Preliminary Studies for the LHCb Vertex Detector Vacuum System

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Abstract

We lay down some general considerations which will serve as a starting point for design studies of a realistic LHCb vertex detector vacuum system. Based on these considerations, we propose a design strategy and identify issues to be further studied. In particular we try to outline some boundary conditions imposed by LHC and LHCb on the vacuum system. We discuss two possibilities for the LHCb vertex detector vacuum system. The preferred strategy uses a differentially pumped vacuum system with the silicon detectors separated from the beam line vacuum. Some estimations on static vacuum pressures and gas flows are presented.

1 Introduction

The purpose of this note is to lay down some general considerations which will serve as a starting point for design studies of a realistic LHCb VD vacuum system. Based on these considerations, we propose a design strategy without the ambition to solve here all issues associated with it. The note is organized as follows. In section 2 we remind briefly of the general layout of the LHCb experiment, highlighting those parts which have to be integrated with the LHC vacuum. We try to outline in section 3 some boundary conditions imposed by LHC and LHCb on the vacuum system. In section 4 we discuss two possibilities for the LHCb VD vacuum system. Some estimations on static vacuum pressure and gas flows for the prefered strategy are given in section 5. In section 6 we discuss some operational aspects and suggest a possible vacuum layout. Finally, we summarize in section 7.

2 Overview of LHCb

Figure 1 shows the LHCb detector [1], with the silicon vertex detector (VD) located around the interaction region. At this location, the beam pipe is replaced by a ~1.8 m long section with a diameter of about 1 m, which accommodates the VD. This vacuum tank is provided with a thin forward window covering the full LHCb detector acceptance. This window is interfaced to a long (~19 m) and narrow (~5-40 cm variable diameter) chamber that runs through the rest of the LHCb detector.

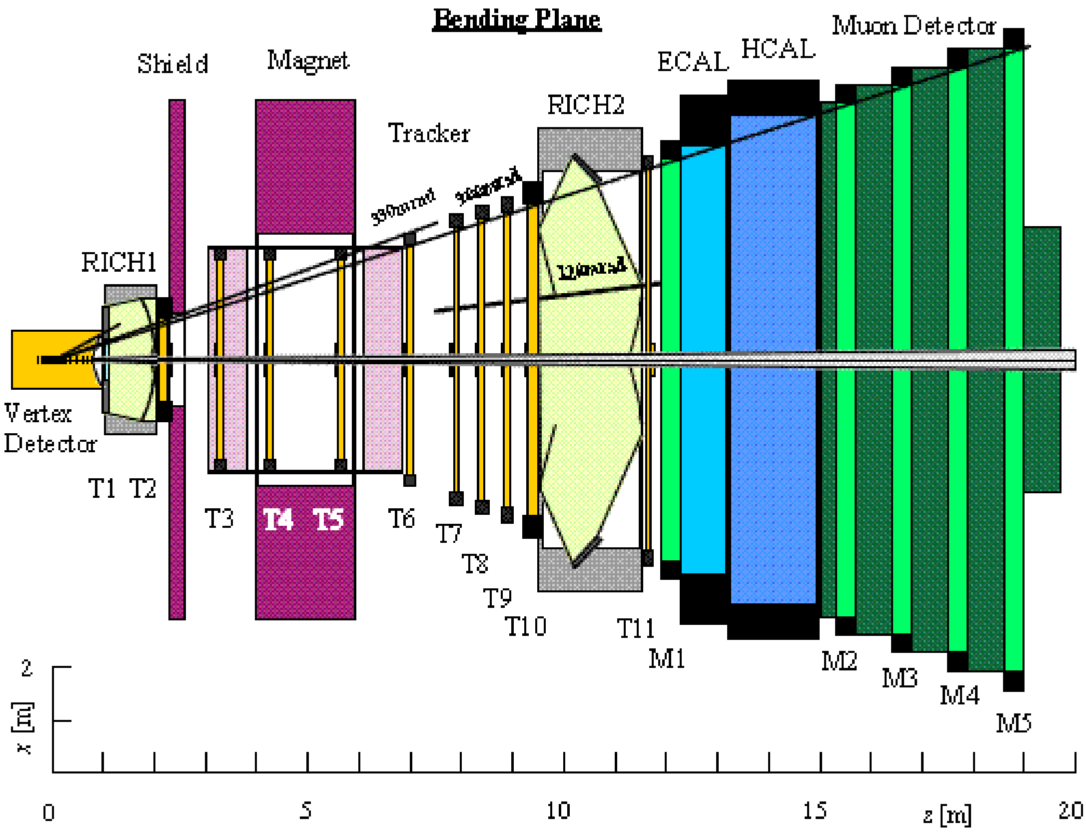


Figure 1: *LHCb detector*

The VD must provide precise measurements of track coordinates close to the interaction region. The physics performance is optimized by placing the silicon planes as close as possible to the location of the primary vertices. The edges of the silicon detectors are positioned at 8 mm from the nominal beam axis, a distance smaller than the required LHC aperture during injection. The VD consists of 19 silicon stations above and 19 below the beam axis. During LHC beam filling, the silicon stations of the upper and lower detector half should be moved away from the beam by 3 cm. After injection is finished and stable beam conditions are achieved, the two detector halves can be moved into position close to the beams. The interaction point (nominal z = 0) for the stored proton beams is inside the VD. In the present design, each station consists of two (~182°) disc sections of silicon detectors, with circular (r) and radial (ϕ) strips, respectively. Each r or ϕ detector dissipates 10-20 watt of electrical power, mainly due to the front-end electronics. The operating temperature of the silicon is in the range of –25 to + 10 °C. The Si detectors are positioned perpendicular to the beam (see figure 2). A complete station is about 0.4 mm thick. Tracking coverage extends radially from 8 to 40 mm from the beam axis. Furthermore, to accommodate for a small overlap region (a few mm) between the top and bottom stations, the former ones will be staggered in the z direction (presently by 2 cm) with respect to latter ones. Optimization by Monte-Carlo techniques is underway to define the final positions and geometry of the Si detectors.

LHC-B silicon vertex detector

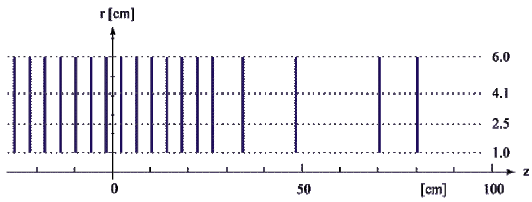
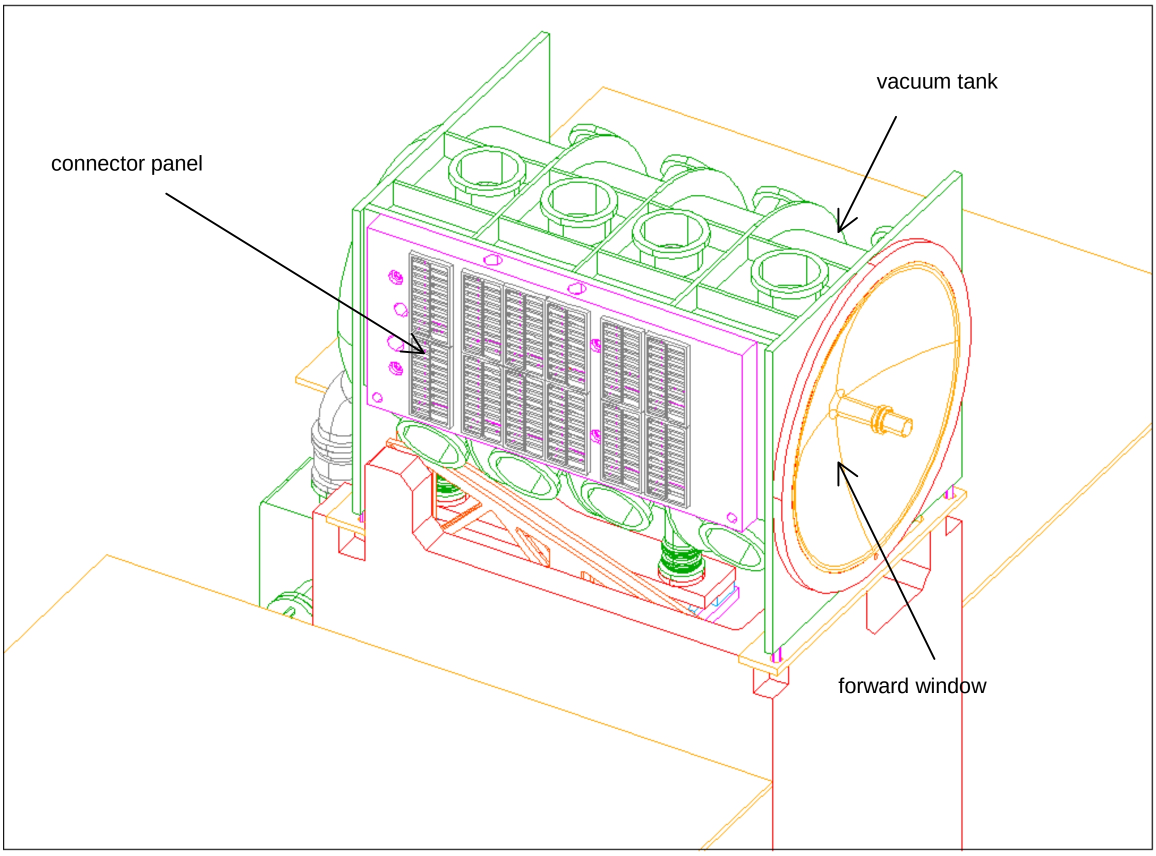


Figure 2: *Arrangement of the r and* ϕ *Si detectors.*

In figure 3 a view of the current VD mechanical design is shown. More details can be found in Ref. 2. One essential feature of this design is that the detector halves are mounted on an internal frame which is mechanically decoupled from the vacuum tank by use of bellows.


vacuum tank
connector panel
forward window

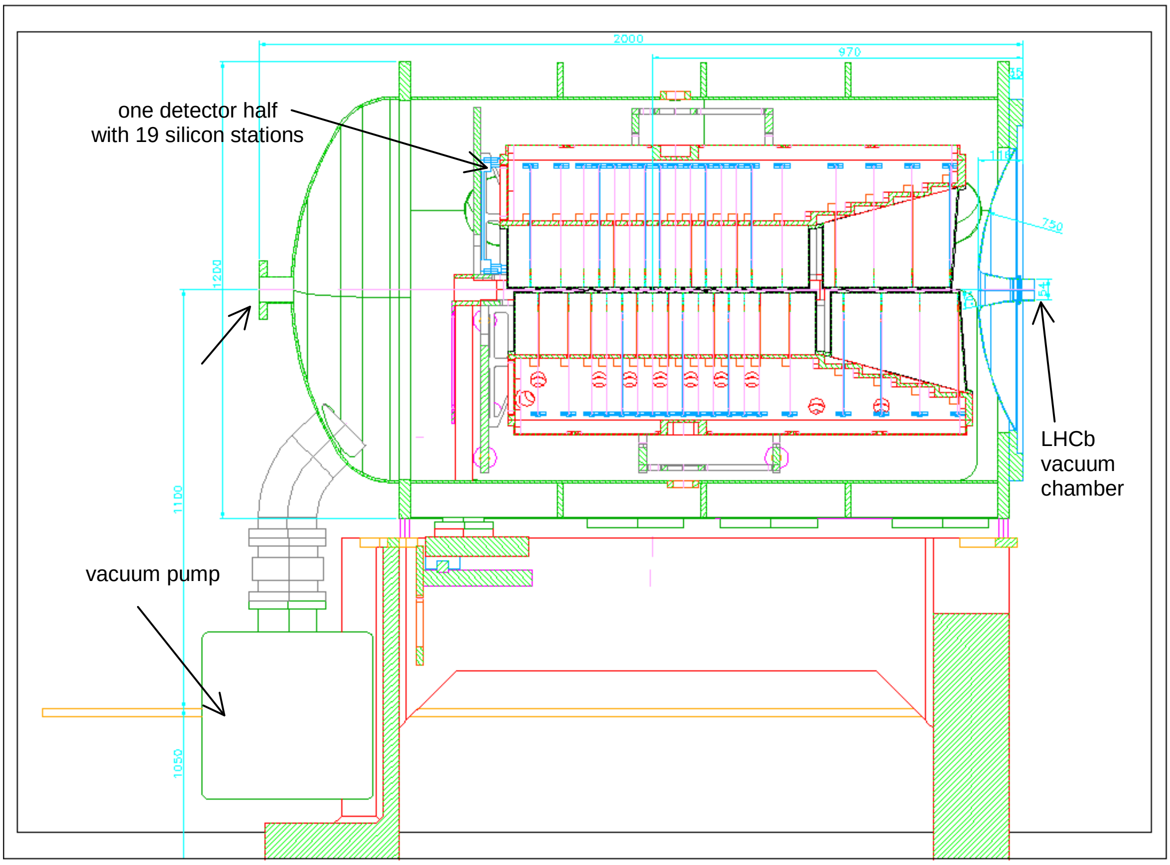

one detector half
with 19 silicon stations
LHCb
vacuum
chamber
vacuum pump

Figure 3: Views of the silicon vertex detector and its vacuum tank .

3 Vacuum requirements

We outline here some known boundary conditions and some basic requirements for the vacuum along the beam path through the LHCb detector, imposed by both the LHC operation and the aimed LHCb physics performance.

3.1 LHC beam line

The vacuum layout of the LHC section before the VD is not yet fully specified. We assume here that this section will be a "warm" section, such that the VD is well decoupled from the closest cryogenic section located in the first dipole (D1), about 20 m before the LHCb IP. This is important, since the operating temperature of the cryogenic beam line sections is 1.9K (super-fluid helium temperature), which puts some specific constraints on the nearby vacuum sections.

The LHCb vacuum chamber running through the LHCb detector is of a small diameter (~5-40 cm) with respect to its length of about 20 m. As a consequence of this large length/diameter ratio, the vacuum conductance (from entrance to exit) is low (of the order of a liter/s). Pumping only at the exit and entrance of the LHCb vacuum chamber seems inappropriate for realizing a sufficiently clean vacuum along its full length. This dictates the need for distributed pumping along the chamber. Work was done at CERN on the pumping and activation characteristics of TiZr getter alloys which can be activated at about 200 °C [3], below the structural deformation temperature limit for some types of aluminium. Therefore, coating the LHCb vacuum chamber with this kind of non-evaporable getter (NEG) material is presently considered as the baseline solution. It is important to remember that no valve can be placed between the VD vacuum chamber and the LHCb vacuum chamber, because of the too large fluxes of background particles which would be generated. The getter material can only be reactivated a finite number of times before its pumping efficiency degrades to an unacceptable level. In addition, reactivation of the getter materials requires heating the LHCb vacuum chamber, and therefore, probably also implies retracting a number of LHCb detector subsystems located around the vacuum chamber. This imposes some constraints with respect to venting, and therefore with respect to maintenance of the VD. The use of such getter materials will also put a limit on the acceptable diffused flow from the VD to the LHCb vacuum chamber, depending on the capacity of the deposited NEG layer.

The nominal limit density for gas molecules (assuming hydrogen) inside the LHC storage ring is approximately $1.6*10^9$ molecules/cm^3. Under these conditions the stored beams are expected to have a lifetime of about 60 hours [4]. The limits on the integrated density and the gas composition inside the LHCb section are not yet defined. Here, we assume that, considering only the LHC beam lifetime reduction by static pressure effects, a residual pressure of about 10^{-7} mbar (of hydrogen at room temperature) over about 2 m is an acceptable vacuum pressure limit. This would correspond to about 0.01% of the integrated density over the complete LHC ring, when taking a limiting value of $2.7*10^6$ cm * $1.6*10^9$ molecules/cm^3.

Because of radiation damage, the Si detector performance is expected to degrade. The current strategy is to have a possibility to replace the Si stations once a year, although there are hints that a longer cycle could be used. Here, we consider that the VD will require maintenance operations invoking venting to atmospheric pressure once a year. We foresee the construction of a dedicated wake field suppressor which could be rapidly installed in place of the two detector halves if those must be taken out for maintenance. In this way, and if necessary, LHC could come back into operating conditions while the VD is being serviced.

In the above discussion, we only considered the beam lifetime limit due to the static pressure. We expect however that more constraints will have to be taken into account, in particular from pressure dynamical effects (ion or electron induced beam instabilities), and with respect to the composition of the VD residual gas. The vacuum mass spectrum of LHC is expected to contain almost no high-mass molecules or helium. The main gas component is hydrogen [4]. The LHC vacuum group is currently working on the quantification of these constraints from the point of view of the LHC machine operation. Ultimately, the LHCb vacuum system must be stable and reliable enough in order not to negatively influence the continuous operation of LHC, both during beam filling and during beam storage time.

3.2 LHCb performance

From the physics point of view, the beam-gas luminosity sets the limit on the acceptable static pressure. At a pressure of 10^{-7} mbar (assuming hydrogen) along the path of the circulating beams through the vertex detector (length 1.2 m) the beam-gas luminosity amounts to about $3*10^{30}$ cm^{-2}*s^{-1}, taking into account a beam with a current of 0.85 A. This value represents about 1.5% of the nominal LHCb luminosity of $2*10^{32}$ cm^{-2}*s^{-1}. This seems to impose a stronger constraint on the acceptable static pressure than the previously mentioned effect on the LHC beam lifetime.

If, in the mechanical design, a separation of the vertex detector vacuum from the LHC vacuum is necessary, the separating walls may only minimally affect the particle trajectories by multiple scattering. We assume here that a thickness of the order of 0.1 mm aluminum (or an equivalent fraction of radiation lengths for other materials) is acceptable. Intensive optimization studies (by Monte-Carlo simulation) are being carried out by the collaboration to quantify more precisely the affordable amount of material thickness.

Based on the above considerations, we aim at a static (partial) pressure of ~10^{-8} mbar for hydrogen (and lower values for other rest gas components).

4 Design considerations for the vertex detector vacuum system

We have considered two options for the VD vacuum system:

1. An "open" system, where the complete Si detectors are located in the same vacuum as the LHC beams.
2. A "semi-closed" system, in which the Si detectors are partially separated from the LHC beam vacuum. The two vertex detector halves are each enclosed in a thin walled vacuum box. A pumped conductance connects each of these two detector volumes and the LHC beam line vacuum.

4.1 Open vertex detector vacuum system

In case no separation between the detectors and the LHC beam line vacuum is foreseen, the beam line pumps and surfaces will be exposed directly to outgassing from vertex detector components. Substantial outgassing can be expected from the electronics, cables, connectors, temperature sensors, heaters, bondings, thermal interface materials, hybrid and silicon mountings, glues, etc. In an "open" design, all these components should exhibit low enough outgassing rates in order to obtain a static pressure of the order of 10^{-8} mbar along the beam path, throughout the detector. For example, the use of Kapton-insulated wires is being considered for the signal wires of the Si stations, either in the form of twisted pairs or as flat cables (about 22000 wires in total). This will result in a major outgassing source. The average wire length is about 1 m. The total outgassing area is of the order of 10 m^2. Assuming an outgassing rate of 10^{-7} mbar*liter*s^{-1}*cm^{-2} for Kapton after 40 hours of pumping (as we measured it at NIKHEF) the total gas load would be about 10^{-2} mbar*liter/s (>90 % water). If a beam line pressure of 10^{-8} mbar is to be maintained during operation, the required pumping speed on the VD vacuum chamber should be of the order of 10^6 liter/s. This is not easily realized using standard ion-getter pumps, titanium sublimation pumps, cryogenic pumps or turbomolecular pumps, and considering the geometry of the VD. We thus conclude that (some) decoupling of the detector components from the beam line vacuum is required in order to reach a pressure of 10^{-8} mbar on the beam axis of the VD system within an acceptable time.

4.2 Semi-closed vacuum system

In figure 4 a possible semi-closed vacuum system is sketched. Note that there are no separation valves between the chambers enclosing the two detector halves and the beam line. At the position of the vertex detector the amount of material between the interaction point and the LHCb detector must be minimized to reduce multiple scattering. The present design uses an aluminum foil of about 0.1 mm thickness for the separation of the detector vacuum from the beam vacuum. The foil exhibits a complex (corrugated) shape to accommodate for the configuration of the Si stations. The tolerable differential pressure (Δp_{crit}) of such a foil was estimated to be in the order of a few mbar (before buckling). A fixed conductance (e.g. a tube) connects each of the two detector enclosures to the beam line vacuum. If needed, this conductance can be pumped halfway (as indicated with the intermediate pump). The role of this bypass conductance is to guarantee that no damaging differential pressure can build up between the detector volume and the beam line volume. The conductance is, however, low enough to result in an efficient decoupling of the two vacuums under normal operating conditions. One can refine this model by using a spontaneously variable conductance, such as a pressure relief element: the conductance is small in normal vacuum conditions and it spontaneously increases when the pressure difference enters a given range. However, the design of such an element strongly depends on the value of Δp_{crit} . This value can only be calculated with sufficient confidence once the design of the separating foils has been fixed. An other option is to optimize the vacuum in the detector volume by minimization of the outgassing rates, such that less decoupling is required, i.e. a larger conductance (larger opening) can be afforded between the detector volume and the beam line vacuum.

In the sketch of figure 4, bellows mounted sideways from the top and bottom detector halves are used for leading all electrical wires to a panel mounted on the outside of the LHC beam line housing. The flexibility of the bellows allows for vertical motion of the two detector halves. In addition, they serve as pumping ducts for the detector enclosures. Their total conductance must be larger than the conductance of the bypass tube to ensure that the main flow of gas goes through the bellows.

Electrical feedthroughs:

For one detector half, approximately 11000 wires must be connected to vacuum feedthroughs. This requires a large number of connectors mounted on panels on the beam line housing. Since the VD vacuum system is differentially pumped, in case of a leak (from e.g. a feedthrough) the LHC beam line is not directly exposed. The leak would first be signalled in the detector volume by a rising pressure, leaving some time for the control system to close the LHC beam line gate valves to the storage ring.

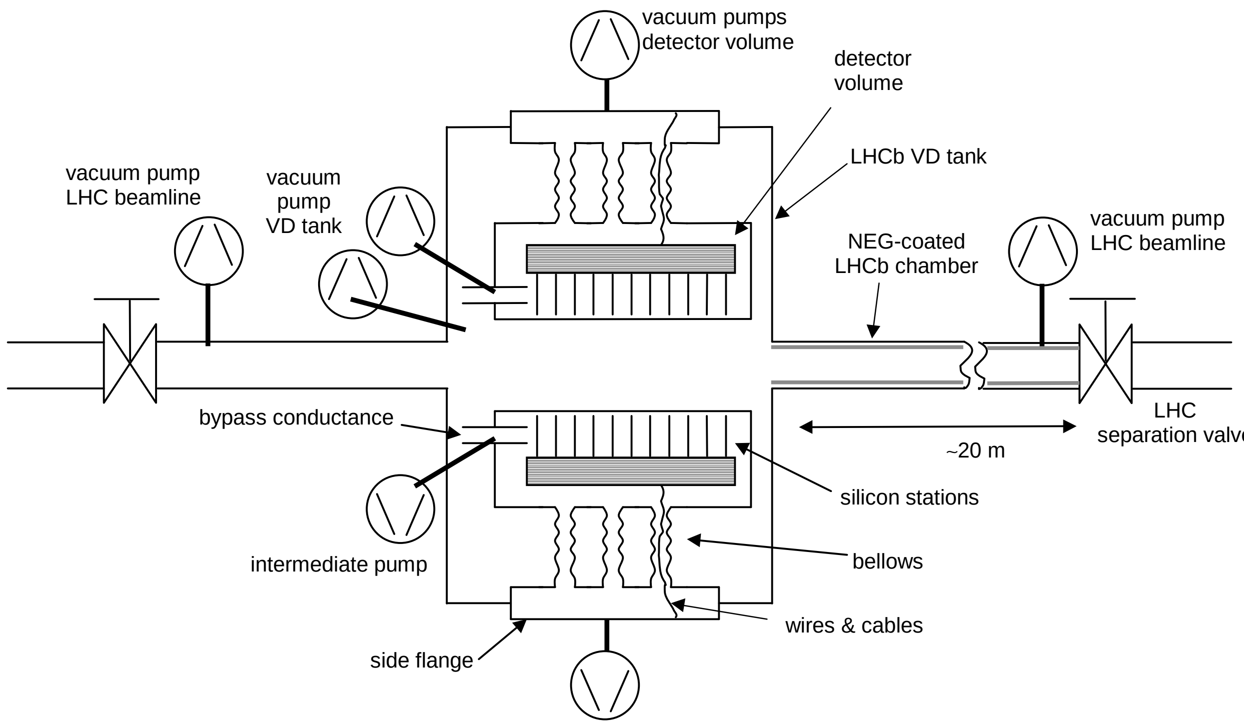


Figure 4: *Schematic layout of a semi-closed vertex detector vacuum system.*

Si detector cooling system:

We are investigating at NIKHEF the possibility to use liquid CO_2 as a coolant for maintaining the operating temperature in the range of –25 to + 10 °C for the vertex silicon detectors. Such a CO_2 -based cooling system exhibits a high radiation resistance. In case of a leak, CO_2 is easily pumped away (in contrast to e.g. water or helium). Seals for the cooling system will be permanent (welds, brazings). The operating pressure of CO_2 would be 14.2 bar (absolute pressure) at a temperature of –30 °C.

Seals:

For seals between the atmosphere and the beam line vacuum we intend to use all-metal gaskets (Helicoflex/Conflat) which exhibit a high radiation resistance and low outgassing rates. For seals between the inside of the detector enclosures and the beam line, which are pumped both on the primary and secondary vacuum sides, we propose to use Viton seals.

5 Properties of a semi-closed LHCb vertex detector vacuum system

A first investigation was made to study the properties of the semi-closed vacuum system proposed in the previous section. Using MathCad [5] a simple static flow model was made based on a small set of assumptions on materials, pump sizes and types. These assumptions are summarized, together with the calculation results, in table 1. Here, effects related to the LHC beams are not taken into account.

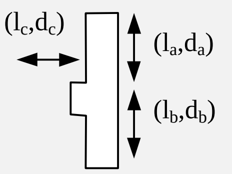
Each of the two detector enclosures was connected to a pump with a pumping speed of 180 liter/s for nitrogen via ten bellows of 40 mm diameter and 400 mm length. The total conductance of the ten bellows amounted to about 160 liter/s for nitrogen. 11400 wires from each detector half were distributed evenly among the bellows. The assumption in this case is that the internal diameter is not restricted significantly by the wires from the silicon stations. Furthermore it is assumed that the vacuum resistance of the (hollow) side flange, on which the electrical feedthroughs are mounted, is negligible. The pumping speed to the beam line housing (the VD tank) was set to 2*1930 liter/s for hydrogen (ion getter + titanium sublimation pump). The bypass conductance was simulated with a tube of 200 mm length and 4 mm diameter (conductance in molecular flow regime of about 0.04 liter/s for nitrogen). A pump with 60 liter/s pumping speed for nitrogen was connected to the middle of this bypass tube (although it might be possible to combine this “intermediate” pump with the pumps of the detector volume). Note also that the geometry and positioning of the bypass conductance was not yet optimized with respect to decoupling of the two vacuums and to differential pressure build-up in case of a leak.

The results given in the first column of table 1 (case I) were obtained by using an outgassing rate for Kapton of 10^{-7} mbar*liter*s^{-1}*cm^{-2}, a value that we measured at NIKHEF (after 40 hours of pumping at 20 °C). The outgassing rate used for the metal surfaces (aluminum and steel) was assumed to be 10^{-10} mbar*liter*s^{-1}*cm^{-2} [7,8]. The outgassing rate used for the bellows was 10^{-9} mbar*liter*s^{-1}*cm^{-2} (based on experience). After 40 hours of pumping, the dominant outgassed component is expected to be water for Kapton and hydrogen for metal surfaces. For the detector volume, the vacuum housing, cooling plates and bellows, have outgassing rates between 7.5*10^{-7} and 1.4*10^{-5} mbar*liter/s, whereas the Kapton cables give a much larger gas load of about 1.1*10^{-2} mbar*liter/s. Other components of the detectors (such as the electronics, hybrids, glues, etc.) were ignored, since a final design with known outgassing rates is not yet available. However, the 11400 signal wires are likely to be the dominant outgassing source.

The outgassing rates for the components in the beam line vacuum (bellows, VD tank and detector housing) were all of the same order of magnitude, between 7.9*10^{-6} and 2.9*10^{-5} mbar*liter/s. The total outgassing rate amounted to 3.8*10^{-5} mbar*liter/s, a value much larger than the total gas load from the upper and lower bypass tubes (2*10^{-8} mbar*liter/s). Our model neglected a potential gas source for the VD beam line vacuum: the detector enclosures may have small leaks because of microscopic holes in the welds. The production of the detector housing from aluminum foil is underway and an experimental investigation will be made to address this issue.

Given the above input conditions to our simple model, we calculated that a pressure of 1*10^{-4} mbar in the detector volume and 9.9*10^{-9} mbar in the VD tank can be achieved. The flow to the intermediate pump was about 7.5*10^{-6} mbar*liter/s, whereas the flow to the beam line from the upper and lower bypass tubes amounted to 2*10^{-8} mbar*liter/s. This shows that the efficiency of the intermediate pump in reducing the flow to the beam line housing is high. Since one could expect lower outgassing rates after longer pumping times and for temperatures lower than 20 °C, or by the choice of other materials, we also show the results (case II) obtained when replacing the outgassing rate of Kapton by 10^{-9} mbar*liter*s^{-1}*cm^{-2}. The results show that the final pressure obtained in the primary vacuum is not sensitive to the values used for the outgassing rates of the component located in the secondary vacuum, for this specific bypass conductance. This indicates that the decoupling of the two vacuums is efficient. Note also that, in this case, the final pressure in the detector volume is much reduced (1.2*10^{-6} mbar instead of 1*10^{-4} mbar), which leaves some room for optimization of the bypass conductance (as a matter of fact, in case II, the flow from the upper and lower bypass tubes becomes –1.2*10^{-9} mbar*liter*s^{-1}, i.e. the intermediate pump pumps on the beam line vacuum).

Properties LHCb Vertex detector vacuum system

Stage	Item		Unit	I	II
	Pumping time		[hours]	40	>>40
detector volume	**Pumping speed in upper AND lower detector volume**		$[\frac{\text{liter}}{\text{sec}}]$	**2*180**	**2*180**
	Pressure		[mbar]	**1.0e-4**	**1.3e-6**
	Out-gassing	Kapton flat cable	$[\text{mbar}\cdot\frac{\text{liter}}{\text{sec}}]$	1.1e-2	1.1e-4
		connectors T- sensors heaters bondings hybrid/Si mountings thermal interfaces		0	0
		Housing		7.5e-7	7.5e-7
		Cooling plates		1.4e-6	1.4e-6
		Bellows 10 pieces d = 40 mm L = 400 mm		1.4e-5	1.4e-5
		Total		1.1e-2	1.3e-4
	Detector housing leaks		$[\text{mbar}\cdot\frac{\text{liter}}{\text{sec}}]$	0	0
	Flow to intermediate pump crossing		$[\text{mbar}\cdot\frac{\text{liter}}{\text{sec}}]$	7.5e-6	8.5e-8
Intermediate pump		a b c	[*mm*]	**l_a = 100 d_a = 4 l_b = 100 d_b = 4 l_c = 0 d_c = 63**	
	Pumping speed		$[\frac{\text{liter}}{\text{sec}}]$	**60**	**60**
	Pressure		[mbar]	**1.5e-7**	**1.7e-9**
	Flow to beam line from upper AND lower detector volume		$[\text{mbar}\cdot\frac{\text{liter}}{\text{sec}}]$	2.0e-8	-1.2e-9
LHC beam line	**Pumping speed**		$[\frac{\text{liter}}{\text{sec}}]$	**2*1930**	**2*1930**
	Pressure		[mbar]	**9.9e-9**	**9.9e-9**
	Out-gassing of all surfaces in the beam line	Beam line	$[\text{mbar}\cdot\frac{\text{liter}}{\text{sec}}]$	7.9e-6	7.9e-6
		Bellows outside		2.9e-5	2.9e-5
		Al-detector housing		1.5e-6	1.5e-6
		Total		3.8e-5	3.8 e-5

Outgassing values and surface areas

one detector half, 19 silicon stations

Kapton cables :

Flat cable with pitch 0.5 mm
1 Silicon station has 600 wires
for 19 stations $A_{kapton} = 11.4\ m^2$

case I:
20 °C / 40 hours pumped ,
assuming 10^{-7} mbar*liter*s^{-1}*cm^{-2}

case II:
minimized outgassing rates (cooling on, pumped more than 40 hours, etc.)
assuming 10^{-9} mbar*liter*s^{-1}*cm^{-2}

Metallic components :

Al housing A = 0.75 m^2
Al cooling plates A = 1.44 m^2

SS 10^{-10} mbar*liter*s^{-1}*cm^{-2}
Al 10^{-10} mbar*liter*s^{-1}*cm^{-2}
bellows 10^{-9} mbar*liter*s^{-1}*cm^{-2}

bellows facing beam line A = 2*1.45 m^2
vessel facing beam line A = 7.9 m^2

Table 1: vacuum properties of the LHCb vertex detector semi-closed vacuum system used in our model.

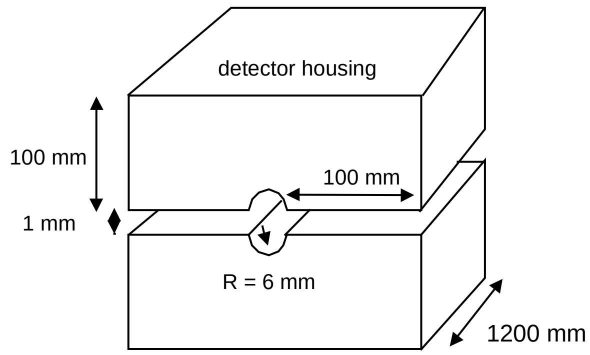


Figure 5: *Model for estimating the static pressure offset along the beam path between the detector housings.*

We also addressed the following issue. During beam injection both vertex detectors are moved away from the beam path by 3 centimeters. During beam storage both detectors are brought close to each other with a spacing of about 1 mm, as sketched in figure 5. The vacuum conductance from the center of the structure towards the pumps is much reduced. In conjunction with outgassing, this could result in an unacceptable rest gas density in the proximity of the beams.

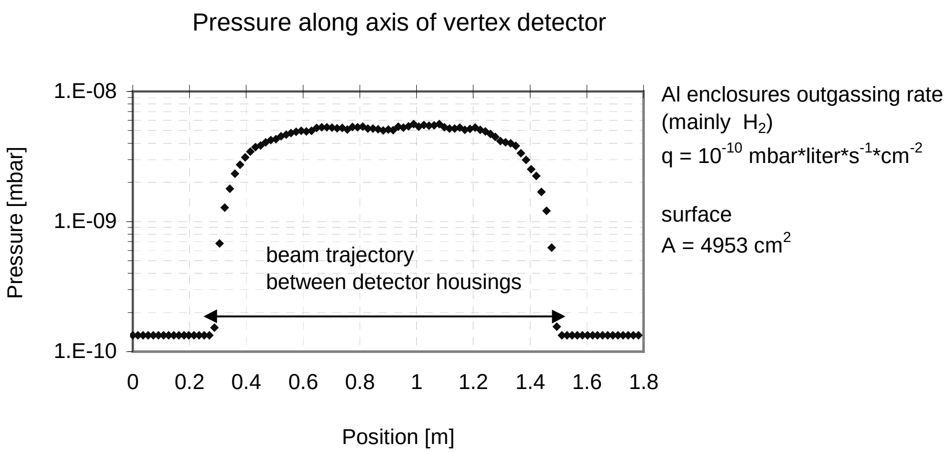


Figure 6 : *Pressure along the beam path through the vertex detector.*

Using Molflow [9], a program that simulates molecular flow, the pressure along the beam path was calculated. Here, we only took into account the structure shown in figure 5 and the vacuum tank with its pumps. The pressure profile along the beam axis was calculated for an (hydrogen) outgassing rate (from the aluminum detector housing) of 10^{-10} mbar*liter* s^{-1}*cm^{-2}. The result is shown in figure 6. The average pressure along the beam trajectory is about 5 to 6*10^{-9} mbar for hydrogen. This is a value smaller than the pressure obtained in the vacuum tank in the previous calculation. Therefore, this effect does not represent a serious obstacle, with respect to residual hydrogen gas density. Note however, that the situation will be somewhat worse in case the enclosure has been exposed to humidity. In this case, the main outgassed component would be water (at start-up). For water, the vacuum conductance to escape the narrow space between the two enclosures is reduced by a factor 3. Furthermore, the ionization cross section (by a 7 TeV proton beam) for water is about a factor 5 higher than for hydrogen. Although careful treatment of the aluminum foils and VD (by e.g. cleaning, pre-baking, appropriate venting procedures, etc.) can reduce the water coverage, it is not clear to what extent the outgassing of water will contribute. The outgassing rate for water could range from 10^{-8} to 10^{-10} mbar*liter*s^{-1}*cm^{-2} at start-up, and from 1*10^{-11} to 5*10^{-11} mbar*liter*s^{-1}*cm^{-2} after 10 hours of pumping [7,8]. In the latter case, a density of 1.5 to 7.5 *10^{-9} mbar would result for the above Molflow model. We also point out that the two detector halves could always be retracted to the open position in case LHC operation is hindered, obviously at the cost of LHCb data taking time. In the near future, we will perform some test measurements on a prototype system to address this issue.

Given a static pressure of about 10^{-8} mbar (H_2) and assuming that the first section of the LHCb vacuum chamber facing the VD tank has a 5 cm diameter, one could expect a diffused flow from the VD tank towards the NEG-coated section on the order of 10^{-6} mbar*liter/s. This continuous H_2 gas load from the VD tank (or the load by other gases) might be problematic and needs to be further investigated. Various gas components, in particular those that might be less efficiently pumped by the NEG coating (such as water, inert gases, etc.) or which affect its efficiency (e.g. CO), need to be taken into account.

This issue will be addressed by simulations and measurements, once more detailed information is obtained about the various components present in the VD vacuum.

Neither ion-induced desorption [10] nor electron multipacting effects [11] were considered here. These might be particularly visible in the 1.2 m long section with reduced diameter (~12 mm) between the detector housings. For instance, a simple estimation for ion-induced desorption in this section shows that the critical condition for the product of the ion-desorption yield (η) and the LHC beam current (I) lies probably in an unsafe region, $(\eta I)_{crit} \approx 1.8$ A (with $(\eta I)_{crit}$ as defined in Ref. [10]). Therefore, special coatings (e.g. by in-situ evaporation of Ti) might be necessary for the aluminum foil to ensure low outgassing, low ion-desorption yield and low secondary electron yield. These issues are presently being studied in cooperation with by the LHC vacuum group. We also disregarded, so far, beam cleaning effect.

It is important to note that a full in-situ vacuum bake-out is not applicable to the LHCb VD system. The maximum temperature this system can sustain might be well below 100 °C. For the same reason, the use of NEG material is not possible since this needs an activation temperature of at least 200 °C [3]. However, a bake–out of the separation foil and other components prior to installation and, perhaps, a partial in-situ bake-out can be considered. This would lower the outgassing rate [7,8].

6 Operation

It is clearly to early to layout a complete model for the vacuum control at this stage. However, some general considerations regarding operation of the VD vacuum system can already be outlined, which might have an impact on the logistics of the LHCb experiment and LHC machine.

6.1 Start-up from atmospheric pressure

Since the thin aluminum foil of the vertex detector can tolerate only a small pressure difference, the pump-down from atmospheric pressure is a critical step requiring some precaution. The LHC gate valves should be closed at all times during this procedure. One might use a dry fore-vacuum pump that evacuates simultaneously the detector and beam line vacuum. During this pump-down time an “auxiliary” bypass conductance should be present between the two volumes. The pump-down speed can be adjusted by pumping through an appropriately chosen restriction. In this way the pressure difference over the separation foils can easily be maintained smaller than 1 mbar. However, this might require a relatively long pump-down cycle (a few hours).

6.2 Venting

In the case of venting (with e.g. dry nitrogen), the detector and the beam line vacuum will both be brought to atmospheric pressure simultaneously, with the auxiliary bypass conductance open. During the vent cycle care must be taken not to exceed the differential pressure limit for the foil. Venting is done (like for pumping down from atmospheric pressure) through a restriction in the vent-line. The vent pressure must be limited to atmospheric pressure to avoid buckling the exit foil of the vertex detector. This can be achieved e.g. by use of an adequate burst disc mounted on the vacuum system. The LHC gate valves should be closed at all times during this procedure. For access to the inside of the VD, a set of precautions to minimize contamination with moisture will have to be defined.

Note that there is no valve between the VD vacuum chamber and the LHCb vacuum chamber. In case distributed getter materials are used, a reactivation will be needed at the next pump-down. Before this can be done, the pressure in the LHCb vacuum chamber must be below a certain pressure value, which means the VD vacuum must also have reached a certain pressure.

6.3 Access to the experimental area

In case the LHCb detector experimental area needs to be accessed, the gate valves to the LHC ring should be closed automatically upon entering the area. Special attention should be paid to access to the connector panels, which constitutes the major potential source of leaks.

6.4 Controls

For operation of the detector with the circulating proton beams the LHC separation valves need to be opened.
Some prerequisites must be defined, eg.:

a. the pressure inside the complete LHCb detector system is less than a specified pressure,
b. the gas composition of the LHCb detector system is within specifications,
c. the LHC storage ring and LHCb vertex detector have reached stable vacuum conditions.

At this moment, a control strategy is being studied. A full-scale model will be used for testing of the control system. The VD vacuum control must be integrated with the LHC beam handling and vacuum control system.

6.5 Preliminary design for the vertex detector vacuum system

In figure 7 a possible layout is shown of the vacuum system described in the previous sections. Although this layout might evolve in the future, it illustrates the (minimum) amount of equipment required for such a system. Some level of redundancy has been taken into account, though a full safety model was not yet investigated.

The silicon detector housings are each pumped using two turbo-molecular pumps (e.g. with a pumping speed of 180 liter/s for nitrogen and 140 liter/s for hydrogen). These can be closed off using Viton sealed gate valves at the detector side. Both turbo pumps have their own low and high vacuum gauges (e.g. Pirani/Penning). They are backed either by a single dry fore-vacuum pump (e.g. a dry scroll type fore-vacuum pump) or each by one such pump. The fore-vacuum pump has a low vacuum gauge and a Viton sealed gate valve at its inlet. The bypass conductance between beam line and detector housing is pumped in the middle using a turbo molecular pump (e.g. with a pumping speed of 56 liter/s for nitrogen and 45 liter/s for hydrogen). The fore-vacuum connection is common to the detector housing turbo pumps. Two combined ion-getter / titanium sublimation vacuum pumps are installed on the beam line vacuum (e.g. with a pumping speed of 1930 liter/s for hydrogen). The VD tank is equipped with a low and high vacuum gauge. A quadrupole mass analyzer might also be required. The 20 m long chamber through the LHCb detector has a diameter of ~5-40 cm and is assumed to be pumped by distributed NEG. As already mentioned (section 2.1) research is done on TiZr getter films which can be activated at low temperature (200 °C). The entire LHCb vacuum system (LHCb chamber and VD tank) can be closed-off from the storage ring using gate valves on both side. Additional pumps and pressure gauges (not shown on the figure) might be present within this section.

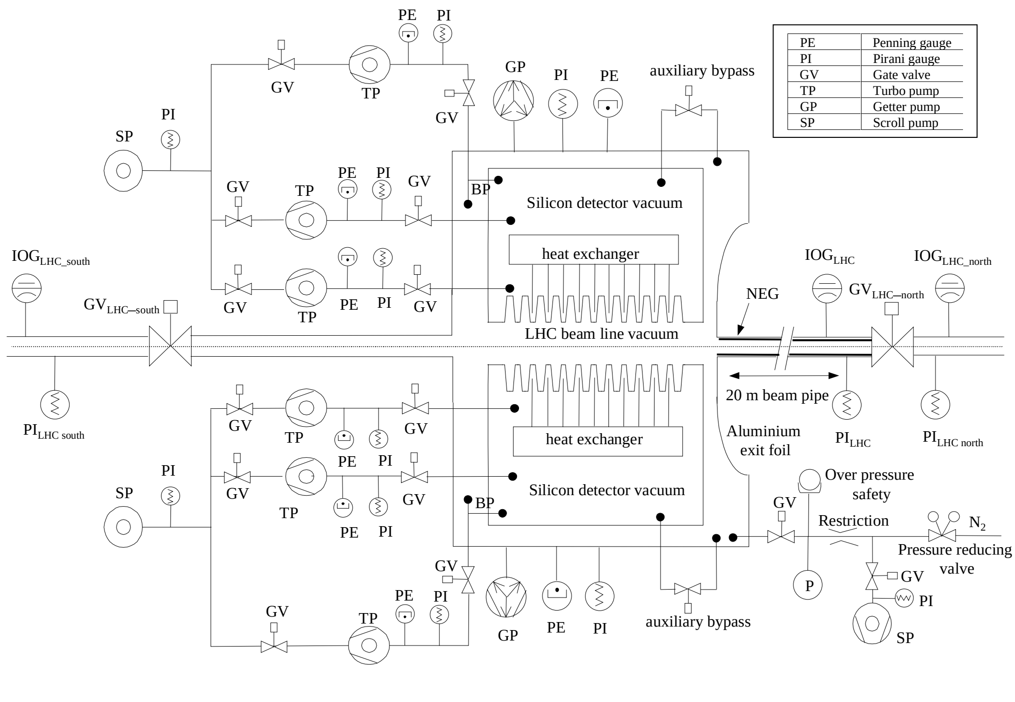


Figure 7: Preliminary layout of the VD vacuum system. The venting and pump-down system is shown on the bottom right corner. BP indicates the fixed bypass conductance. LHC pumps are not shown.

7 Summary

We have presented a proposal for the vacuum system of the LHCb silicon vertex detector. The primary vacuum, seen by the LHC beams, is efficiently decoupled from the detector vacuum by use of a differential vacuum system: the complete silicon stations and signal wires are located in an aluminum box which is connected at all times with the primary vacuum via a pumped conductance. This ensures that no differential pressure builds up across the 0.1 mm aluminum foil separating the detectors from the beams. We presented first calculations which indicate that acceptable (static) vacuum conditions can be achieved. Further studies are needed with respect to dynamical effects in relation with the LHC beams.

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