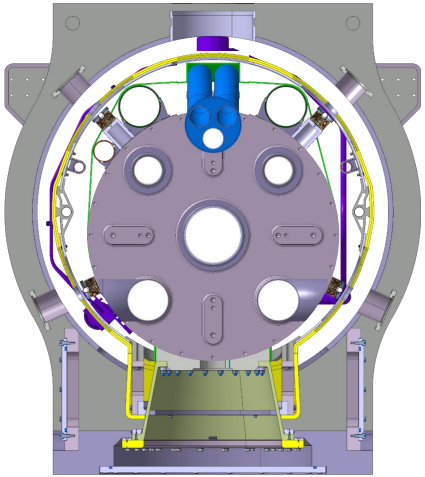
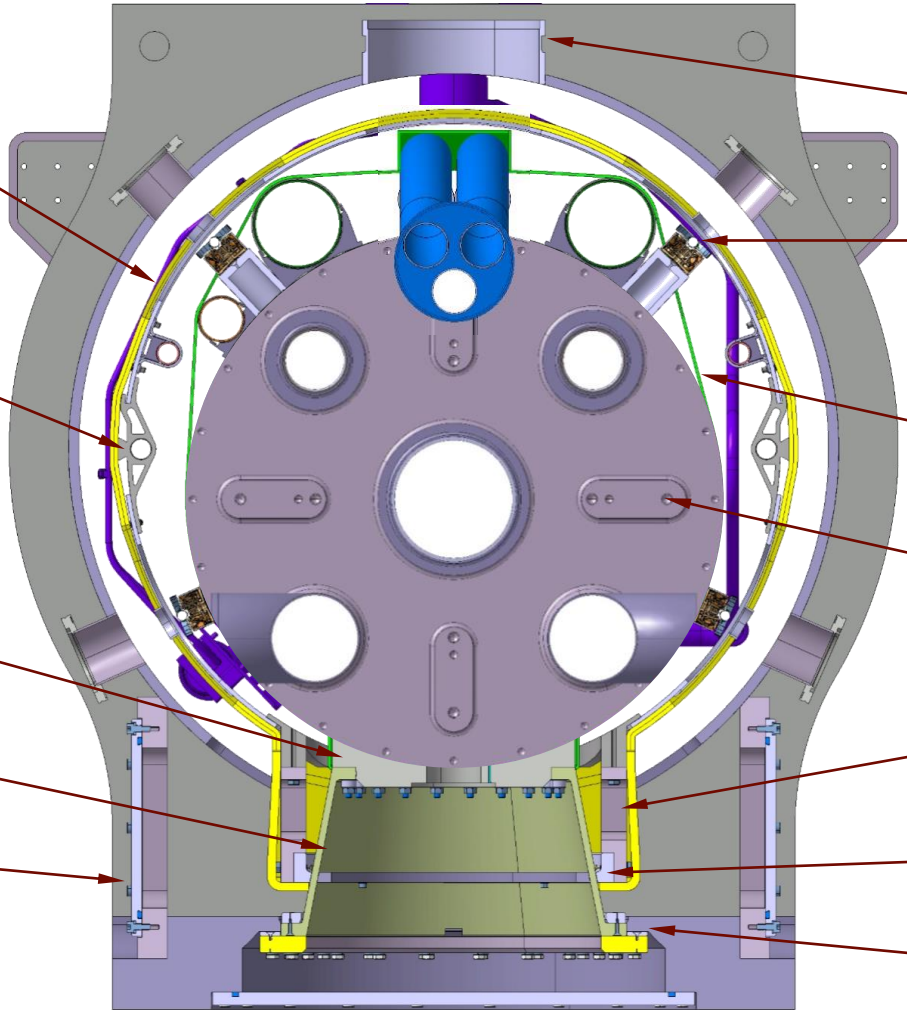


Cryostat assembly at CERN

D. Ramos on behalf of the cryostat team
G. Barlow, B. Luís, A. Seller, M. Struik, A. Vande Craen, D. Murge, L. Williams, O. Id Bahmane, F. Savary and many others…

12th HL-LHC Collaboration Meeting, 19th to 22nd September 2022

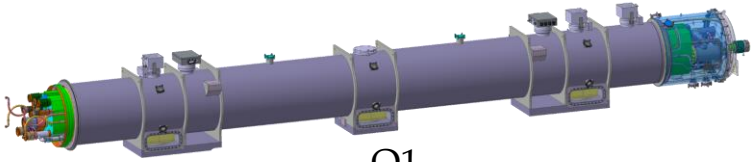

MLI 2x15 layers
Thermal shield with active cooling
Cold mass saddle
GFRE cold mass support post
Access doors
Pressure relief valve on insulation vacuum volume
Targets for cold mass position monitoring through frequency scanning interferometry
MLI 10 layers
Cold mass alignment references (4x)
Thermal shield supports
Heat intercept
Alignment shim

Outline

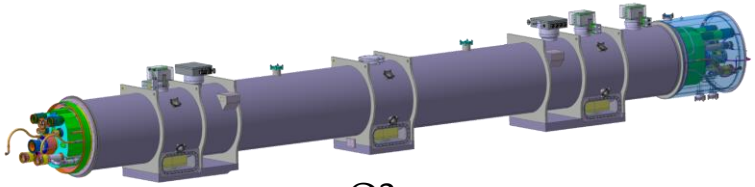
- Assembly phases and workflow
- Assembly facility and tooling
- Experience with D2 prototype
- Plans

Cryostat “species”

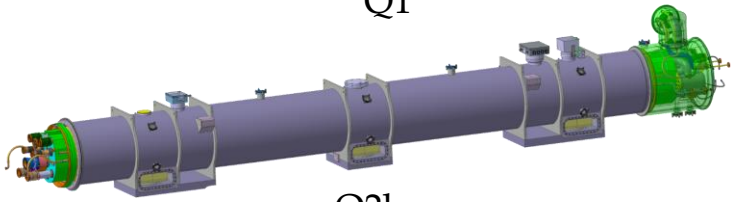
Q1a



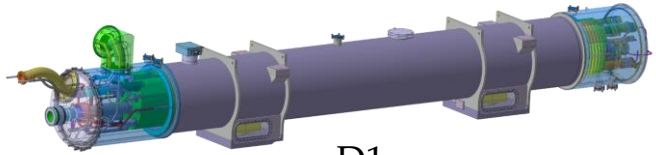
Q1



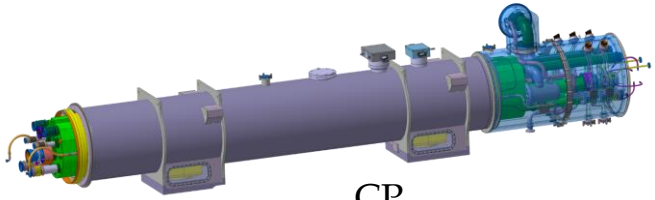
Q3



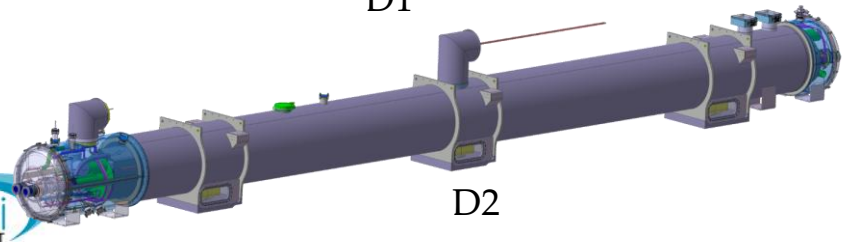
Q2b



D1



CP

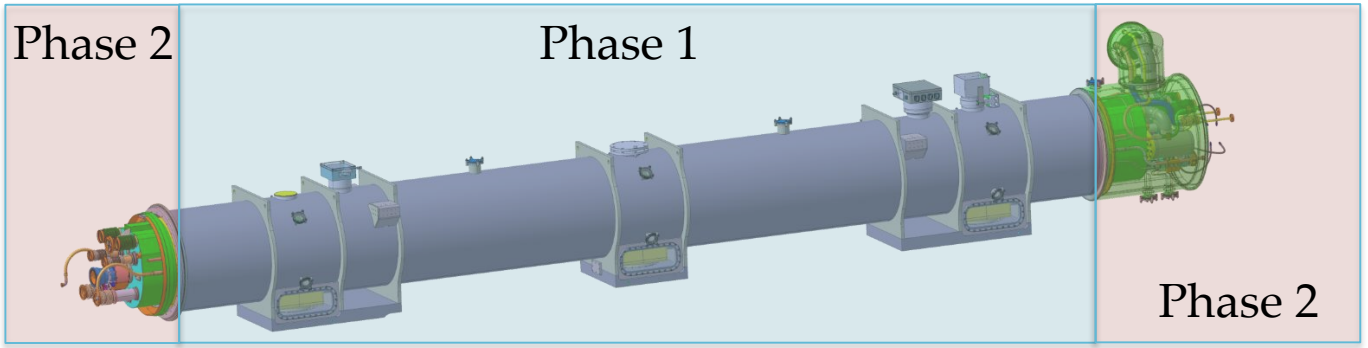


D2

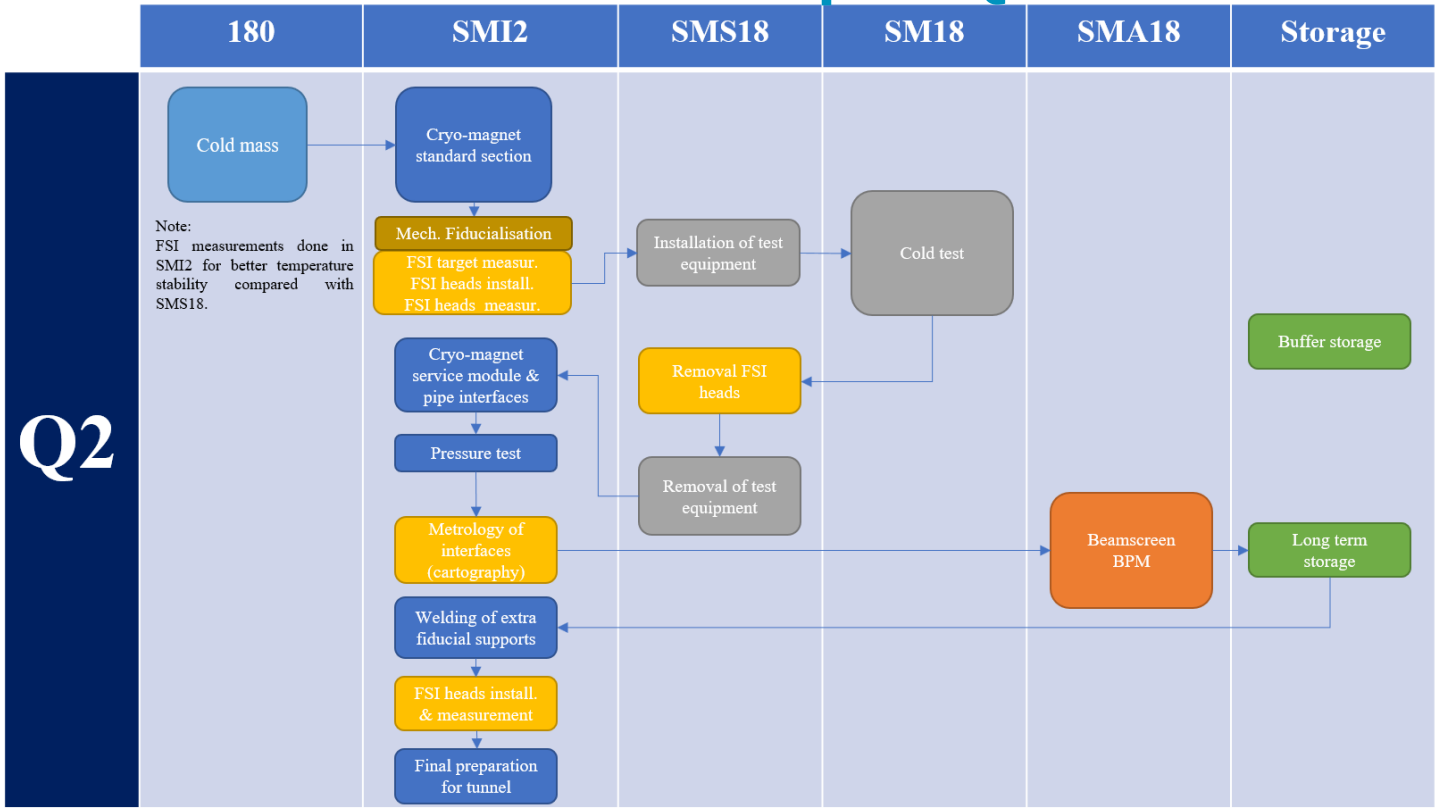
Modular(ish) design but nearly all different once ready for the tunnel

Cryostat assemby in phases

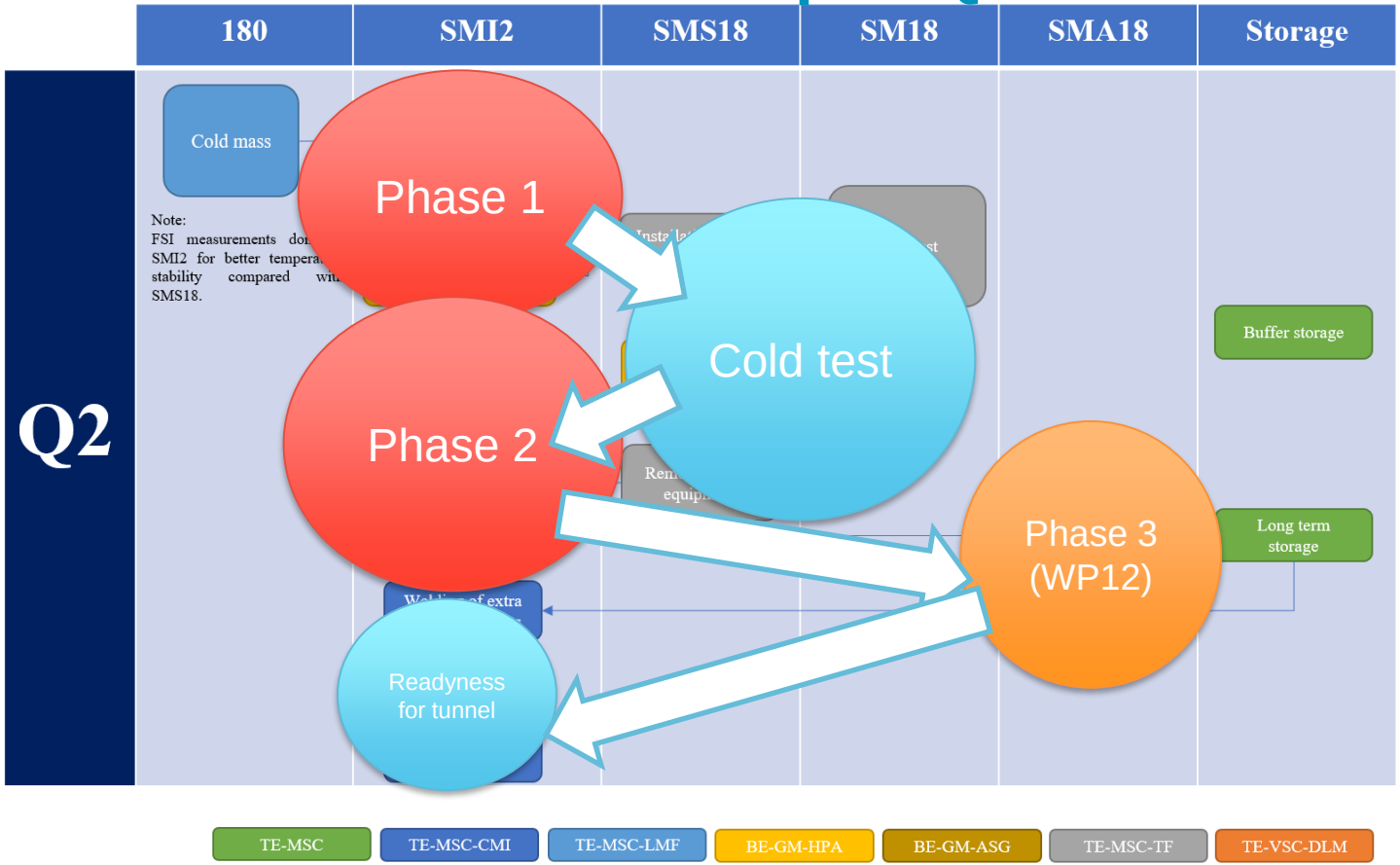
- Phase 1: ready for horizontal cold test, i.e. cold mass on cold supports, inside vacum vessel and interfaces for test bench
- Phase 2: ready for the tunnel, i.e. with crygenic service modules and pipe interfaces
- Phase 3: beam vacuum and BPM (by WP12)



Workflow example: Q2a/b

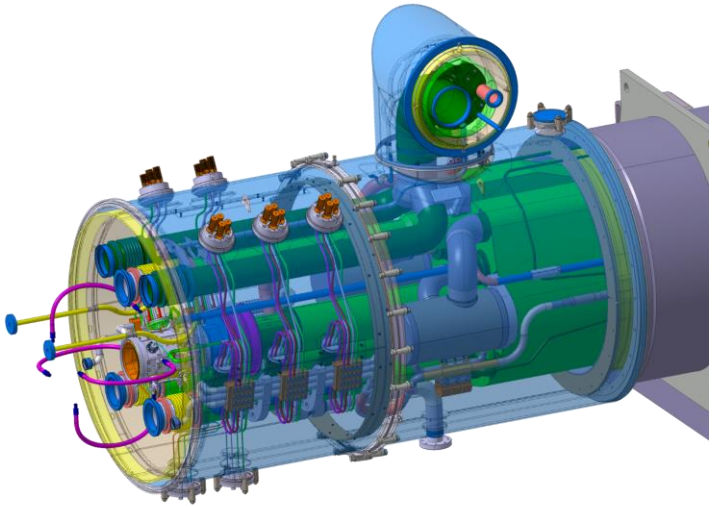


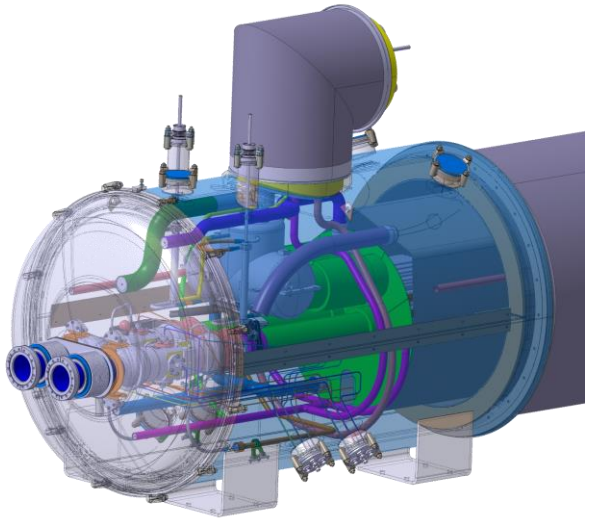
Workflow example: Q2a/b



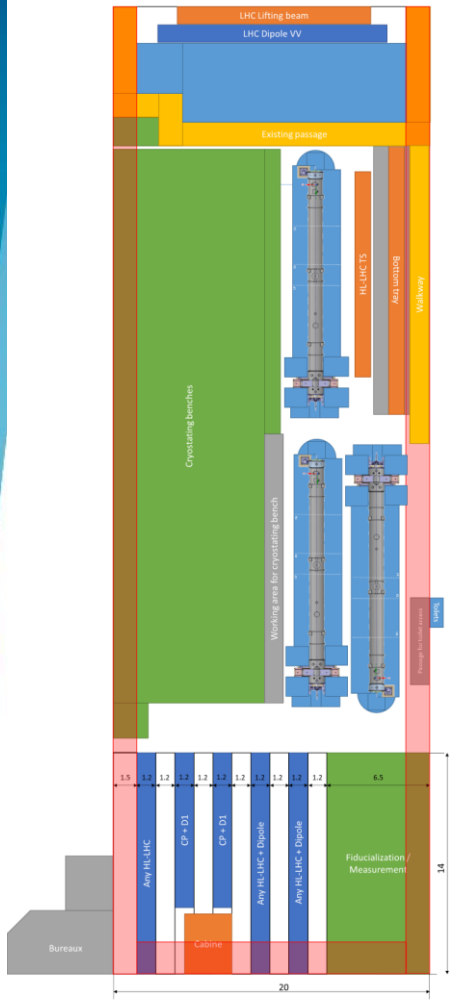
CP and D2 exceptions: Test after phase 2

- CP: local conduction cooled leads
- D2: finger heat exchanger



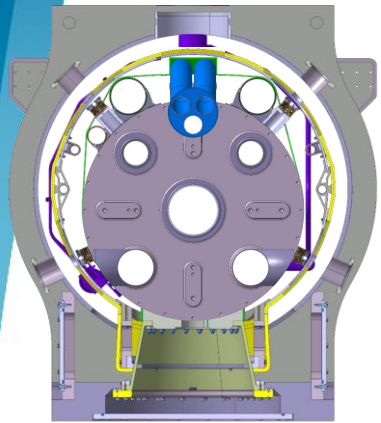


Cryostat assembly facility (SMI2)

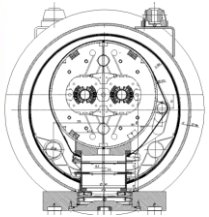


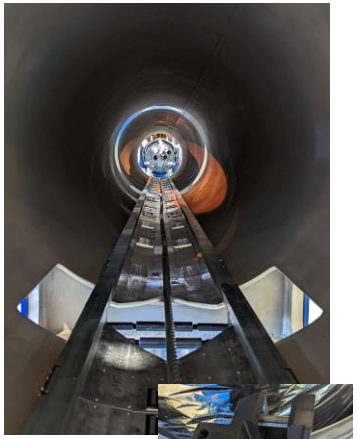
- Cryostat assembly area of 1200 m^2 equipped with two 40 tonne overahead cranes
- 3 cryostat assembly tools:
  - New: HL-LHC, LHC MS and connection cryostats
  - LHC Dipole (dedicated)
  - LHC SSS, with recent adaptations for 11T and connection cryostats for collimators
- 3 HL-LHC Service module assembly workstations (cryostating phase 2), with possibility to install a 4th bench
- 2 thermal shield assembly benches, one for HL-LHC and one for LHC repairs
- Dedicated laser tracker area for fiducialization
- Multi-purpose assembly area with capacity up to 5 cryomagnets

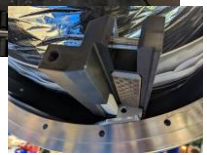
Cryostat assembly tooling at CERN



- Cold mass external diameters ranging between 570 and 630 mm. Thermal shield diameter 780 mm.Vacuum vessel with 890 mm internal diameter. Length up to 15 m. ~1.7 tonne/m length
- Two concepts of cryostating tooling at CERN
  - Cold mass supported on rollers at the ends for short cold masses. Suitable for cold masses up to ~6 m length
  - Cold mass supported on the same interfaces interfaces as inside the cryostat. Temporary rails inserted into the vacuum vessel. Uses sleges with flat plain bearings made from low friction material

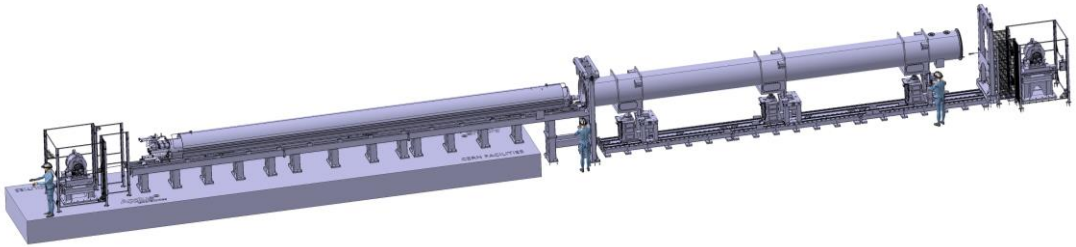






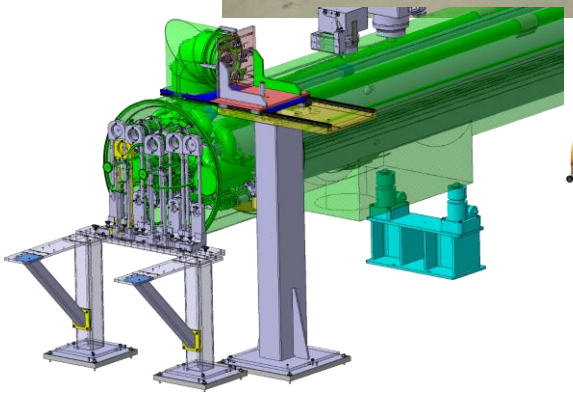
Cryostat assemby tooling (phase 1)

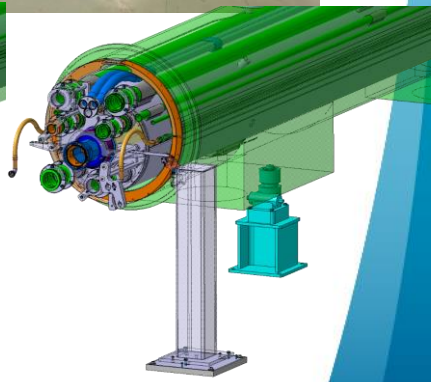
- New cryostating tooling designed around the requirements of MQXF cold mass but configurable for all HL-LHC cryostats
- One additional tool for assembly of Q1/3 in the US: reduced version of CERN tool, specific for this cryomagnet
- To save space, the tooling of LHC matching section (MS) cryostats was dismantled and the new HL-LHC made compatible with these LHC cryostats as well
- The facility remains suitable for long term maintainability and repairs on all cryostat types



Service module assembly tooling (phase 2)

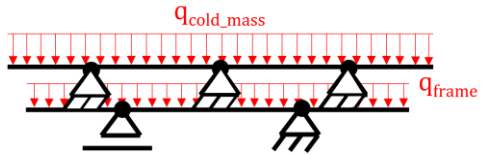
- Position and geometrical control of interfaces for welding:
  - Jumper
  - Interconnects between magnets
- 3 workstations under installation with possibility to expand with one additional station
- Cryomagnet aligned in the tooling using cold mass end covers as reference
  - Avoid needs for laser tracker
  - Physical positioning of all interfaces wrt cold mass
- Tolerances of +/-1 mm at magnet interconnects, +/-2 mm at jumper interconnect
- Modular design allows to assemble all types of WP3 cryomagnets in any workstation, with minimal reconfiguration work

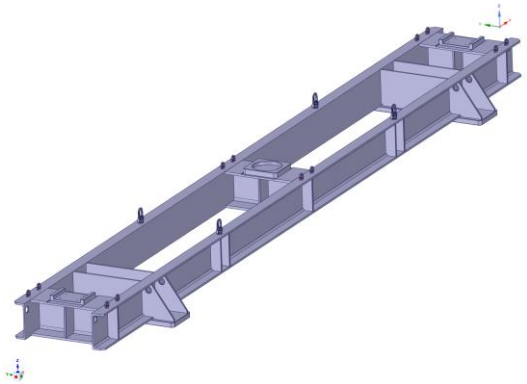


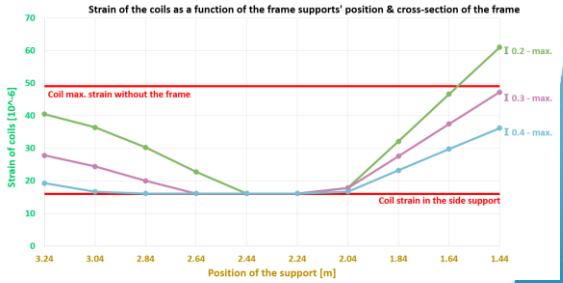


Handling tooling

- Frame for transport of Q2 cold masses on site
  - Provides a well defined support interface and isostating support over the trailer bed
  - Reduces flexural strain on coils by a factor 2.5
- Lifting beam designed to fit all types of HL-LHC cold masses and assembled cryomagnets





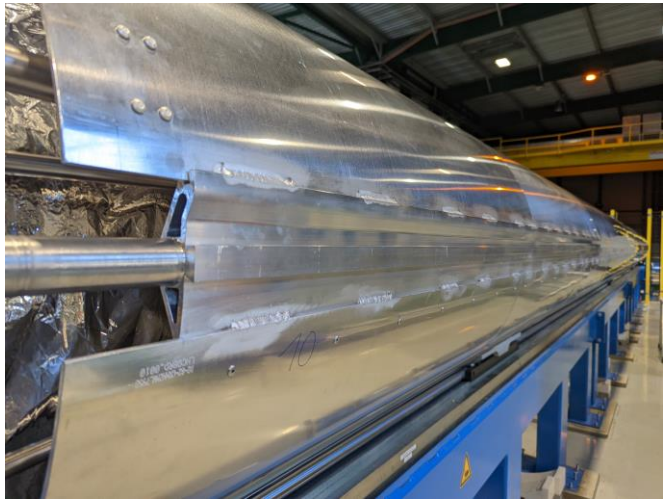


Experience with D2 prototype

- D2 prototype was configured for cooling at the test bench with a longitudinal heat exchanger intead of the baseline finger heat exchanger. The remainder of the cryostat and support system was still conform to baseline
- The thermal shield and the support systems are identical in all WP3 cryostats
- D2 prototype was the first assembly representative of the HL-LHC design, allowing to validate:
  - Handling of real load on the tooling (D2 is the heaviest 24 tonne cold mass and 32 tonne cryoassembly)
  - Friction when sliding on rails and consequent pulling load on the winch
  - Support assembly procedure and CM weight transfer from tooling to cryostat
  - Relative alignment of cold mass and vacuum vessel

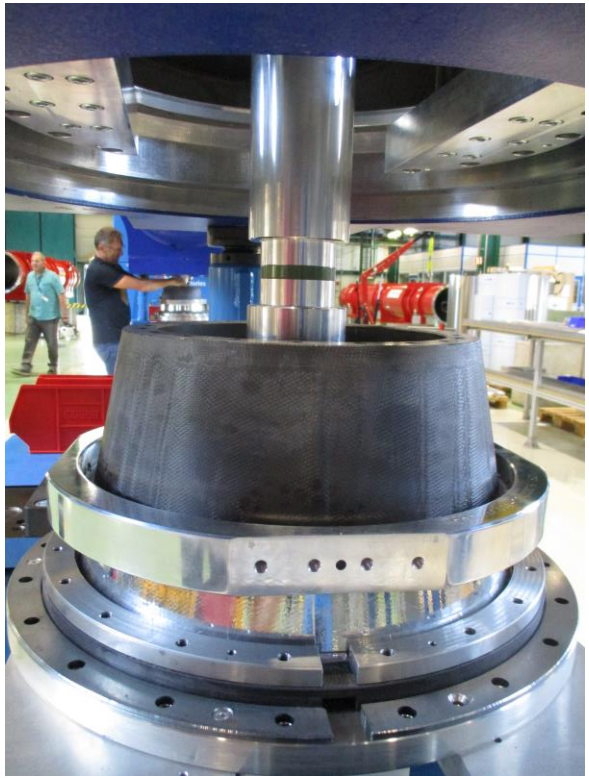
Cold mass onto thermal shield

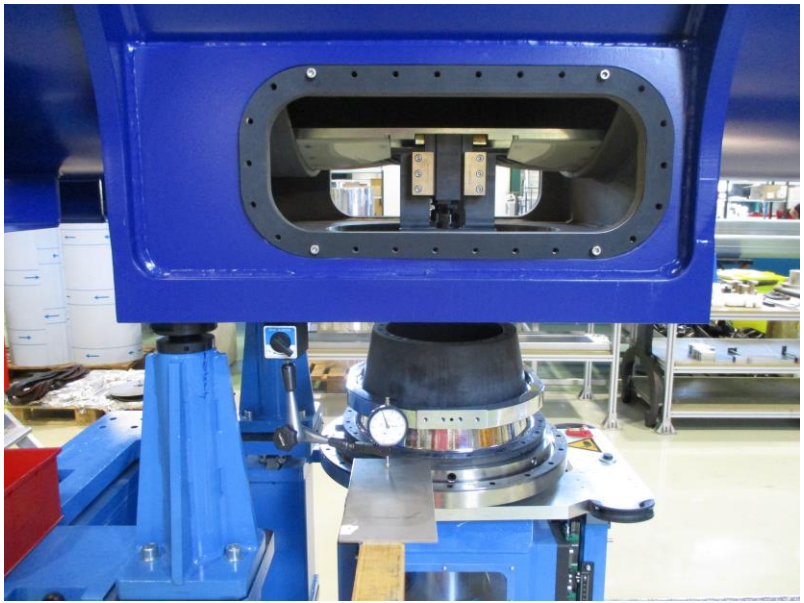
Themal shield welding



MLI

Support posts and rails in place

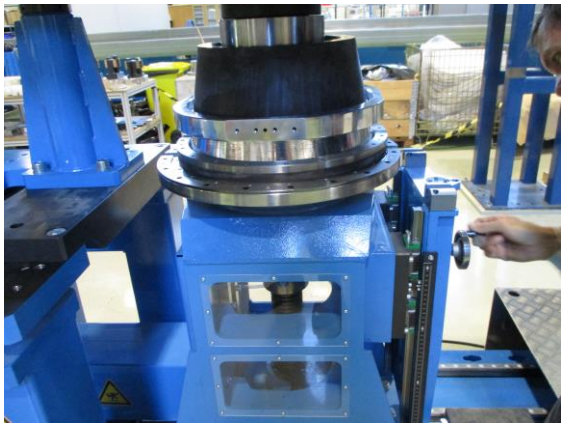


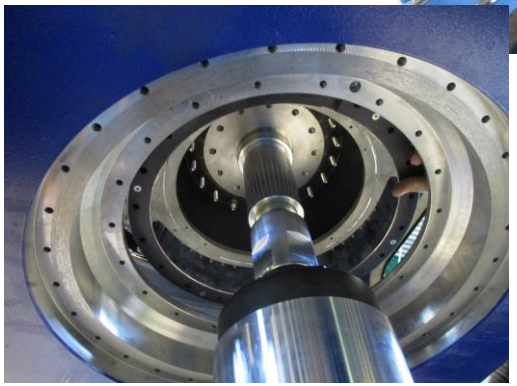


Cold mass insertion

Cold mass stabilisation, lifting, and removal of rails

Assembly of support posts and load transfer

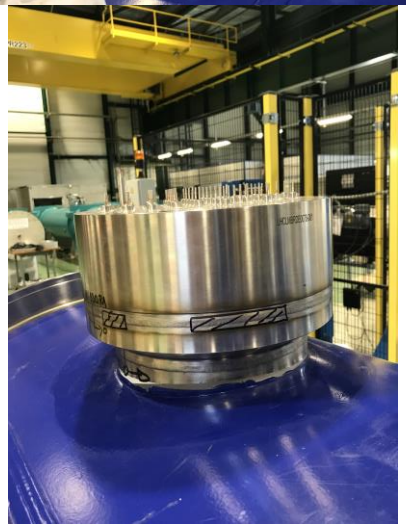


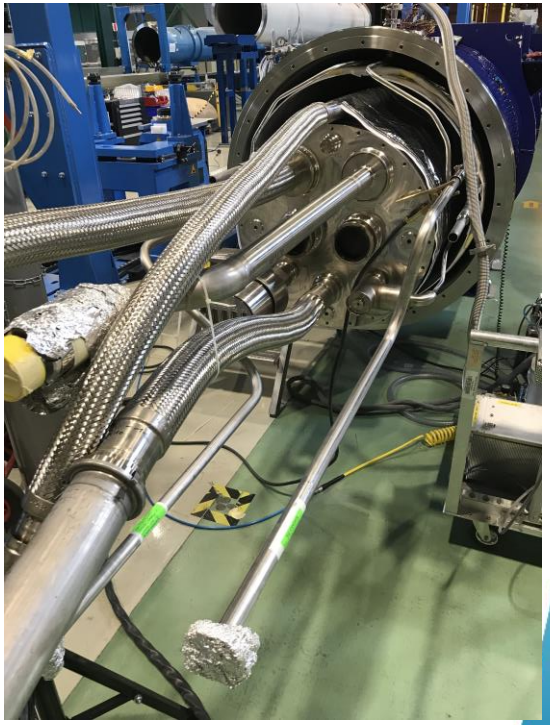


Alignment check, Thermal shield supports, MLI, Closure

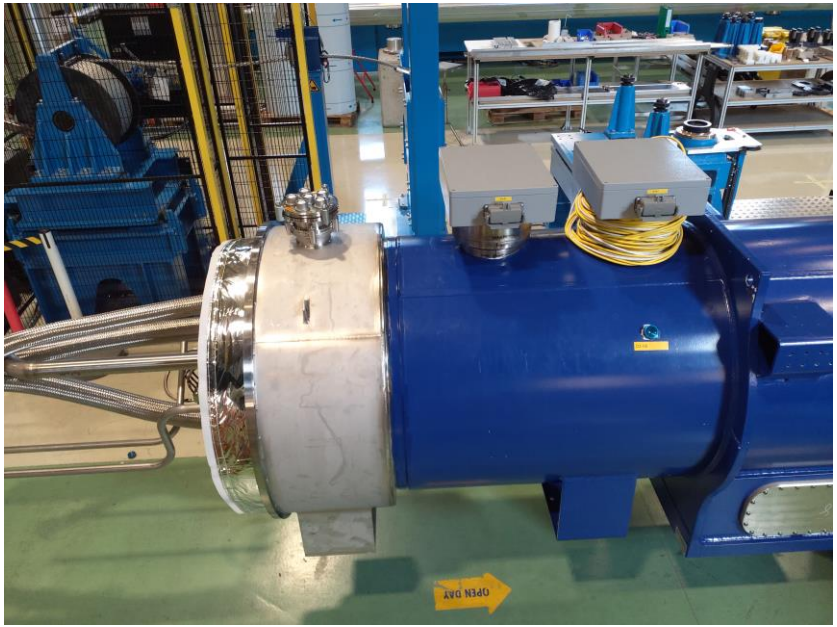
Removal from assembly bench

Instrumentation and interfaces to test bech





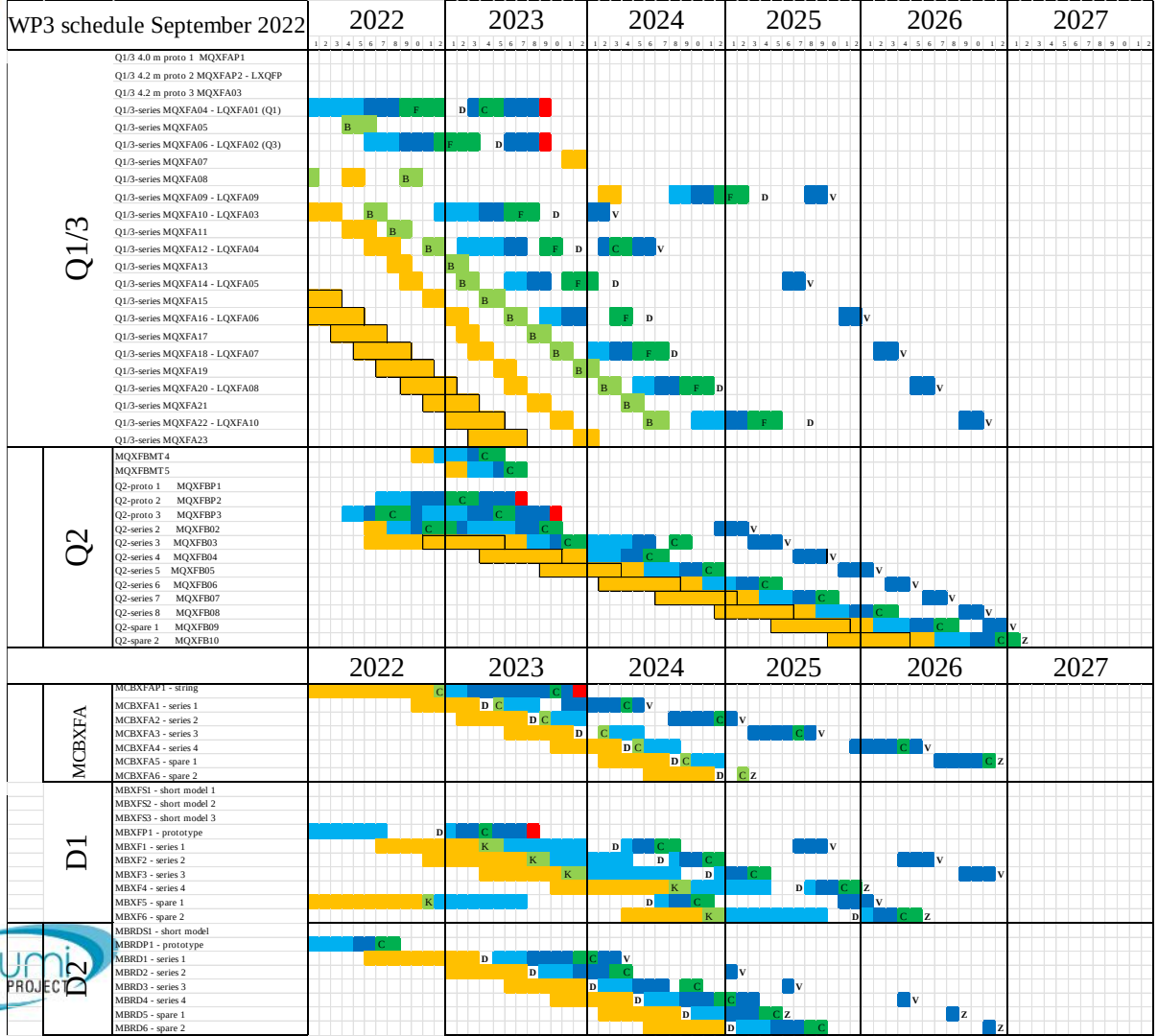
Ready for connection to test bench



Quantities to be assembled

- Q1/3 (cold tested between phase 1 and phase 2)
  - (10 u. Phase 1 assembled at FNAL)
  - 1 u. Preparation for cold test at CERN
  - 10 u. Phase 2 cryostating
- Q2a/b (cold tested between phase 1 and phase 2)
  - 4 u. (out of 6) MQXF in short test cryostat
  - 11 u. Phase 1 cryostating
  - 10 u. Phase 2 cryostating
- CP (cold tested after phase 2)
  - 6 u. Phase 1 cryostating
  - 6 u. Phase 2 cryostating
- D1 (cold tested between phase 1 and phase 2)
  - 6 u. Phase 1 cryostating
  - 5 u. Phase 2 cryostating
- D2 (cold tested after phase 2)
  - 1 u. Phase 1 (completed), configured for cold test in direct connection bench
  - 6 u. Phase 1
  - 6 u. Phase 2
  - 6 u. Phase 2+ i.e. Busbar jumper, “stripping and plugging”

Equivalent work volume at CERN: ~35 full cryo-assemblies



[Link to schedule September 2022]

- **Priority to cold test of MQXFB and D2** which are not tested prior to assembly in the cold mass
- Phase 2 assembly used for resource levelling
- Assembly spans over **4 years, aiming at constant workload and stable assembly team**
- The plan is to finish cryostat assembly by end 2026 (spares included) leaving **6 months schedule float** to the start of installation
- Average assembly rate **~9 equivalent cryo-assemblies per year**
- Total work load: **63000 hours**

Conclusion

- Two distinct assembly phases, each requiring specific tooling
- Tooling for phase 1 is operational and was validated with D2 prototype, as well as with Q1/3 at FNAL. Procedures have been iterated based on experience with first assembly. Inspection plans (MIP) and documentation management processes have also been tested and iterated.
- Tooling for phase 2 is manufactured and installation has started. Procedures are being prepared based on mockup assemblies.
- ~35 equivalent cryoassemblies will go through SMI2 facility over 4 years requiring 63000 hours of direct work (~9 FTE)