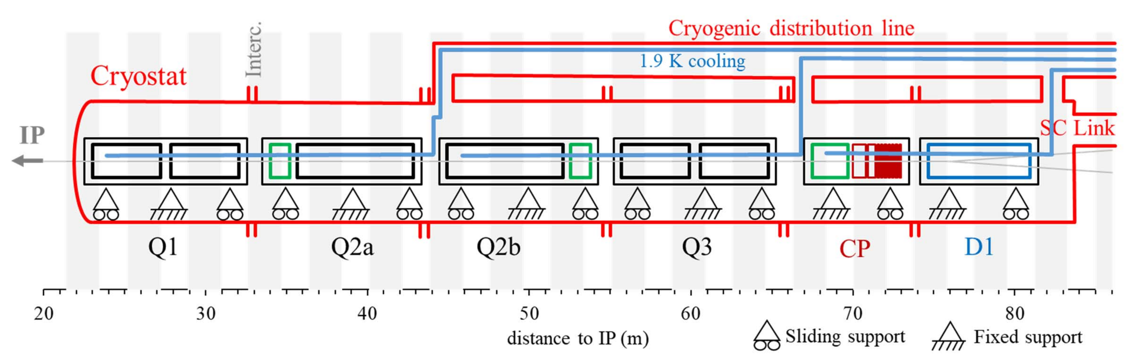
Cryostats for the HL-LHC magnets: Pre-series production, assembly infrastructure and project plans

Délio Ramos*, Alisdair Seller, Arnaud Devred, Attilio Milanese, Ezio Todesco, Frederic Savary, Herve Prin, Michael Struik, Oussama Id Bahmane, Susana Izquierdo Bermudez, Victorio Sanchis Ortola and Yann Leclercq

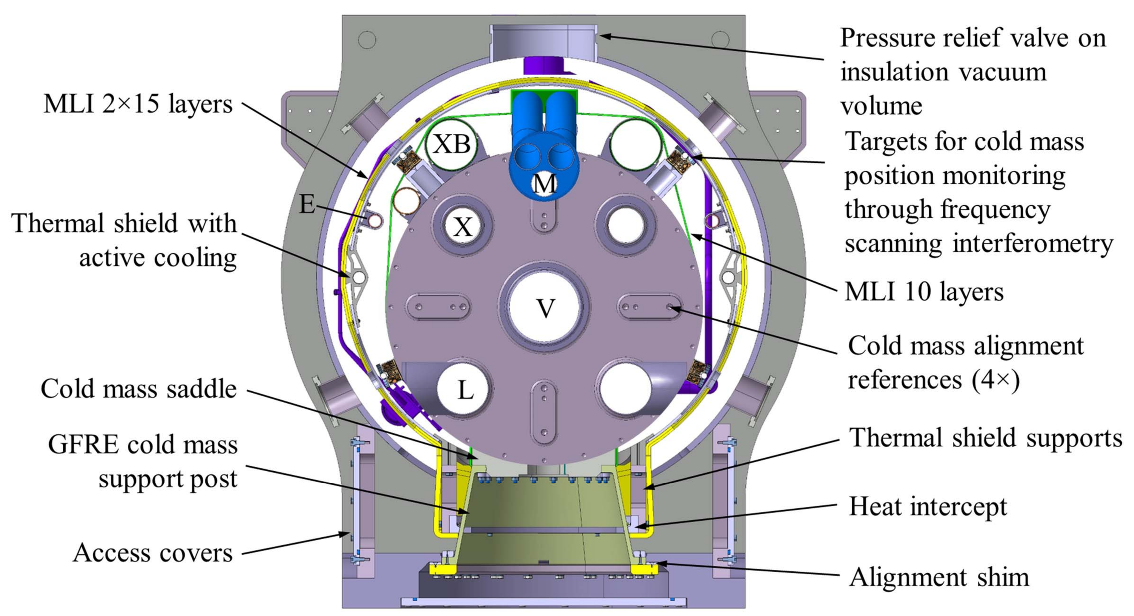
CERN, Geneva, Switzerland

Abstract. The superconducting system of the High Luminosity LHC project (HL-LHC) at CERN comprises a total of 38 new cold masses, prototypes and spares included, all requiring cryostats for magnet operation at 1.9 K. These cryostats shall ensure optimal thermal performance, as well as magnet alignment stability over the machine lifetime. Specific cold mass dimensions and a multitude of interfaces related to cryogenics, power supply and instrumentation resulted in 19 cryostat assembly types. Having so many design variants relative to the number of units to be built is a challenge in terms of cost, resources, and schedule management. Our answer was the development of a modular concept maximising component sharing between cryostat types, which also allows for a common assembly infrastructure. To date, manufacturing of cryostat components is nearly finished, and a pre-series comprising the first cryostat assemblies for each cold mass type has been built up to the stage of readiness for cold testing. This paper presents our experience and lessons learnt from component manufacturing and first assemblies, how we set up an assembly hall with purpose-built tooling, and insights on logistics and resources. We also explain our plans to ensure timely delivery of the cryostat assemblies, without compromises to the high reliability level expected for equipment that will become part of the 27 km long particle collider.



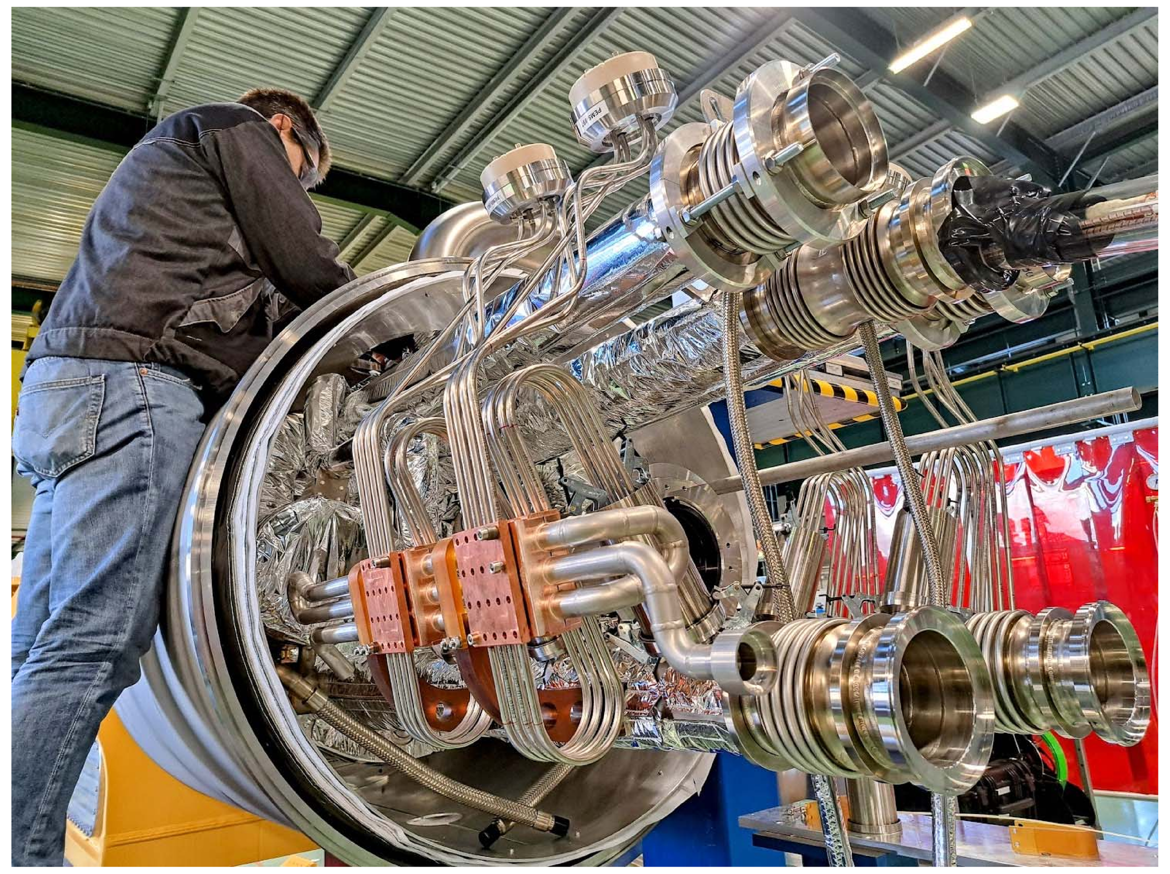
1. Introduction

- The High Luminosity LHC project at CERN involves replacing the existing focusing quadrupoles, separation dipole, and recombination dipole on both sides of the ATLAS and CMS experiments. A total of 28 cryoassemblies, including prototypes and spares, will be installed in the machine tunnel, with 19 design variants required due to tunnel slope and interface constraints. The assembly process is split into two phases, allowing for testing of Nb_3Sn triplet magnets between phases.



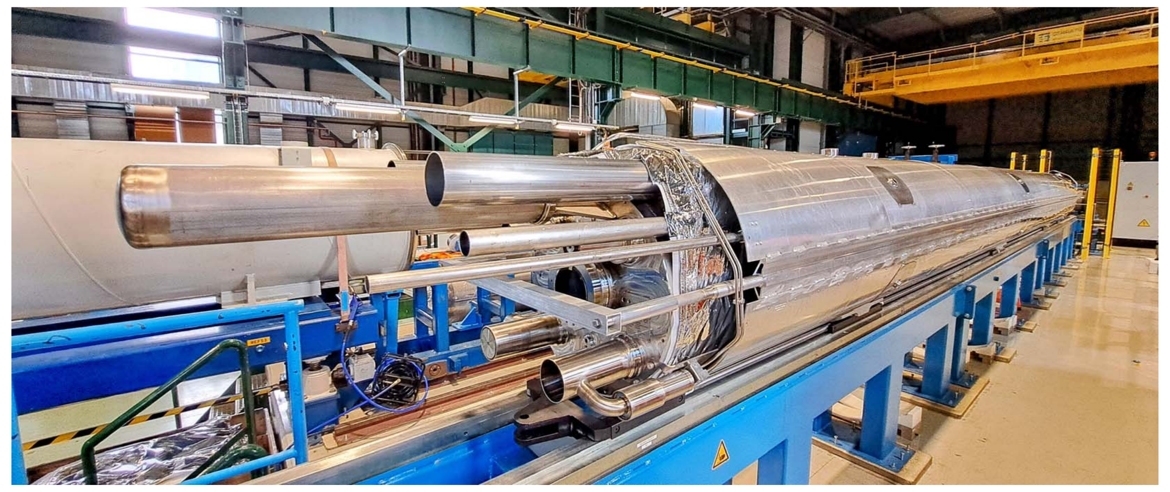
2. Manufacturing of main components

- The vacuum vessel fabrication was subcontracted as a build-to-print supply, but the contractor was allowed to change manufacturing aspects to reduce costs. Leaks were found in some vessels during the leak test at CERN, requiring repairs and additional tests.
- The support posts were made from glass fibre reinforced epoxy, and the manufacturing process was optimized to meet strength and stiffness requirements. The contractor faced difficulties in ensuring pressure at the corners during curing, resulting in porosities on the finished parts, but was able to meet the specification after process improvements. Multiple support posts were rejected after machining due to out of tolerance dimensions caused by stress relaxation.
- The global pandemic impacted both the vacuum vessel and support post contracts, causing communication difficulties and travel restrictions.
- In-house production was chosen for the thermal shields, utilizing existing competencies at CERN and optimizing available resources. The thermal shield subassemblies are built on idle time between cryostat assemblies to avoid the need for large storage space and road transport.



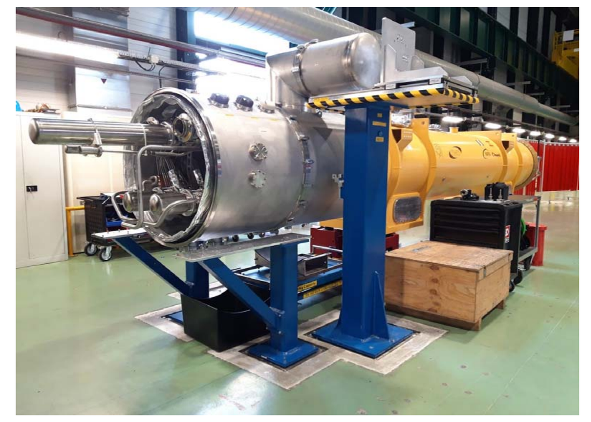
3. Assembly infrastructure

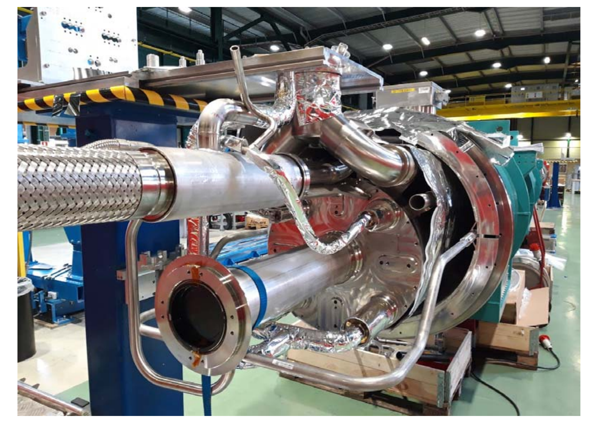
- The cryostat assembly hall at CERN was previously used for the construction, repair, and consolidation of main dipoles and quadrupoles, as well as R&D activities.
- The building consists of two bays equipped with overhead cranes and has an access shaft to the LHC for cryoassemblies up to 15 m in length.
- The main assembly bay has an area of 1300 m^2 and is equipped with two overhead cranes of 40 tonne capacity.
- The HL-LHC tooling was made compatible with both new cryoassemblies and the LHC matching section quadrupoles, allowing decommissioning of previous tooling.
- The cold mass insertion tooling, designed and built in industry, uses steel rails and plain bearings with embedded solid lubrication for precise and safe insertion of the cold masses into the cryostats.



4. Logistics, quality control and data traceability

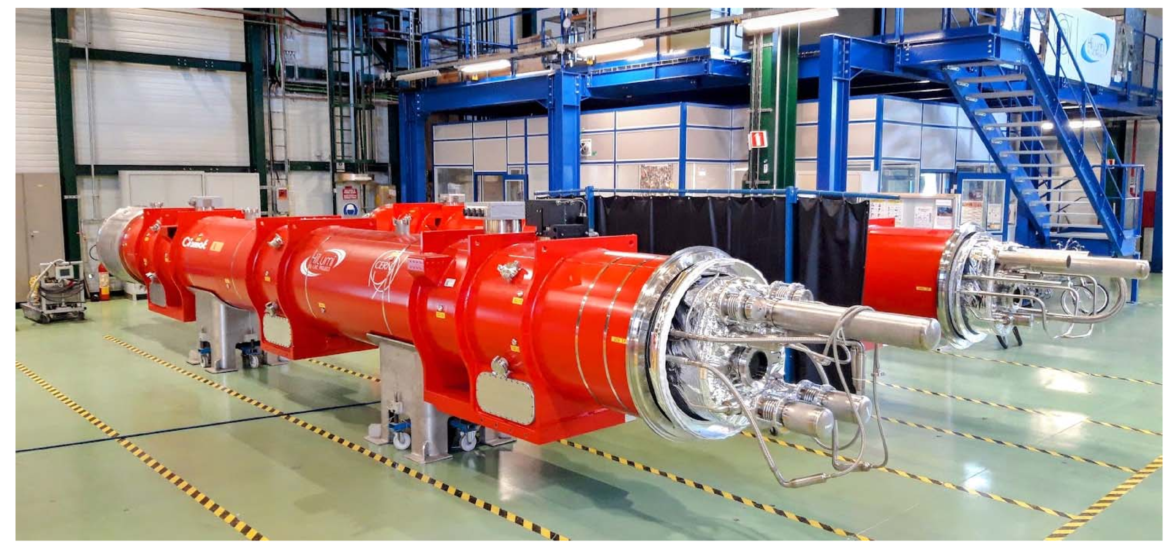
All components undergo thorough checks and are assigned identification numbers for traceability. The engineering data management system (EDMS) and stock management share the same database, ensuring efficient documentation. An electronic manufacturing inspection plan (MIP) is implemented to monitor the assembly process, including tests and inspections. Prior to installation, cryoassemblies are subjected to a global pressure and leak test.





5. Experience from first assemblies and plans

- At CERN, the first units of CP, D1, and Q2a have been fully assembled and will soon be installed in the String Facility. Two Q2a and two Q2b have been assembled up to phase one. At FNAL, one Q3 and one Q1 have reached phase one of assembly. The assembly of cryostats for HL-LHC magnets is ongoing, with a target production rate of about 15 finished cryoassemblies per year.



6. Conclusion

- Most cryostat components have been produced and stored.
- The first cryoassemblies have been completed and will soon be installed for system testing.
- An integrated quality management system is in place for quality control and traceability documentation.
- Practical experience gained during assembly has led to updated procedures and tooling improvements, which will be shared with new team members as production rate increases.

*Delio.Ramos@cern.ch