Chapter 3

The interface to the LHC machine

3.1 Beampipe

The beampipe design is particularly delicate since the LHCb experiment is focussed on the high rapidity region, where the particle density is high. The number of secondary particles depends on the amount of material seen by incident primary particles. The mass of the beampipe and the presence of flanges and bellows have a direct influence on the occupancy, in particular for the tracking chambers and the RICH detectors. Optimisation of the design and selection of materials were therefore performed in order to maximize transparency in these critical regions [12, 13].

3.1.1 Layout

The beampipe, schematically represented in figure 3.1, includes the forward window of the VELO covering the full LHCb acceptance and four main conical sections, the three closer to the interaction point being made of beryllium and the one further away of stainless steel.

Beryllium was chosen as the material for 12 m out of the 19 m long beampipe, for its high transparency to the particles resulting from the collisions. It is the best available material for this application given its high radiation length combined with a modulus of elasticity higher than that of stainless steel. However, its toxicity [14], fragility and cost are drawbacks which had to be taken into account in the design, installation and operation phases. Flanges, bellows and the VELO exit window are made of high strength aluminium alloys which provide a suitable compromise between performance and feasibility. The remaining length, situated outside the critical zone in terms of transparency, is made of stainless steel, a material widely used in vacuum chambers because of its good mechanical and vacuum properties. The VELO window, a spherically shaped thin shell made of aluminium 6061-T6, is 800 mm in diameter and was machined from a specially forged block down to the final thickness of 2 mm. The machining of the block included a four convolution bellows at its smallest radius. The first beampipe section (UX85/1), that traverses RICH1 and TT (see figure 3.2), is made of 1 mm thick Be, includes a 25 mrad half-angle cone and the transition to the 10 mrad half-angle cone of the three following beampipe sections. In order to avoid having a flange between the VELO window and UX85/1, the two pieces were electron beam welded before installation. Sections UX85/2 (inside the dipole magnet) and UX85/3 (that traverses the Tracker, RICH2, M1 and part of ECAL) are 10 mrad beryllium cones of wall thickness varying from 1

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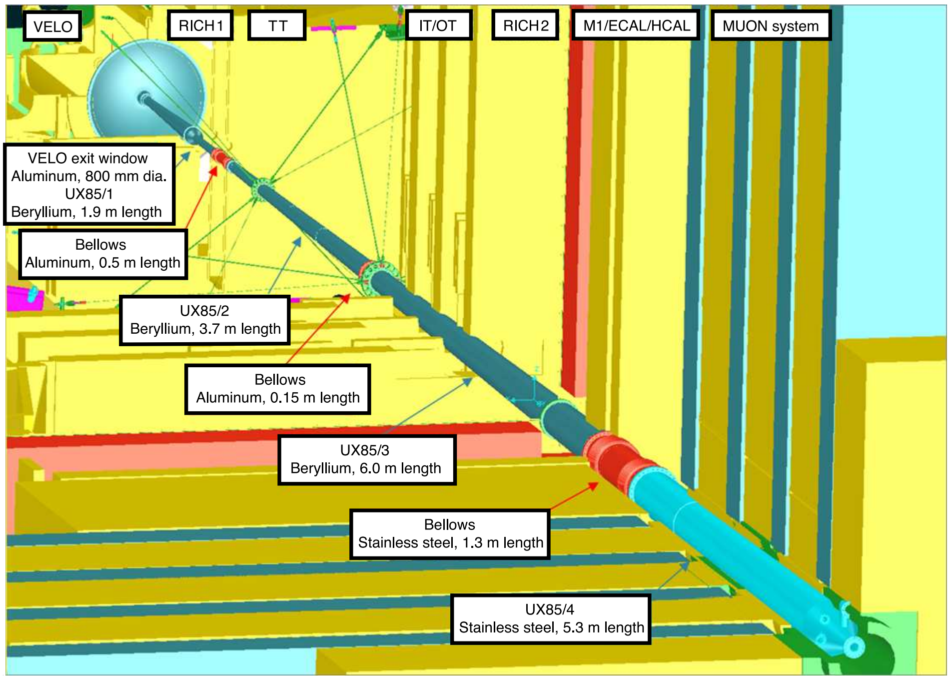

Figure 3.1: The 19 m long vacuum chamber inside the LHCb experiment is divided into four main sections. The first three are made of machined beryllium cones assembled by welding and the fourth of stainless steel. Bellows expansion joints provide interconnect flexibility in order to compensate for thermal expansions and mechanical tolerances.

to 2.4 mm as the diameter increases from 65 up to 262 mm. UX85/3 is connected to a stainless steel bellows through a Conflat seal on the larger diameter. The transition between aluminium and stainless steel is formed using an explosion bonded connection. The three Be beampipes were machined from billets up to 450 mm long and assembled by arc welding with a non-consumable electrode under inert gas protection (TIG) to achieve the required length. TIG welding was also used to connect the aluminium flanges at the extremities of the tubes.

The UX85/4 section completes the 10 mrad cone and includes a 15° half-angle conical extremity that provides a smooth transition down to the 60 mm final aperture. It was manufactured from rolled and welded stainless steel sheet of 4 mm thickness. A copper coating of 100 μm was deposited before assembly on the downstream side end cone to minimise the impedance seen by the beam. The aluminium and stainless steel bellows compensate for thermal expansion during bakeout and provide the necessary flexibility to allow beampipe alignment. Optimised Ultra High Vacuum (UHV) flanges were developed in order to minimise the background contribution from the various connections in the high transparency region [15]. The resulting flange design is based on all-metal Helicoflex seals and high strength AA 2219 aluminium alloy flanges to ensure reliable leak tightness and baking temperatures up to 250°C. A relatively low sealing force allows the use of aluminium and a significant reduction of the overall mass compared to a standard Conflat flange.

Another important source of background is the beampipe support system [16]. Each beampipe section must be supported at two points, with one fixed, i.e. with displacements restrained in all directions, and the other movable, the latter allowing free displacements along the

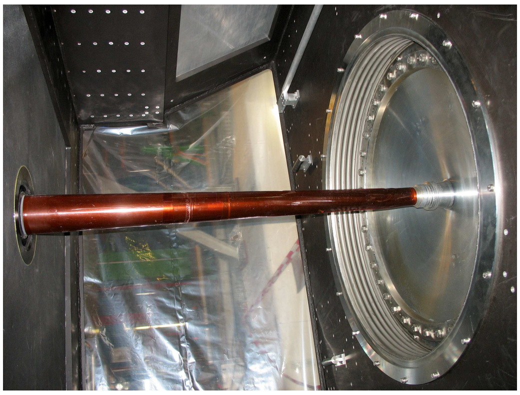

Figure 3.2: View of the VELO exit window and UX85/1 beampipe as installed inside the RICH1 gas enclosure.

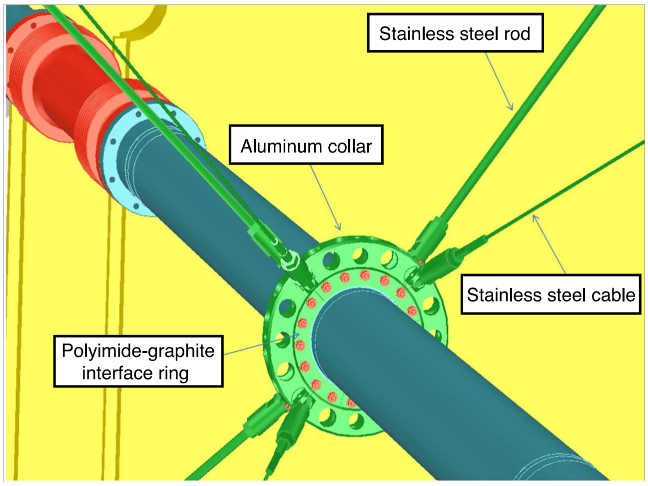

Figure 3.3: Optimised beampipe support inside the acceptance region. A system of eight high resistance cables and rods provide the required rigidity in all directions. A polyimide-graphite ring split in several parts, which are bolted together between the collar and the beampipe, prevents scratches on the beryllium and reduces local stresses at the contact surfaces.

beampipe axis. The fixed supports, which must compensate the unbalanced vacuum forces due to the conical shape of the beampipe, are each constructed using a combination of eight stainless steel cables or rods mounted under tension, pulling in both upstream and downstream directions with an angle to the beam axis (figure 3.3). Where a movable support is required to allow thermal expansion, four stainless steel cables are mounted in the plane perpendicular to the beampipe, blocking all movements except along the beam axis. The support cables and rods are connected to the beampipe through aluminium alloy collars with minimised mass, and an intermediate polyimide-graphite ring to avoid scratching the beryllium and to reduce stresses on contacting surfaces.

The experiment beam vacuum is isolated from the LHC with two sector valves, installed at the cavern entrances, which allow interventions and commissioning independently of the machine vacuum system.

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3.1.2 Vacuum chamber

In order to achieve an average total dynamic pressure of 10^{-8} to 10^{-9} mbar with beam passing through, the LHCb beampipe and the VELO RF-boxes are coated with sputtered non-evaporable getter (NEG) [17]. This works as a distributed pump, providing simultaneously low outgassing and desorption from particle interactions with the walls. Another purpose of the NEG coating is to prevent electron multipacting [18] inside the chamber, since the secondary electron emission yield is much lower than for the chamber material. The UHV pumping system is completed by sputter-ion pumps in the VELO vessel and at the opposite end of the beampipe in order to pump non-getterable gases. Once the NEG coating has been saturated, the chamber must be heated periodically (baked out) to 200°C, for 24 hours, in order to recover the NEG pumping capacity. The temperature will have to be gradually increased with the number of activation cycles, however it is limited to 250°C in the optimised flange assemblies for mechanical reasons. Before NEG activation, the vacuum commissioning procedure also includes the bakeout of the non-coated surfaces inside the VELO vacuum vessel to a temperature of 150°C. Removable heating jackets are installed during shutdowns covering the VELO window and the beampipe up to the end of RICH2. From there to the end of the muon chambers, a permanent system is installed. As there are no transparency constraints, the insulation of the beampipe inside the muon filters is made from a mixture of silica, metal oxides and glass fiber, whilst the heating is provided by standard resistive tapes.

Such an optimised vacuum chamber must not be submitted to any additional external pressure or shocks while under vacuum, due to the risk of implosion. Hence, it must be vented to atmospheric pressure before certain interventions in the surrounding detectors. Saturation of the NEG coating and consequent reactivation after the venting will be avoided by injecting an inert gas not pumped by the NEG. Neon was found to be the most suitable gas for this purpose because of its low mass and the fact that it is not used as a tracer for leak detection, such as helium or argon. However, commercially available Ne must first be purified before injection. A gas injection system installed in the cavern will provide the clean neon to be injected simultaneously into both VELO beam vacuum and detector vacuum volumes, as the pressure difference between the two volumes must be kept lower than 5 mbar to prevent damage to the VELO RF-boxes (c.f. section 5.1).

3.2 The Beam Conditions Monitor

In order to cope with possible adverse LHC beam conditions, particularly with hadronic showers caused by misaligned beams or components performance failures upon particle injection into the LHC, the LHCb experiment is equipped with a Beam Conditions Monitor (BCM) [19]. This system continuously monitors the particle flux at two locations in the close vicinity of the vacuum chamber in order to protect the sensitive LHCb tracking devices. In the case of problems, the BCM system will be the first to respond and will request a dump of the LHC beams. The BCM connects to both the LHCb experiment control system and to the beam interlock controller of the LHC [20]. As a safety system, the BCM is equipped with an uninterruptable power supply and continuously reports its operability also to the vertex locator control system through a hardwired link.

The BCM detectors consist of chemical-vapor deposition (CVD) diamond sensors, which have been proven to withstand radiation doses as high as those that may occur in LHC accident

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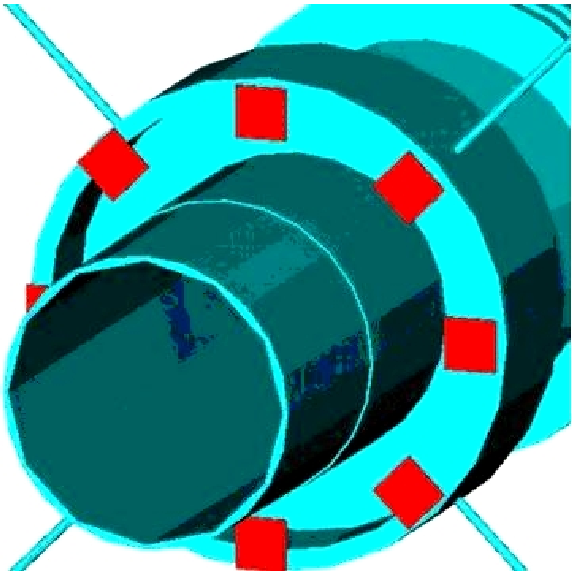

Figure 3.4: Schematic view of the eight CVD-diamond sensors surrounding the beampipe at the downstream BCM station.

scenarios. In order to assure compatibility of the signals with those from other LHC experiments, the dimensions of the sensors are the same as those of the ATLAS and CMS experiments, i.e. their thickness is 500 μm, the lateral dimensions are 10 mm $\times$10 mm, with a centered 8 mm $\times$8 mm metallized area. The metallization is made of a 500 Å thick gold layer on a 500 Å thick layer of titanium. The radiation resistance of the metallization has been studied with the exposure of a 4 mm^2 surface to 4×10^{15} protons of an energy of 25 MeV over 18 hours. No sign of degradation was observed.

The two BCM stations are placed at 2131 mm upstream and 2765 mm downstream from the interaction point. Each station consists of eight diamond sensors, symmetrically distributed around the vacuum chamber with the sensitive area starting at a radial distance of 50.5 mm (upstream) and 37.0 mm (downstream). Figure 3.4 shows the downstream BCM station around the beampipe. The sensors are read out by a current-to-frequency converter card [21] with an integration time of 40 μs, developed for the Beam Loss Monitors of the LHC.

Simulations were carried out with the GAUSS package [22] to study the expected performance of the BCM. Unstable beam situations are described in a simplified way in generating 7 GeV protons at 3000 mm upstream of the interaction point in a direction parallel to the beam and in calculating the energy deposited in the BCM sensors caused by these protons. All sensors experience an increase of their signals due to hadronic showers produced by the protons in intermediate material layers. Assuming that during unstable LHC beam condition, the beam comes as close as 475 μm (approximately 6 times its RMS) to the RF foil of the VELO (see section 5.1), it would take 40–80 μs of integration time (or about 20 LHC turns) for the BCM to detect the critical situation and request a beam dump.