OPTIMISING MACHINE-EXPERIMENT INTERVENTIONS IN HL-LHC

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Abstract

The luminosity reach of the HL-LHC experiments implies new constraints for the protection of the inner triplets from the machine debris. In general activation levels will increase a factor of 15-30 from the 2015 values (LS1), affecting both radiation tolerance of equipment and maintenance scenarios. The design of new equipment takes into account these constraints and the entire layout of tunnel equipment near the interaction regions will allow for simplified maintenance. In particular, new absorbers will replace the existing protection of the machine-experiment cavern boundaries, with an optimised layout of the region. This paper summarises the main constraints (both physical and operational) existing at the region, together with the solutions adopted to reduce worker's dose.

INTRODUCTION

When the Proton (or ion) bunches traveling in opposite directions traverse each other at the IP there is a probability that two or more particles will come close enough to interact. The event generates a number of high-energy collision products, some having an electric charge (like pions+/-, protons, etc.), other being neutral (like neutrons, gammas etc.). Some of these particles leaving the IP could impinge on the front face of the inner triplet superconducting quadrupole Q1, producing a quench. For the LHC, special purpose absorbers called TAS stop these secondary particles and concentrate the radiation, allowing a safe operation of the triplets.

LHC TUNNEL-MACHINE INTERFACE

Due to the proximity to the interaction region, (z<19 m) the TAS absorbers are surrounded by a massive shielding to reduce the background radiation in the detectors generated by the interactions taking place in the TAS. TAS absorber and its surrounding are a highly radioactive environment and form an integral part of the forward shielding of both ATLAS and CMS.

Existing Equipment

The typical machine-interface region is a dead-end volume extending from the end of the inner triplet Q1 to the start of the TAS (20.8<z<22.1m, Figs. 1 and 2). Due to the shielding requirements, the access to that area is very narrow (60 cm wide passage for personnel from the tunnel wall to the beam line equipment's), and the space surrounding is limited in all directions. Only 1.3 m are available longitudinally to house multiple equipment essential for operation:

- a Helium tightness dome (which secures the close region in the experimental area in case of Helium release from the triplet)
- a Beam Positioning Monitor (BPM)
- two all-metal gate vacuum valves
- a module containing a residual gas analyser + ion pump + Non-Evaporable Getter (NEG) cartridge+ diverse gauges Bayard Alpert, Penning and Pirani gauges ("VAX module")
- bellows
- services ancillaries (piping and cabling).

Routine operations (i.e. alignment) are very difficult to perform and equipment replacement in case of failures needs to be done manually by a single person, without the possibility of lifting systems.

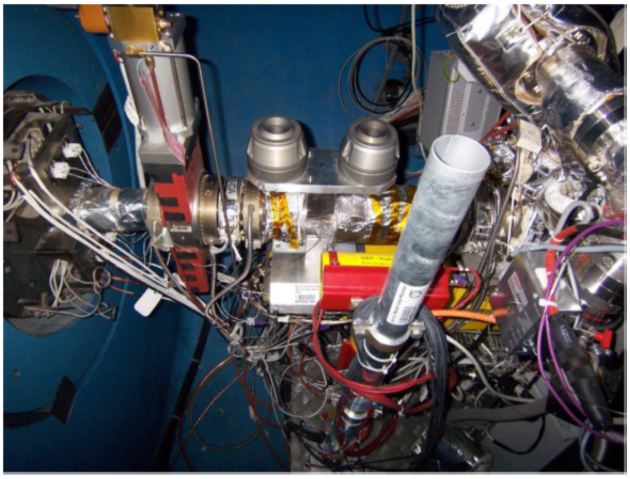

Figure 1: TAS-Q1 region close to P1. From the left, TAS, bellows, experimental sector gate valve, BPM and alignment plate, sector gate valve. Services include cabling for power & signals, pneumatic and pumping lines.

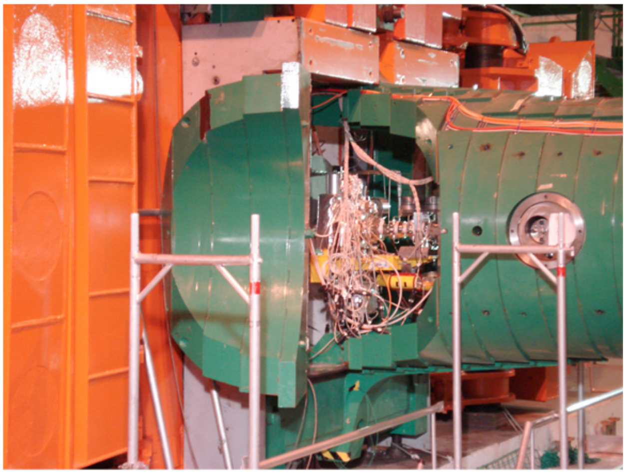

Figure 2: Q1-TAS region close to P5. From the right, TAS (inside steel shielding, in green), bellows, experimentalsector gate valve, BPM and alignment plate, machine sector gate valve.

For HL-LHC operation, a new triplet and a new TAS (TAXS) will be installed. The TAS functionality, position and principles will remain, adopting a permanent water-cooling to cope with the increased deposited energy and radiation level, but the new design will address the limitations as outlined above.

Radiation

Multiple studies [1, 2]about the residual dose rates in the whole LHC machine, and in particular both in ATLAS & CMS show that the values following HL-LHC operation (3000/fb) are likely increasing by a factor which is consistently between 15 and 30 times the values measured in the latest Long Shutdown (LS1). This is of key importance for the regions close to the TAS, as there is little room to improve the current situation: No modifications of the massive steel and concrete shielding (which tightly surround the equipment) are possible, and also alignment requirements for the last BPM will become critical for operation, thus requiring more frequent survey interventions.

As Low As Reasonably Achievable (ALARA)

ALARA [3] is a structured approach to the optimization of radiation risk. This optimization starts in the design phase and implies to take into consideration all the measures allowing reducing the workers dose during interventions.

In the TAXS region, the new design optimization focused on the use of reduced activation materials and improving (reducing time and avoiding contact during handling) or eliminating the need of interventions. In the TAS-Q1 region, there is little room to improve the current "access" situation: in the HL-LHC area, it will still be a dead-end zone where no modifications of the massive steel and concrete shielding (which tightly surround the equipment) are possible.

The situation could be substantially improved by relocating the equipment to the other side of the TAS [4] (inside the experimental caverns), where the forward shielding structures would have to be slightly modified, however with a negligible loss of performance. The available volume in that region is also scarce during operation, but at every yearly-programmed shutdown, the massive steel shielding structures are dismounted or opened to give access to the detectors.

For this new location (sketched in Fig. 4), the new constraints on the region are both geometrical and radiological:

- The equipment will be situated at height (about 15 m in ATLAS and 9 m in CMS),
- Has to be compatible with detector operation
- Has to be "transparent" to opening procedures
- Must not increase the radiation background
- Must not increase the residual dose rate due to the shielding modifications
- Additional materials present in the area must be radiation compliant.

However, a big asset is that after the removal of the forward shielding structures, remote handling is possible and the intervention times can be drastically shortened or done keeping a much safer distance respect to the one existing at the tunnel side when already considered during the design and construction phase of the new TAXS.

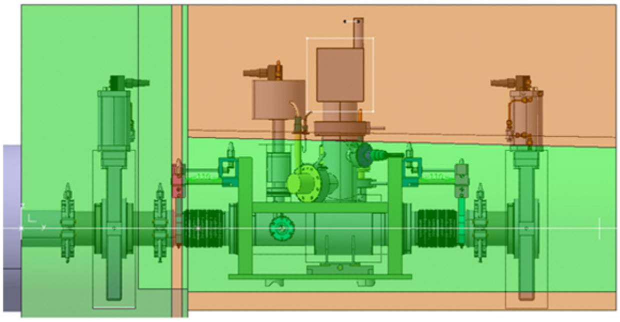

Figure 3: Envelopes for the VAX equipment defined in collaboration with the experiments, green region has no impact, orange needs machining of the forward shielding structures.

TUNNEL-MACHINE INTERFACE CHANGES FOR HL-LHC

The proposal for HL-LHC started revising the need of each equipment and services. The exercise resulted first in the integration of the element requiring more interventions, the BPM within Q1 (being in secondary vacuum improves reliability, and eliminates the need of independent alignment), and second the installation of a new-cantilevered support in the experimental cavern, which includes guiding columns and self-plug-in connectors hosting both electrical and pneumatic lines. [5] The support is made in Aluminium alloy for radiation reasons.

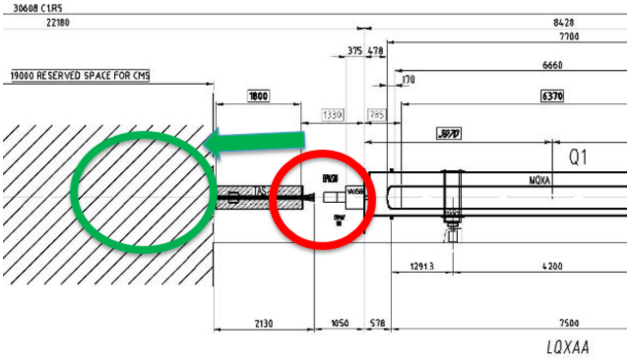

Figure 4: Proposed relocation of the VAX equipment from the tunnel (dead end, tight volume) to the experiment and the BPM is integrated inside of Q1. Although the requirements of the experiments impose new constrains, better handling will allow significantly reducing intervention doses.

The main components are arranged in three independent modules that can be vertically handled and are guided with step-precision to their isostatic feet placed on the support. The insertion/dismantling of each module is thus done vertically with the overhead crane, together with a screw-actuated bellows system connecting each module longitudinally.

Figure 3 shows a side view of the relocated equipment and the impact on the experimental shielding (orange regions are in conflict with experiment shielding structures). The mechanism used for the longitudinal connection of the modules, (shown in Fig. 6) relies on quick release clamps actuated by screws; a similar system being used for the remote connection of LHC collimators.

The cantilevered support (shown in Figure 5) is fixed to the corresponding forward shielding structures, and can be aligned in order to provide a new reference platform for the components. The first module containing the DN 63 sector valve will be fixed to the TAXS (ID 60), while the modules containing the VAX and the last sector valve will have a bigger internal diameter to relax alignment tolerances and can be pre-aligned in respect to the support at the surface.

Integration of Services

Given the tight space, maintenance, remote handling and intervention constraints, a detailed identification of all cabling, and piping requirements for the different elements is a key part of the current design phase.

A stepwise optimization process has been chosen for the integration of the required services. This started first with the definition of approximate volumes required for the supply of the main elements (cabling, piping with baking and insulating jackets). This then allowed the conceptual design of the detailed distribution of each to the female connectors required for the quick plug-ins, themselves attached to the cantilever support. In this iteration, the available size of the connectors, tolerance requirements for misalignments and limitations for the connection/disconnection forces were the design drivers.

For the overall connection of the individual modules, the respective male plug-in will allow for a direct connection by gravity. In order to allow for a detailed testing of this approach and the corresponding design choices, the above considerations, as well as the distribution of each connector to the equipment will be further validated by a prototype in fabrication for 2017. It is important to note that both cabling and connectors will have to be radiation hard and possibly require additional qualification.

Radiological Assessment

The radiological hazard assessment [6] assumed a fully open detector configuration in order to account for the worst possible exposure scenario for personnel intervening in the region of interest. For the latter, FLUKA simulations [7,8] were performed for two scenarios, one with and a second one without the proposed vacuum installation, in order to study the corresponding changes of residual dose rates. In this process, the same irradiation conditions and cooling times were used for both LHC experiments (ATLAS and CMS).

In the current baseline, the vacuum equipment will be installed during LS3, before LHC Phase 2 operation and the High Luminosity (HL) LHC program starts. After LS3, it is assumed that LHC will run three consecutive years of physics program followed by a one-year long shutdown. For long-term operation comparison, the LHC operation was assumed until LS6 (2038) and the expected residual dose rates were estimated for LS4 and LS6 with one month and one year cooling times respectively.

Since the vacuum equipment will be installed in LS3, the previous LHC operation (thus contribution to the residual dose rates) was not considered for these simulations and only the relative increase in residual dose rate was analysed.

As seen in Figure 7, the impact of the additionally installed equipment will be in the worst case a factor 2.5–3.0 higher residual dose rates for the ATLAS cavern, but only close to equipment when the cylindrical and octagonal shielding are removed. In CMS the corresponding increase will be about a factor 2 to 2.5, again with the Rotating Shielding open, and only close to the newly installed equipment.

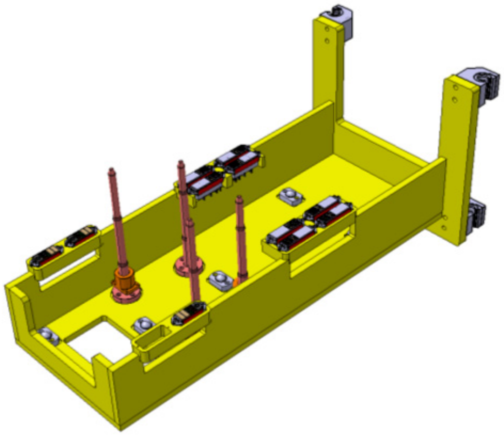

Figure 5: New support for the VAX structures. (1.3 m long, 0.4 m wide). Female quick electrical connectors, spherical isostatic supports and guiding columns are shown.

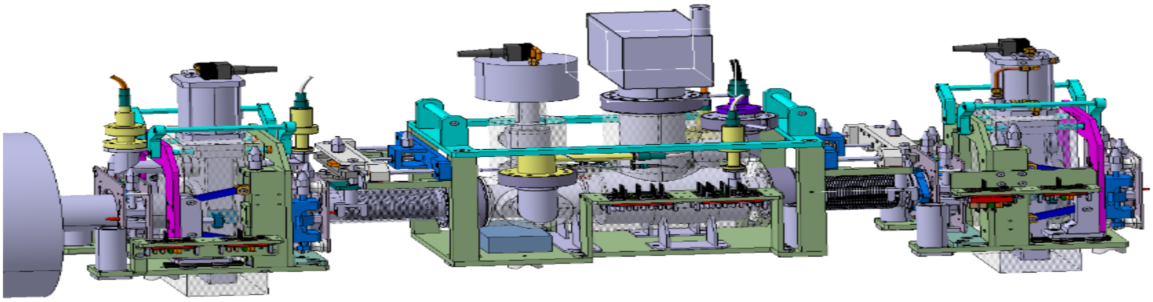

Figure 6: Detailed view of the modules optimized for independent handling. Central module contains the VAX, while modules 1 and 2 contain the gate valves. Plug-in connectors and quick release bellows for interconnection of the modules are shown. The support structure (shown in Fig. 5) is intentionally omitted.

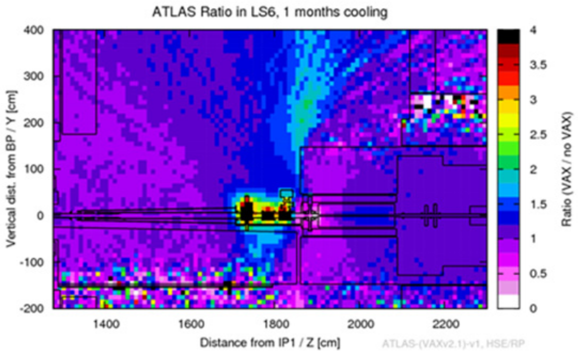

Figure 7: Radiological assessment of the impact of the new equipment in ATLAS detector. Residual dose ratio (VAX-NO VAX) after 1 month cooling.

CONCLUSION

The high-luminosity upgrade of LHC will lead to a significant increase of residual dose rates in critical areas of the machine and experiments, thus leading to new challenges for the maintenance and routine interventions in LHC, especially close to the inner triplets. The performed ALARA analysis of the machine-interface region (a dead-end zone with the most restrictive cross-section of the entire LHC tunnel) lead to a proposal for a new layout with relocated and radiologically improved equipment and the use of remote handling for the installation and removal of the VAX components. The requirement of routine operations will be minimized as much as possible and can be done either remotely or from a sufficiently far distance. The increase of residual dose rates close to the relocated equipment within the experimental caverns are locally constrained near the equipment and well optimized in terms of overall intervention requirements. In order to allow for a best optimized design and final approval, prototyping is ongoing for 2017, allowing not only to evaluate the final design, but also for a first training of the required operations.

ACKNOWLEDGEMENT

The authors would like to thank all the WP8 members, equipment experts & involved groups for their commitment, which is crucial to make this upgrade possible. **This Research is supported by the HL-LHC project**

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