Chapter 8

Collider-experiment interface

F. Sanchez Galan[1], H. Burkhardt[1*], F. Cerrutti[1], A. Gaddi[1], J.L. Grenard[1], L. Krzempek[1], M. Lino Diogo dos Santos[1], J. Perez Espinos[1], M. Raymond[1] and P. Santos Diaz[1]*

[1]CERN, Accelerator & Technology Sector, Switzerland
[*]Corresponding authors

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8.1 Overview

The HL-LHC targeted luminosities for the four main experiments (Table 8-1) will require upgrades of multiple subsystems in In particular, the LHCb experiment subsystems as the vertex locator (VELO), the ring-imaging Cherenkov (RICH) detectors and the tracking system will undergo a major upgrade in LS2, and its surrounding protection systems will be upgraded with neutral absorbers (TANB) to allow to reach the HL-LHC foreseen peak luminosity as from Run 3. Also, in LS2, ALICE will replace its beam-pipe for a new one, with smaller diameter and will also replace its tracking system, time projection chamber and will install a new fast interaction trigger detector. In ATLAS and CMS during Long Shutdown 2 (LS2) and Long Shutdown 3 (LS3) the inner tracker, trigger system, calorimeter, and muon detection systems capable of operating at the foreseen pile-up density, increased radiation environment and minimisation of activation will be replaced. [1][2][3] [17].

Table 8-1: Nominal design luminosities for p-p operation for the HL-LHC. In parenthesis, the value envisaged as "ultimate". The luminosities for the LHC Run 2 are also included for comparison. Total targeted integrated luminosity in CMS and ATLAS is 3000 fb-1 about 10 years after upgrade.

Experiment	Peak Luminosity (cm^{-2} s^{-1})		IP
	HL-LHC	LHC	
ATLAS	$5(7.5) \times 10^{34}$	$1(2) \times 10^{34}$	1
CMS	$5(7.5) \times 10^{34}$	$1(2) \times 10^{34}$	5
ALICE	1×10^{31}	1×10^{31}	2
LHCb	2×10^{33}	2×10^{32}	8

Besides the high-luminosity experiments, the ALICE and LHCb experiments will be upgraded and continue operations during the HL-LHC era. The ALICE experiment, which prepares upgrades of several subsystems and the online–offline system for data acquisition and processing during LS2, will continue the Pb-Pb ion and proton-Pb ion collision program up to LS4, aiming to collect in total 10 nb^{-1} for Pb-Pb collision at top energy plus 3 nb^{-1} for Pb-Pb collision at reduced energy for low-mass dilepton studies and 50 nb^{-1} for p-Pb plus p-p reference runs. As ion beams will still be available during the HL-LHC operation after LS3, the ATLAS and CMS experiments will also participate in the Pb-Pb and p-Pb collision program within the capabilities and constraints from the upgraded inner triplet magnets and available apertures. The LHCb experiment plans for an upgrade during LS2 to allow operating at instantaneous luminosities of 2×10^{33} cm^{-2} s^{-1} (ten times their current design luminosity), that remains compatible with the present magnet layout of the machine in LSS8. This will increase the level of collected data much beyond the Run 2 rate (between 1.7 and 2.2 fb^{-1} per year). The increase in luminosity will mean an increase of collision debris, and the introduction of a Neutral Absorber (TANB) is planned to protect the D2 separation dipole and the downstream cryogenic magnets. Operating in these conditions, LHCb expects to collect 50 fb^{-1} of data until LS4, when a second major upgrade of the detector might be envisaged that would open the possibility of operating at with a luminosity of around 1.8×10^{34} cm^{-2} s^{-1} to allow the collection of 300 - 500 fb^{-1} of data to fully exploit the flavour physics potential of LHC. This later major upgrade is presently under study within the HL-LHC project, albeit not yet part of the baseline HL-LHC project, in particular to understand the implications on operations and the impact to the ATLAS and CMS experiments, and to anticipate modifications to the installed hardware in LSS8 in view of optimizing interventions before the foreseen increased activation levels.

At present, no forward physics experiment has been officially approved to be operated in the LHC tunnel in LSS1 and LSS5 after LS3, apart the detectors required for the ion operation. The presently installed elastic scattering and diffractive physics experiments TOTEM, ATLAS/ALFA and, AFP are assumed to be dismantled during LS3. To what extend they will be replaced with other projects is still under discussion.

The major changes of the layout of the machine in the high-luminosity regions around IP1 and IP5 also result in significant changes in loss patterns in the experimental insertions and backgrounds to the detectors. This is followed up by continuous efforts organized within the LHC background study working group (LBS) to monitor backgrounds in the present LHC and to understand the observations by matching them to evolving, detailed simulations. The reduction of tolerances in the collimation hierarchy and the increase in aperture for the HL-LHC potentially increases losses on tertiary collimators and losses reaching the detector region. As expected, backgrounds and losses were in fact observed to increase with beam energy and intensity. Under normal conditions, they have remained at comfortably tolerable levels for the experiments. The beam-induced backgrounds observed in the detectors are dominated by beam-gas scattering. Efforts to maintain and if possible, further improve the excellent vacuum conditions around the experiments are important to keep backgrounds low at the HL-LHC.

Studies are ongoing on the possible operation scenarios including crabbing schemes, luminosity levelling, collision crossing angles, etc. The goal is to evaluate the limits from the pile-up density that can be afforded whilst maintaining high efficiency for physics signals. Furthermore, studies on possible accident scenarios and associated risks for the machine and experiments have been initiated (see Chapter 7). The studies address failure scenarios of machine components during operation e.g. crab cavity failures [5][6], asynchronous beam dumps, or rarer events like mechanical failures with obstacles in the beam, to name the major ones. The background and failure scenario studies are being updated to follow modifications in the design details and to examine the impact of any new components. The possible impact of recent updates to the HL-LHC baseline as the hollow electron lens on accidental beam losses and backgrounds has not yet been studied in detail. From what is known so far, it is likely that the hollow electron lens will not result in fast accidental beam losses and that its impact on backgrounds will be minimal.

The hardware and equipment involved in the machine-experiment interface for the HL-LHC operation include:

- The passive absorbers for charged (TAXS) and neutral (TAXN and TANB) particles designed to primarily protect the nearby superconducting magnets from the radiation coming out from the interaction region, and simultaneously provide a background reduction to the experiments from beam interactions in the collimators and beam gas;
- The forward shielding in the experimental caverns, in particular the part that is close to the LHC machine tunnels, designed to minimize the background radiation in the detectors and to protect personnel from the highly activated elements during access and maintenance activities;
- The experimental beam pipes, covering in particular the part around the interaction region but more widely the design, handling, and routine operation procedures for the vacuum sector from Q1-left-to-Q1-right.

The design considerations and required upgrades and modifications for the HL-LHC operation are described in the next Sections.

8.2 The charged particles passive absorber – TAXS – TAXS

The high-luminosity regions of LHC at P1/ATLAS and P5/CMS are equipped with passive absorbers for charged particles (TAS) [10] installed on both sides of the interaction region at the transition of the experimental caverns to the LHC tunnel. Their main function is to reduce the heat load and radiation to the superconducting quadrupoles in the straight section from the collision debris coming out of the interaction region. In parallel, the TAS completes the forward shielding of the experiments and participates in the background reduction to the experiments.

The design of the new TAXS absorbers for the HL-LHC for IP1 and IP5 is based on the existing ones, thus maintaining the same shielding configuration, with the following modifications and improvements:

- The beam pipe aperture increases to 60 mm in diameter from the present 34 mm. This aperture is compatible with all possible beam optics versions foreseen for the HL-LHC operation and impacts on the background conditions for the experiments.
- No internal ionization chamber is foreseen in the TAXS.
- The cooling power increases to dissipate the approx. 780 W deposited in the TAXS during beam operation conditions of the HL-LHC including a safety margin which allows for operation at ultimate luminosity of 7.5×10^{34} cm^{-2} s^{-1} (see Ref. [11]).
- The vacuum chamber inside the TAXS will be amorphous carbon (a-C) coated. No baking will be needed. The design of the TAXS remains compatible with the mechanical and geometrical constraints from the surrounding shielding of the experiments.

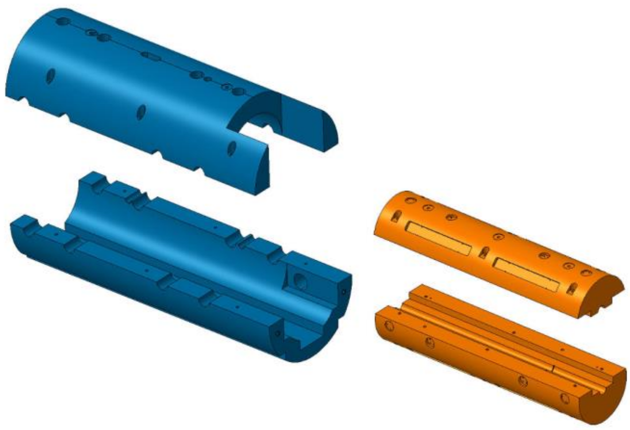


Figure 8-1: Exploded view of the ATLAS TAXS (orange) and its surrounding cradle (blue)

The key design and operation parameters are shown in Table 8-2 and Table 8-3 below.

The exchange from the TAS to TAXS will be done from the experimental caverns and could happen both at the beginning and/or at the end of LS3. Performed simulations regarding estimated radiation levels show that the effect of leaving the TAS in the current location does not affect the dose received by the workers for the routine operations performed in the experimental caverns [15]. The overall procedure is being optimized such as to minimize the exposure of personnel to radiation in compliance with the ALARA principle and the overall planning of the activities in the LHC tunnel and experimental caverns.

Table 8-2: TAXS design parameters from ref. [11].

Characteristics	Units	Value
Distance from IP1 to front flange	mm	19050
TAXS absorber length	mm	1800
TAXS absorber diameter	mm	500
Nominal beam height from floor	mm	1100 at IP1 and 950 at IP5
Nominal longitudinal tunnel slope		+1.236% at IP1 and -1.236% at IP5
Nominal transverse tunnel slope		0.0%
Maximum floor loading	MPa	<0.5
Beam tube straight absorber section (two beams in one tube) Inner radius	mm	30
Supports range of motion		± 30 mm at installation, ± 5.0 mm horizontal and vertical Stops in z (beam axis) at operation.
Absorber cooling		Water and ambient air

Table 8-3: TAXS operation parameters from ref. [12].

Characteristics	Units	Value
Aperture diameter	mm	60
Absorbed collision power at 5×10^{34} cm^{-2} s^{-1}	kW	0.5
24 hr average absorbed collision power (80%)	kW	0.4
Maximum internal beam tube temperature at 5×10^{34} cm^{-2} s^{-1}	C	< 50
Peak power density	mW/cm^3	290
Peak dose	GGy	2
Lifetime alignment operations [1 per opening]		20

8.2.1.1 The TAXS absorber and the relocated VAX in ATLAS/P1

The current Vacuum Assemblies for eXperimental Areas (VAX) are installed inside the LHC tunnel, following Q1 and in a dead end and extremely narrow and difficult access environment. Radiation will increase until LS3 and after that during the HL-LHC operation, making the need of improving access and reducing dose to people during eventual interventions a must. Due to the nature of the shielding (massive steel pieces installed previously in the experiments and tunnel infrastructure) mean that the tunnel cross-section cannot be enlarged at these particular locations.

To solve this, all elements belonging to the VAX will be positioned inside a new support structure, cantilevered with respect to a baseplate that is attached on the fixed forward Shielding structures (JN monobloc, shown in blue surrounding the TAXS in Figure 8-2). The VAX support baseplate has an embedded alignment mechanism that can be manipulated from a distance. The new support will also provide support for the last part of the experimental beam pipe (VJ chamber).

Bellows and quick disconnects installed on either side of the vacuum modules inside the support structure will allow for a fast exchange with remote tools in case of problems. The installation of two flanges, one on the experiment side and one towards the machine, will allow for redundancy and easy decoupling of vacuum sections in case of failures. A permanent bake-out system for the modules will be installed.

Figure 8-2 shows the updated layout of the Forward Regions in ATLAS. On the IP side of the TAXS the assembly module of vacuum equipment (VAX) will be installed as previously described. To do so the present forward luminosity detector (LUCID) will have to be moved towards the IP for the HL-LHC. The module consists of two all-metal gate valves (DN80), the VAX module with ports for the ionic pump, the gas (Ne) injection/extraction line, the quick flanges and intermediate bellows as shown in Figure 8-5. The removal of the different modules and its ancillary services will be fully remote controlled.

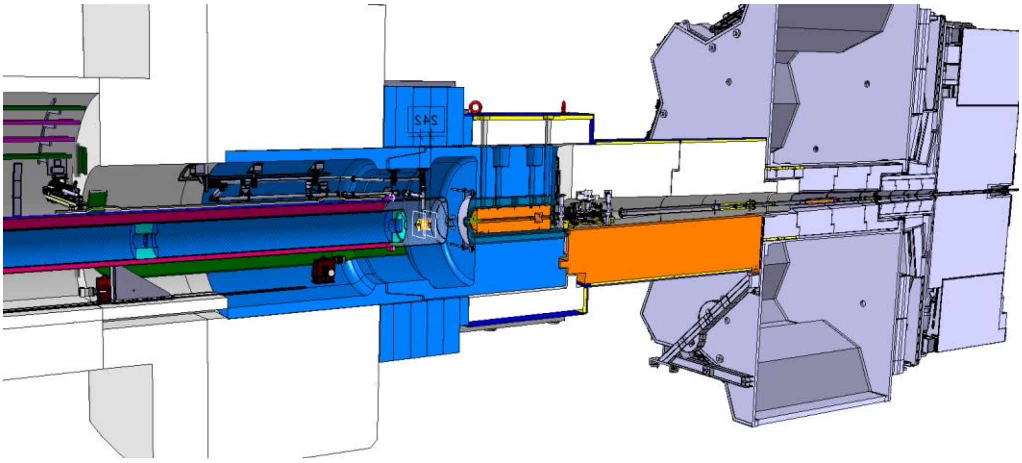


Figure 8-2: 3-D view of the TAXS region from Q1 (machine side, on the left) to ATLAS Endcap toroid (in grey). The layout corresponds to the Run 3 configuration. Q1 is followed by the TAXS absorber (first piece in orange, inside the blue shielding), and the vacuum assembly module (VAX). The foreseen modifications required to host it in the experimental area concern the Forward Shielding (JFC upper shown in white, lower bridge shown in orange) and Endcap Toroid Shielding (JTT in grey).

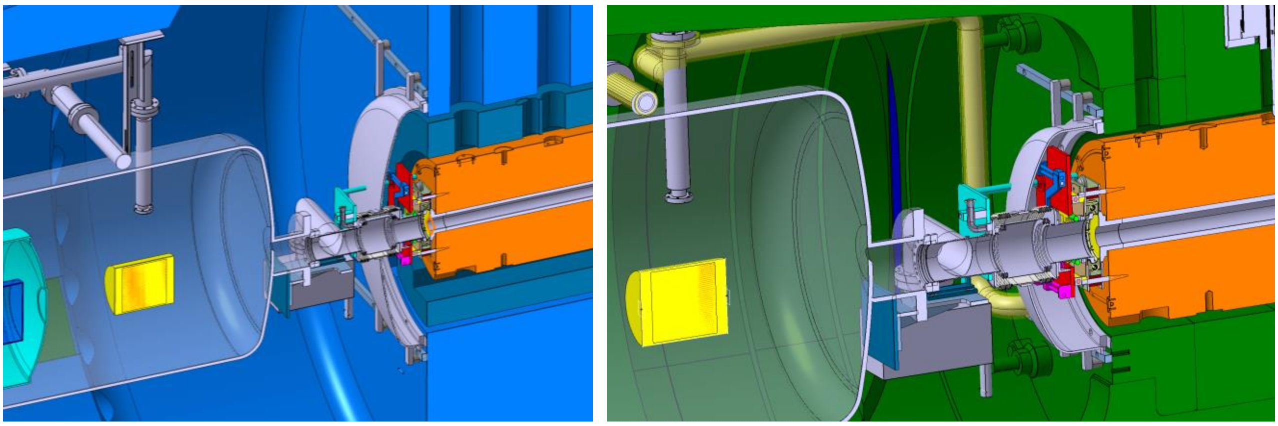


Figure 8-3: [Left]- Zoom into the IP1 Q1-TAXS region as foreseen for the HL-LHC. TAXS (orange) is shown inside its cradle shielding (dark blue). The BPM (yellow) will be placed inside the Q1 secondary vacuum and quick connector, double pump which requires no access and the He tightness dome will remain in the very limited region (grey elements). The gate valves and current VAX assembly will be moved to the experimental caverns. [Right] Zoom on IP5 Q1-TAXS region as foreseen for the HL-LHC.

Modifications of the ATLAS forward shielding elements will be required to integrate the relocated vacuum elements (VAX, all-metal gate-valves). Background studies based on a preliminary geometry of the shielding, have been performed by ATLAS and show that the overall performance is within the current acceptable range. More detailed studies will be performed once a more final shielding geometry is defined, in order to check if additional shielding is required or not.

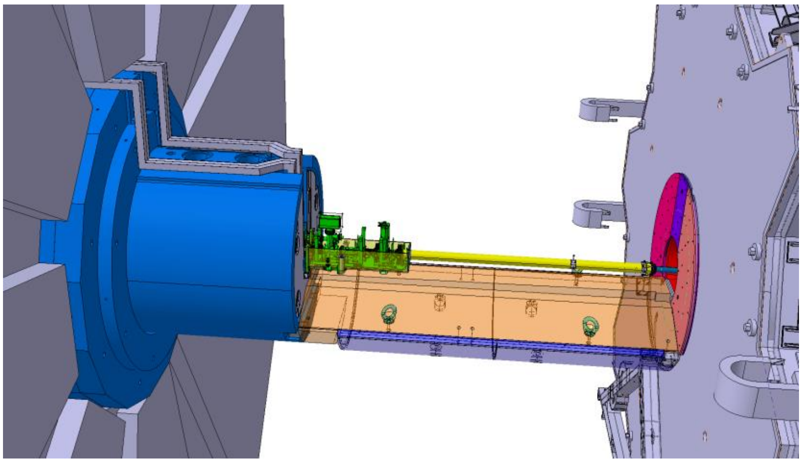


Figure 8-4: 3D view of the forward shielding region with the relocated VAXS and services. The layout corresponds to a phase in the detector access procedure where the octagonal and cylindrical part of the JFC shielding are removed. The passage of the services for the vacuum equipment module (cabling and gas injection/pumping pipes) is shown in grey.

During routine Year-end Technical Stop (YETS) periods, the, ATLAS Endcap Toroid (ECT) opens and slides towards the TX1S shielding without removing the vacuum pipe. At present, all the beamline elements in the region (VJ & VT chambers) are compatible with the inner bore of the ECT, but the size of the new VAX elements will exceed the present envelopes. To allow the full opening of the ATLAS endcap toroid without dismantling any vacuum component, the first disk of the plug shielding is placed inside the toroid inner bore tube (JTT) [8].

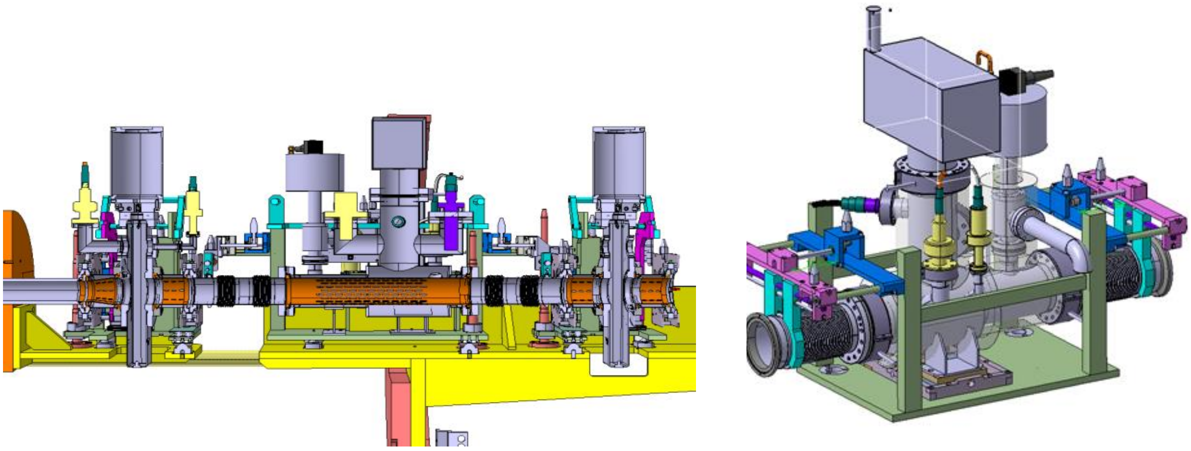
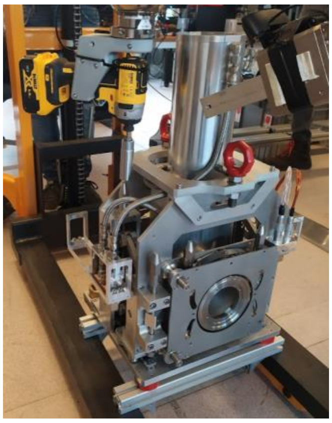


Figure 8-5: [Left] Cut of the Vacuum module assembly (VAX) to be installed on the IP side of the TAXS with all-metal gate valves. Right: the valves are closed in case of remote exchange of the vacuum pump module (Right). Note that the cantilever support structure is not shown in the right picture.



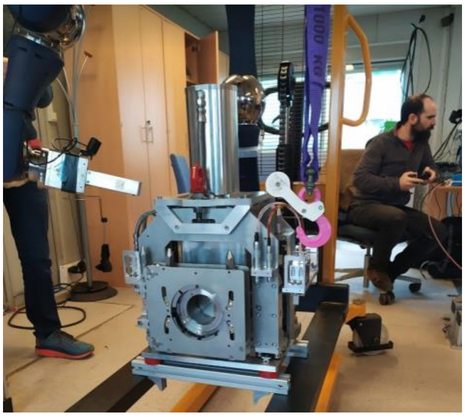


Figure 8-6: Left: All-metal gate sector valve prototype belonging to the vacuum module assembly (VAX) for the IP side of the TAXS. Right: The valves will be remotely disconnected in case of exchange.

The internal bore will be fully compatible with the new vacuum equipment and will provide a safe clearance in case of the detector opening. Shielding performance will be kept by adding extra-material (nose-shape) onto the JFC2. Due to this, the usual opening routine will be only slightly affected.

As the proposed JTT modification preserves the shielding volume, it should be transparent to the operation of the detector. It affects however the support of the experimental vacuum chamber, where a solution is being developed.

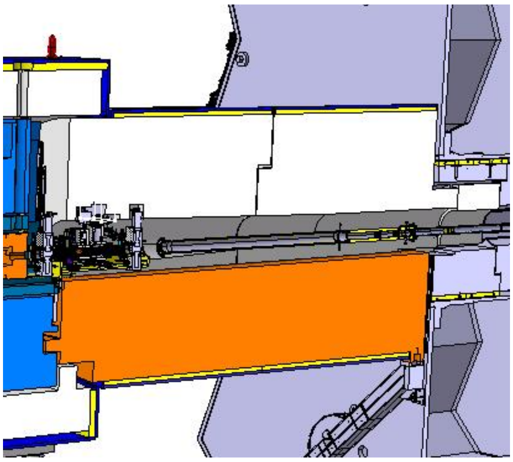


Figure 8-7: Detail cut view of ATLAS forward shielding structures that need to be modified. The shielding consists of two parts: The cylindrical core and the octagonal back. Three pieces called JFC1 ("the bridge", in orange"), JFC2 (white) and JFC3 (white) are used for the core and two pieces called "JFS3 upper" and "JFS3 lower" (on the left, surrounding the blue nose monobloc) are used for the octagonal back.

As the equipment installed on the IP side will be exposed to higher particle fluxes, resulting in higher (× 3) residual doses, the use of optimised material such as Aluminium or low carbon & low cobalt stainless steel will be promoted. Studies on the activation levels and impact to detector background are ongoing, to fully validate this baseline layout [9].

Other shielding modifications (machining) are needed to accommodate the passage of services to the relocated VAX:

- Forward shielding bridge structure “JFC1” (machining below VAX support frame);
- Forward shielding disk at TAS side “JFC2” (machining slots for all-metal gate valve heads and VAX);
- Forward shielding disk at ATLAS Toroid side “JFC3” (include nose for shielding JTT);

- ATLAS Toroid shielding plug “JTT1” (increase bore diameter to host VAX and gate valve heads in ATLAS Standard openings).

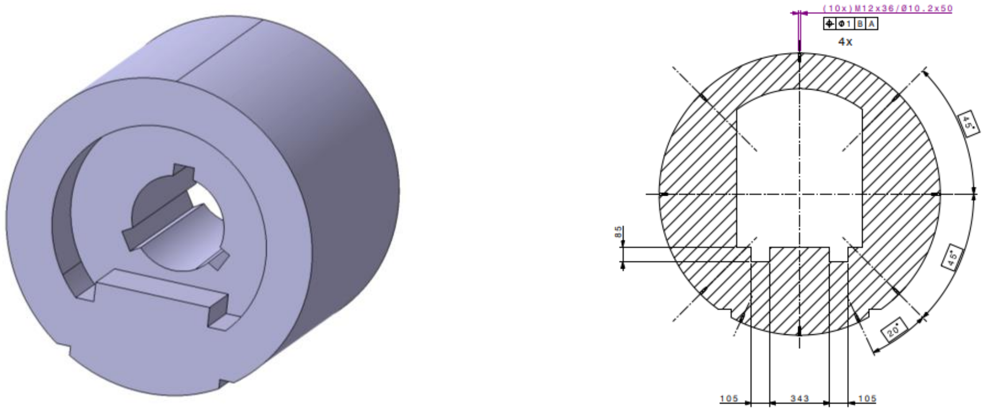


Figure 8-8: 3D view of the ATLAS Toroid shielding plug (JTT, in grey). Only the first of the four disks is shown. For present LHC configuration (left) the disk is a single block, while it will be modified for the HL-LHC (right) will be modified and the shielding will be done in two parts: an outer cylinder with a tailored bore, and an internal block attached to the JFC2 module (Figure 8-9).

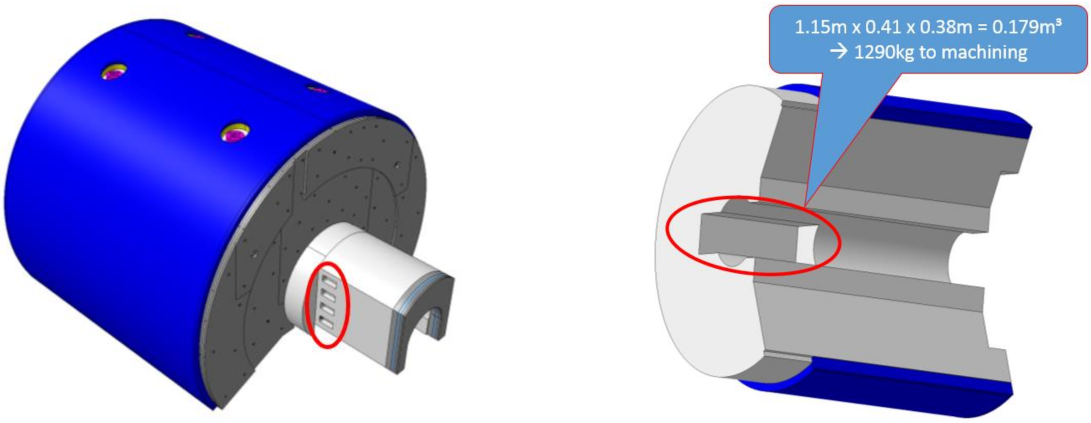


Figure 8-9. Left: 3D view of the ATLAS JFC2 module. Presently the module is a cylindrical shaped block, while for the HL-LHC an “extra nose” shielding will be bolted to fill the gap required in JTT for the detector opening without removing VAX. Right: proposal for machining JFC3 subject to ATLAS agreement.

Figure 8-10. Left: View of the “extra nose” shielding (3 tons) manufactured by VMV METAL Ltd (Bulgaria) during LS2. Right: New 11-ton ATLAS Toroid shielding plug (JTT), manufactured by PAEK (Pakistan).

8.2.1.2 The TAXS absorber and the relocated VAX in CMS/P5

As is the case for ATLAS, in CMS large shielding structures are situated surrounding the TAS and beampipe in the forward regions. Although conceptually similar, the mechanics are different and opening of these large, cantilevered structures is done by rotating them, using a "classical" hinged system. The updated layout for the CMS experiment is shown in Figure 8-12.

The assembly module for the vacuum equipment is similar to that for ATLAS, with minor modifications to adopt it to the shielding layout. As for ATLAS, there are some conflicts with the presently installed shielding that can be resolved with minor modifications:

A new plug for the fix iron nose will be built and shielding elements of the rotating shielding will be either removed or modified to allow the integration of the displaced VAX equipment. There is no further conflict with the detector opening as the new module will occupy basically the volume of the presently installed support module, shown in yellow in Figure 8-14 and Figure 8-16. The installation of the vacuum equipment (all metal gate valves-quick connectors), bellows and VAX module on the new beam pipe support will require the relocation of the services (Grey beam over the support at Figure 8-16 left). The passage of the services is challenging but possible using the channels on the Fixed Iron Nose (FIN) left open when the rotating shielding closes.

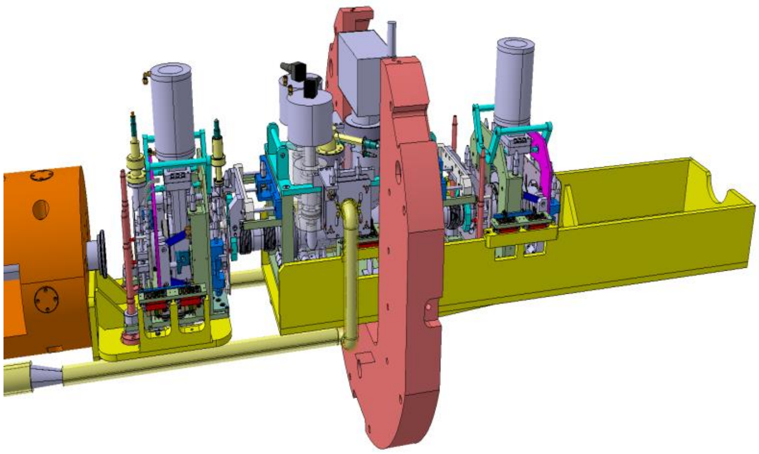


Figure 8-11: Right- cut of the Vacuum module assembly (VAX) installed on the IP side of the TAXS with all-metal gate valves.

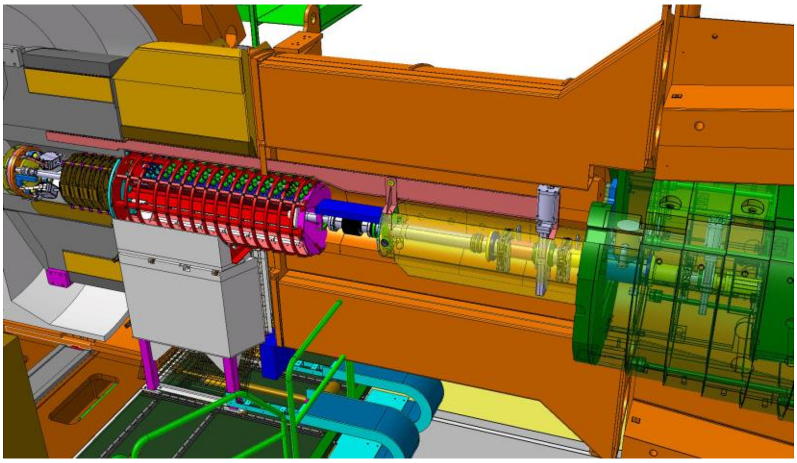


Figure 8-12: 3D view of the CMS forward shielding region with the TAXS and vacuum module. The layout corresponds to the Run 3 configuration. The TAXS absorber is located on the right inside the Fixed Iron Nose shielding (FIN, in green) and the surrounding rotating shielding (in orange). The relocated vacuum assembly module (VAX) on the IP side is shown inside the baseplate support (transparent yellow).

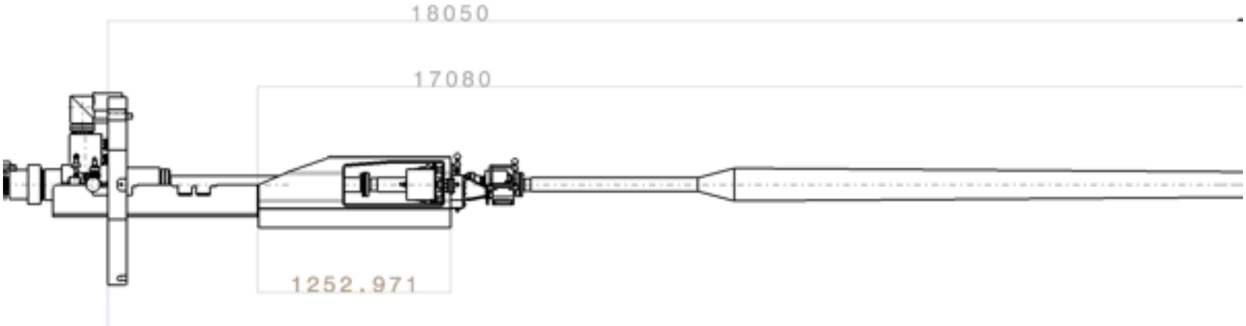


Figure 8-13: 2D drawing of the CMS beam pipe forward region. The new VAX support will extend until 17080 from the IP and will serve as a connection for the new relocated ion pump cantilever support (1253 mm in length towards the IP from the 17080 VAX support interface plate).

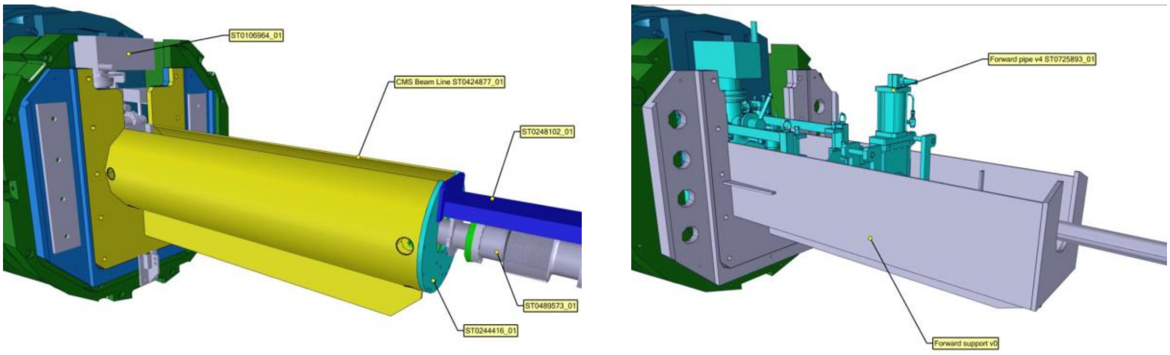


Figure 8-14: Left:3D view of the current CMS beam pipe support (yellow) in front of TAS. Right: the new VAX support structure (grey) will support the relocated VAX equipment (blue) and the ion pump cantilever support. The layouts correspond to the open detector configuration.

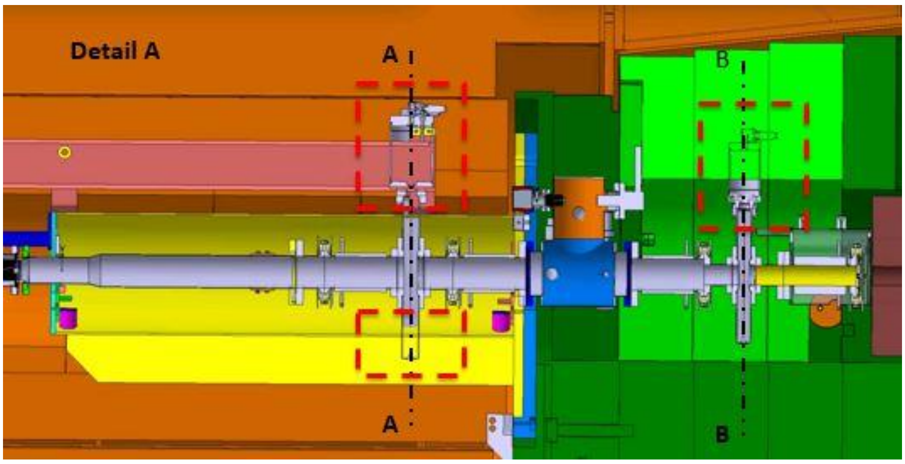


Figure 8-15: Cut of the CMS forward shielding showing the relocated VAX inside the yellow beam pipe support module. The end of the TAXS is shown at the right end. The required modifications in the Forward shielding (orange) and Fixed Iron nose (green) are highlighted by the dashed red boxes. Details of the beam pipe support and the cable tray required to be modified are shown on the left.

Figure 8-16: Photos showing the CMS forward shielding during access. The small rotating shielding is open, showing the yellow beam pipe support module. Details of the beam pipe support (yellow structure at the tip of the cylindrical tallow support) and the cable tray (Aluminium structure over the yellow support) to be modified are shown on the right picture.

8.2.2 The neutral particle passive absorbers - TAXN, TANB

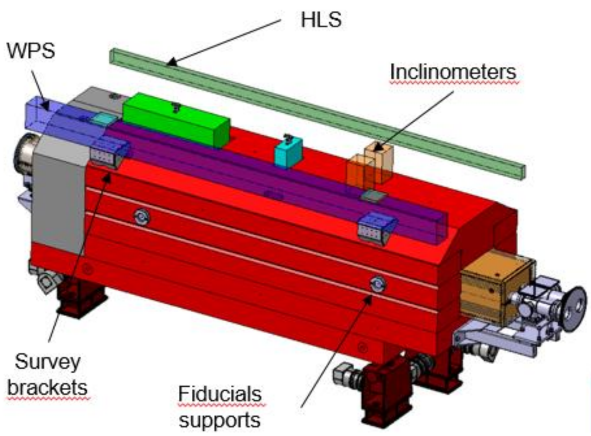
A TAXN absorber will be installed on both sides of IP1 and IP5 located between the separation/recombination dipole pair D1 and D2 and contain the transition from the single common beam pipe to the two separate pipes for the incoming/outgoing beams, replacing the existing TAN absorbers. The TANB absorbers are new elements in the LHC tunnel and were already installed during LS2 on both sides of P8, located in front of the separation/recombination dipole D2. Differently from the TAN and TAXN, the TANB is situated away from the recombination Y chamber.

8.2.2.1 The TAXN for IP1 & IP5

The design of the new TAXN absorbers for P1 and P5 (Figure 8-17) is based on that of the presently installed TAN, with the following modifications and improvements:

- In the HL-LHC layout, the position of the TAXN is displaced by approximately 14 m towards the IP compared to the present situation, and the available longitudinal space is reduced by approx. 160 mm.
- The vacuum chamber has a fixed aperture, which combined with a specially designed TCLX collimator with movable jaws just downstream towards D2, provides the maximum protection efficiency at all beam optics scenarios for the HL-LHC. The chamber will be NEG-coated and the TAXN will provide enhanced baking capabilities (250°C with a 50°C/h heating rate).
- Active water cooling will be required to dissipate the expected approx. 1.8 kW of deposited heating power from the beam, expected during the HL-LHC operation including safety margins which allows for operation up to ultimate luminosities of 7.5×10^{34} cm^{-2} s^{-1}. The expected peak dose is 4.5 Gy for 3000 fb^{-1} (see Ref. [13]).
- Improvements in the mechanical design of the absorber will be incorporated to the design in order to allow optimized installation and maintenance activities.
- A dedicated slot for beam instrumentation for luminosity monitoring (BRAN) will be maintained, whereas the BRAN will adapt its transversal dimensions to the HL-LHC optic configuration (aperture and beam distance inside TAXN).

- A Zero Degree Calorimeter (ZDC) will be integrated in a dedicated slot inside the TAXN. ZDC will adapt its transversal dimensions to the HL-LHC optic configuration (aperture and beam distance inside TAXN).
- The TAXN will reuse most of the external shielding of the TAN and will act as support for nearby vacuum equipment. Support feet will allow the TAXN to be compatible with remote alignment.



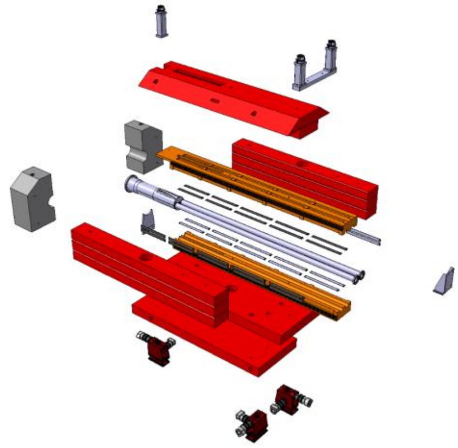
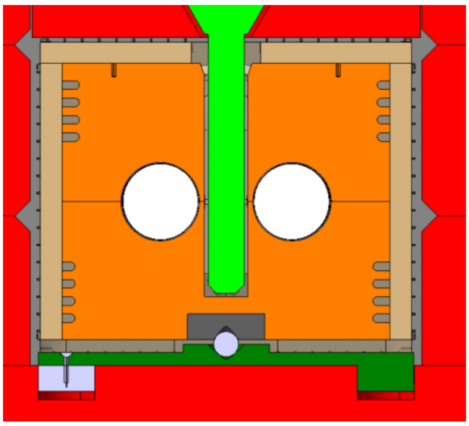


Figure 8-17: Left: 3-D drawing of the TAXN and its surrounding equipment. Right: Exploded view of the TAXN. Y chamber (grey) is surrounded by the Cu absorber (orange) embedded onto a heating jacket (not shown) for bake-out purposes. This subsystem is itself enclosed in the TAN steel shielding (red). Ancillaries as feet (remotely aligned), heating strips, cooling pipes, alignment supports, and marble blocks are also shown. The top lid is being redesigned to be compatible with the BRAN luminosity detector and Zero Degree Calorimeter (ZDC).

Since the first version of the TDR, several important changes affected the TAXN design: The external steel shielding from the TAN (shown in red in Figure 8-18) will be reused, allowing a waste reduction of 100 Tonnes (25 Tonnes per TAN), and the alignment feet will be remotely actuated as it will be the case for the surrounding elements.



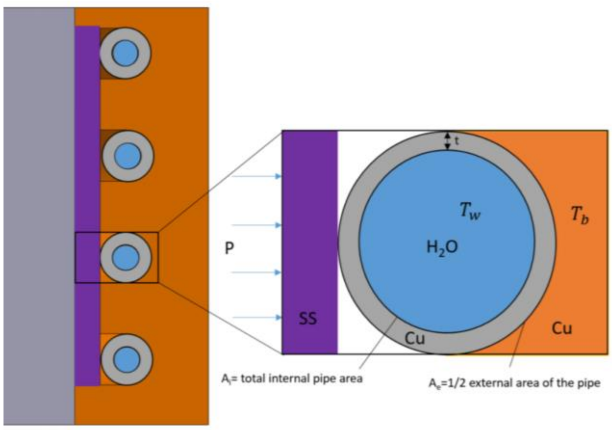


Figure 8-18: Left: Front view of the absorber inside the TAXN (non-IP side). Parallel vacuum chambers are embedded onto the Cu absorber (orange), containing the water cooling pipes at its lateral edges. In light brown, the heating jacket surrounds the subsystem. A removable insert (green) was designed to be compatible with the Zero Degree Calorimeter (ZDC). Right: Detail of the cooling principle, with stainless steel channels allowing water flow.

At the beginning of 2020, ATLAS and CMS requested the space for a ZDC detector. Some changes in the absorber were performed, and the external shielding will still be kept with the exception of the top cover, (a new one will be manufactured to be compatible with the BRAN and ZDC). Changes in the surrounding tunnel equipment (mainly cable routing, rack location and handling with remotely actuated cranes) are currently under revision. Figure 8-19 shows the TAXN integration drawings with the present tunnel equipment.

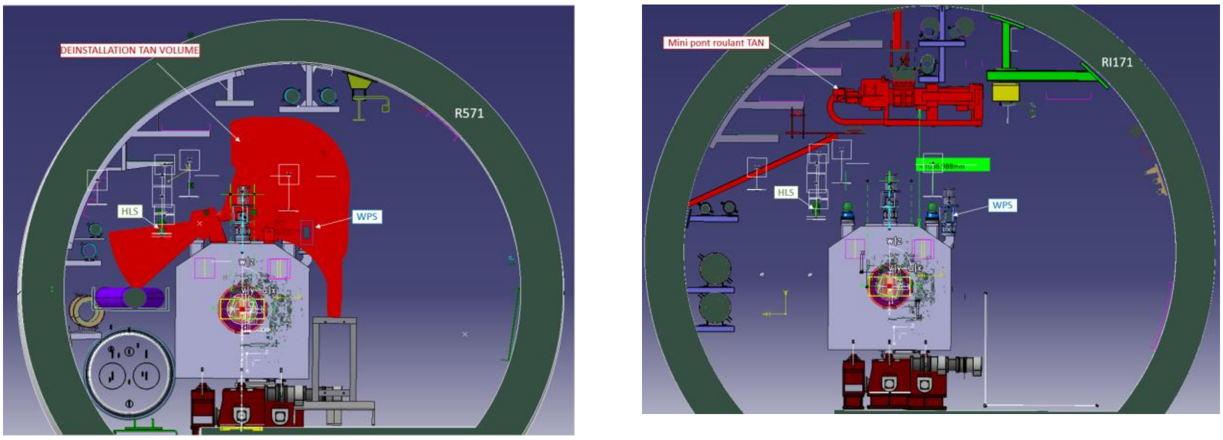


Figure 8-19: View of the TAXN inside the LHC tunnel and current auxiliary cranes used for handling the forward detectors inside TAXN. Left: CMS crane path will collide with surrounding equipment (mainly alignment wire positioning system). Right: ATLAS crane principle will be kept.

The TAXN design is described in detail in the Technical Specifications Documents for P1 and P5 [14] respectively, while its interfaces with surrounding equipment including ZDC and BRAN detectors are described in Ref. [20]. Conceptual description, technical requirements and design parameters of the recombination chamber (Y-chamber) which will be installed during LS3 inside the TAXN absorber are described in a separate document released by WP12 [18]. The key design and operation parameters are shown in Table 8-4 and Table 8-5.

Table 8-4: Key design parameters for the TAXN of P1 and P5 (under approval).

Parameter	Unit	Value
Aperture separation (from the transition point) entrance end	 mm mm	 151.1 161.1
TAXN length from flange to flange	mm	4300
Total absorber length (minimum)	mm	3310
Internal absorber length	mm	2400
Length of separated pipes	mm	3450
Maximum TAXN width	mm	1150
Maximum TAXN height (from two beam centreline)	mm	550
Shielding radius (from two beam centreline)	mm	530
Nominal beam height from floor	mm	1100/950
Beam tube facing IP (two beams in one tube) Inner diameter Thickness Flange size	 mm mm 	 250 2 DN273
Beam tube away from IP (two beams in two tubes) Inner radius Thickness	 mm mm	 88 1.5
Vacuum chamber to alignment fiducial tolerance	mm	± 1
Supports range of motion	mm	± 10.0 [h & v]
Absorber cooling		Demin. Water

Table 8-5: TAXN operational parameters.

Characteristics	Units	Value
Absorbed collision power at 5×10^{34} cm^{-2} s^{-1} 7.5×10^{34} cm^{-2} s^{-1}	kW	1.2 1.8
Maximum internal beam tube temperature	C	50

The TAXN absorber length has been optimised for radiation shielding and starting from the current TAN design, as studies performed by WP10 [21] have shown that the protection levels for the region are adequate. Indeed, the fact that the power deposition inside the TAXN for the worst case of p-p operation is highly peaked at the side of beam entry allowed a reduction in length for the absorber, as shown in Figure 8-20.

The aperture of the Y-chamber inside the TAXN has been set to 85 mm after several studies proving that the gain in protection to the D2 assembly in case of a smaller aperture would be minor (around 2 W reduction, which represents about 10% of the total input power). Manufacturing tolerances could lead to a small increase of this aperture (i.e 88 mm)

These studies also show that a shorter absorber can be equally efficient, gaining about 1m in longitudinal length (see Figure 8-21). Shorter options would be feasible using a denser material such as Tungsten, however, using Tungsten as the core absorber material may increase manufacturing and technical challenges (both thermal & mechanical) compared to copper. Therefore, so this possibility is kept as an option for the final technical design of the absorber if available space due to integration of surrounding equipment becomes critical.

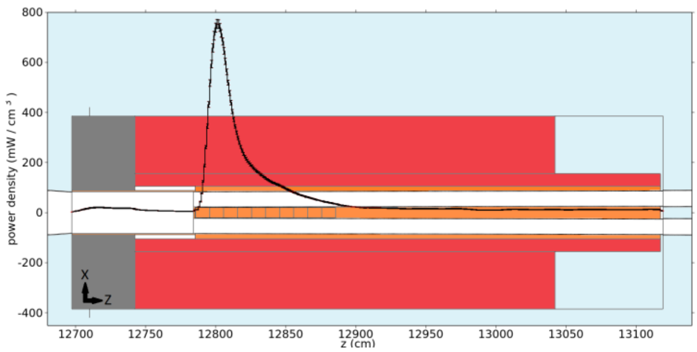


Figure 8-20: TAXN geometry showing the peak power deposition profile in case of a Cu absorber. Most of the power is deposited in the first part of the absorber.

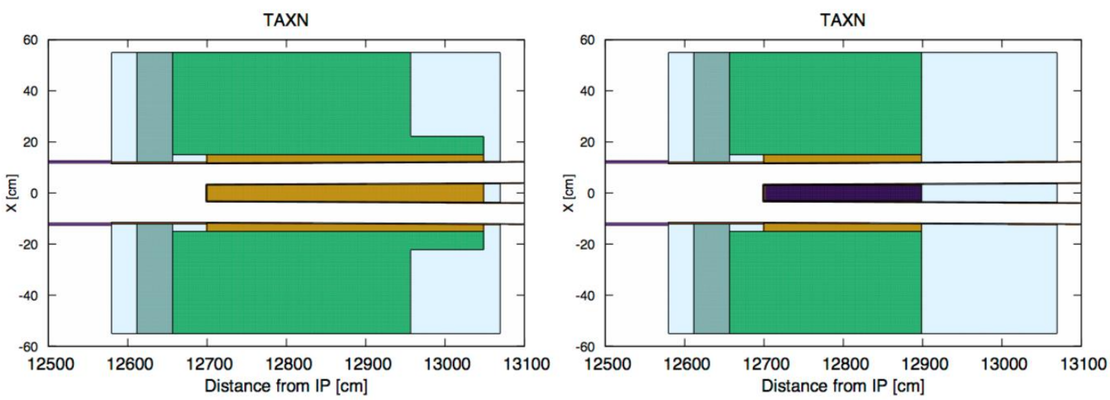


Figure 8-21: TAXN geometry using different material for the core absorber: Cu (left), Inermet180 (right). Maintaining the same efficiency (approx. 22-25 λ_{int}) a gain in length of 1.5m can be obtained.

8.2.2.2 The TANB for IP8

During the LHC design stage, it was estimated that absorbers would only become necessary for luminosities above $L = 10^{33}$ cm^{-2} s^{-1}. The original request by LHCb was for luminosities of up to $L = 4 \times 10^{32}$ cm^{-2} s^{-1}, thus IR8, where the LHCb experiment is located, could be designed without absorbers. More detailed studies on energy deposition in IR8 [16] have been made recently, to assess to which extent absorbers are required for the luminosity upgrade in IR8 with luminosity up to $L_{HL} = 2 \times 10^{33}$ cm^{-2} s^{-1}.

With $L_{HL} = 2\times10^{33}$ cm^{-2}s^{-1} and the inelastic cross section σ_{pp} = 85mb, there will be 1.7×10^8 inelastic collisions per second at the interaction point of LHCb. The inelastic collision power is carried off by neutrals (mostly neutrons and photons) and charged particles (mostly pions and protons), that leave in both directions from the IP. Detailed Fluka simulations have estimated the energy deposition around IP8 at 2×10^{33} cm^{-2} s^{-1} luminosity without TAS and compared it to that at IP1 and IP5 at 1×10^{34} cm^{-2} s^{-1} luminosity with TAS. The studies have shown that the TAS is only really effective as protection for Q1. The energy deposition in the triplet depends on the crossing angle in IP8. Changing the beam screen orientation has a negligible effect on the energy deposition. As conclusion, the LHCb luminosity upgrade with 2×10^{33} cm^{-2} s^{-1} appears to be operable without a TAS installation, and that instead a protection (in the form of a minimal TAN scenario) is recommended to reduce the heat load on the D2 magnets to well below their quench level.

Several energy deposition studies with different configurations of absorbers and masks situated in specific locations upstream of D2, as shown in Figure 8-22 and Figure 8-23 were performed: a classical TAN located at the Y chamber, a cold mask placed inside the D2 and a “mini-TAN” situated at ~ 1.9 m from the D2-IP face. The studies showed that protection levels of the latest are the highest, and thus, a “mini-TAN” (TANB) with a minimum size of 340 × 200 mm with a 500 mm long Inermet180 absorber situated at ~ 1.9 m from the D2-IP face would efficiently protect the D2 from the interaction debris at the foreseen luminosity of 2×10^{33} cm^{-2} s^{-1} for LHCb (See Figure 8-23).

The integration of the TANB in the current LHC lay-out required the relocation of the BPM’s situated between D2 and the TCTPH and the change of some vacuum elements (bellows & beam pipe). The TANB was successfully installed as the first HL-LHC element in the LHC tunnel during LS2 [19].

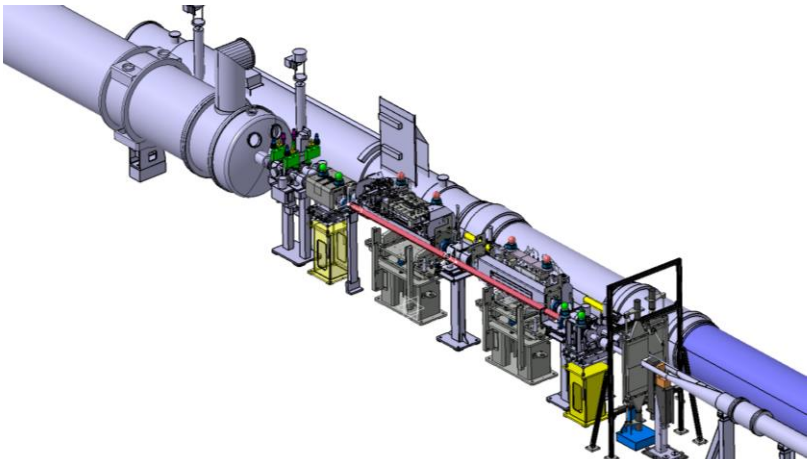


Figure 8-22: 3D layout of the D2 region after LS2. The new TANB (above located on top of yellow support on the left) is situated between D2 and the TCTPH collimator. BPM’s (located on top of above yellow support on the right) are relocated to the vicinity of the Y-chamber, shown on the right side of the picture.

Thermal analysis has been performed showing that the TANB will not need to be water-cooled (estimated heat deposition is below 20 W).

The total weight of the new equipment is around 800 kg and was transported as a single piece.

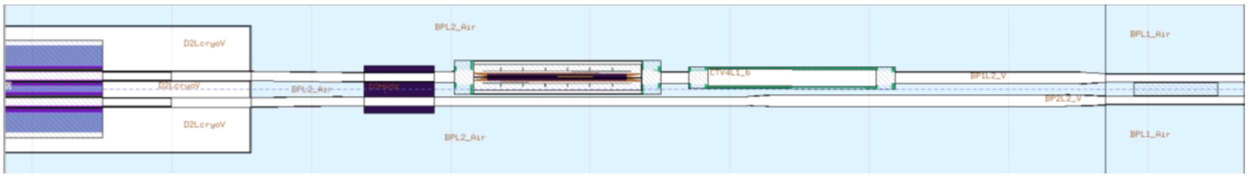


Figure 8-23: 2D layout (top view) of the D2 region as considered for the FLUKA analysis. The new TANB (-black) is situated between D2 (white) and the TCTPH collimator. Y-chamber is shown on the right side of the picture.

An innovative alignment plate with all the actuators situated in the transport side of the tunnel has been developed (see Figure 8-24 and Figure 8-25) and was installed to support the TANB, in order to reduce dose to personnel during future alignment operations of the TANB absorbers and the relocated BPM assemblies. Alignment will be manual, although automation could be developed and implemented at later stages.

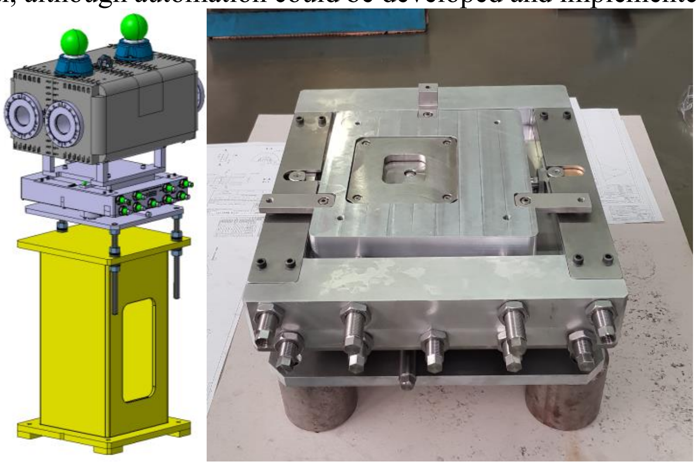


Figure 8-24: Left: 3D drawing of the TANB as installed in LSS8. The inner part is made of high-density tungsten, while the surrounding box provides baking capabilities. Right: TANB alignment plate, with all the actuators situated at the transport side to reduce dose to personnel.

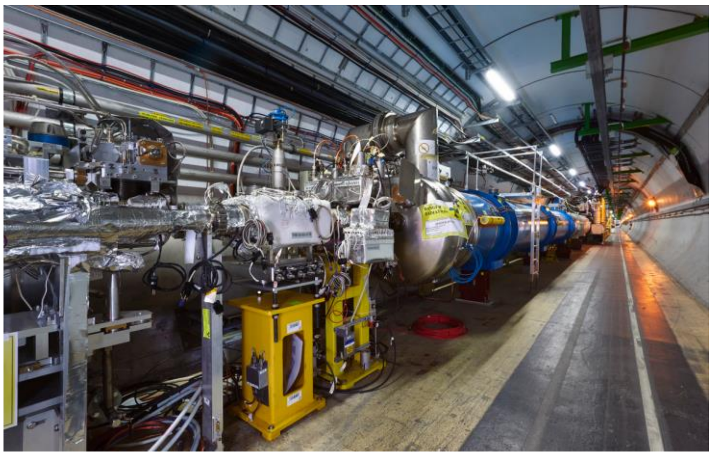


Figure 8-25: One of the 2 TANB installed in LSS8 (1 per side). The alignment plate can be seen (actuators protruding from the black label between the TANB and the standard yellow support).

8.3 Experimental beampipe modifications

The situation of the beam pipes of the experiments, all modified (or being modified) from the original LHC start, is reported in Table 8-6. No further modification is foreseen for the HL-LHC.

Table 8-6: Original and reduced inner beam pipe radii located at the IPs vicinity.

IP	Original r_{min} [mm]	Reduced r_{min} [mm]	Experiment	When
1	29	23.5	ATLAS	LS1
2	29	19 (central part)	ALICE	LS2
5	29	21.7	CMS	LS1 & LS2
8	5	3.5	LHCb, VELO	LS2

The activation levels in the experimental beam pipes, in particular for the high-luminosity experiments ATLAS and CMS, and the activation levels in vacuum chambers and the central tracking detectors need to be considered already during Run 3 but become significant in particular after a few years of operation in Run 4 at high-luminosity. The development of special handling tools and careful planning during maintenance activities and final dismantling will be needed to minimize the dose during interventions.

8.3.1 Beam pipe for ATLAS

For ATLAS, the central beryllium beam vacuum chamber of 7.382 m length and placed around the interaction point was exchanged with a new one with a reduced aperture of 47 mm to accommodate the new inner pixel detector layer (IBL) as shown in Figure 8-26 [7]. Preparations for a new, all-silicon inner tracker scheduled for installation during LS3 will continue in LS2 [17].

The conical vacuum chambers up to the forward TAS absorber were also exchanged to new aluminium ones in order to minimize the material activation and dose during interventions. The already installed permanent bake-out system is maintained. The last part of the conical chambers upstream of the TAS and the chamber support system would have to be exchanged during LS3 to adapt to the relocated VAX, with new apertures and layout as explained in Section 8.2.1.1.

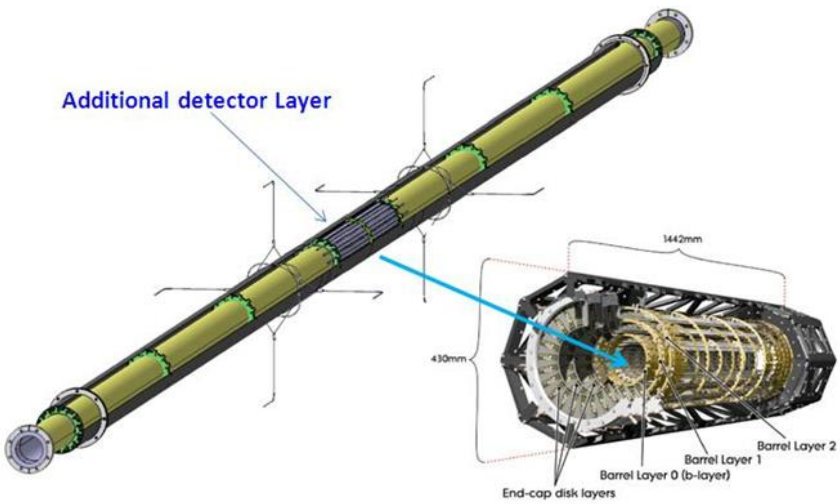


Figure 8-26: The updated ATLAS central vacuum chamber and the new inner detector.

8.3.2 Beam pipe for CMS

A new 6.24 m long central beryllium vacuum chamber will be installed in CMS during LS2 with the same aperture as the previous one installed during LS1 (i.e. 43.5 mm), but without the conical ends as depicted in Figure 8-27.This central pipe will be compatible with the existing Pixel detector and also with the new Inner Tracker detector currently under design for the Phase 2 upgrade [3]. A smaller bellow at 3.2 m from the IP has been designed to match the reduced diameter of the next Endcap beampipe section and the supports have been adapted to the new geometry.

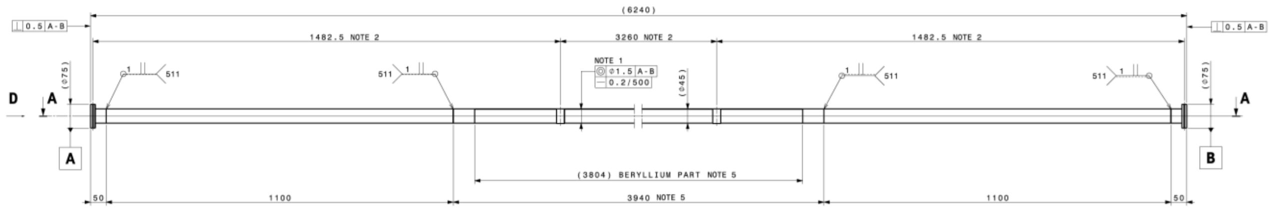


Figure 8-27: The updated CMS central vacuum chamber.

The conical vacuum chambers up to the forward TAS absorber will be exchanged to aluminium ones during LS2 to minimize activation and dose during interventions and a new beam-pipe support will be installed at 15.6 m from the IP, replacing the one currently located at 13.5 m from the IP. As for ATLAS, the last section (forward pipe) will be further modified during LS3 to adopt to the new layout and apertures for the HL-LHC operation. No permanent bake-out system is installed. The pumping station presently installed at the end of the experiment will be moved forward towards the TAS region as indicated in Figure 8-28 and Figure 8-13.

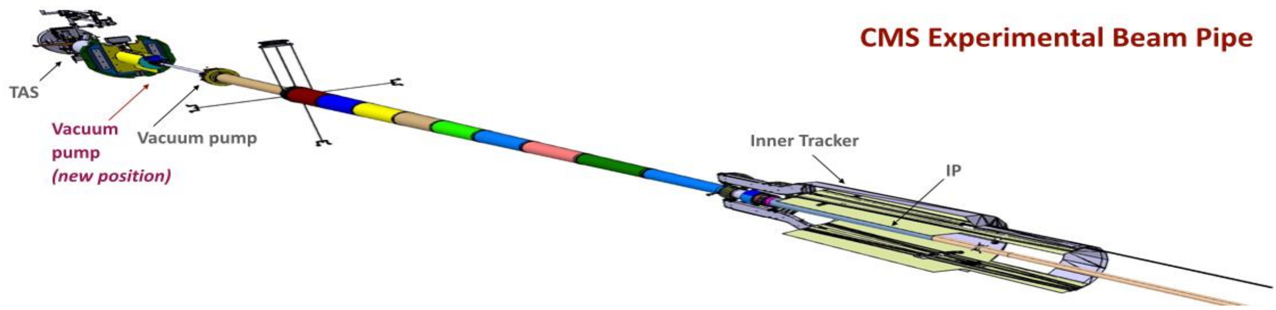


Figure 8-28: The full CMS vacuum chamber layout (single side) from the IP to the TAS. The present and future position of the proximity pumping station is indicated.

8.3.3 Beam pipes for ALICE and LHCb

New reduced-aperture central vacuum chambers will be installed during LS2 for ALICE and LHCb. The new ALICE beampipe geometry was officially approved in the LMC meeting in September 2014. While LHCb will follow a major upgrade in LS2 [4] to meet the new experimental challenges due to the increased luminosity, some changes described in Ref. [4] are still under approval.

After LS2 upgrade (both for ALICE and LHCb), no further changes to the experimental vacuum chamber geometry and layout is needed for the HL-LHC operation, although the vacuum chambers in the matching sections of IR1 and IR5 will still need modifications.

At LHCb the Vertex Locator (VELO), which allows for precise measurements of primary and displaced vertices of short living particles, is one of the detectors that will be upgraded in LS2. The LHCb updated VELO detector will operate in the same mode as presently: open to 30 mm aperture during injection, ramp, squeeze and adjust, but it will move closer to the beam axis, from the current 8.4 mm to 3.5 mm, once stable physics mode is established in the machine, coping with higher radiation and data rates

8.4 References

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