Design Options for Vacuum Chambers in the LHC Experiments

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Abstract

The proposed new Large Hadron Collider (LHC) at CERN will require a new generation of vacuum vessels transparent to the particles resulting from collisions.

Experience at CERN in the design of similar vessels for high energy physics experiments, such as those in LEP, SPS and ISR will be extensively used. However, the LHC experiments impose new demands on vacuum vessel design. The size of experiments will increase, creating difficulties for the mechanical supports. Radiation levels in the interaction region will also be higher, limiting the choice of materials. Fortunately, the last few years has also seen considerable advances in lightweight materials, making new options available.

In this paper, the choices for experimental vacuum chamber design are reviewed in the context of the rather different demands of the proposed LHC experiments. Design optimisations are presented and a preliminary layout given for each experiment.

1. INTRODUCTION

The LHC (Large Hadron Collider) is the proposed next-step collider for physics at CERN. It will provide Proton-Proton collisions with up to 14 TeV centre of mass energy and a nominal luminosity of 10^{34} $cm^{-2}s^{-1}$. The distance between the magnetic fields of the inner triplets is 40m, but the length which is free for experiments and therefore requires a special vacuum chamber, is 32m.

Current designs plan for four experiments. ATLAS and CMS are general purpose high luminosity proton-proton experiments, substantially larger than the present LEP detectors. Alice is the proposed detector for the dedicated operation with heavy ions. The fourth experiment is proposed to be a B- physics experiment of smaller dimensions, but still requiring a specially developed vacuum chamber.

Although these experiments are not planned for installation until 2002 at the earliest, it is important that the beampipe boundary conditions in terms of effect on physics performance and physical interface are defined at an early stage. In addition, development of any new materials or processes must be advanced to ensure time for adequate testing of these machine critical components.

The requirements for an interaction region vacuum chamber will be discussed point by point, followed by a summary presenting currently favoured options for the design. The text will focus on ATLAS and CMS, being the largest experiments and presenting perhaps the most difficult problems. However, most comments apply equally to the other two experiments.

2. VACUUM CHAMBER REQUIREMENTS

2.1 Vacuum

The large ATLAS and CMS experiments need an experimental beampipe 32m long. A simple layout of such a chamber, within the outline of the CMS experiment, is given in figure 1. The vacuum in this pipe must be maintained by the use of ultra-clean materials and adequate pumping. The pressure distribution between pumps in a long tube is parabolic in form and even with the cleanest materials is largely limited by the spacing of the pumps and the beampipe conductance.

The pressure in the experimental region of the vacuum chamber will be limited by beam-gas interactions. If these interactions are too numerous they will result in an unacceptable background of events for the detectors. In addition, beam induced ion bombardment of the walls may lead to ion induced desorpsion of gas and a run- away pressure increase. Initial calculations for LHC beam parameters show a maximum acceptable pressure to be of the order of 10^{-8} Torr.

To maintain such a pressure, assuming a 120mm diameter chamber, would require intermediate pumping at 8 to 10m from the interaction point (I.P.). Due to the sensitive position of these pumps inside the experiments, causing radiation background a careful weight optimisation will be performed.

2.2 Transparency

In terms of transparency the experimental beampipe can be divided into three regions as shown in figure 1.

In the central region, up to ± 2m from the I.P. the main requirement is to allow the undisturbed passage of the maximum possible fraction of the particles produced in collisions to the detectors. The most effective way to achieve this is, of course, to put the detectors inside the vacuum chamber. This is being proposed for the vertex detector in the ALICE experiment, however, there are a number of technical problems with this approach, such as the feedthrough of power and cooling supplies, and the effect of the components on the vacuum. Other experiments plan to mount their detectors outside a central chamber designed for maximum transparency.

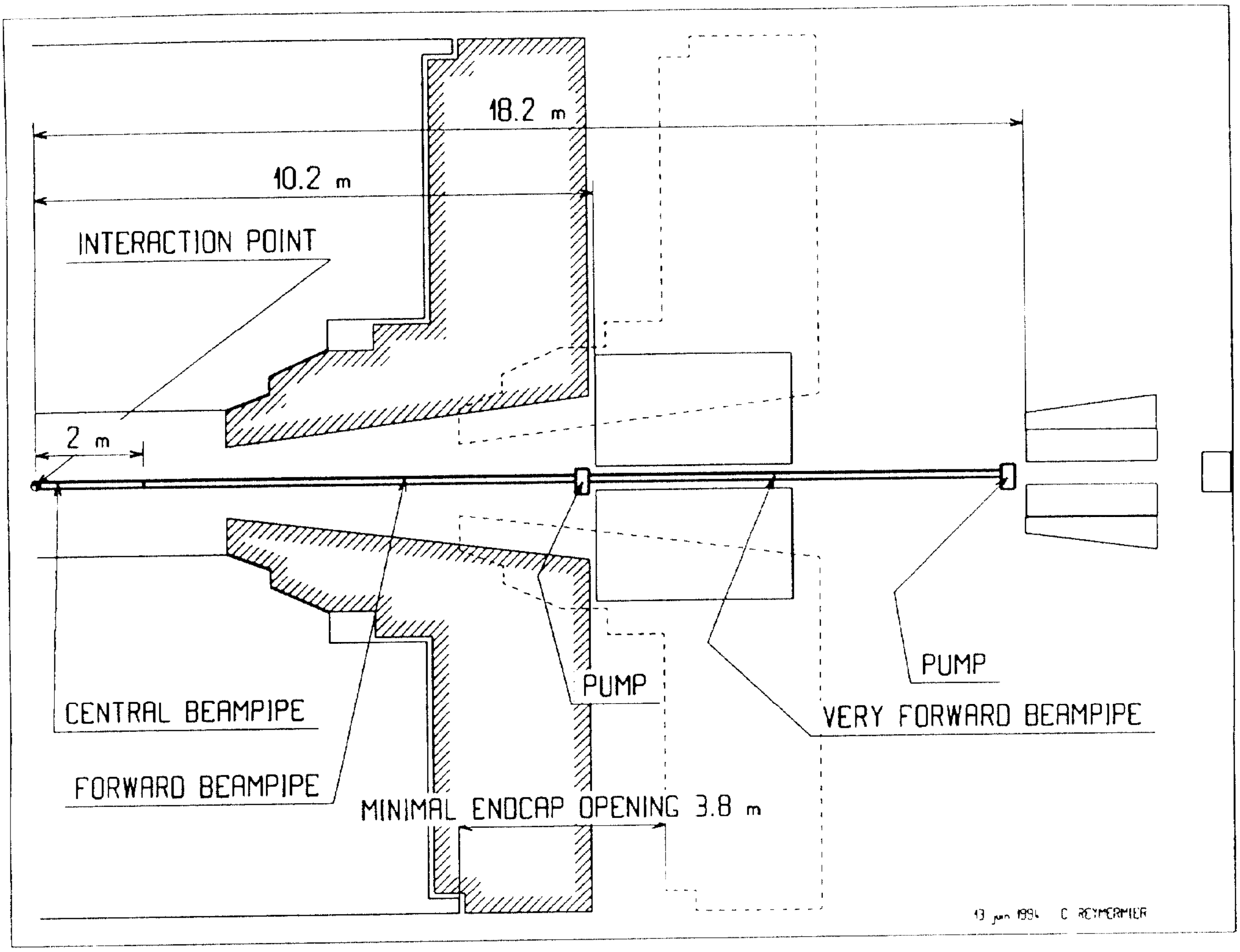

Figure 1. Sketch showing Half-Section through an LHC Proton-Proton Experiment.

The second region for transparency requirements is that from about 2m to 10m on both sides of the I.P. The forward detectors in this region benefit from a high transparency, but it is also important that a minimum of interactions take place with the chamber that could produce background events. Large diameter cylinders or cones are proposed for this region.

The third region from 10m to 15m on both sides sees an even higher level of radiation. The overall mass of material close to the beamline must be minimised to reduce back-scattering, generation of neutron background and high induced radiation levels.

Several good analyses of the choice of materials and geometry for interaction region chambers have been written, such as [1]. Experience exists both at CERN and elsewhere with the use of beryllium, aluminium, titanium, stainless steel and fibre-epoxy composite in a number of geometries. Radiation levels in the experimental region could be high enough to exclude the use of epoxy resins due to degradation of material. However, active research is under way to develop radiation hard matrix materials for such composites.

In terms of transparency and mechanical properties, beryllium is the best material for vacuum chambers and will almost certainly be used for the central region. However, the high cost and safety issues inherent with beryllium mean that it is unlikely to be used in the forward regions.

More recently, the re-commencement of production of beryllium- aluminium alloys has re- opened the possibility of using this material. Material properties and transparency are (not surprisingly) somewhere between the two parent metals. However, the fact that the alloy is weldable gives a wider variety of manufacturing options.

Finally, carbon-carbon composites (carbon fibres in a graphite matrix) can be considered. These materials were originally developed for high temperature applications such as rocket nozzles. They are radiation resistant, transparent, can in principle be baked out to ultra-high vacuum standards and the residual induced activity would be low.

2.3 Support

The central beampipe region can be supported from fixed points in the inner detectors by means of wires or thin struts. This method is currently used in LEP experimental beampipes.

The various access scenarios for the future LHC detectors require the complete end-cap section of the experiment to move relative to the vacuum chamber as shown by the dashed line in figure 1. This means that there will be about 12m of beampipe without access to a fixed support point, either on the experiment or the surrounding environment.

Despite using lightweight, stiff materials, free spans longer than 3m must be avoided to prevent coupling between bending deformations and external pressure forces which would lead to premature failure of the tube by buckling [1].

This demands that the beampipe is supported at regular intervals by some stiff structure which is either an integral part of the beampipe, or mounted to the inside of the experiment.

2.4 Assembly and Installation

It is clear from experience with LEP that the LHC experiments are unlikely to run for more than a few months without the need for minor technical interventions. Furthermore, the detectors themselves will be upgraded and changed as the physics requirements develop. It is therefore important to decide at what level of intervention the beampipe will be removed, and how. It is planned that the experimental beampipe will be removed only during major shutdowns, perhaps once per year. At these times it may also be necessary to modify the beampipe to follow the evolution of the experiment.

It is not practical to handle a 32m beampipe in one piece, therefore it must be made in sections. This raises the question of how these sections are joined. Lightweight aluminium vacuum flanges were developed for LEP. However, the particularly high particle fluxes at small angles in LHC mean that these joints have much more of a detrimental effect by producing neutron background. Therefore the possibility of welding and cutting the beampipe in- situ is being seriously investigated.

Another important consideration is the level of radiation in the experimental interaction region. Radiation levels have been estimated and shown to reach as high as 10^4 Gy in a year of running at an average luminosity of 10^{34} cm^{-2} s^{-1} [2]. The levels are high enough to require special attention when selecting radiation sensitive materials such as composites. The highest levels occur close to the beampipe in the forward direction.

The resulting induced radioactivity has also been estimated and has to be carefully taken into consideration because of the potential dose to personnel and the eventual disposal of activated materials. Whilst the anticipated levels of induced radioactivity are comparable with those which exist in some areas around CERN accelerators, this will be the first time they occur around the detectors in a collider. An estimation of dose rates likely to result from induced activity in the forward region of a high luminosity experiment such as ATLAS suggests that after 30 days of activation and one day of cooldown contact doses around the Very Forward Calorimeter beampipe could be as high as 10mSv.h^{-1}, hence limiting permitted access for personnel to less than one hour per year. This problem may have to be solved by the use of remotely controlled flanges or even robots.

3. DESIGN OPTIONS

Table 1. summarises the currently considered options for the vacuum chamber of the ATLAS and CMS experiments.

4. ACKNOWLEDGEMENTS

This paper represents the work of the CERN working group on interaction vacuum chambers for LHC.

5. REFERENCES

[1] C. Hauviller, "Design of Vacuum Chambers for Experimental Regions of Colliding Beam Machines", 1993 Particle Accelerator Conference, Washington DC, U.S.A. May 1993.

[2] G.-R. Stevenson, A. Fasso, A. Ferrari and P. Sala, "The Radiation Field in and around Hadron Collider Detectors", IEEE Trans. on Nucl. Sc. vol. 39-6, pp. 1712-1719 Dec, 1992.

Table 1
Design Options for ATLAS and CMS Interaction Beampipes

Region	Material	Shape	Supports
Central I.P. to ±1m	1. Beryllium 2. Carbon-Resin composite	1. Smooth tube, 120mm dia. 2. Smooth tube, 50mm dia.	1. Wires fixed to inner detector
Forward ±1m to ±10m	1. Aluminium alloy 2. Beryllium-Aluminium alloy 3. Carbon-Resin composite 4. Carbon-Carbon composite	1. Cone 2. Smooth tube, 120mm dia. 3. Stiffened tube, 120mm dia	1. Rolling supports on end caps 2. Fixed supports on end caps
Very Forward ±10m to ±16m	1. Aluminium alloy 2. Carbon-Resin composite 3. Stainless Steel	1. Smooth tube 2. Stiffened tube	1. Cantilevered from machine 2. Support in cavern