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First LHC beam induced tracks reconstructed in the LHCb VELO

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Abstract

The Vertex Locator of the LHCb experiment has been used to fully reconstruct beam induced tracks at the LHC. A beam of protons was collided with a beam absorber during the LHC synchronisation test of the anti-clockwise beam on the weekend 22^{nd}-24^{th} August 2008. The resulting particles have been observed by the Vertex Locator. The LHCb Vertex Locator is a silicon micro-strip detector containing 21 planes of modules. Tracks were observed passing through up to 19 modules (38 silicon sensors). A total of over 700 tracks were reconstructed, and are being used to study the calibration and alignment of the detector.

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1. Introduction

The large hadron collider (LHC) accelerator at CERN and its four large detectors (ALICE, ATLAS, CMS, and LHCb) are currently being commissioned in preparation for the start of physics data taking. 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 many subsystems of the experiments has proceeded during 2008 as the final construction was completed.

The LHC accelerator is also being commissioned. The LHC's clockwise beam transfer system was tested on the 8$^{\text{th}}$ August 2008, when particle bunches were sent through the transfer line from the SPS to the LHC and through the ALICE experiment. The anti-clockwise beam synchronisation test occurred on 22$^{\text{nd}}$ August when single proton bunches were transferred into the LHC beam pipe and passed about 3 km around the LHC.

On the evening of 15$^{\text{th}}$ June 2008, while preparing the ALICE detector for taking cosmic data the Silicon Pixel Detector showed a pattern never seen before. Longitudinal lines of hits were seen along one or two ladders. The ALICE pixel detector had observed hits from particles produced in a beam absorber during an LHC injection test [1], one of the first signs of life from the LHC accelerator in the experiments.

This paper reports the first full reconstruction of tracks through multiple detector planes, using the complete LHCb pattern recognition and tracking software, from particles induced by the LHC beam. These tracks were reconstructed using the LHCb Vertex Locator (VELO) during beam collisions with an absorber as part of the LHC anti-clockwise synchronisation tests.

2. LHCb VELO

The LHCb VELO is a silicon microstrip detector designed to reconstruct primary proton-proton collision vertices and secondary vertices from b-hadron decays. The detector consists of two halves, centred around the beam, with 21 modules each. Each module consists of two half-discs of silicon sensors measuring hits in R and Φ co-ordinates. The detector has a forward geometry with the LHC beam passing through the centre of the circle made by the silicon modules on each detector half. Figure 1 shows one of the assembled detector halves prior to insertion in the experiment.

Fig. 1. A photograph of a section of one assembled detector half of the LHCb VELO. A set of modules with half-disc silicon sensors are visible.

The two detector halves are attached to retractable bases. During stable LHC collisions the inner active strips of the detector will be only 8 mm from the LHC beam. However, during LHC injection the detectors will be retracted by 30 mm from their operational position. The detectors were in the retracted position for the observations reported here.

The LHCb detector [2] is intended to reconstruct tracks at small angle to the beam, and has a polar angular acceptance of $50 - 300$ mrads. The VELO is the first element of the spectrometer with collisions between the clockwise and anti-clockwise beams occurring in the region surrounded by the first set of modules. The forward going (clockwise in the LHC beam sense) particles produced in the collisions then pass through the other elements of the LHCb detector: the tracking detectors, ring imaging cherenkov detectors, calorimeters and muon stations. The forward geometry of the VELO detector means that, unlike many other components at the LHC, it was not possible to commission the VELO detector *in situ* with cosmic rays.

3. Anti-clockwise Beam Synchronisation Test Interactions

The LHC injector chain makes use of the existing accelerators on the CERN site. The final stages of this chain involves protons being accelerated in the SPS accelerator before being fed along one of the two transfer lines into the LHC.

A beam absorber, known as the TED, is located in the SPS to LHC transfer line about 340 m from the LHCb cavern [4]. The TED beam absorber consists of 4.3 m of material and contains a graphite core. As part of the LHC synchronisation test, bunches of protons were collided with the TED. One shot occurred every 48 seconds, with each shot containing up to 5×10^9 450 GeV/c protons. As the TED was designed to be capable of absorbing a beam of 10^{13} 450 GeV/c protons per 17 s there was no risk in operating the sensitive VELO modules during these collisions. After the TED collisions, the beam was injected into the LHC and collided with a mobile beam stopper, and later injected through LHCb. The VELO was turned off during these later phases in order to prevent any risk to the detector.

The resulting particles produced in the collisions between the proton beam and the TED beam absorber passed through the LHC tunnel and the LHCb experiment. The particles passed through the LHCb detector in the reverse direction, *i.e.* passing through the detector in the sense of first through the muon stations and then emerging through the VELO detector.

4. Tracks reconstructed in the LHCb VELO

The VELO group and other LHCb colleagues prepared the special detector configuration and software for these tests in the week preceeding the collisions: the triggering and timing was set up; the data acquisition was tested in the required configuration; special on-line and off-line monitoring was commissioned. Simulated events were produced in the expected geometry and with the expected rates to test the pattern recognition and tracking configurations.

In order to observe tracks in the VELO it was necessary to set up the sampling time of the front-end chips to detect the particles produced in the collisions. The timing was set up with respect to a trigger signal from the scintillator pad detector of the LHCb calorimeter system [2]. The front-end chip [3] of the VELO has a 40 MHz sampling frequency (the LHC beam crossing frequency). The front-end chip is usually configured so that the signal pulse is primarily contained within one 25 ns time sample. However, for the initial test the front-end chip was set up to have a slightly longer pulse shape thus increasing the signal to noise of the detectors and maximising the probability of cleanly observing particles.

As the timing could only be tested with a beam, the VELO was initially setup to readout fifteen consecutive 25 ns time samples: again maximising the chance of observing the particles from the collision. The analogue data from each time sample is digitised and processed by a series of algorithms to produce clusters. An example on-line monitoring plot used to determine the sampling time is shown in figure 2. The ADC count sum from clusters observed in the detector is shown against the time sample, the rise and fall of the pulse shape is visible on the plot and the timing is seen to be correct to within 25 ns: the peak is observed in the central time sample.

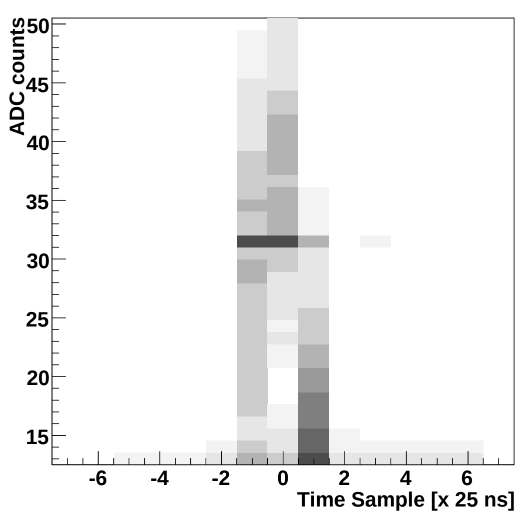

Fig. 2. An example on-line monitoring plot used to determine the sampling time. ADC counts of reconstructed clusters in the silicon sensors are plotted for the fifteen time samples recorded, with darker colours indicating more entries.

Having determined which time sample contained the data, the corresponding clusters were passed to pattern recognition and tracking routines. For the initial test five modules of the detector in each half were readout (twenty silicon sensors). The very first triggered event was observed in the VELO, and tracks reconstructed through all five planes in each half. This first event with fully reconstructed tracks induced by the LHC beam was observed at 17:36 on Friday 22$^{\text{nd}}$ August 2008 and is shown in figure 3. In total around 50 events were observed during this run, which lasted approximately one hour.

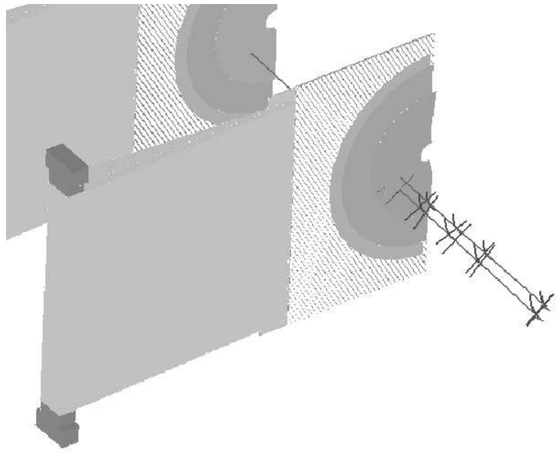

Fig. 3. The first event observed in the LHCb VELO on 22$^{\text{nd}}$ August 2008. Hits are observed in R and Φ co-ordinate measuring silicon sensors and tracks are reconstructed through the five module of the detector that were readout. The hit strips on all five modules are indicated but, for clarity, only two modules are shown.

Given the success of this observation, the LHC operations team agreed to provide a further set of collisions on the TED on Sunday 24$^{\text{th}}$ August. The full VELO system that was commissioned at that point was readout. Tracks were reconstructed through up to 19 of the 21 modules in each half of the detector, an example event is shown in figure 4. Combining the information from the R and Φ co-ordinate measurements made with the two silicon sensors in a module allows 2D space-points to be obtained. Space-points were observed across the full surfaces of the silicon sensors, as shown in figure 5 (a). Hits were observed in modules throughout the detector, as shown in figure 5(b). However, the efficiency of cluster reconstruction varied as the data processing calibration constants had not been tuned for the individual channels on the modules, this is visible in the reduced number of points in some sensors. The number of tracks per event is shown in figure 6, in total more than 700 tracks were reconstructed during the collision period, which lasted 70 minutes.

Preliminary resolution and alignment studies using the algorithm described in [5] have been conducted. The preliminary results demonstrate that no significant movements have occurred in the detector system during insertion or commissioning and a resolution compatible with that obtained during testbeam studies [6] is anticipated.

5. Summary

The LHCb VELO has fully reconstructed the first tracks from particles induced by the LHC beam. Tracks have been reconstructed with up to 19 independent 2D space-points (38 silicon sensors). This is an important

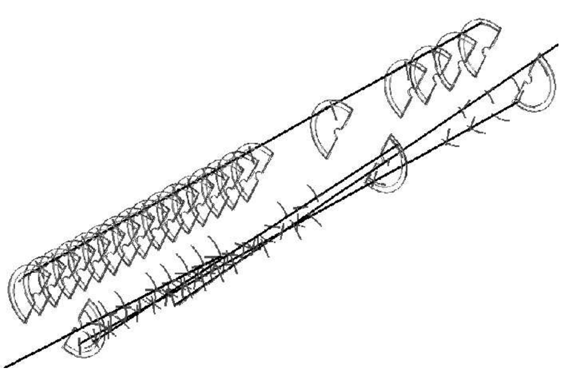

Fig. 4. An example event observed in the LHCb VELO on 24$^{\text{th}}$ August 2008. Tracks are reconstructed through space-points on 19 modules of the detector. All modules are shown on one side of the VELO. Only three modules are shown on the other side to allow the hit R and Φ strips to be more visible.

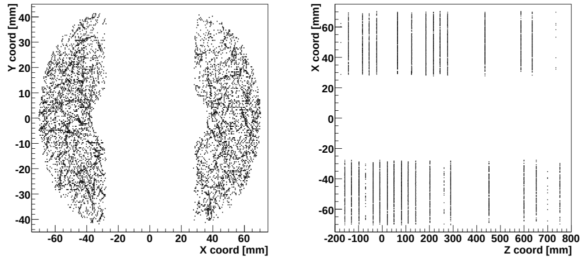

Fig. 5. The plot shows the distribution of reconstructed space-points on tracks. (a) the left plot shows the distribution in the plane of the sensors (XY). (b) The right plot shows the distribution along the beam (Z direction).

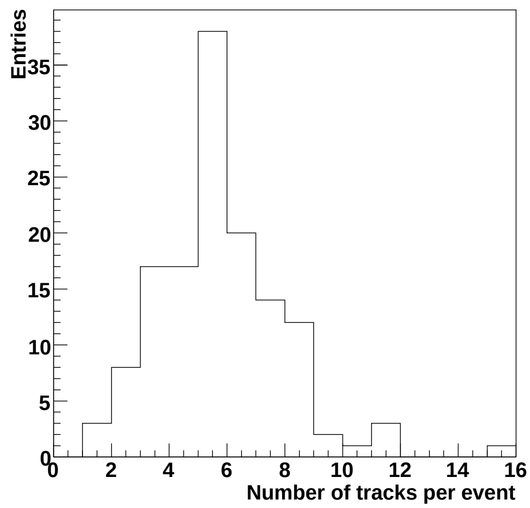

Fig. 6. The number of tracks reconstructed per event in the events observed on 24^{th}August.

milestone in the operation of the detector and the collected data sample of 700 tracks is being used to understand the calibration and alignment of the detector.

6. Acknowledgements

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