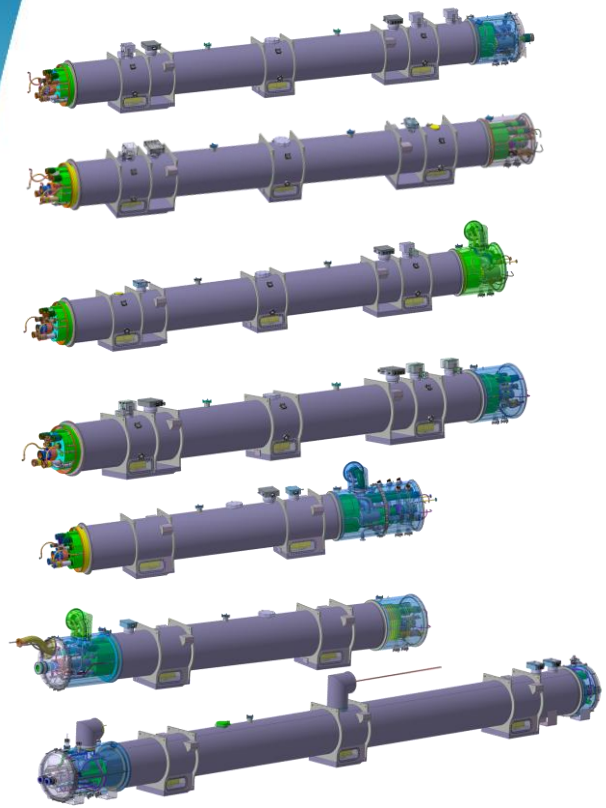
Satus of cryostat activities at CERN

D. Ramos on behalf of the WP3 cryostat team
J. Mouleyre, V. Sanchis, A. Seller, M. Struik, D. Murge, O. Id Bahmane, F. Savary, R. Diaz Vez and many more…

14th HL-LHC Collaboration Meeting, October 2024

Cryostat types

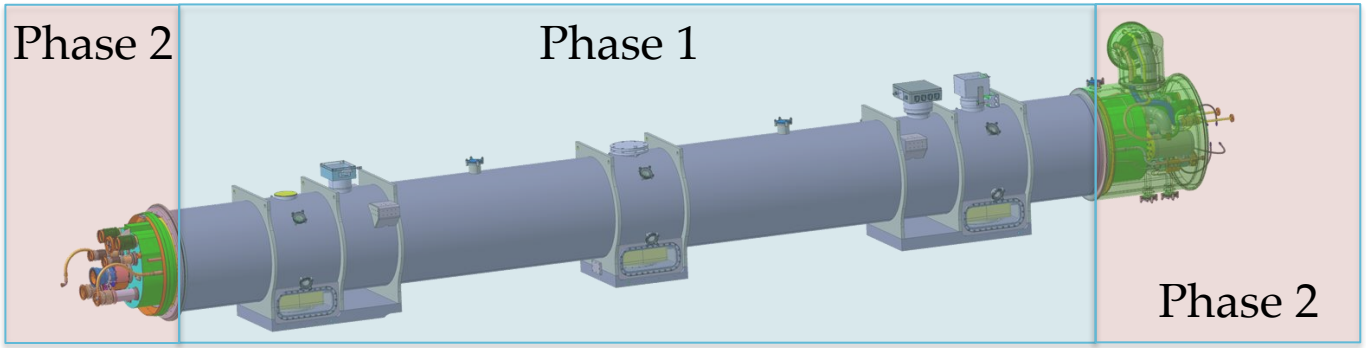


	String	IR1 Left	IR1 Right	IR5 Left	IR5 Right
Q1	QQXFE	QQXFK	QQXFE	QQXFE	QQXFK
Q2a	QQXFG	QQXFC	QQXFG	QQXFG	QQXFC
Q2b	QQXFJ	QQXFN	QQXFO	QQXFR	QQXFL
Q3	QQXFF	QQXFM	QQXFF	QQXFF	QQXFM
CP	QCXFC	QCXFE	QCXFF	QCXFG	QCXFH
D1	QBXFC	QBXFE	QBXFF	QBXFG	QBXFH
D2	-	QBRD			

- 19 cryostat types for 28 units installed in the LHC
- The String was initially replicating IR5 Left but the QXL reconfiguration impacted all cryostats with jumpers. Because the change was not applied to the String, 3 additional cryostat types were created.

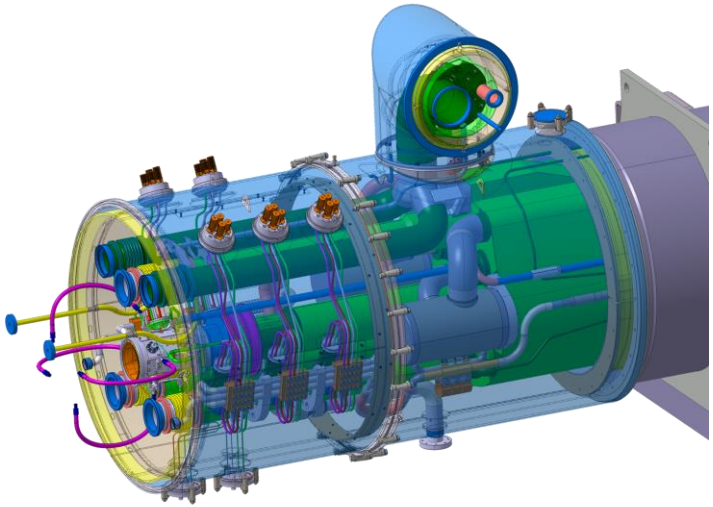
Cryostat assemby in phases

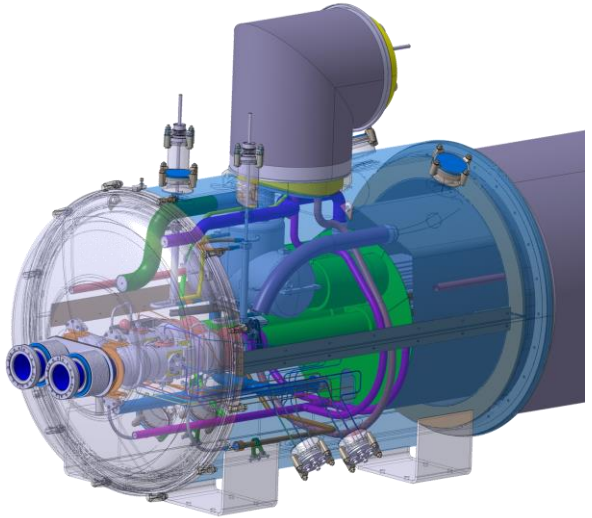
- Phase 1: cold mass on cold supports, inside main vacuum vessel, with complete cold mass instrumentation. Ready for magnet cold testing in the case of Q1, Q2, and D1
- Phase 2: final LHC interfaces, i.e. with crygenic service modules and piping configured for the installation slot
- Phase 3: beam vacuum and BPM (by WP12). Ends covers in the case of Q1, D1 and D2



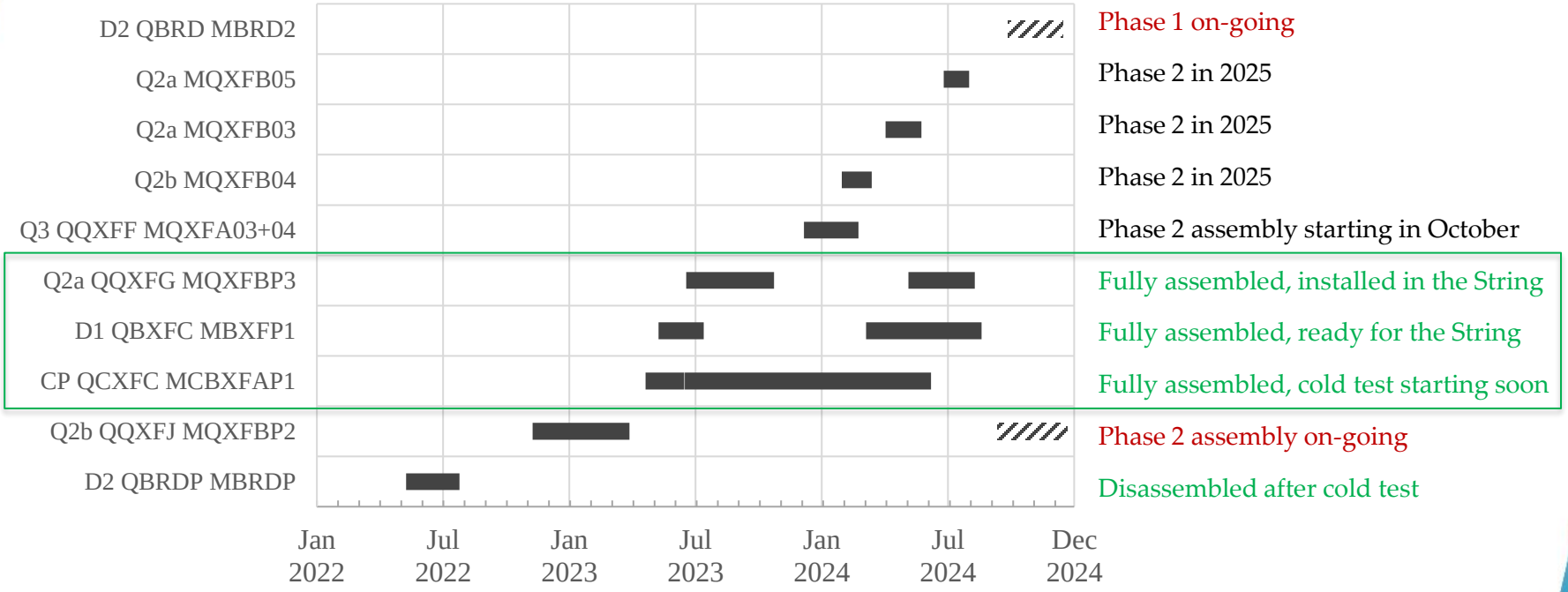
CP and D2 exceptions: Test after phase 2

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





Assembly status

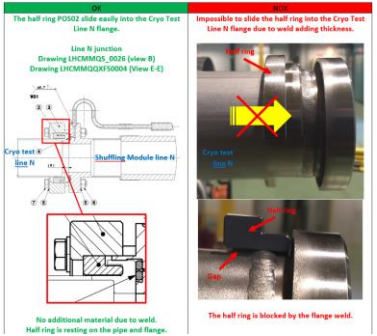


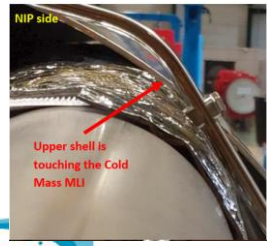
D2 QBRDP MBRDP

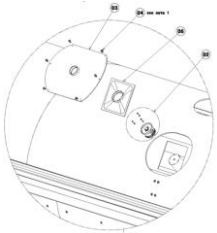
- First HL-LHC cryostat assembly
- May to July 2022 (11 weeks)
- Validation of cold mass insertion tooling with the heaviest cold mass
- See presentation from 2022 collaboration meeting (Uppsala) for a detailed description of the assembly process
- Cryostat disassembled after cold test and components stored as spares

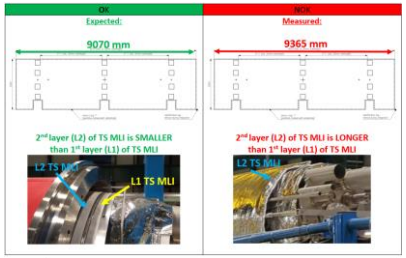
Q2b QQXFJ MQXFBP2 - Phase 1

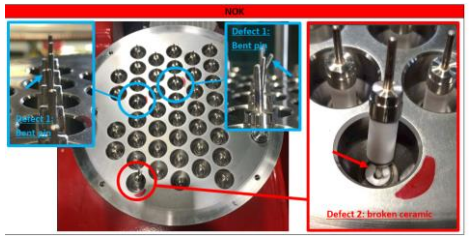
- Phase 1 assembly November 2022 to March 2023. Took more time than D2 (18 weeks) because of several issues:
  - Thermal shield in contact with pumping lines due to oval shape. Tooling was improved, and rolling of shells now anticipates welding distortion.
  - Modification of FSI patch positioning on thermal shield
  - Non-conformity on MLI blanket
  - Broken ceramic feedthrough required replacing of cover flange. PCB assembly improved
  - MLI caught fire during thermal shield welding: safety measures improved
  - Weld over thickness incompatible with test flange
- Multiple improvements done on procedure and QC documents





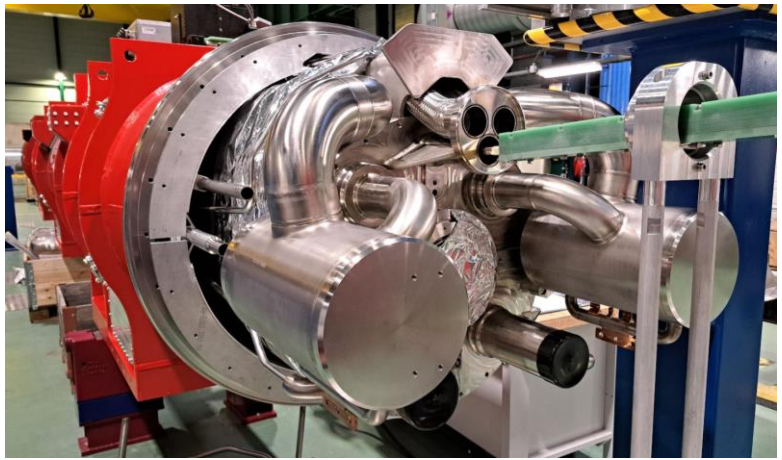






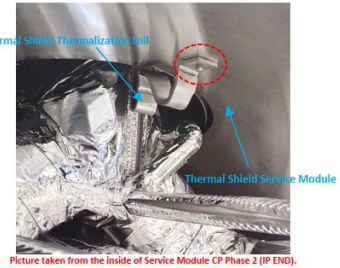
Q2b QQXFJ MQXFBP2 - Phase 2

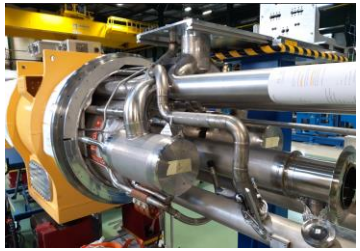
- Phase 2 assembly started in September 2024,
- The goal is to finish before end of December (14 weeks), for installation in the String in January
  - But is incurring delay due to bellows non-conformities (see slide 19)

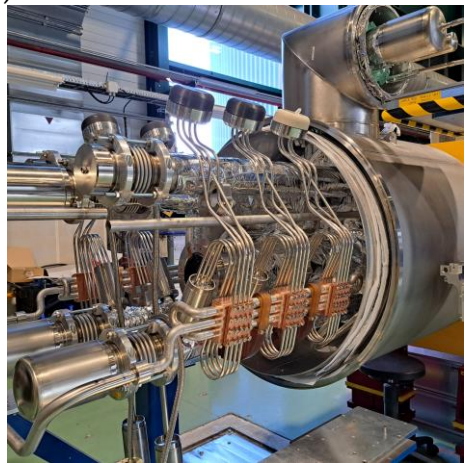


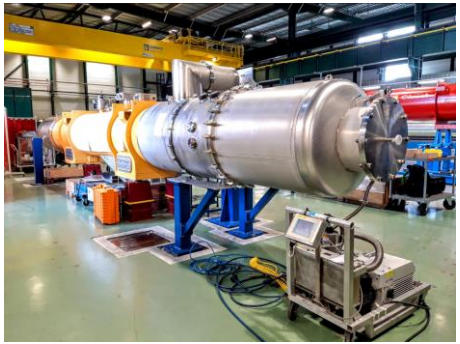
CP QCXFC MCBXFAP1

- Trouble free Phase 1 assembly in May-June 2023 (8 weeks)
- Phase 2 took from June 2023 to June 2024 (51 weeks)
  - The most complex assembly, with over 200 welds
  - First-time use of interface welding station. An alignment issue was found, requiring additional work on the tooling
  - Impacted by late delivery of bellows expansion joints
  - First assembly of complex pipe system on phase separators and jumper
  - First assembly of current leads
  - First global pressure and leak test
- Lots of experience gained. Next assemblies are expected to take much less time (less than 20 weeks)



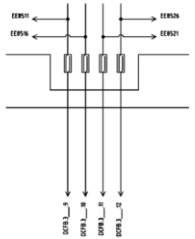
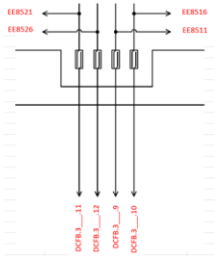
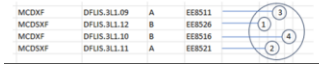
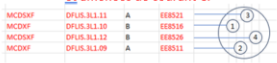




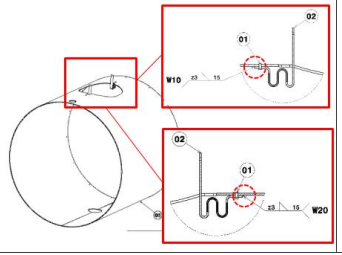
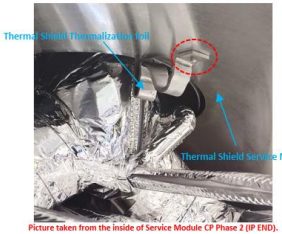


CP non-conformities

LHC-QCXF-QN-0006

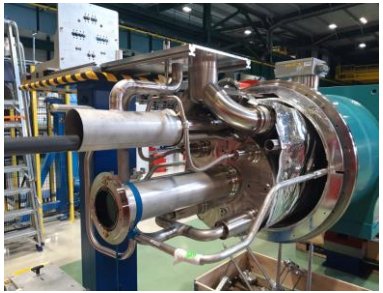
OK	NOK
Branchements effectués selon le plan **LHCLMCXFE0001 V. AB** ELEC. AND INSTRUMENTATION SCHEMES - CORRECTOR PACKAGE	Branchements effectués lors de l'installation de l'amenée de courant **PEMS #976 sur CP phase 2 HCQCXFC010-CR000001**
	
Correspondance entre amenées de courant DFLIS.3 et amenées de courant CP	Correspondance entre amenées de courant DFLIS.3 et amenées de courant CP
	

LHC-QCXF-QN-0004

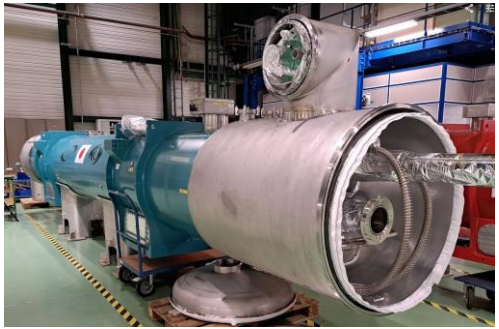
OK	NOK
Thermal Shield Thermalization foils (X2) welded on Thermal Shield Service Module according to drawing LHCQCXF_0059 V. AA	Thermal Shield Thermalization foils (X2) NOT welded on Thermal Shield Service Module
	

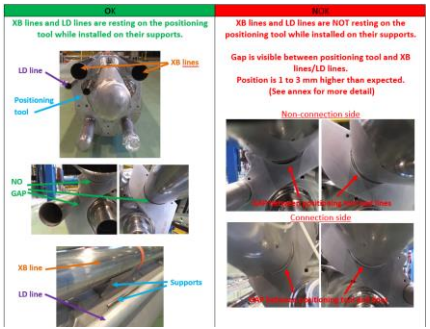
Decision: use as is for the String. Rework when configuring for use as machine spare

D1 QBXFC MBXFP1



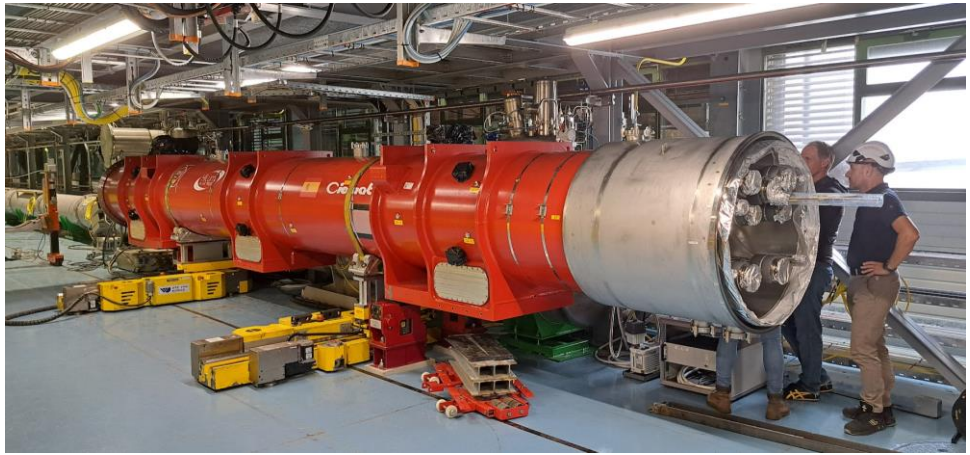
- Phase 1 done from May to July 2023 (9 weeks)
  - Position of N and XB lines was off but could be corrected by re-machining pipe supports
  - Error in V-tap wiring required corrective action on IFS
- Phase 2 from March to August 2024 (24 weeks)
  - Work performed without major issues
  - A first-time assembly as with all units completed so far
  - Will soon be installed in the String once the QXF jumper interface is ready

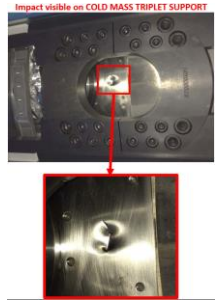


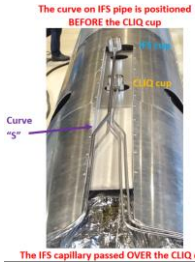


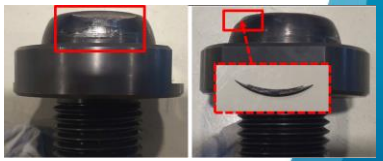
Q2a QQXFG MQXFBP3

- Phase 1 done July to October 2023 (18 weeks)
  - Re-machining of LD and XB lines to compensate offset between cold mass end covers and cylinder
  - Impact on cold mass saddle of unknown origin
  - Error when bending the IFS capillary
  - Error when handling over the cryostating tooling because of wrong procedure being used
- Phase 2 done May to August 2024 (14 weeks)
  - Done in parallel with D1 phase 2, also with no issues
  - Now installed in the String







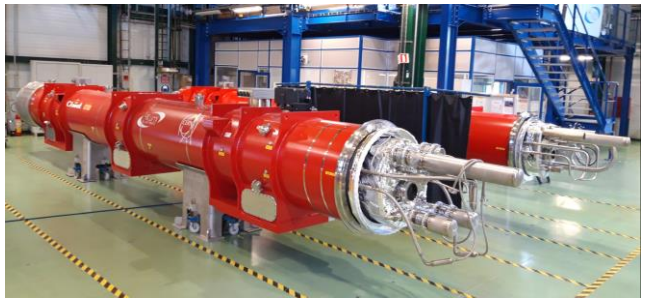


Q3 QQXFF MQXFA03+04

- Arrived from FNAL end November 2023
- Prepared for connection to cold test station at CERN from December to February 2024
- Leak found on cold mass circuit when connected to cold test station. Attempts at localising the leak could not exclude the cryoassembly
- Before starting phase 2 assembly: Replacement of M-N flanges followed by global pressure and leak test
- Assuming no leak, it is expected to be ready for installation in the String by February 2025

Q2b MQXFB04 & Q2a MQXFB03 & Q2a MQXFB05

- Phase 1 assembly finished for the three units
  - 5 to 7 weeks assembly time per unit
  - Tooling has been optimised
  - Procedures are mature
  - Teams are well trained
- Phase 2 requires to know the installation slot
  - will start in 2025 after sorting based on cold test results



D2 QBRD MBRD2

- Assembly started end September
- Expected ready for cold test by mid-December
- First time installation of finger heat exchanger
- After cold test:
  - remove testing interfaces
  - cut the temporary busbar line
  - partially assemble the busbar jumper (thermal shield and vacuum vessel done in the tunnel due to transport constraints)

Cold mass insertion tooling

- Cold mass insertion tooling is fully operational.
- Improvements made for better (and safer) accessibility.
- Stabilization columns were split for more clearance under the crane hook.
- Limits on jack displacement adjusted to avoid control issues.



Phase 2 welding stations

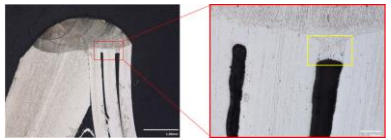
- Provides precise interface references for holding and checking the position of pipe extremities during and after welding.
- All stations are modular and can be adapted to any cryostat variant for management flexibility.
- Started with 3 stations but a 4th station has just been installed to allow more work in parallel.



Components

- All components that were not impacted by the QXL reconfiguration ECR are available, except for expansion joints (next slide)
- The remainder are under production according to the cryostat assembly schedule
  - Machining and components subcontracted
  - Welding is done on the shop floor to optimise resources and allow schedule flexibility
- Thermal shield subassemblies are welded in advance but with a small buffer due to storage restrictions

Bellows expansion joints for the interconnects



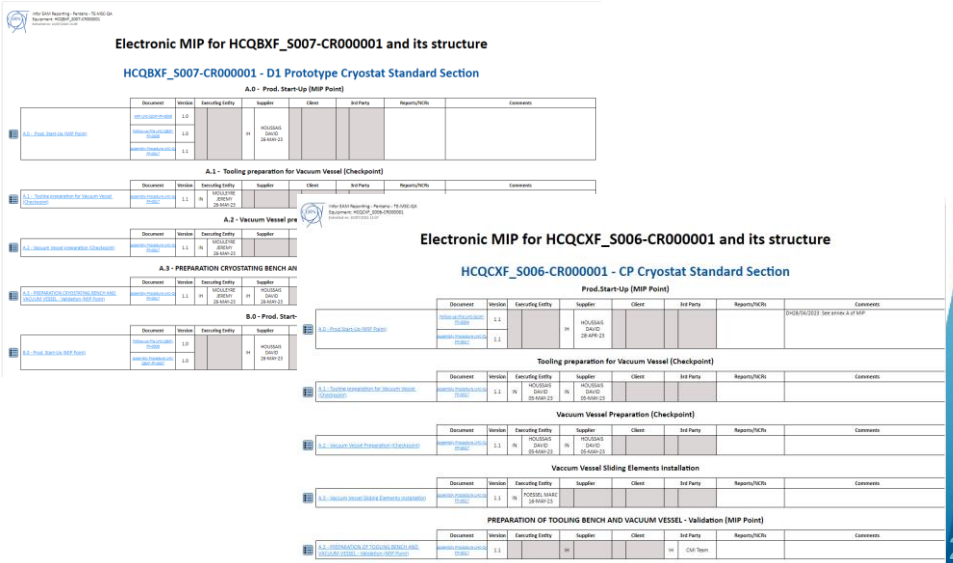
- First manufacturing contract signed for 500 bellows failed to deliver as per specification and resulted in a major delay
- A new supply was necessary to replace the full quantity
  - A new price enquiry and purchase order done to cover the needs for the String. Later followed by a second order to cover six months of cryostat assemblies destined to the LHC.
  - The remainder units needed for the LHC were ordered after a market survey and invitation to tender
  - The same manufacturer won all tenders and is supplying the full quantity, although under separate purchase orders/contracts
- The present manufacturer, despite its good reputation and successful supplies in the past, has so far been unable to deliver on time and the welds are not conform to specification
- This supply is currently on the critical path with a risk of causing delays to the cryostat assembly activities

Combined pressure and leak test

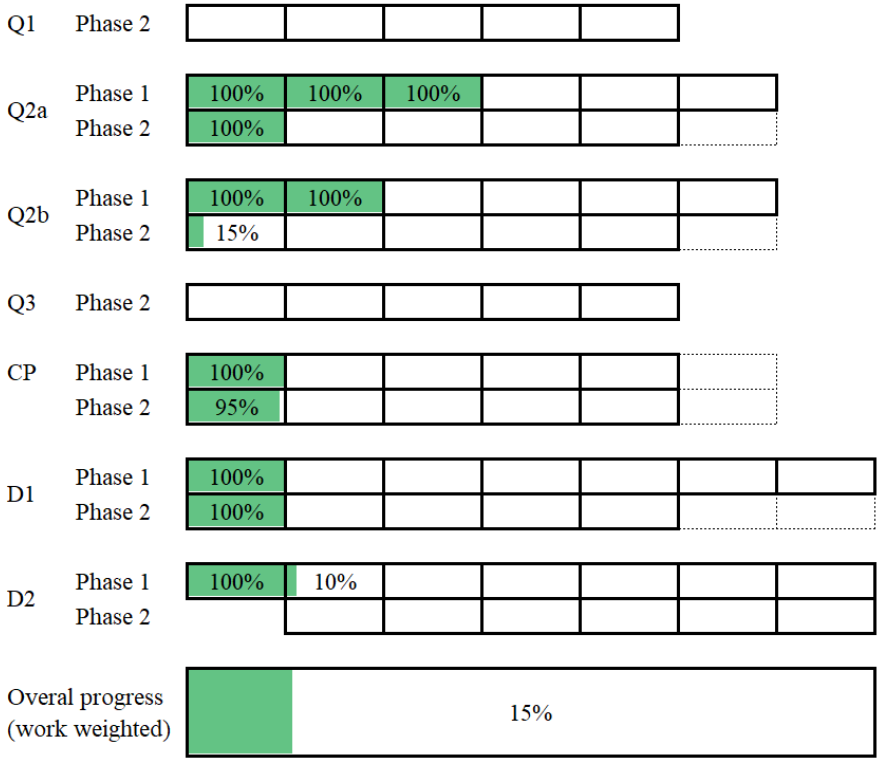
- All cryoassemblies are subjected to a simultaneous pressure and leak test prior to delivery
  - Magnet and busbar circuit: 25 bar (PS 20 bar)
  - Two phase heat exchanger circuit: 5 bar (PS 4 bar)
  - Thermal shield and beam screen circuits: 31.25 bar (PS 25 bar)
- Performed in a configuration comprising all components and joints that will be present during operation. No more welding is done after the test.
- This ensures that any leaks found in the tunnel must be in components or welds made in-situ, therefore also accessible for in-situ repair.
- Done outside working hours.
- Because a leak found at this stage may need disassembly to be accessible for repair, all components and welds have previously been locally tested along the assembly process.

QA

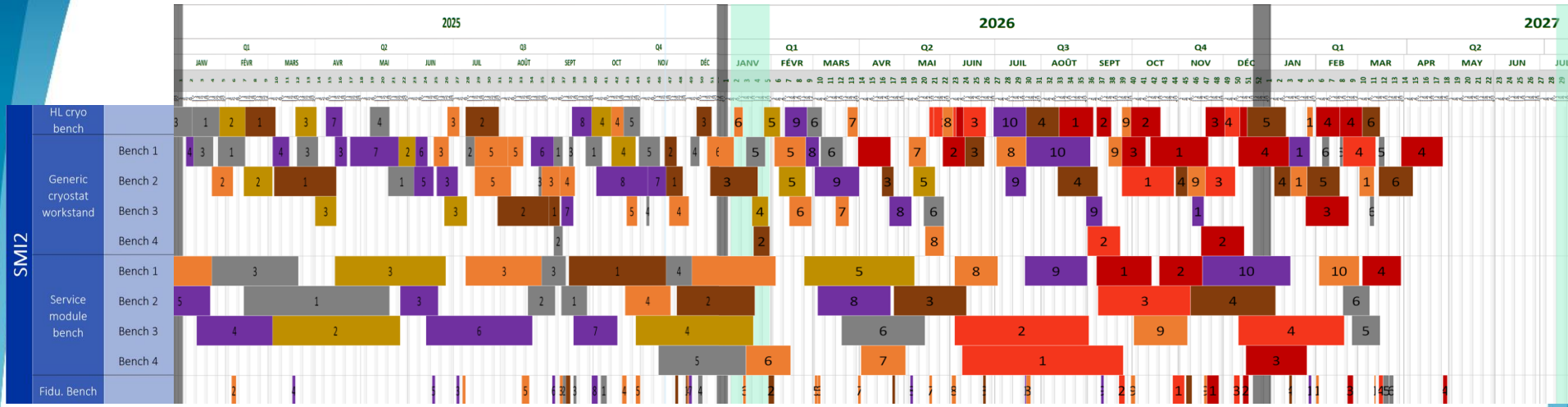
- Detailed procedures for all cryostat types and assembly phases
- Electronic manufacturing inspection plan (e-MIP)
- All QA& QC documents attached to the asset number, accessible through MTF



Overall assembly progress at CERN



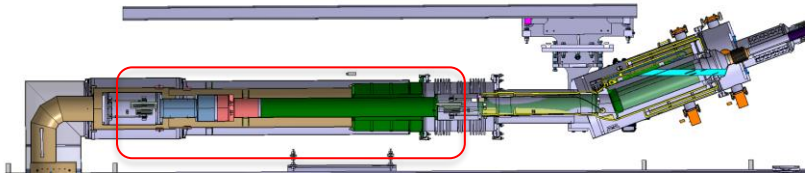
How does the future look like



- Cold mass insertion tooling has an occupancy of 55% on current schedule
- With increase from 3 to 4 Phase 2 welding stations, their overall occupancy is ~70%
- This gives margin some for treatment of non-conformities and schedule changes on upstream activities
- Recruitment of additional team members necessary as workload increases

Cryostats interfacing magnets with SC-links

- Also assembled in SMI2 building but in a separate area
- Schedule is decoupled from magnet cryostat assembly
- Comprise a vacuum barrier and hydraulic plug, separating the magnet cryogenics from SC-link cryogenics
- Between D1 and DFX (**DFM**): Prototype has been completed, series units will follow
- Between D2 and DFM (**DQM**): Cryostat drawings are nearly finished. Busbar detailed design starting soon. Component production starting Q1-2025, assembly starting Q3-2025



During LS3: Q4, Q5, Q10

- Q4
  - Modification of cryostat for operation as stand-alone (presently connected to D2) and layout change
  - New beam screens with aC coating and different orientation (TE-VSC)
  - Implementation of full remote alignment
- Q5
  - New beam screens with aC coating and different orientation (TE-VSC). Requires opening and closing of cryostat end covers
  - Implementation of remote alignment system
- Q10
  - Cryostat complete disassembly and reassembly with new cold mass
  - Cold test

Thank you for your attention