Assembly process and quality control of the magnet cryostats for the HL-LHC project at CERN

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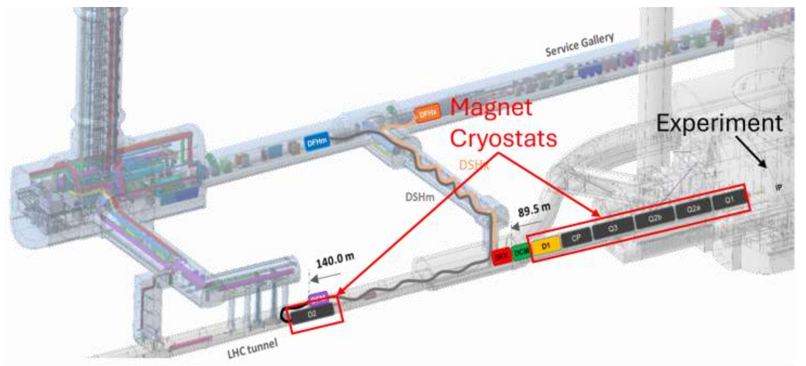
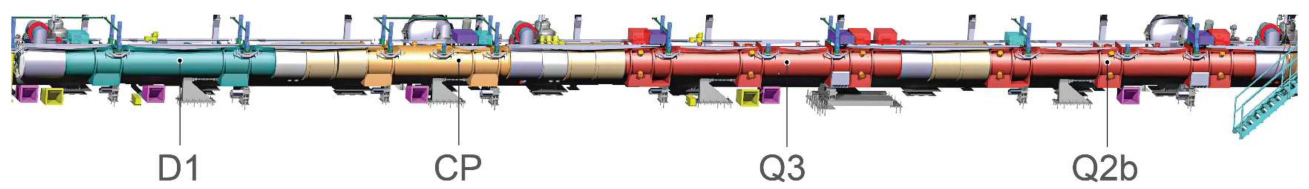
ABSTRACT

As part of the High Luminosity Large Hadron Collider Upgrade (HL-LHC) at CERN, new focusing quadrupoles, separation and recombination dipoles, and corrector magnets will be installed on either side of the ATLAS and CMS experiments. Specific cryostat designs were developed to allow for the operation of these magnets at 1.9K. A base design concept is progressed into 19 cryostat types to comply with requirements that depend on tunnel integration, cryogenics, instrumentation, and cold mass dimensions. The assembly process for the cryostats is split into two main phases: Phase 1 involves inserting the cold mass and thermal shield assembly into the vacuum vessel, while in Phase 2 a so-called service module is added to provide specific features and interfaces for installation in the LHC tunnel. In 2022, the production of the first cryostat began following the completion of the design, the procurement of components, the definition of the assembly process and the availability of a magnet cold mass. This paper presents an overview of the assembly process and the quality controls utilised to ensure consistent high-quality execution during the assembly of each cryostat. It examines several aspects, such as the specialised tooling utilised during the assembly, how strict leak testing requirements are met, as well as detailing some of the issues encountered and lessons learned.

INTRODUCTION

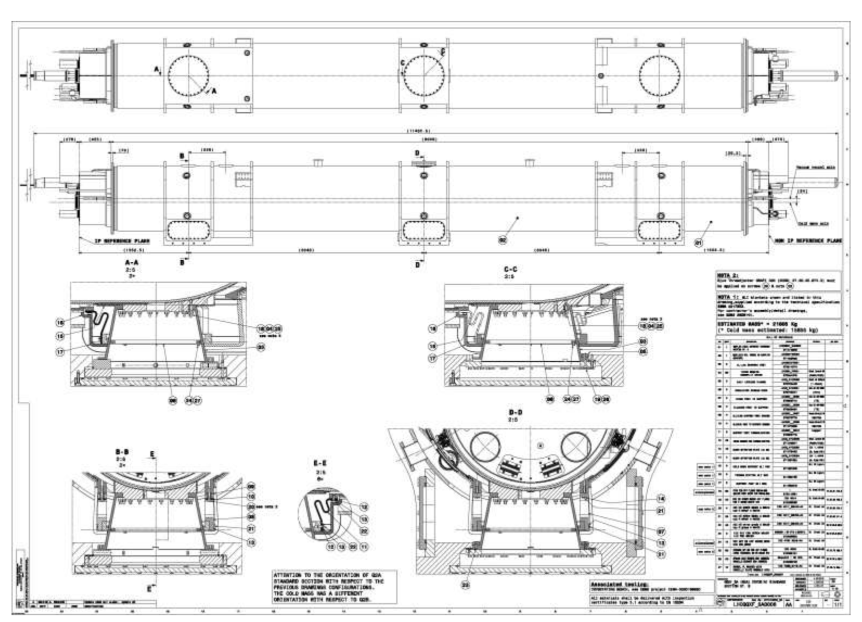
- The High-Luminosity Large Hadron Collider (HL-LHC) project involves replacing a series of magnets located on either side of the ATLAS and CMS experiments. The magnets are distributed through 7 cold masses.
- 7 new cryostats were designed, 1 type for each cold mass, to enable the operation of the magnets at 1.9K.
- Cryostat types are further specialised depending on installation location, with 19 total variants. A total of 38 cryostat/cold mass combinations will be assembled.
- A well-defined assembly process with integrated quality controls is followed to ensure reliable and repeatable cryostat assembly.

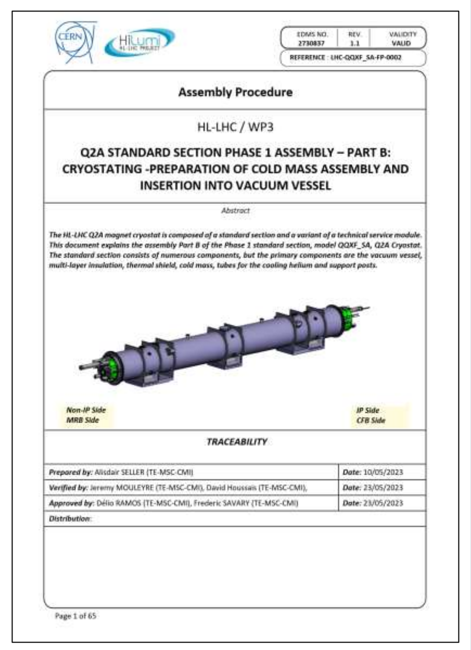




QUALITY SYSTEM

- Assembly drawings and procedures define and describe the assembly steps.
- Follow-up files (FUF) are filled out during the assembly to track progress and note comments.
- Electronic Manufactuing and Inspection Plans (e-MIP) track the completion of major QC checks and manufacturing steps directly in CERN's EAM system.
- Welding books specify and track completion of all the welds.





ASSEMBLY - PHASE 1

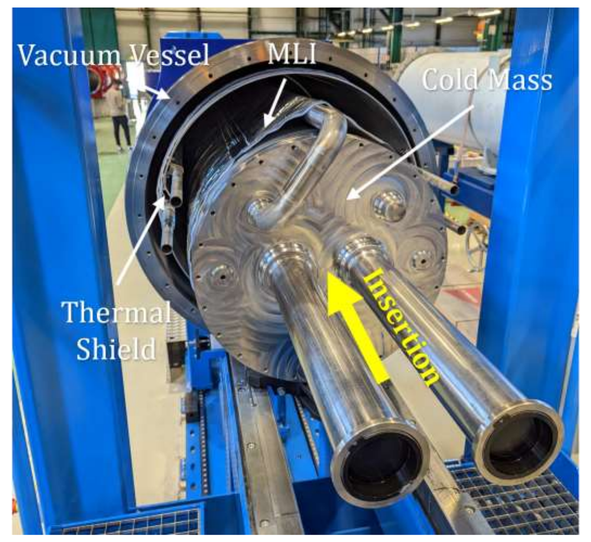
Duration: ≈6 Weeks

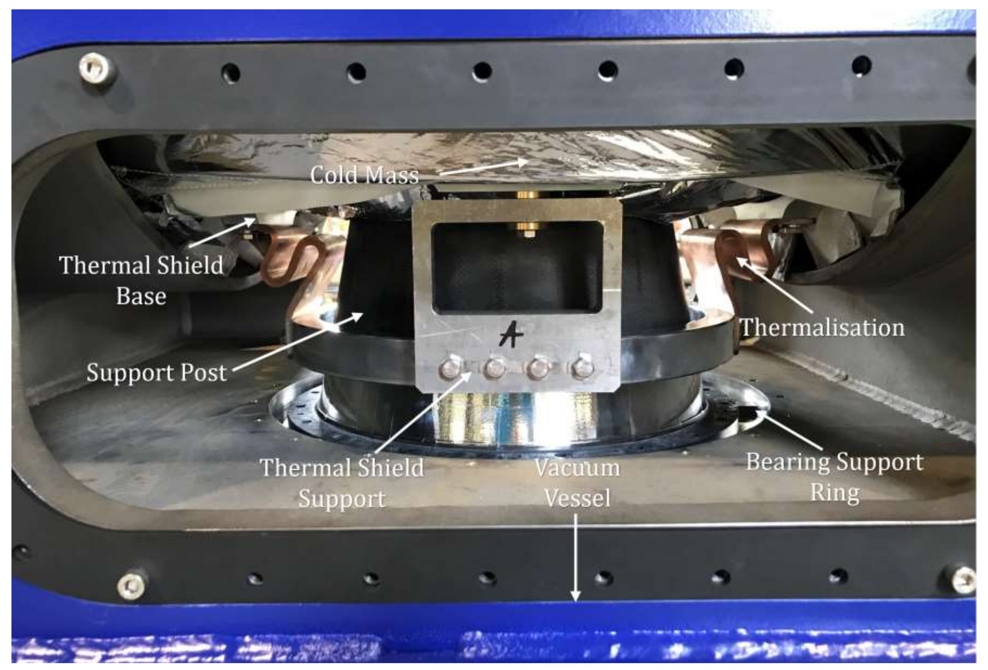
Part A

1. Configure the Phase 1 tooling bench for the type of cryostat being assembled, moving the supports and jacks into position.
2. Place the vacuum vessel onto the tooling's vacuum vessel supports.

Part B

1. Weld the stainless-steel pipes to the upper diameter of cold mass.
2. Place the lower thermal shield with multi-layer insulation (MLI) onto the tooling's trolly.
3. Place the cold mass assembly into the thermal shield assembly.
4. Wrap the cold mass in MLI and weld the upper thermal shield sections to complete the cylindrical shell.
5. Verify the conformity of the assembly.
6. Insert the cold mass assembly into the vacuum vessel using the winch.





7. Lift the cold mass using the jacks and install the support posts.
8. Partially lower the cold mass - aligning cold mass and vacuum vessel around the support posts.
9. Install the vacuum vessel's cold mass bearing supports.
10. Lower the cold mass onto the bearing supports.
11. Measure the alignment between the cold mass and the vacuum vessel and if necessary, correct the alignment.
12. Install the thermalisations and supports between the support post and the thermal shield.
13. Wrap the support post in MLI.
14. Close the vacuum vessel's bottom and side flanges.

Part C

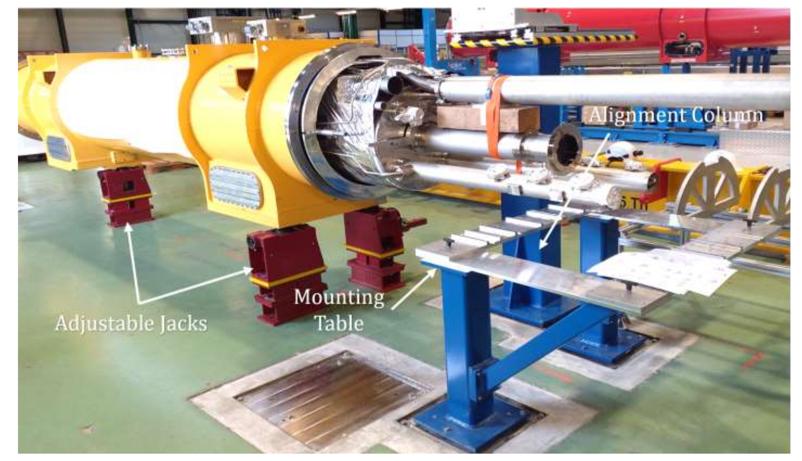
1. Solder, install and weld the instrumentation system wires, interface flanges and boxes on top of the cryostat.
2. Weld the piping connections and caps for connection to the cold test bench.

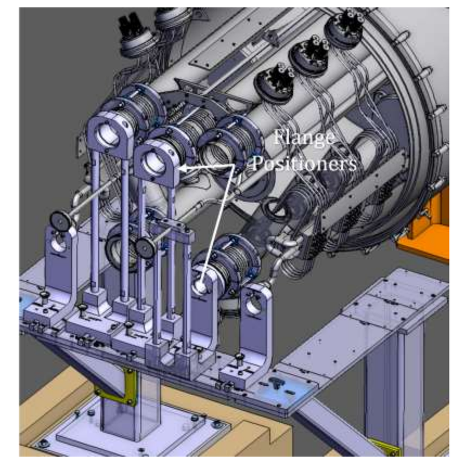
ASSEMBLY - PHASE 2

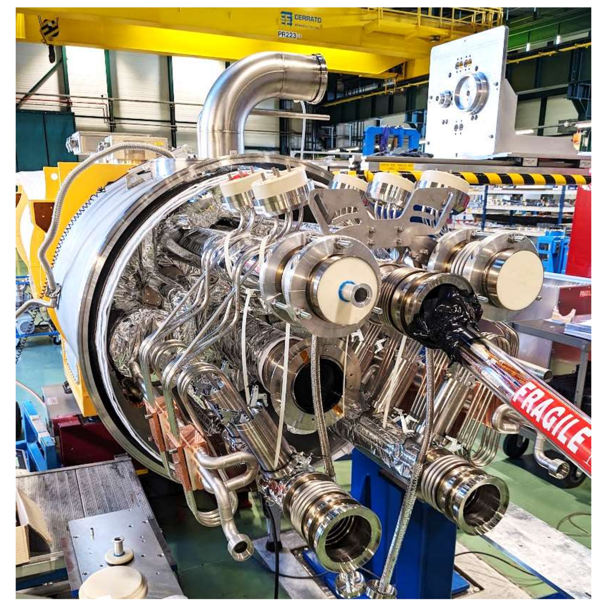
Duration: 2.5 to 4 Months

Part A

1. Configure Phase 2 tooling bench, move the jacks, table and columns into position.
2. Align the cold mass to the Phase 2 tooling bench using dial gauges.
3. Prepare flange positioners.





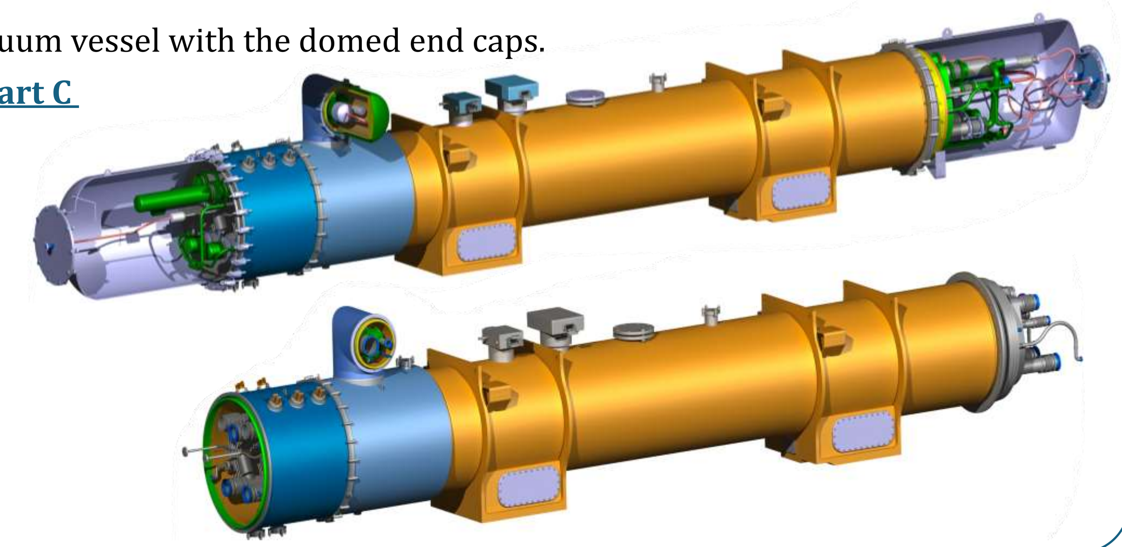


Part B

1. Cut the pipes to length and prepare them for welding.
2. Position the wide range of components: pipes, bellows, flexible hoses, flanges, phase separators and supports, using the flange positioners which mimic the final interface position.
3. Weld the components, with a final positioning tolerance of +/- 2mm.
4. Validate the welds through visual inspection, radiography and helium gas tracer leak testing methods.
5. Install thermal shield and vacuum vessel extensions.
6. Weld the temporary fittings for the pressure test, creating circuits grouped by design pressure.
7. Close the vacuum vessel with the domed end caps.

Part C

1. Execute the combined pressure and leak test, pressurising all circuits at 1.25x design pressure with helium whilst a pump and leak detector create a vacuum in the vessel, simultaneously validating structural integrity and leak tightness.
2. Remove the domed ends and cut off all the pressure test caps and connections to leave the final interfaces for installation in the tunnel.



ISSUES ENCOUNTERED AND LESSONS LEARNED

- The thermal shield was not rigid enough and started to open once the upper section was installed, causing the upper sheets to touch the top of the cold mass assembly. Remedied by rolling upper shells with a smaller radius and introducing shims.
- Fabricating the specialised clamshell leak test vacuum boxes from aluminium took too long and limited the design possibilities. Fabrication was changed hanged to 3D printing, reducing the cost, and the design and fabrication times.
- Welding and cutting all temporary pressure test components is proving very resource-intensive. The alternative of using clamped or bolted pressure test fittings is being investigated, this could significantly reduce assembly time.

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