A LHCb-VELO module as beam quality monitor for proton therapy beam at the Clatterbridge Centre for Oncology

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Abstract:

The progress in detector technology, driven by the needs of particle tracking and vertexing in the present LHC and its upgrade (sLHC), has led to the design of silicon sensors with low mass, high granularity, high speed and unprecedented radiation hardness. The sensors designed for such a harsh environment can be profitably used for instrumenting the control systems of therapeutic hadron beams. The high granularity and readout clock speed are well suited for monitoring continuous beam currents. The low mass allows reduced interference with the beam whilst monitoring its profile with high precision. The high resolution and sensitivity to minimum ionising particles allows monitoring of the beam spot position by measurement of the halo in real time, without any interference with the beam spot used in therapy.

Introduction

The LHCb-VELO detectors are semi-circular silicon devices used to provide the radial (R) and azimuthal (Φ) coordinate in the LHCb [1] reference system. The innermost sensitive area of the sensors (Figure 1) is located at a radius of only ~8 mm from the LHC beam centre. The sensors are 300 µm thick. They are readout using 40 MHz clock speed Beetle [2] ASIC and LHCb-VELO data acquisition system (DAQ) [3]. The R and Φ sensors are precisely mounted back to back to form a module capable of providing the space point of the crossing particle in the LHCb reference frame. The VELO modules are arranged in two halves, each comprising 21 modules, mounted in two moving bases which can close in and form a fully sensitive cylinder around the interaction region with inner and outer radius of 8 mm and 46 mm, respectively (Figure 2). The LHCb-VELO sensors have been designed to withstand the severe radiation environment generated by the particles emerging from the high energy proton collisions at the LHC. Detectors made with similar technology have been proven to be radiation hard to unprecedented doses of hadron radiation (over 10^{16} 1MeV neutron equivalent cm^{-2}) [4, 5].

The particular geometry of the VELO modules (with respect to the Vertex detectors of other LHC experiments) and the excellent radiation tolerance of these devices, prompted an investigation of their capability of measuring the beam spot and the beam halo of the proton beam for eye cancer therapy at the Clatterbridge Hospital Centre for Oncology.

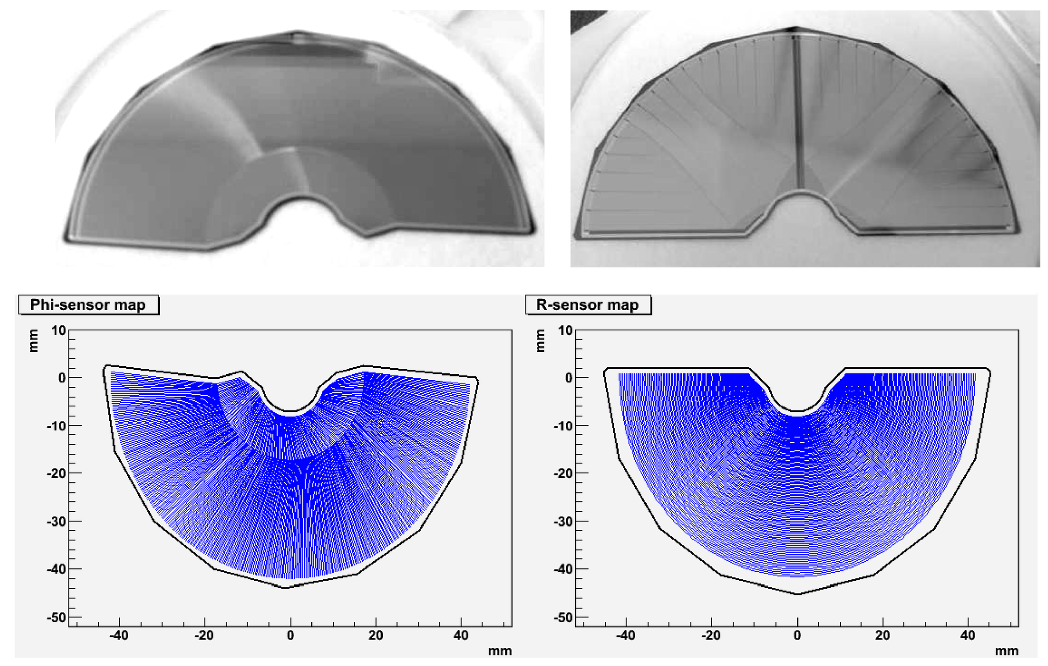
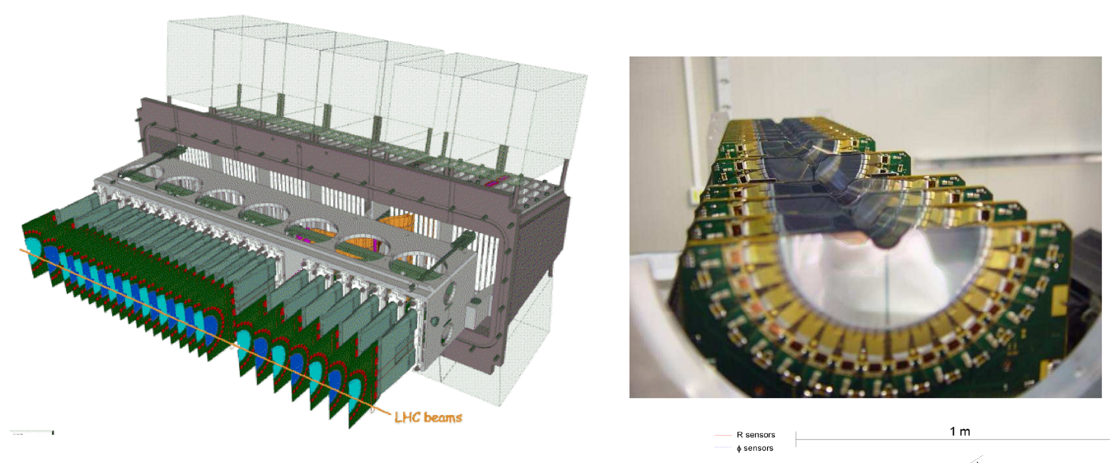


Figure 1. Photo and cartoon of the Φ (left) and R (right) measuring LHCb-VELO sensors. Each sensor has 2048 microstrips, to be AC coupled to the readout electronics (the 40MHz clock speed Beetle chip).



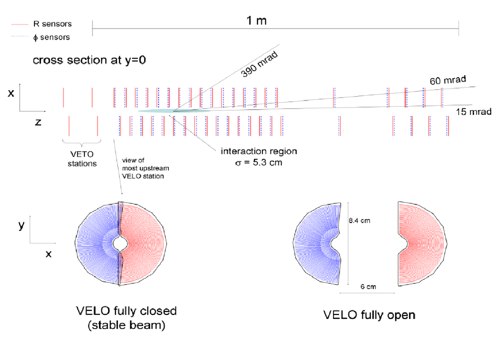


Figure 2. One half of the LHCb-VELO detector showing the arrangement of the 21 stations. The detector comprises two halves that close together, to provide full angle coverage of the track emerging from the interactions.

The measurements

The Scanditronix MC-60 cyclotron of the Clatterbridge Cyclotron for Proton Therapy [4] provides a circular beam of 62 MeV protons with a practically continuous current. The intensity of the therapy beams can be up to 10 nA, with a flat beam spot width of 34 mm. The beam spot is collimated with brass cylinders with apertures of various diameters. Figure 3 shows a picture of the experimental arrangement, with a 15 mm diameter brass collimator at the beam output.

We measured both the beam spot (size and homogeneity) and the beam halo with the module at various distances of from the collimator. The measurements have been performed with the LHCb-VELO modules located at 25, 110 and 153 mm from the collimator (Position P1, P2 and P3 respectively). Figure 4 shows the beam spot relative profile intensity at P1. Figure 5 shows the beam halo at the three different positions, Figure 6 the 180° halo at position P1 and Figure 7 the divergence of the beam spot halo in air with additional measurements at 70 and 230mm.

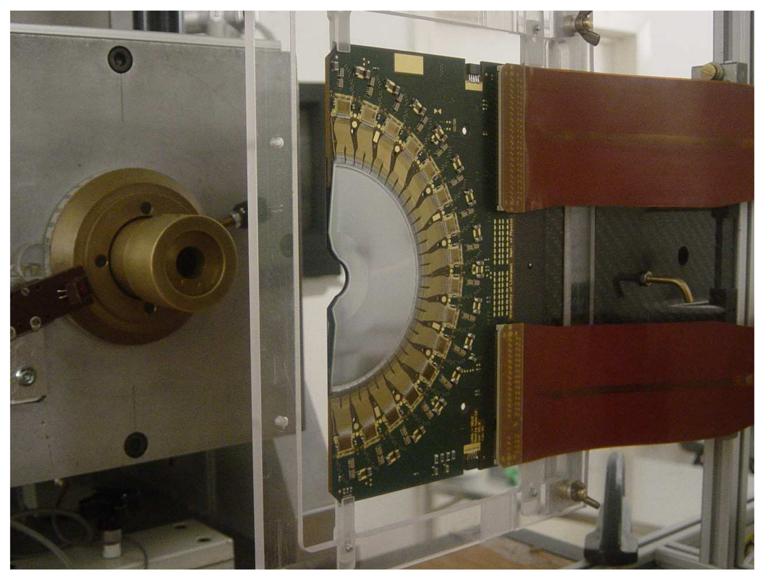


Figure 3. Beam collimator and LHCb-VELO module.

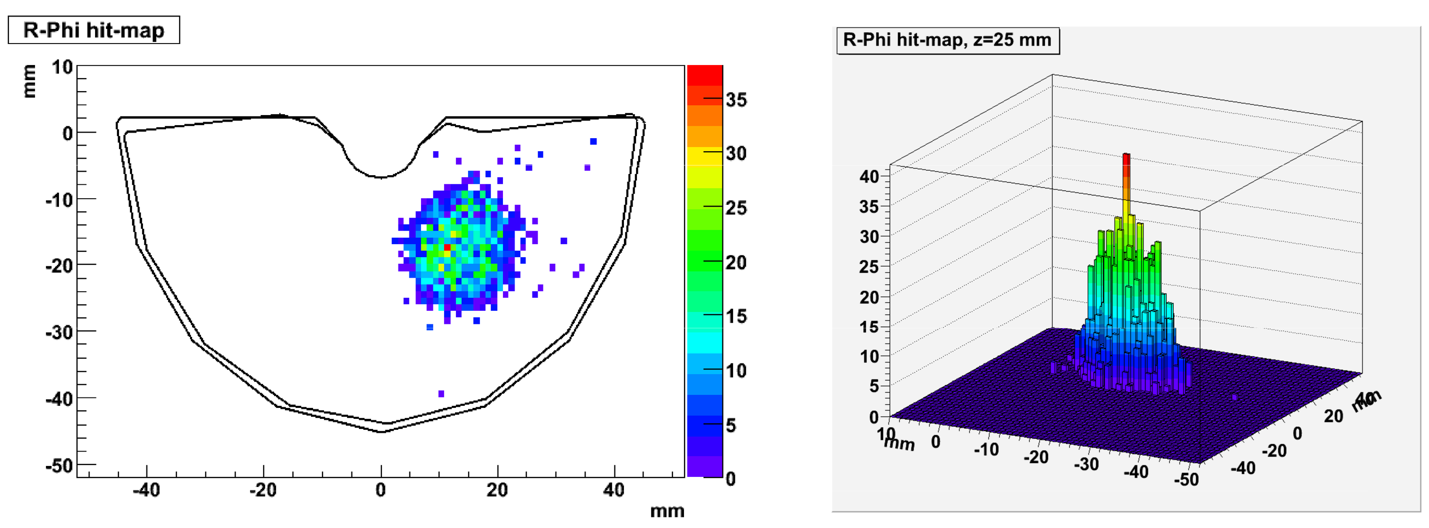


Figure 4. Hit map of the beam spot emerging from the 15 mm collimator at P1.

Summary

The LHCb-VELO modules have been proven very effective for imaging the beam spot and the halo of the proton therapy beam of the Cyclotron accelerator of the Clatterbridge Hospital. Although the measurements here shown have been performed with sensors designed for an LHC Vertex detector, the results suggest that similar devices designed with a geometry optimised for the application can be profitably used for the beam monitoring instrumentation in real time thanks to their low mass, high speed and resolution.

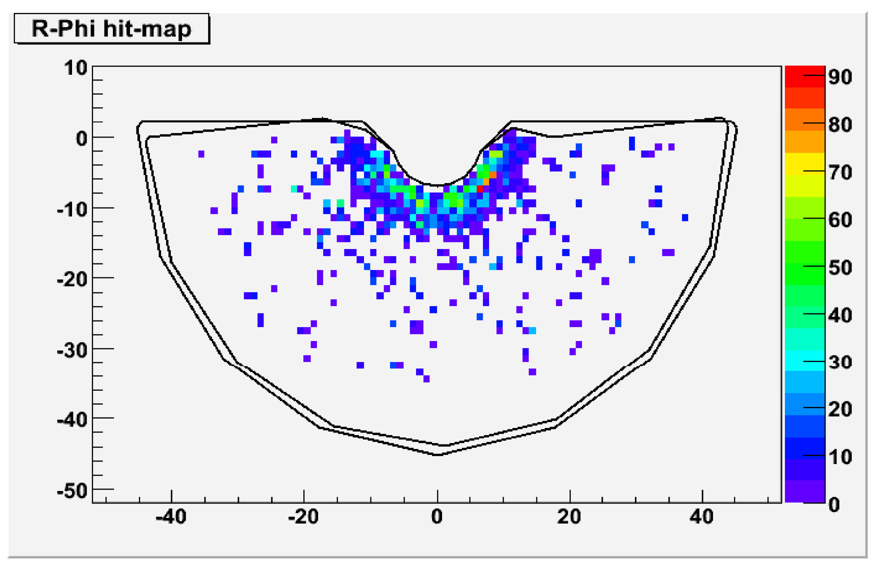


Figure 6. 180° beam halo at P1.

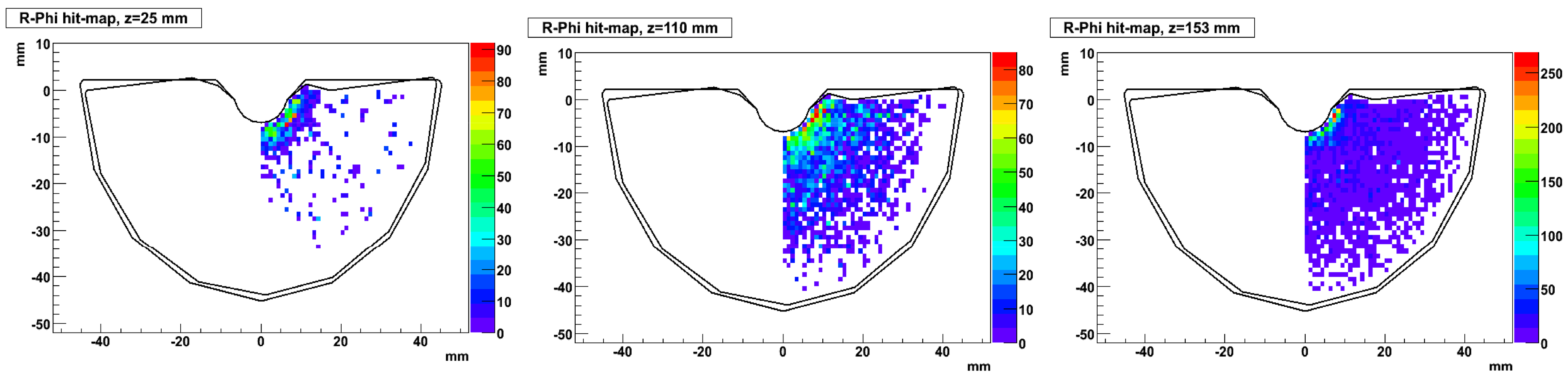


Figure 5. Beam halo hit distribution at distances P1, P2 and P3 from the collimator (see text).

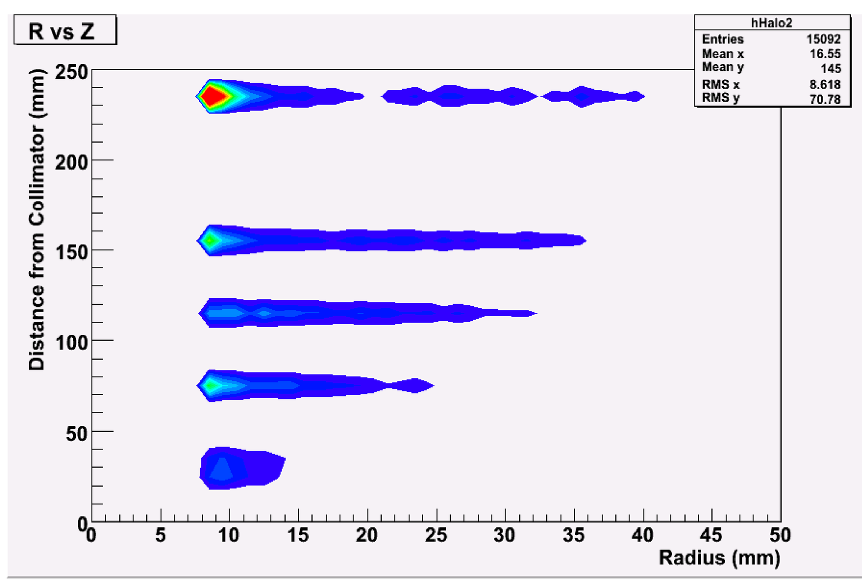


Figure 7. Divergence of the beam spot halo with distance from the collimator in air.

Acknowledgements

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