is positioned around the interaction region of LHCb.

The VELO is a silicon micro-strip detector made up of two detector halves, each containing 44 semi-circular silicon strip sensor planes. When the LHCb is recording collision data, the active area of the silicon sensors is positioned only 8 mm from the beamline and extends out to 42 mm. For protection during the proton injection of the LHC the VELO halves can retract by 3 cm. The VELO sensors come in two types, one which measures the radial distance from the beamline, R, and one which measures the azimuthal angle, $\phi$. These sensors are arranged in 42 pairs (called modules), 21 on each side, along the beamline allowing measurement of both co-ordinates at the $z$-position of each module. There are also 4 pile-up veto modules located upstream of the interaction region which contain only an R sensor. The majority of sensor planes are made from 300 µm n-on-n silicon containing 2048 strips with pitch varying between 40 µm and 100 µm.

## 2. VELO Performance

### 2.1. Hit Resolution

The resolution of hits on the VELO sensors is dependent on the geometry of the strips on the sensors. When charge created by a particle traversing the sensor is collected by only one strip ('binary' situation), only the position of that strip is known. However, when the charge is shared between several strips the charge distribution can be used to determine the position more precisely [2]. Smaller strip pitch increases the likelihood of this charge sharing allowing for more precise resolution. Larger projected angles also cause the charge to be spread more evenly through the sensor. The results of measurement of the hit resolution using 2010 data are shown in Fig. 1. The trends in varying strip pitch and projected angles agreed with expectations and the best resolution obtained was 4 µm. This is considerably better than the binary situation and is the best vertex detector resolution at the LHC.

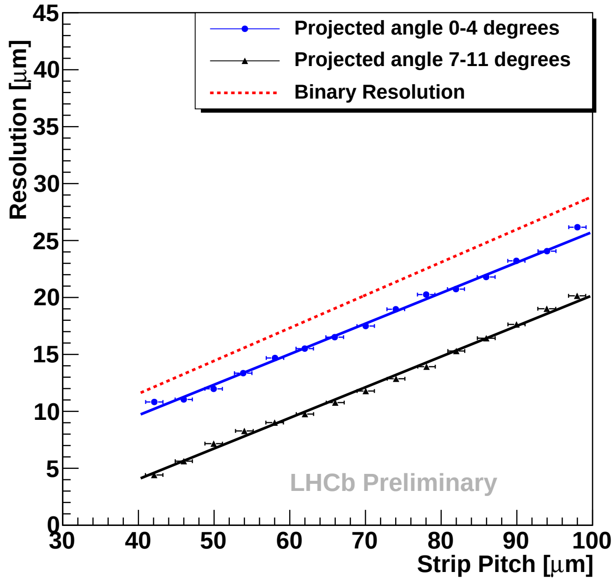


Figure 1: Resolution of the hits on an R-sensor vs. strip pitch for two bins of projected angle. The dashed line indicates the binary resolution for digital detector behaviour.

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## 2.2. *Primary Vertex and Impact Parameter Resolution*

The PV resolution is important for accurately separating the PV from the secondary vertices. Fig. 3 shows the resolution of the $x$ and $y$ co-ordinates of the PV plotted against the number of tracks. For a typical PV made from 35 tracks, resolutions of $\sigma_{x,y}$ =12 µm and $\sigma_z$ = 65 µm were measured, showing excellent performance of the VELO.

The Impact Parameter (IP) is the distance of closest approach of a track to the PV and is widely used in selections and the LHCb trigger to identify long lived particles such as beauty hadrons and reject short lived background. The main contributions to the IP are the single hit resolution, and the amount of multiple scattering before detection. Fig. 2 shows the IP resolution plotted against the $1/p_T$ of the track, with an intercept of $\sigma_x$ = 12.6 µm. The IP resolution here is indicative of the VELO's excellent resolution performance, achieving < 35 µm IP resolutions for $p_T$ > 1 GeV tracks.

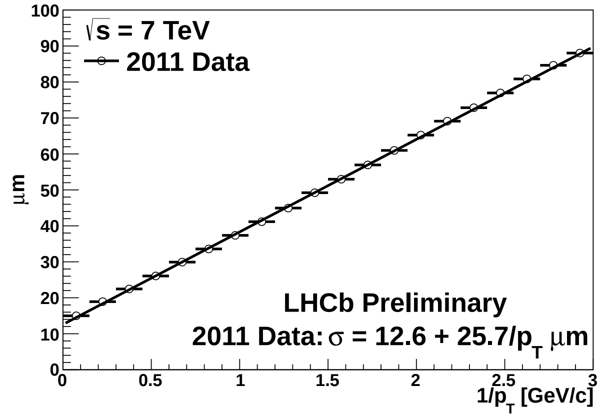


Figure 2: Resolution of the $x$ co-ordinate of the impact parameter vs. $1/p_T$ tracks used in the fit from 2011 data.

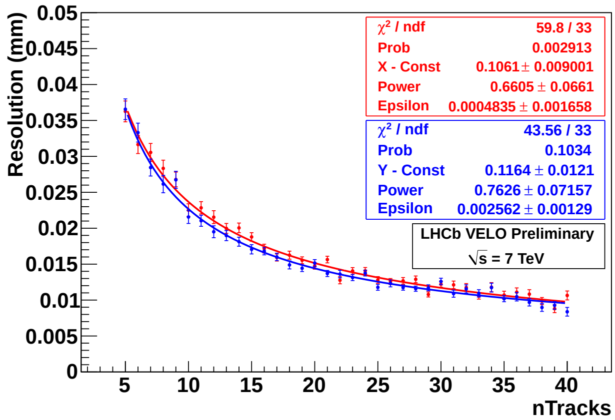


Figure 3: Resolution of the $x$ and $y$ co-ordinates of the reconstructed PV vs. the number of tracks used in the fit from 2011 data.

## 2.3. *Signal vs. Noise*

As described in the introduction, the VELO has both R and $\phi$ sensors. To bring the signal from the strips to the processing electronics at the periphery of the sensor, a second metal layer is used. This second layer is isolated from the first by a 3 µm thick $SiO_2$ layer. Due to the organisation of these metal routing lines and their extra capacitance, the noise is dependent on the type of sensor as well as the position on the sensor. Fig. 4 shows the variation of the signal to noise (S/N) ratio as a function of radius. For R sensors the noise increases with radius, with the minimum S/N measured being ∼ 17.

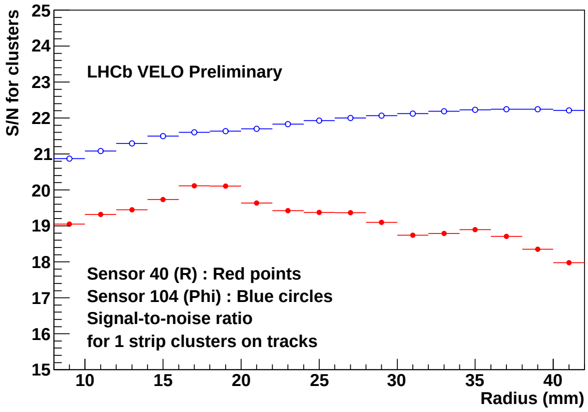


Figure 4: Signal vs. Noise for R and $\phi$ sensors for 1 strip clusters plotted against sensor radius.

## 3. Summary

The VELO has been operated successfully for the 2010 and 2011 data taking, and continues to do so in 2012. The performance has been excellent, with a best hit resolution of 4 µm and PV resolution of $\sigma_{x,y}$ =12 µm for 35 track PVs. The signal to noise ratio also continues to be impressive with an average value of ∼ 20. Radiation damage to the sensors has also been investigated and is reported elsewhere in these proceedings.

## References

[1] The LHCb Collaboration, The LHCb Detector at the LHC, JINST 3 S08005 (2008)

[2] E. Belau et al., Charge Collection in Silicon Strip Detectors, Nucl. Instrum. Meth., 214 (1983) 253-260