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CH-1211 Geneva 23
Switzerland

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ENGINEERING CHANGE REQUEST

WP11: 11 T DIPOLE FULL ASSEMBLY POINT 7

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

The operation with proton and ion beams foreseen in the High Luminosity LHC configuration requires upgrading the Large Hadron Collider (LHC) collimation system by installing additional collimators in the warm insertions and in the dispersion suppression (DS) regions. To this end, in the baseline scope of the HL-LHC, WorkPackage 11, it is foreseen to substitute in the DS region at point 7 two 14.3 m long 8.33 T standard LHC main dipoles (MB) each with a cryo-assembly composed by a pair of 5.5 m-long 11 T dipoles with in the middle a 3.3 m long bypass cryostat in which is hosted the TCLD collimator. A pair of 5.5 m long 11 T dipoles delivers approximately the same bending strength of 119 T.m, at the nominal operating current of 11.85 kA, as one LHC main dipole (MB). Fine-tuning of the integrated field strength over the energy range during ramp is envisaged by using a –nested- trim power converter. The 11 T twin-aperture dipoles will operate at 1.9 K in series with the remaining MBs of the sector.

DOCUMENT PREPARED BY:	DOCUMENT TO BE CHECKED BY:	DOCUMENT TO BE APPROVED BY:
Daniel Schoerling et al.	**HiLumi-WP11-Integration** C. Adorisio, G. Arduini, V. Baglin, M. Barberan, I. Bejar Alonso, M. Bernardini, C. Bertone, C. Boccard, L. Bottura, G. Bregliozzi, M. Brugger, S. Bustamante, F. Cerutti, J. P. Corso, B. Delille, A. Devred, R. de Maria, S. Evrard, P. Fessia, R. Folch, J.-F. Fuchs, C. Gaignant, M. Giovannozzi, J.-L. Grenard, M. Lamont, M. Modena, Y. Muttoni, T. Otto, E. Page, B. Salvant, F. Savary, J. Sestak, R. Steerenberg, L. Tavian, M. Tavlet, C. Vollinger, J. Wenninger	P. Collier (on behalf of LMC) L. Rossi (on behalf of the HL-LHC project)

DOCUMENT SENT FOR INFORMATION TO:

ATS Group Leaders

SUMMARY OF THE ACTIONS TO BE UNDERTAKEN:

[List the main actions to be undertaken]

Note: When approved, an Engineering Change Request becomes an Engineering Change Order.

1. INTRODUCTION

The High Luminosity LHC baseline foresees to upgrade the LHC collimation system to cope with higher proton and beam intensities and in particular for increased diffractive losses in the LHC P7 due to interaction between primary beam and collimators [1]. This upgrade must take place in LS2 in order to allow full exploitation of the beam properties already in Run 3 of the LHC. To this end, it is foreseen to substitute in the DS region at point 7 two 14.3 m long 8.33 T standard LHC main dipoles (MB) each with an assembly consisting out of a pair of 5.5 m-long 11 T dipoles surrounding the bypass cryostat (length 2.2 m) and the Target Collimator Long Dispersion suppressor (TCLD) (length 1 m). A pair of 5.5 m long 11 T dipoles delivers approximately the same integrated strength of 119 T.m at the nominal operation current of 11.85 kA as one MB. Fine-tuning of the integrated strength all over the energy range will be done by using trim power supplies, delivering up to 250 A, as the 11 T twin-aperture dipoles will operate at 1.9 K in series with the remaining MBs of the sector.

The quench protection hardware, namely the quench detection system, the quench heater power supplies and related ancillary equipment such as interface modules of the corresponding racks and cabling need to be upgraded to ensure magnet protection. Moreover, the new arrangement of current leads for the trim circuit calls for specific quench detectors and current monitoring.

The present state of the concerned areas is shown in Figures 1 and 2.

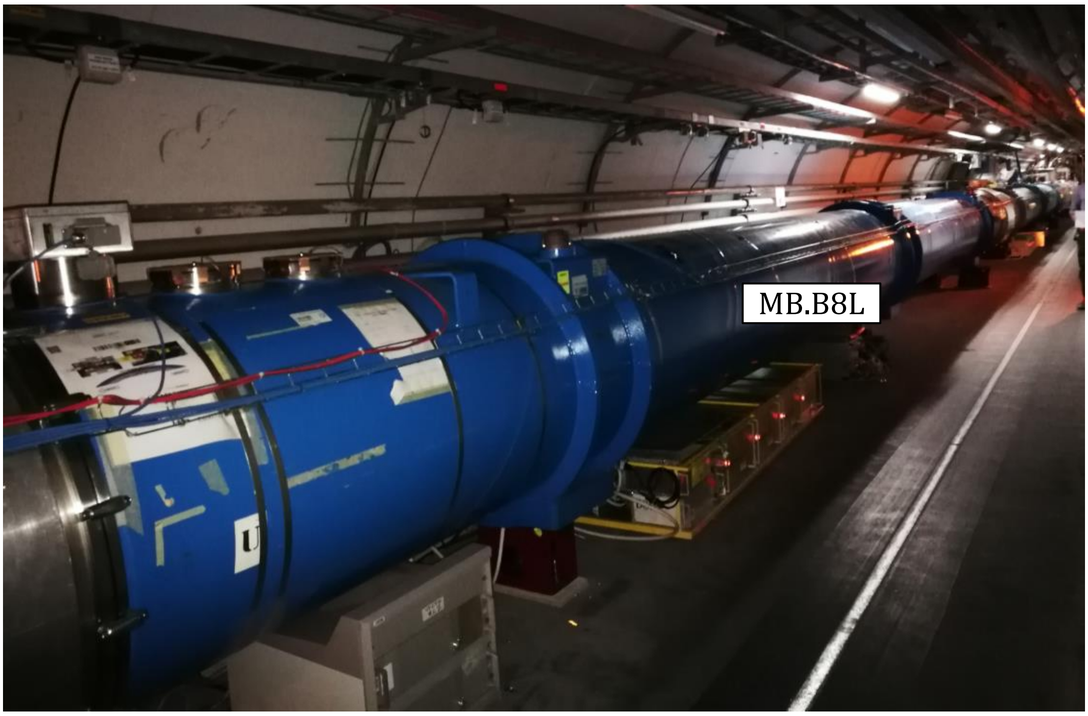

Figure 1 — Picture of area under change, 8.L7 at R72 – present MB.B8L7

Figure 2 — Picture of area under change, 8.R7 at R78 – present MB.B8R7

2. REASON FOR THE CHANGE

As above mentioned, the increased intensity of the proton beam and ion beam in the High Luminosity LHC configuration necessitates to place collimators in the cold region, to protect the dipoles in the DS region. In the present LHC configuration, there is no room left for this installation. The only possible solution is the replacement of two 14.3 m long 8.33 T standard LHC main dipoles (MB) each with an assembly consisting out of a pair of 5.5 m-long 11 T dipoles to make room for a central bypass cryostat (length 3.3 m) hosting the TCLD collimator (length 1 m).

3. DETAILED DESCRIPTION

It is foreseen to exchange the following two MBs:

- **MB.B8L7** (LBARA.8L7)
- **MB.B8R7** (LBBRB.8R7)

The magnets are installed at the following positions:

- **MB.B8L7** (LBARA.8L7): distance from IP7: -300.224 m, distance from IP1 (DCUM): 19693.9384 m, half-cell 8.L7, called following **P7 left side**
- **MB.B8R7** (LBBRB.8R7): distance from IP7: 284.564 m, distance from IP1 (DCUM): 20278.7264 m, half-cell 8.L7,, called following **P7 right side**

In detail, the changes comprise the following:

P7 left side

- Removal of the present main dipole **MB.B8L7** (LBARA.8L7, circuit RB.A67)
- Installation of the 11T dipole full assembly at the MB place. The assembly is composed of two dipoles of equal bending strength and shorter magnetic

length (Cryo-assembly A and B) and a bypass cryostat in the middle, providing cryogenic and electrical continuity between them.

- After that, installation of a new TCLD collimator between the two magnets, on the beam line 2 (internal beam, or passage side) will follow.

P7 right side

- Removal of the present main dipole **MB.B8R7** (LBBRB.8R7, circuit RB.A78)
- Installation of the 11T dipole full assembly at the MB place: Cryo-assembly A and B, and a bypass cryostat in between.
- After that, installation of a new TCLD collimator between the two magnets, on the beam line 1 (external beam, or QRL side) will follow.

Layout drawings LHCLSS__0029/LHCLSS__0030 (LHC layout for the DS region at point 7) and LHCLSSH_0013/LHCLSSH_0014 (HL-LHC layout for the same zones) show the changes induced by the implementation of the TCLD collimator and the two short 11T dipoles where there was one 8.33T/14.3m long dipole magnet on each side of P7. Figures 3 and 4 show as an example the section of the LHC layout for P7 left before and after the change.

The components to be installed (Table 1), to be kept (Table 2), to be displaced (Table 3) or to be removed (Table 4) are listed below.

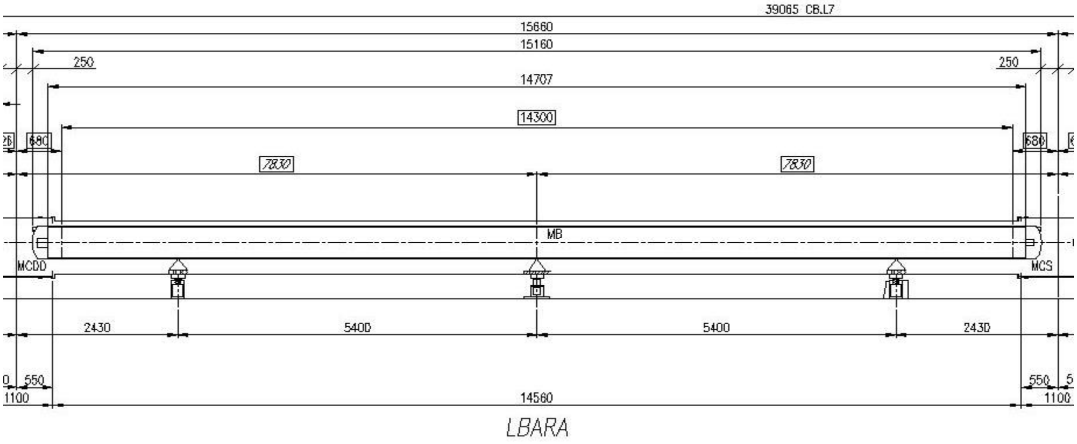

Figure 3: Section of LHC layout for P7 left (from LHCLSS__0029) – Replaced magnet.

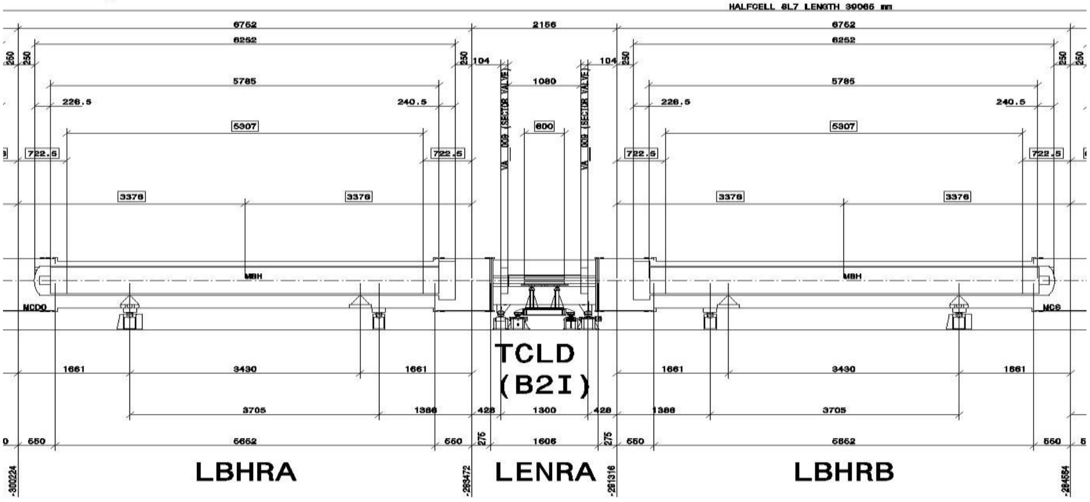

Figure 4: Section of HL-LHC layout for P7 left (from LHCLSSH_0013) – New components

3.1 Integration

The integration is described in detail in the document [2].

3.2 Beam dynamics

The bending angle of the beam is kept the same thanks to the same integrated field generated by the pair of 5.5 m-long 11 T dipoles as by an MB. The same integrated field is achieved by powering the 11 T pair in series with the MBs and by using a trim power supply, so no orbit distortions will be generated due to differences in transfer function of the main and the 11 T dipoles.

The field stability is the same, as the 11 T dipoles are connected in series with the MBs, so the current in all magnets is identical during standard operation. It is currently investigated by WP2 if voltage peaks from flux jumps are uncritical for the power converter operation and have any negative effect on the field stability.

The field quality is worse than for the MBs, in particular the sextupole component b_3 is larger. The latest field quality table of the 11 T dipoles can be found in [3]. Beam dynamics studies [4] have shown that the expected field quality is such to leave dynamic aperture essentially unaffected, both at injection and collision energy. For the LHC reset current of 100 A, this specification is met, no modification is required.

The same type and number of spool pieces as currently installed in the MBs will be installed in the 11 T dipoles (LBARA.8L7: MCS and MCDO; LBBRB.8R7: MCS, for symmetry reason a MCDO will be installed but not connected to the circuit).

The effect of the sagitta is taken into account by positioning the magnets such that the beam uses most effectively the available mechanical aperture considering that, unlike the main dipoles, the 11 T magnets are straight. Note that the beam screen is identical to that installed in the MBs of LHC. The exact position of the 11 T magnets will be agreed between WP2, WP11, and WP15 and will be documented through the WP11 Machine Interface Working Group.

3.3 Vacuum modifications

In order to provide beam vacuum continuity of the 11 T full assembly, the continuous beam line of the replaced dipole magnet must be segmented and adapted to accommodate the functioning of the TCLD collimator and the 11T magnets. The installation of the TCLD collimator, operating at room temperature, imposes a new sectorization of the vacuum lines and new transitions between cold and warm vacuum lines. The improved pumping strategy for these new vacuum sectors is proposed in [5].

Inside the 11T magnets (LBH type) the standard LHC-type beam screens will be installed for both beam lines (cold bore inner diameter 50mm). Regarding the bypass cryostat (LEN type) there are two different configurations, one for each beam line, depending if it is the collimated or the non-collimated line.

For the collimated line, there will be one bellow to ease its mounting/dismounting and one sector valve installed on each side of the TCLD. The sector valves are then connected to the cold-warm transitions (short and long versions, located upstream and downstream respectively) and followed by the standard Plug-in-Module (PIM). The collimator itself will represent an added vacuum sector, described in detail within the TCLD ECR (under preparation by EN-STI) after on-going tests. A vacuum port (LHCVSTB_0010 – position5) is integrated in the cold/warm transition, between the sector valves and the continuous cryostat, to allow the RF ball tests.

For the non-collimated line, a new concept of conduction cooled copper cold bore has been developed to reduce the equipment needed on this line of the bypass cryostat. It will be thermalized at both of extremities by two hoses routed from the M3 line, feeding superfluid helium at 1.3 bar to the collars brazed around the line. The copper cold line is linked to the PIMs at the extremities. A standard LHC-type beam screen is inserted in the cold line. To accommodate all the described equipment within the existing space, special short beam screen bellows had to be design and manufactured.

The insulation vacuum continuity is ensured by the LEN cryostat.

Table 1: Components to be installed

Equipment name	**DCUM** [m]	**IP7** [m]	**Comments**
LBHRA+ **LENRA+** **LBHRB** – 11T Full assembly	19693.9384 m 19700.6904 m 19702.8464 m	– 300.224 m – 293.472 m – 291.316 m	Composed of 2 cryoassemblies + 1 bypass cryostat.
2 DYPB double racks	-	-	1 DYPB under LBHRB and 1 DYPB under MB.B9L7. See 2.45, [2]
1 Power Converter for 11T.8L7	-	-	Installation of a new PC named RYABA01 at RR73. See 2.4.4, [2]
2 crates for QDS + **trim leads protection** Equipment	-	-	To be installed at RR73. See 2.4.5, [2]
(**1 half-rack**)	-	-	To be installed at RR73. TBD. See 2.4.5, [2]
3 additional BLMs			See 2.4.8, [2]
Exclusion areas at L7	-	-	See 2.4.6, [2]
Circuit breakers	-	-	2 (racks) x 2 (F3/F4) x 4/circuit, so a total of 16 circuit breakers
LBHRC+ **LENRB+** **LBHRD** – 11T Full assembly	20278.7264 m 20285.4784 m 20287.6344 m	284.564 m 291.316 m 293.472 m	Composed of 2 cryoassemblies + 1 bypass cryostat.
2 DYPB double racks	-	-	1 DYPB under LBHRC and 1 DYPB under MB.A9R7. See 2.45, [2]
1 Power Converter for 11T.8R7	-	-	Installation of a new PC named RYABA01 at RR77. See 2.4.4, [2]
2 crates for QDS + **trim leads protection** Equipment	-	-	To be installed at RR77. See 2.4.5, [2]
(**1 half-rack**)	-	-	To be installed at RR77. TBD. See 2.4.5, [2]
(Metallic structure)	-	-	To be installed at RR77. TBD. See 2.4.5, [2]
3 additional BLMs at R7	-	-	See 2.4.8, [2]
Exclusion areas at R7	-	-	See 2.4.6, [2]
Circuit breakers	-	-	2 (racks) x 2 (F3/F4) x 4/circuit, so a total of 16 circuit breakers

Table 2: Components to be kept

Equipment name	**DCUM** [m]	**IP7** [m]	**Comments**
VPGFE.8R7 – Pumping group	20282.9930 m	288.83064 m	Placed on the QRL.

Table 3: Components to be displaced

Equipment name	**DCUM** [m]	**IP7** [m]	**Comments**
VYCTP.A8L7	19694.9034 m	– 299.259 m	Valve control equipment rack placed under present MB.B8L7
QYCGB.8L7	19700.8034 m	– 293.359 m	Cryogenic control rack placed under present MB.B8L7
Cable trays			Cable trays need to be displaced to tunnel wall at TCLD area
VPTCB.8R7 – Pump	20282.9930 m	288.83064 m	Placed under present MB.B8R7.
VYCTP.A8R7	20289.1214 m	294.959 m	Valve control equipment rack placed under present MB.B8R7
QYCGB.8R7	20285.4864 m	291.324 m	Cryogenic control rack placed under present MB.B8R7
DYPQ.B8R7	20287.3364 m	293.174 m	Present under MB.B8R7. To be displaced under MB.A8R7
Electrical derivation boxes	-	-	Installed on cable trays. See [6]
Cable trays			Cable trays need to be displaced to tunnel wall at TCLD area

Table 4: Components to be removed

Equipment name	**DCUM** [m]	**IP7** [m]	**Comments**
LBARA.8L7 (MB.B8L7)	19693.9384 m	– 300.224 m	
DYPB.B8L7	19697.1594 m	– 297.003 m	Protecting present MB.B8L7
RYSA01 rack at RR73	-	-	It will be replaced by the new RYABA01 (11T Power converter)
LBBRB.8R7 (MB.B8R7)	20278.7264 m	284.564 m	
DYPB.B8R7	20281.9464 m	287.784 m	Protecting present MB.B8R7
RYSA01 rack at RR77	-	-	It will be replaced by the new RYABA01 (11T Power converter)

3.4 Cryogenics modifications

In between the 11 T dipole cryostats a bypass cryostat is placed. This bypass cryostat causes a severe increase of the hydraulic impedance in the insulation vacuum-space compared to today's installation. In case of a cold helium leak from the cold mass into the insulation vacuum space, as identified as Maximum Credible Incident (MCI) in [7], sufficient safety valves have to be installed to limit the cryostat pressure to below 1.5 bar.

An investigation whether the MCI-discharge flow occurring on one side of the cryogenic bypass can be at least partly shared with the other side, without introducing an excessive pressure drop, showed that such sharing is insufficient. Therefore, each side of the cryogenic bypass is to be considered as an individual hydraulic sector with respect to MCIs and it must be made possible that the full flow can be taken by valves on either side of the bypass.

The first possibility is to equidistantly distribute along each of the individual hydraulic sectors, a minimum of 8xDN200 (CERN drawing LHCQBA_S0202 for cryodipole plug) insulation vacuum release valves.

The second possibility is to install on the longer hydraulic sector 8xDN200 valves and on the shorter hydraulic sector 5xDN200 valves, under the condition that the 5xDN200 valves are placed not further than 15 m distance from the cryogenic bypass and that the total hydraulic sector length is less than 30 m. In this scenario the cryostat pressure can be as well limited to below 1.5 bar. The calculation follows the MCI outlined in [7].

The dispersion suppressor (DS)-cryostats, installed on one side of the cryogenic bypass, have one non-spring-loaded DN200 release valve in the middle of their hydraulic sector (LBBRB.11L7-DCUM: 19591.0034 and LBARA.11R7-DCUM: 20381.6614, EDMS #1291202). This non-spring loaded DN200 valve is designed such to function first whenever an incident occurs under personal access conditions. It opens at an overpressure of 50 mbar, corresponding to a mass flow of slightly less than 1 kg/s at 90 K. The spring loaded valves open at 80 mbar overpressure thus leaving 30 mbar budget available for the cryogenic bypass, in case a non-spring loaded valve is only installed on one side of the bypass. The pressure drop across the cryogenic bypass alone has been assessed to be ~22 mbar. The remaining ~8 mbar are considered too little a margin for reliable distinction in opening between the spring and non-spring loaded valves, yielding to the hazard that actually the spring loaded valves open before the non-spring loaded valve.

Therefore, the following changes shall be performed:

- Non-spring loaded valves shall be foreseen on both sides of the cryogenic bypass;

- Springs have to be added to the valve in the middle of the hydraulic sector on the DS-cryostat (LBBRB.11L7-DCUM: 19591.0034 and LBARA.11R7-DCUM: 20381.6614, EDMS #1291202).

No specific cryogenic instrumentation is foreseen for the cryogenic bypass itself. However, since there will be now two 11-T magnet cold masses they will each have to be equipped with temperature sensors in the pressurized superfluid helium enclosure, so the number of sensors will be doubled compared to today’s situation.

3.5 Geometry and alignment modifications

The installation of the 11 T dipole full assembly requires the alignment of two 11 T dipoles, the bypass cryostat and the TCLD collimator compared to previously only one MB magnet. In detail, the following operations have to be performed:

First, the marking on the floor of the beam points, jacks heads position of the non-standard 11 T dipoles but also the beam points and component axis of the bypass cryostat and of the new TCLD collimator is required. A specific care will be brought to the jack configuration of the dipoles, as not standard.

Second, 12 jacks per 11 T dipole full assembly will be installed.

Third, EN-SMM-ASG will align the jacks’ heads at their nominal position, prior to the installation of any component.

Fourth, the 11 T dipole magnets will be installed and fifth, an initial alignment of the dipoles will be carried out with respect to the adjacent cryo-magnets. Following, as sixth step, the bypass cryostat will be installed and the TCLD collimator will be inserted as last component to be installed.

Seventh, an initial alignment of the dipoles will be carried with respect to the adjacent cryo-magnets and the alignment of the TCLD and cryo-bypass will be carried out from the both 11T adjacent dipoles.

After this pre-alignment, the 11 T dipole full assembly smoothing w.r.t. the adjacent components will be performed once all interconnections are closed, and the sector has been cooled down during the regular arc smoothing activity.

Roll measurements can only be performed by adding an inclinometer on a specific cylinder interface located on the plate that supports the survey socket on the tunnel transport side and on the double jack side.

To do all alignment operations described above, the MAD-X file providing the beam positions of the components must be available at least two months before any survey activity in the LHC tunnel. Drawings giving the positions of the jacks heads with respect to the component beam points must be available at least two weeks before the jack marking in the LHC tunnel.

3.6 Main dipole chain and trim circuit

The modified circuit layout of RB.A67 (with trim circuit **RTB8.L7**) and RB.A78 (with trim circuit **RTB8.R7)** is shown in Figure 3 and 4. A detailed description of the circuits is provided in [8], Section 2.1-2.7. The RB circuit characteristics before and after the change are summarized in Table 5. For the circuit RB.A78 the 11 T dipole full assembly will be placed after the second energy extraction system, creating a little dissymmetry in the RB circuit.

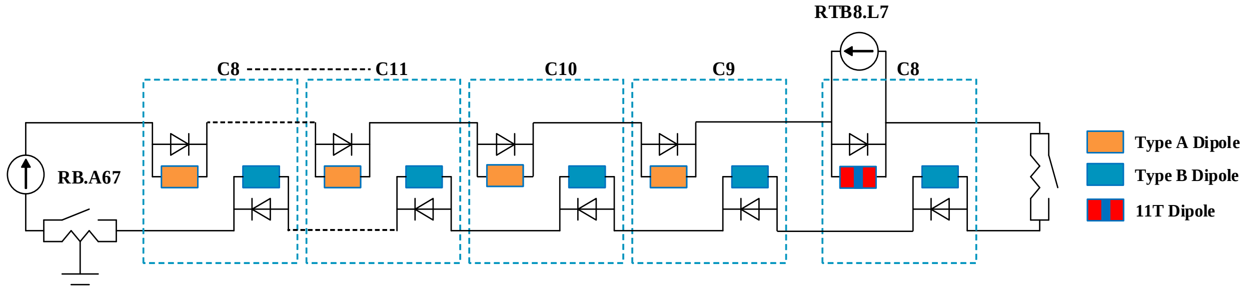

Figure 3. Main dipole circuit RB.A67 configuration for the HL-LHC with the 11T trim power converter.

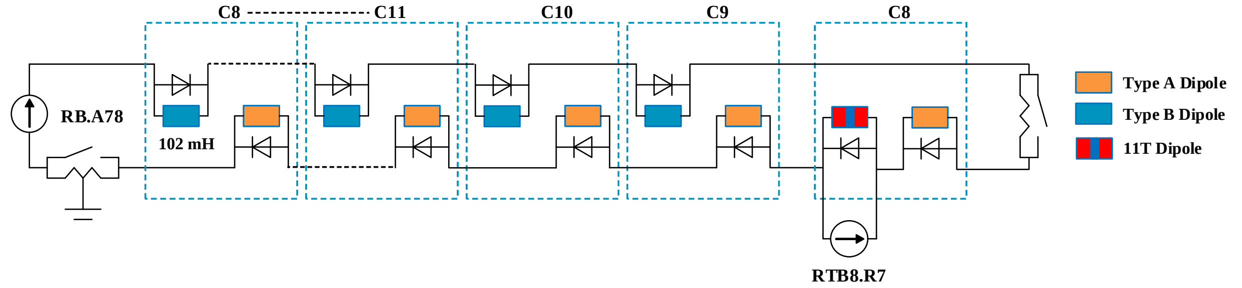

Figure 4. Main dipole circuit RB.A78 configuration for the HL-LHC with the 11 T trim power converter.

Table 5: RB circuit characteristics in the current LHC configuration and after the introduction of 11 T dipole full assembly for circuits RB.A67 and RB.A78, updated from [1].

	Circuit	LHC	HL-LHC
Maximum required RB PC voltage	RB.A67, RB.A78	171 V	171.6 V
Total RB circuit inductance	RB.A67, RB.A78	15.708 H	15.734 H
RB circuit DC cable resistance	RB.A67, RB.A78	1 mΩ	1 mΩ
RB circuit crowbar resistance	RB.A67, RB.A78	0 mΩ	0 mΩ
RB circuit energy extraction resistance	RB.A67, RB.A78	140 mΩ	140 mΩ
RB circuit natural time constant	RB.A67, RB.A78	15700 s	15740 s
Energy extraction time constant	RB.A67, RB.A78	112 s	113 s
Maximum required Trim PC voltage	RTB8.L7, RTB8.R7	NA	5V
Trim circuit inductance	RTB8.L7, RTB8.R7	NA	0.132 H
Trim circuit DC cable resistance	RTB8.L7, RTB8.R7	NA	13 mΩ
Trim circuit crowbar resistance	RTB8.L7, RTB8.R7	NA	70 mΩ
Trim circuit natural time constant	RTB8.L7, RTB8.R7	NA	10 s
Maximum common voltage of the trim circuit in case of energy extraction	RTB8.L7	NA	433 V
	RTB8.R7		425 V
Maximum common voltage of the trim circuit in case of energy extraction + earth fault	RTB8.L7, RTB8.R7	NA	910 V

3.7 Power converters and services

For the operation of the 11 T dipole magnets the trim circuit power converters have to be added.

3.7.1 RB power converter

No modifications are applied to the RB power converters

3.7.2 Hardware requirements

Two additional R2E-HL-LHC600A-10V power converters will be added to the service galleries RR73 to power RTB8.L7 and RR77 to power RTB8.R7. A detailed description of the power converter functional requirements is detailed in [8]. The power converters racks will replace the RYSA01 in both RR73 and RR77.

3.7.3 Power converters control

The 11T trim power converters will be controlled by FGCLite. They will be connected to the already existing WorldFIP network in RR73 and in RR77. For 11T trim power converters, one agent will be added to the CFC-SR7-RL7A network in RR73 and another agent will be added to CFC-SR7-RR7C network in RR77.

3.7.4 Power converters services

The power converters will require the following services as indicated in Section 4.2:

- AC cabling per converter: 3P+N 20 Arms from ERD1
- DC cabling per converter: 2 x 70 mm^2 per polarity
- Demineralized water cooling: 4 l/min at 3.0 bar of differential pressure drop

3.7.5 Power converter interface with PIC

The power converter connection with the PIC system is detailed in Section 3.7.5. The connection to the power converter will be done via a standard 12-pin female Burndy connector.

3.8 Quench detection system (QDS) modifications

For the protection of the 11 T dipoles, newly developed quench detection systems adapted to the specific properties of Nb_3Sn superconducting magnets (uQDS type) will be deployed. In addition, dedicated DAQ systems for the supervision of the quench heater circuits (DQHSU) will be provided.

3.8.1 Hardware

To assure the quench detection system, two crates are needed per IP side and will be installed in the service galleries RR73 (left side) and RR77 (right side). A detailed description of the integration of these racks is provided in [2].

The dipole quench detection crates DQLPU.B8L7 and DQLPU.B8R7, which are installed in protection racks DYPB.B8L7 and DYPB.B8R7, will be dismantled and removed from the LHC tunnel.

3.8.2 Location

The QDS for the protection of the 11 T dipoles and the associated quench heater circuit supervision unit (DQHSU) will be located in underground areas RR73/RR77 using the remaining free space in QPS protection racks DYPG01=RR73 and DYPG01=RR77.

3.8.3 Interlocks

This non-standard QDS will be integrated into the existing QPS internal current loop. While the connection to the powering interlock controller (PIC) will not change, it is foreseen to update the QPS quench loop controllers for circuits RB.A67 and RB.A78 in order to achieve a faster reaction time.

3.8.4 Controls

The physical layout of the QPS fieldbus needs to be slightly modified. This concerns segments CBW.IP7.DR7H, CBW.IP7.DL7J, CBW.IP7.DT7A and CBW.IP7.DT7F. The changes concerns only the number and position of field-bus clients; it does not affect any other active equipment like repeater or front-end computers.

The QPS software layer stack and the LHC circuit synoptic need to be updated to be able to interact correctly with the newly installed devices. In particular, this will require the implementation of several new application-programming interfaces (API) and the definition of the corresponding set of signals.

3.9 New Quench Protection System (nQPS) modifications

The replacement of one regular dipole in circuits RB.A67 (half-cell B8L7) and RB.A78 (half-cell B8R7) by new 11 T dipoles will create an exception in the nQPS system affecting in particular the detection systems for aperture symmetric quenches. In order to preserve the full nQPS functionality, it is necessary to implement a series of modifications.

3.9.1 Location

The DQLPU type S protection crates currently installed in racks DYPB.B8L7 and DYPB.B8R7 will be relocated to racks DYPB.A9L7 and DYPB.A9R7.

3.9.2 Configuration

The firmware of the nQPS electronics needs to be updated to take into account the new configuration. The respective documentation must be revised as well.

3.9.3 Controls

As mentioned before, the QPS software layer stack and the LHC circuit synoptic need to be updated with respect to the non-standard nQPS configuration.

3.10 Changes to the racks containing the heater discharge units

For the protection of 11T magnets, two non-standard QPS racks will be installed in the machine tunnel per IP side (underneath the cryostats). A new, non-standard design was established, to take into account that the quench detectors will be located in the RRs (see Section 3.8) and to accommodate the 16 quench heater power supplies per side instead of the previously installed 4 standard LHC MB quench heater power supplies. The quench heater power supply will accommodate redundancy in the powering of the F3 & F4 UPS distribution lines.

A detailed description of the integration of these racks is provided in [2].

3.10.1.1 DQHDS firing speed

The response time of the DQHDS units in firing is 2ms, which is considered sufficient.

3.10.1.2 Redundancy configurations

Since the full 11 T magnet cannot withstand the loss of more than two out of sixteen DQHDS units, powering redundancy must be incorporated. To ensure redundancy each rack is powered with four F3 and four F4 AC inputs together with twice four circuit breakers per rack. In addition, each DQHDS unit will be modified in such a way that its trigger circuit will have a redundant powering from F3 and F4. However, the capacitors will still be energized by either F3 or F4.

Monitoring of the proper connections of the quench heater discharge cables ot the magnet IFS will be performed.

3.10.1.3 Rack containing the heater discharge units

A new rack type upgrading the current DYPB rack had to be designed to allow for installing 16 quench heater power supplies and allow maintenance during LHC operation. In addition to this, the DQHDS units must be upgraded to be compatible with the availability requested by the protection of the 11 T dipoles.

3.10.2Location

The non-standard QPS racks will be placed at (see the grey boxes in Figure 5):

- L7: 1 rack under 11T dipole + 1 rack under MB.B9L7;
- R7: 1 rack under 11T dipole + 1 rack under MB.A9R7.

Four new racks will be installed in the machine. One spare unit will be manufactured.

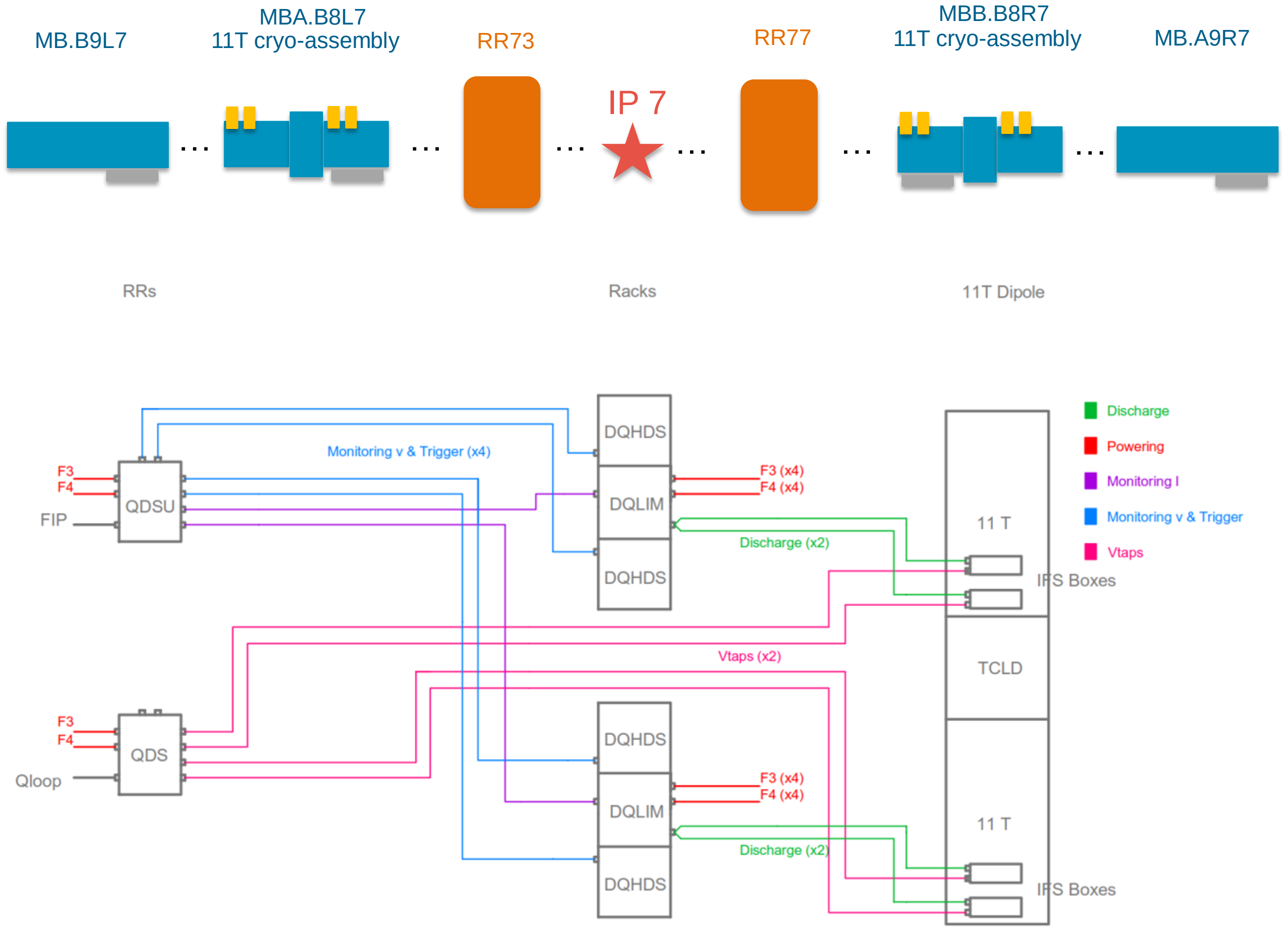

Figure 5. Location of the new DYPB for the 11T dipoles.

3.11Powering Interlock System (PIC)

The Powering Interlock System (PIC) is designed to ensure the permission for powering the different electrical circuits with superconducting magnets installed around the LHC. It interfaces power converters, quench detection systems, technical services (AUG, UPS, cryogenics, etc.) and is a client of the Beam Interlock System (BIS) in order to request a beam dump when necessary. The two new 11 T dipoles will be connected in series with the RB.67 and RB.78 main dipole circuits requiring a trim power converter each, which have to be connected to the PIC. The interlock requirements of the 11 T circuit are summarized in Table 6.

Table 6: Interlock requirements

Interlock case	**PIC Action on RB Circuit**	**PIC Action on Trim Circuit**	**Beam Dump[1]**
Quench in RB circuit	Fast Power Abort	Fast Power Abort	Yes
Powering Failure in RB Circuit	Slow power Abort	No action	Yes
Powering Failure in Trim Circuit	No action	Slow Power Abort	Yes
QDS trip in the trim current leads	No action	Fast Power Abort	Yes
Switch opening request by RB PC	Fast Power Abort	Fast Power Abort	Yes
Cryo-failure	Slow Power Abort	Slow Power Abort	Yes

[1] The trim circuit will be considered as essential from the PIC side, which means unmaskeable at the BIC level.

3.11.1 Hardware

The hardware interfaces of the PIC are standardized and are defined according to the type of electrical circuit. There are currently 6 different listed types (A, B1, B2, C, D) [9] grouped into 4 different patch panels (CIPPA, CIPPB, CIPPC, CIPPS). Since the configuration of a PIC is generic, there are some hardware interfaces that remain unused. For the two PIC in P7, the current interface configuration contains a free “B1 type” hardware interface on the CIPPS patch panel, which will be used to connect the new 11 T trim power converters. Moreover, the quench loop of the trim circuits will have the peculiarity of being connected to the QDS dedicated for the surveillance of the trim current leads (see Section 3.12, Protection of Trim Current Leads))

The proposed implementation will fulfil the requirements summarized in Table 6:

- If a quench in the RB circuit or an EE switch opening occurs, a general fast power abort action on both PIC will be taken through the global protection mechanism [10].
- If a powering failure occurs, a slow power abort action will be taken only on the faulty circuit (RB or Trim).
- If a failure is detected on the current leads of the Trim circuits, a fast power abort of the trim circuits will be triggered.
- A cryo failure will cause a slow power abort of both RB and Trim circuit because the same status of the Cryo interlock is sent from a unique Cryo PLC to both arc PIC.

3.11.2 Configuration

The LHC main dipole circuits have the feature of being interfaced with the two adjacent PIC of the arcs (even and odd), sharing the same quench loop, and their power converters located on the even side. The new 11 T trim power converters will be located at the odd side of the arc (RR73 and RR77) and connected to the corresponding PIC as independent circuits.

3.12 Protection of trim current leads

The trim circuit (RTB8) for each of the 11 T dipoles will be powered through a set of 2 x 2 resistive current leads. The protection of the four trim leads will require monitoring of the lead voltages and currents. These signals will be evaluated by a standard HL-LHC quench detection system (uQDS), which initiates the necessary action e.g. a fast power abort of the concerned trim circuit.

3.12.1 Hardware

The additional quench detection crates need to be installed inside RR73/RR77 (ground floor). There is not enough space to integrate these units in protection racks DYPG01=RR73 and DYPG01=RR77. For the additional space, the adjacent half rack DYPIB01 (shared with the PIC half rack CYCIP01) will be used.

For the measurement of the lead currents, current sensors of the Hall type and clamped to the power cables will be installed in RR73 and RR77.

3.12.2 Interlocks

The new QDS for the trim current leads needs to be integrated into the hardwired interlock loop for the trim circuits.

3.12.3 Controls

As for the changes above, the QPS software layer stack and the LHC circuit synoptic need to be updated accordingly. In this case, this concerns as well the configuration of the PIC.

3.13 Cabling

Detailed DICs (reference: RQF0908671 (instrumentation), RQF0888406 (PIC), and RFQ0981328 (powering)) have already been prepared and sent to EN-EL. Another WorldFIP fieldbus extension for the trim power converters is requested to BE-CO (RQF0809614). Accordingly, all the cabling concerning the new racks (discharge, monitoring, triggering, control, etc) needs to be installed.

The installation will require the respective set of instrumentation, signal, and hardware trigger and interlock cables. The default QPS interlock cabling traversing the 11 T assembly will need to be modified.

The nQPS instrumentation and interlock cabling need to be modified. All cables going through the 11 T assembly must be re-routed to one of the cables trays on the tunnel wall to not interfere with maintenance operations of the collimators.

Instrumentation cables linking the current lead feed through box with the quench detection crates have to be installed. In addition, there will be the signal cables for the current sensors and the interlock cables, which are local to RR73/RR77.

The nQPS crates below the dipoles located in B8 (both sides), will be moved to a position below A9 and various cables will be re-installed.

Moreover, there is today a DYPQ rack located under MB.B8R7 that will be moved under MB.A8R7. This requires consequently new cabling between the quadrupole cryostat and the new position of the rack. See Fig. 6.

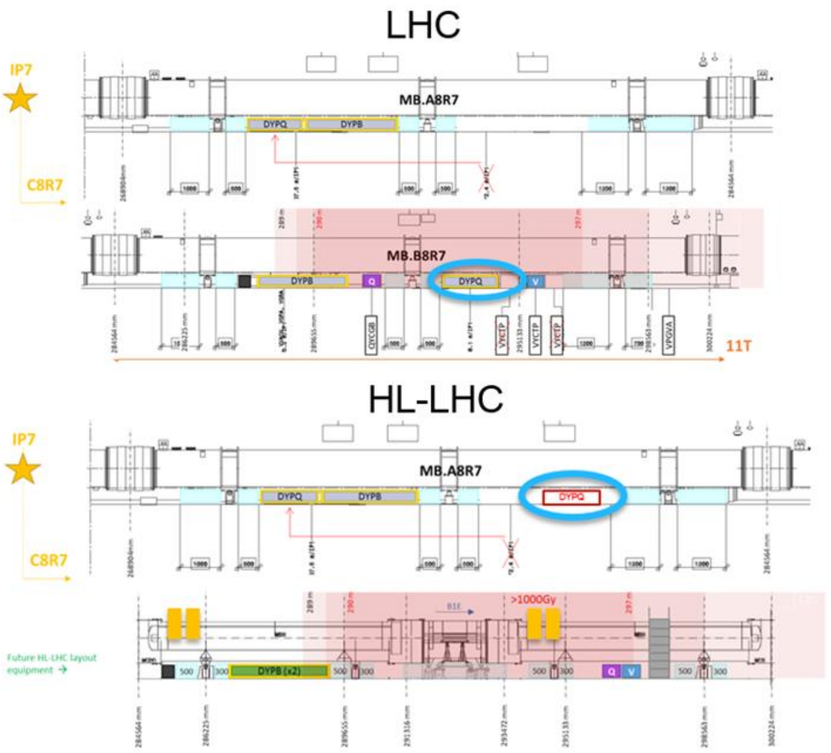

Figure 6. Relocation of the DYPQ that needs to be moved due to the high radiation doses.

4. IMPACT

4.1 IMPACT ON ITEMS/SYSTEMS

LHC Layout	LHCLSS 0029 - IR7 LEFT, CELLS C8.L7 TO C11.L7 LHCLSS 0030 - IR7 RIGHT, CELLS C8.R7 TO C11.R7
Updated layout drawings	LHCLSSH 0013 - IR7 LEFT, CELLS C8.L7 TO C11.L7 LHCLSSH 0014 - IR7 RIGHT, CELLS C8.R7 TO C11.R7
Main dipole chain	Circuits RB.A67 and RB.A78 will be modified. Table 5 provides a comparison of the parameters before and after the change.
MP3	Hardware commissioning powering tests procedures have to be updated and established

4.2 IMPACT ON UTILITIES AND SERVICES

Raw water:	No impact
Demineralized water:	Water pipes (water circuit already existing in RR73 and RR77, but not near the PC). Therefore, pipes should be added to cool each rack providing at least 3 l/min.
Compressed air:	TE-VSC: New sector valves feeding require compressed air cabling.
Electricity, cable pulling (power, signal, optical fibres…):	AC cabling for trim power converters (3P+N 20 Arms (5 mm^2).) DC cabling (2x70 mm^2 per polarity) for connection of trim power supplies (WP17)
DEC/DIC:	TE-MPE: DICs reference RQF0908671 (instrumentation), RQF0888406 (PIC), and RFQ0981328 (powering)

	TE-VSC: DICs (reference RQF0912887 already requested and approved) TE-EPC: RQF0809614 (WorldFIP from trim power converters)
Racks (name and location):	The racks to be installed, displaced and removed are listed in Table 1-4.
Vacuum (bake outs, sectorisation…):	Three new vacuum sectors can be distinguished on each side of P7 after this modification, obtained by installing two new sector valves. The strategy for the pumping of the sectors aside the collimator is described in [5]. Details on the room temperature vacuum sector (TCLD) will be given in TCLD ECR. New beam screen have to furnish the 11 T magnets beam vacuum lines and the non-collimated line in the LEN cryostat. 11T assessment when performing bake-out on vacuum equipment (case under discussion – the outcome of this study will be presented in the WP11 interface working group)
Special transport/ handling:	The equipment listed in Tables 1, 2, and 3 needs to be transported and handled in the tunnel and on ground
Temporary storage of conventional/radioactive components:	The deinstalled equipment (Table 4) may be radioactive and has to be stored. In particular the two main bending magnets: MB.B8L7 and MB.B8R7
Alignment and positioning:	Marking of the beam points and new jacks heads projections on the ground floor, aligning the jacks' heads at their nominal position, initial alignment of the components, then plus smoothing (cold temperature) w.r.t. adjacent components. Marking the new slot and alignment after installation.
Scaffolding:	No impact
Controls:	The modification for the controls of QDS (section 2.7.4), nQPS (section 2.8.4) and of the trim power converters (section 2.7.3) are described in the respective sections. The number of temperature sensors for cryogenics will be doubled. TE-VSC: New gauges and valves to be integrated in SCADA and VAC LDB update.
GSM/WIFI networks:	GSM should be available during the activity as communication means complementary to the red phones in case of emergency.
Cryogenics:	The impact on cryogenics is described in detail in Section 2.4.
Contractor(s):	No
Surface building(s):	No impact
Others:	Modification of the CCC's power application: include the trim power converters of BE-CO and BE-OP The n-line may be around 8 cm too short due to the required deviation in the TCLD section. A solution to this issue is currently under study.

5. IMPACT ON COST, SCHEDULE AND PERFORMANCE

5.1 IMPACT ON COST

Detailed breakdown of the change cost:	The total cost of the deliverables of WP11 required for the change described in this ECR is borne by the HL-LHC project.		
Budget code:	**BC**	**Unit**	**Description**
	92515	TE-MSC-SCD	HL-LHC-WP11 Cable (Personnel)
	92516	TE-MSC-MDT	HL-LHC-WP11 Model (Personnel)

	92517	TE-MSC-LMF	HL-LHC-WP11 Series (Personnel)
	92518	TE-MSC-CMI	HL-LHC-WP11 Cryostat (Personnel)
	92519	TE-MSC-MM	HL-LHC-WP11 Mag. Meas. (Personnel)
	92520	TE-MSC-TF	HL-LHC-WP11 Cold Test (Personnel)
	92529	TE-MSC-LMF	HL-LHC WP11 Tooling (Personnel)
	92608	TE-MSC-LMF	HL-LHC WP11 Series (Personnel) - CONS
	92582	TE-MSC-LMF	HL-LHC WP11 Components (Personnel)
	92570	TE-MSC-SCD	HL-LHC-WP11 Cable
	92571	TE-MSC-MDT	HL-LHC-WP11 Model
	92572	TE-MSC-LMF	HL-LHC-WP11 Series
	92573	TE-MSC-CMI	HL-LHC-WP11 Cryostat
	92574	TE-MSC-MM	HL-LHC-WP11 Mag. Meas.
	92575	TE-MSC-TF	HL-LHC-WP11 Cold Test
	92576	TE-MSC-LMF	HL-LHC WP11 Tooling LMF
	92580	TE-MSC-LMF	HL-LHC WP11-11T-Series-Spares
	92605	TE-MSC-LMF	HL-LHC WP11-11T-Tooling LMF (CONS)
	92753	TE-EPC-MPC	HL-LHC WP06B-4 Quadrant Converters

5.2 IMPACT ON SCHEDULE

Proposed installation schedule:	**P7 right side**: October 2019 (readiness for installation), +4.5 months (installation of the deliverables of WP11), +1 month complete installation with collimator **P7 left side**: February 2020 (readiness for installation) , +4.5 months (installation of the deliverables of WP11), +1 month complete installation with collimator
Proposed test schedule (if applicable):	The full test of the deliverables will be performed on surface before the installation starts. The quality control (QC) in the tunnel is included in the schedule. The ELQA tests are part of the machine commissioning.
Estimated duration:	Not applicable
Urgency:	Not applicable
Flexibility of scheduling:	In case the magnets are ready for installation before the planned date, the planning may allow installing them earlier. In case the magnets are ready for installation after the planned date, LS2 has to be extended according to the current baseline planning. A study how to compress the installation time is currently ongoing to gain some contingency in the planning. The installation can also be performed during an extended technical stop.

5.3 IMPACT ON PERFORMANCE

Mechanical aperture:	No harmful impact on beam aperture is expected by the installation of the 11 T dipoles (see Section 3.2), although the magnet is straight and its mechanical aperture is the same as that of the MBs.
Impedance:	The vacuum installation at point 2 and 7 is equivalent, the impedance impact on point 2 and 7 is the same. Lorenzo Teofili in collaboration with Benoit Salvant will do a study of the impact on the impedance (11 T dipole/empty

	cryostat and the TCLD collimator/cryostat assembly) and present this study beginning of July in the WP11 interface working group meeting.
Optics/MAD-X	No negative impact on beam dynamics is expected. The LHC reference MAD-X file needs to be updated and the exact positioning of magnets has to be agreed on.
Electron cloud (NEG coating, solenoid…)	The stronger magnetic field has an impact on the emission of synchrotron radiation from the beam. In particular it results in an increase of the radiated power and in a shift of the critical energy of the emitted photon spectrum. This in turn increases the number of electrons "photo-emitted" by the chamber walls. Calculations have been performed showing that this increase is very limited, and that no visible effect is expected on the heat load on the cryogenics and on the e-cloud build-up.
Vacuum performance:	No impact on vacuum, cryogenic beam vacuum.
Machine protection	Flux-jumps in the long magnets may require adapting the settings of the quench protection system: These changes may yield to increased hot spot temperatures in the 11 T dipole coils after quench as currently anticipated. The possible impact on performance needs to be studied by WP11. Loss spikes due to beam life time dips in the operational cycle of the LHC may induce temperature spikes in the coils, leading to a quench. This effect may limit the performance (max. number of bunches and bunch intensity) of the LHC. Simulations of the expected energy deposition, the impact on the expected temperature levels and the magnet performance are currently studied and will be reviewed June 5th.
Cryogenics	No impact.
Others:	NA

6. IMPACT ON OPERATIONAL SAFETY

6.1 ÉLÉMENT(S) IMPORTANT(S) DE SECURITÉ

Requirement	Yes	No	Comments
EIS-Access		X	
EIS-Beam		X	
EIS-Machine		X	

6.2 OTHER OPERATIONAL SAFETY ASPECTS

Have new hazards been created or changed?	The 11 T dipole magnet is a pressurized equipment. The 11 T cold mass will be filled with liquid helium. A break of cold-mass helium towards the cryostats’ insulation vacuum space has been identified as a risk, with a MCI mass flow of 30 kg/s at 90 K [7]. A copper cold line in the bypass cryostat will be added (pressurized equipment at 1.3bar nominal design pressure). Interconnection of the trim power converter to the RB circuit and a specific procedure of electrical condemnation should be defined for RB.A67, RB.A78, RTB8.L7 and RTB8.R7 circuits to condemn the electrically connected power converters.

Could the change affect existing risk control measures?	The hazard is of the same kind and of the same order of magnitude as for the currently installed device.
What risk controls have to be put in place?	To mitigate the risk of overpressure, safety relief devices are installed. For a DS hydraulic section of 214 m length, and according to the risk assessment cited (break of cold-mass helium), 8xDN200 cryostat insulation vacuum release valves per 107 m long half-cell suffice to keep the vacuum enclosure pressure below 1.5 bar, whereas in general an excess of 4 more (12 in total) are installed, providing a margin of 300 mbar. The conformity of the pressurized equipment is being addressed by HSE acting as notified body. HSE will deliver the safety clearance for operation and assess the conformity to the European PED. The main dipole circuit are in the interlock for powering phase II, the trims will be also connected to the PIC. The cool down permits will be delivered to allow the safe cool-down of the sectors 67 and 78.
Safety documentation to update after the modification	All the safety documentation asked by the notified body will be archived in EDMS: https://edms.cern.ch/project/CERN-0000183369
Define the need for training or information after the change	No change required for the LHC online training course. The teams intervening on the new equipment need to be trained.

7. WORKSITE SAFETY

7.1 ORGANISATION

Requirement	Yes	No	Comments
IMPACT – VIC:	X		TE-MSC (Sandrine Le Naour) needs to trigger the VIC (Visite d'Inspection Commune) and create the IMPACT
Operational radiation protection (surveys, DIMR…):	X		The area will be surveyed by RP and it is expected that the intervention will be performed under ALARA level 1.
Radioactive storage of material:	X		It is expected that the activation level will allow to store the material in a fenced storage area (supervised radiation zone). Therefore, the radioactive material can be stored in building 180.
Radioactive waste:	X		Volume of radioactive waste will be generated by the worksite itself and will be very limited in volume The removed magnets will be kept as spare Vacuum cleaner for radiological area needed
Non-radioactive waste:	X		Very limited
Fire risk/permit (IS41) (welding, grinding…):	X		The fire permits and the fire mitigation procedures will be defined during the VIC
Alarms deactivation/activation (IS37):	X		The alarms deactivation or activation will be defined during the VIC
Others:	X		This task will be subjected to the WPA coordinated by the LHC coordination team in the framework of the LS2 activities

7.2 REGULATORY TESTS

Requirement	Yes	No	Responsible Group	Comments
Pressure/leak tests:	X		HSE TE-VSC	Work is organized by PSO and was delegated to Arnaud Foussat; PED to be followed Complete leak test will be performed on the entire arc during installation phase.
Electrical tests:	X		TE-MPE	Standard procedures will be applied on the 11 T dipoles as part of the main dipole circuit tests of LHC These procedures have to include the disconnection of the trim power converters when ELQA is performed on RB.A67 or RBA.78.
Others:	X		BE-DSO	PIC will be validated during the DSO tests

7.3 PARTICULAR RISKS

Requirement	Yes	No	Comments
Hazardous substances (chemicals, gas, asbestos…):		X	
Work at height:	X		To be determined during the VIC
Confined space working:		X	
Noise:		X	
Cryogenic risks:		X	The sector will be warmed up and emptied before installation
Industrial X-ray (*tirs radio*):		X	No X-ray testing will be performed in the tunnel. Welds will be inspected only optical with a camera
Ionizing radiation risks (radioactive components):	X		All removed equipment and waste will be tracked by TREC
Electrical risks:	X		The trim current leads are connected to the active part of the MB circuit. The trim current lead active part is being accessible from the flange. Therefore, during the ELQA testing campaign a risk of touching a lively part carrying high voltage is present and mitigation measures have to be taken.
Others:			

8. FOLLOW-UP OF ACTIONS BY THE TECHNICAL COORDINATION

Action	Done	Date	Comments
Carry out site activities:			
Carry out tests:			

Update layout drawings:			
Update equipment drawings:			
Update layout database:			
Update naming database:			
Update optics (MADX)			
Update procedures for maintenance and operations			
Update Safety File according to EDMS document 1177755:			
Others:			

9. REFERENCES

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[4] L. Fiscarelli et al. (2018). "Field Quality of MBH 11-T Dipoles for HL-LHC and Impact on Beam Dynamic Aperture", IEEE Trans. Appl. Supercond. 28 4004005.

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