# Status of LHC Crab Cavity Cryostat

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# Status of LHC Crab Cavity Cryostat *

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## *Abstract*

The complex LHC crab cavity design and the beam-line configuration pose very tight constraints for the cryostat design. An initial assessment of the LHC main RF cryostat points to a new design both from the RF and engineering point of view. The cavity and tunnel constraints are discussed in detail and an initial cryostat design along with the cryogenic circuit is presented.

## INTRODUCTION

A prototype crab cavity in the LHC is foreseen as the first important step to realize a full crab crossing scheme for the phase II IR upgrade of the LHC. At present only the IR4 region hosting the main RF station of the LHC, has a special horizontal dog-leg to separate the beam lines to 42 cm. Elsewhere the separation is 19 cm. Due to the typical size of the RF structures under consideration (800 MHz cavities), a global scheme in the IR4 section is the best choice for the prototype tests. The 800 MHz upper limit was chosen as the best compromise between the LHC bunch length and transverse dimensions of the cavity. In the dog-leg region 800 MHz superconducting cavities can be accommodated because elsewhere the beam line separation is too small.

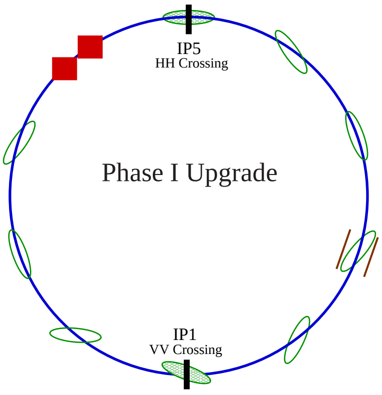

Figure 1: LHC crab crossing phase 0/I scenario anticipated in the time frame of the phase I upgrade.

In this scheme the cavities are placed in the accelerating RF section (IR4, see Fig. 1) to provide head-on collision at one of the interaction points in the LHC ($IP_1$ or $IP_5$). One possible short zone in $IR_4$ is reserved for additional transverse dampers, another much longer one for the capture cavities; both might be necessary for high beam intensities. Therefore, a crab cavity installation relies on the redundancy of one of those systems during the scheduled prototype tests.

## IR4 LAYOUT & INFRASTRUCTURE

The complex structure of the cavity-coupler geometry with the tight LHC beam line constraints make the cryostat design challenging. Fig. 2 shows the present layout in the IR4 region and the anticipated location for the crab cryomodule near the ACN capture cavities.

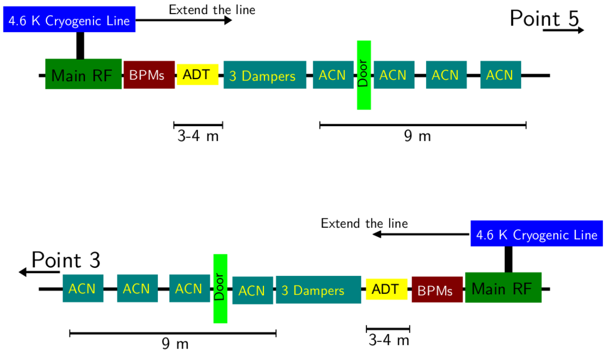

Figure 2: Layout of the IR4 region in the LHC showing the planned crab cavities region reserved for the ACN cavities

The cryostat has either to completely avoid the counter-rotating beam or incorporate it (as in the LHC main RF). But for the inside beam-line closest to large main cryogenic line (see Fig. 3), the available radial space is only 42 cm. Therefore, cavities for both beam lines along with their helium vessels and magnetic shielding should be design to fit within the allowed region. It should be noted that the length of the cryostat should be relatively compact ($\sim$3 m) to avoid longitudinal space constraints if the caputure cavities are required for LHC operation. The only other location would be to fit the cavities within 3-4m space available for the spare damper assuming that it is not required for operation.

A study to accommodate both capture cavities and crab cavities in the available 9m space resulted in a negative conclusion due to engineering difficulties for access and maintainence.

## CRYOSTAT & COMPONENTS

The conceptual design of the cryostat is developed for the by SLAC-LARP cavity design [2] as shown in Fig-

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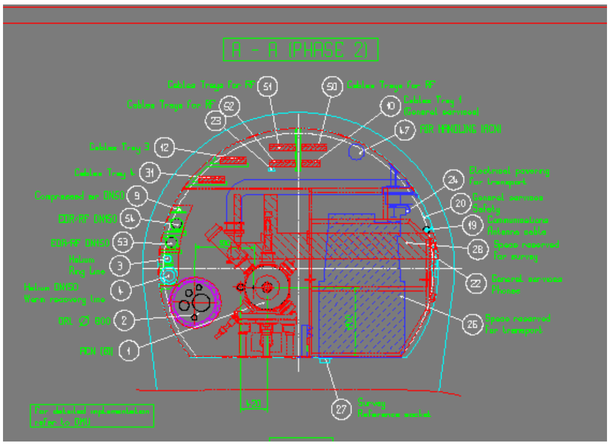

Figure 3: Engineering schematic of the ACN capture cavity region to be potentially be used for the crab cavities which specifies the boundary conditions.

ure 4. During the first test, a two-cell cavity for each beam is anticipated to provide a transverse kick of 2.5 MV. The cryostat design must satisfy the environment limitations for the both beam-lines. In addition, the cryostat should have a modular structure similar to cavities of the LHC main RF system [3]. This allows for additional cavities to be installed if a higher kick voltage is deemed necessary. Thus, the helium box contains interconnection ports for the second cavity. A service port is suggested for the He inlet/outlet ports as well as for the RF couplers (main, LOM and SOM). The cryostat diameter is 900 mm. The outer diameter is constrained by the limited space between Helium vessel and cryogenic line (see Figure 3). Placement of any horizontally oriented couplers is not possible due to the limited space available between beam-lines and QRL. Therefore, a design of the main power coupler which is nominally oriented in the horizontal plane requires a vertical output. Horizontal length of the coupler is limited to ∼150 mm. A possible solution is a T-connection similar to the KEK Tristan-type ERL coupler [4]Note that the central electrode of the coupler has to be cooled. The LOM and SOM couplers for this cavity design are already in vertical plane, and the HOM coupler is connected by a flexible cable to the output port.

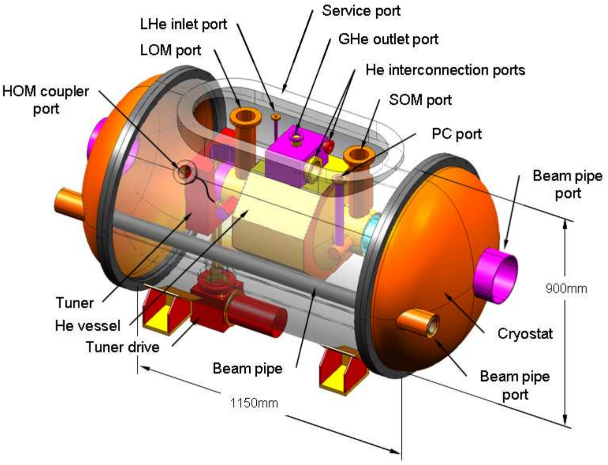

Figure 4: Schematic of the LHC Crab Cavity cryostat.

The cavity tuning concept may use a similar scheme as the LHC main RF cavities one with minimal modification [3]. The specifications for the cavity tuning (for example: tuning range, forces, deformations of each cavity) based on operational scenarios are being defined [6]. In addition mechanical analysis (stress, forces, deformation) of the cavity including helium vessel and couplers has to be performed. In the Figure 4 the LOM and SOM couplers are shown having the diameters determined in Ref [2]. However, realistic concept of the all the couplers is required for the complete cryostat design, see for example, broad-band coupler of the LHC main RF system [5], see Figure 5. The concept should include cooling scheme, tolerance analysis and a detailed scheme for the cavity assembly into the cryostat.

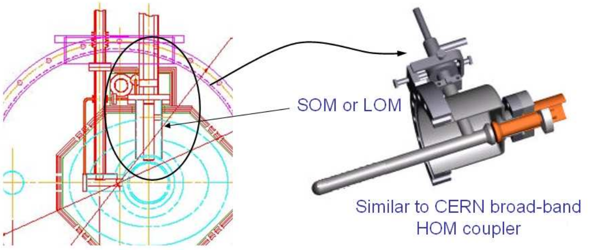

Figure 5: Possible design of the SOM/LOM couplers

The cavity needs two cleaned, RF compensated valves at its ends to protect the cavity SC surface during transport and machine vacuum manipulations. During installation and removal of cavities, breaking part of the machine vacuum should be avoided. Hence also the latter has be confined by two opposing similar valves. The cavity vacuum has to allow the connection of a pumping stand used before and during cool-down and removed during machine operation, supplanted by a permanent ion sputter or similar pump. The vacuum tank will need a working permanently to compensate for micro-leaks through port seals in the cryostat. The cryostat and cavity should be equipped with LHC standard seals, cryogenic connections, cable connectors and gauges (pressure, LHe-level, temperatures) for compatibility reasons. Also CERN safety rules have to be respected concerning pressure vessel regulations for He- and vacuum tank, rupture disks, relieve valves as well as electric power installation for European 230/400 V, 50 Hz with Swiss electrical outlets.

The cryostat has to be transported from ground level to its intended location. It needs to be equipped with stable fix-points for transport, especially for lowering in the shaft. In the tunnel it should either fit standard CERN transport equipment or have its autonomous system. Concerning weight and longitudinal dimensions there should be no true limitation when comparing to the LHC magnets. However, transversely protruding objects (e.g. couplers) have to be limited such that they do not represent an obstacle during transport nor, once installed, penetrate into the LHC transport zone. Also a zone for the surveyors' work in the area should be respected.

RF transmitters and semiconductor electronics have to be protected from the radiation in the tunnel, hence have to be installed behind radiation baffles or in a parallel gallery (see Figure 6). A fast RF vector feedback is required to keep the impedance of the main mode low enough. Therefore the distance between cavity and RF power transmitters should not exceed about 100 m, measured around all corners. This limits the choice where to install this equipment. An SPS 800 MHz transmitter of 60 kW lends itself to be used for the test cavity, avoiding further R&D work and cost; it is overpowered (about 20 kW are sufficient for the crab cavity) but soon will be a CERN standard equipment with several instances, presently under market survey. Cooling water is present for the main RF within the proximity of crab cryomodule and therefore could be supplied with the same system.

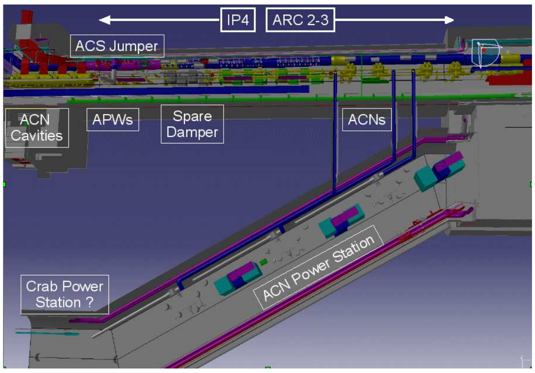

Figure 6: Schematic of the IR4 region with the beam lines and anticipated power station locations.

## CRYOGENIC CIRCUIT

It is anticipated that a 4.5 K helium jumper supply similar to the main RF has to be installed from the QRL near the crab cavity installation. There are some disadvantages from operating at 4.5 K like higher losses, $Q$-degradation over time, microphonics from boiling helium and lower operating gradients which need to be evaluated. If the evaluation mandates a 2 K operation, the cryostat will be equipped with heat exchanger to pump it 2K and equip with proper thermal shielding.

A preliminary cryogenic circuit linked to the QRL for 4.5 K operation is shown in Fig. 7. The helium return line goes to 20 K at 1.3 bar. A back pressure control valve is required to prevent pressurizing the helium vessel since this line serves as a magnet quench heater which can potentially reach 20 bar. A similar circuit also exists for 1.8 K operation where 5 K helium at 3 bar is drawn from the transfer line to generate 1.8 K saturated helium in a manner similar to the magnets. A relief valve and a rupture disk is required for the helium vessel either at 300 K or optionally at 20 K. The 20 K connection is not desired due to potential leaks into the low pressure helium vessel. An additional relief valve shown in Fig. 7 at 300 K would also be needed to lower the pressure in the collection line. The relief valves required to protect the helium vessel is already in place for cryogenic line providing the main RF cavities. If the same 4.5 K helium supply line is utilized for the crab cryomodule, pressuring of helium vessel is not a significant issue and interface to the crab cryomodule will be modified accordingly.

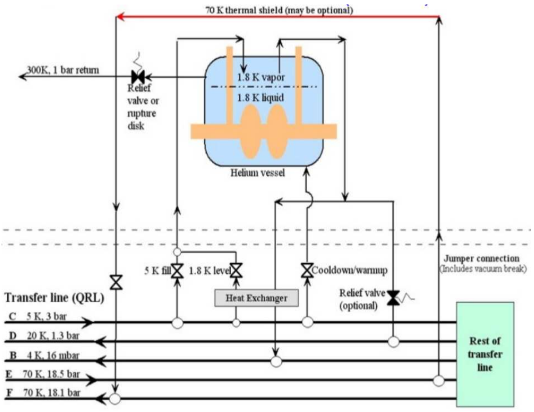

Figure 7: 4.5 K cryogenic circuit envisioned from the crab cryomodule with corresponding relief valves and a return line to 20 K at 1.3 bar. A similar circuit exists for 1.8 K operation where 5 K helium at 3 bar is used in a similar concept as the superconducting magnets to generate saturated helium. A relief valve and rupture at 300 K or optionally at 20 k is required to avoid pressurizing the helium vessel.

## ACKNOWLEDGMENTS

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