Cryogenics : Status and Perspectives towards installation

V. Gahier, on behalf of WP9-Cryo project team

14th HL-LHC Collaboration meeting, Genoa, Italy
08.10.24

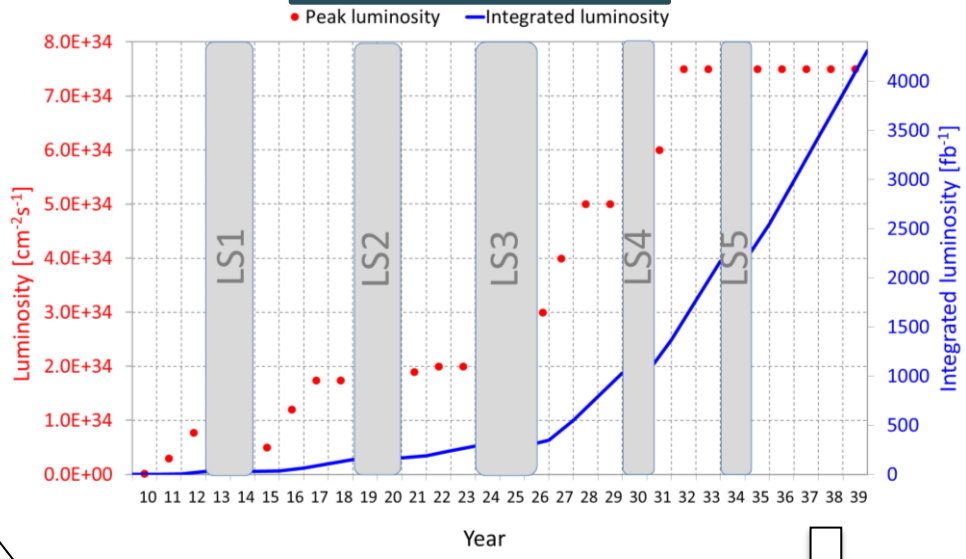
Agenda

- Review of cooling requirements & global scheme
- Refrigerators
- Cryogenic distribution lines
- Other activities or sub-systems
- Schedule, staff
- Way forward

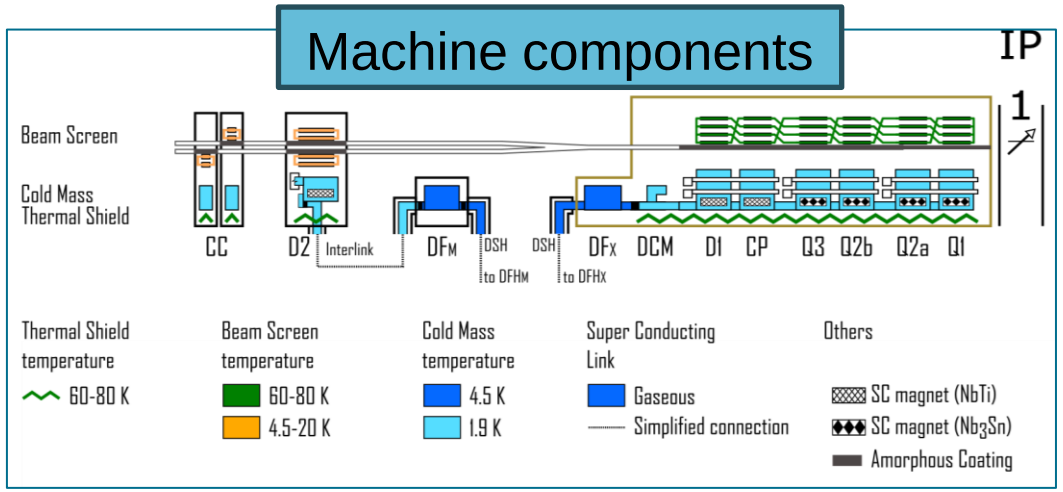
Global scope overview

- **HL-LHC goal** : producing in that period 10 times more data as compared to the nominal LHC operation period.
- Requires an upgrade of the final focusing components both for **machine lifetime** and **performance** by increasing the peak luminosity by a minimum of five times wrt LHC nominal.
- **New superconducting elements** having increased cryogenic demand requires the installation of new Refrigerator and Infrastructure in IP1 and IP5.

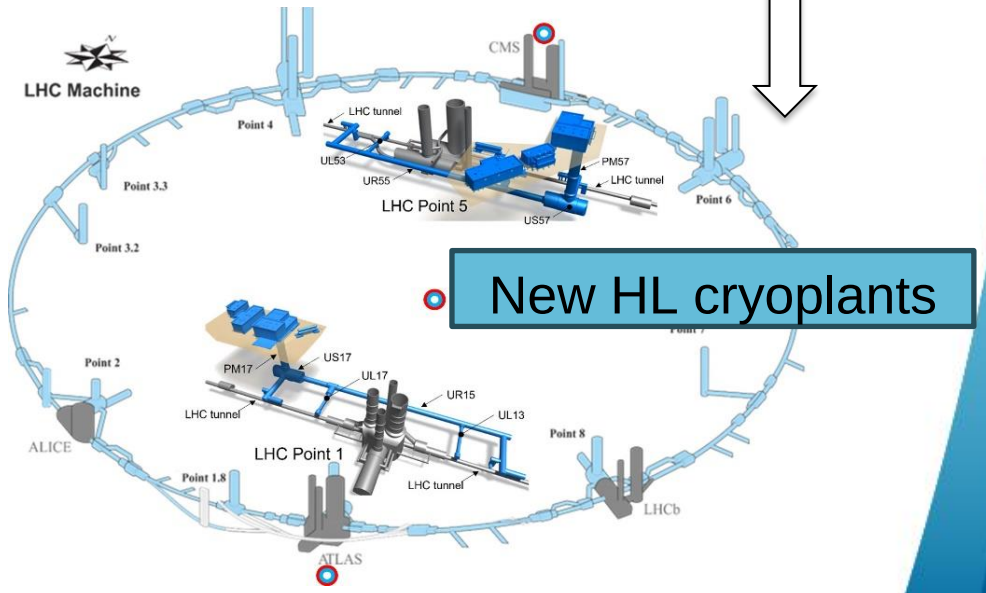
Performance



Machine components



New HL cryoplants



HL-LHC P1/P5 Cryogenic architecture

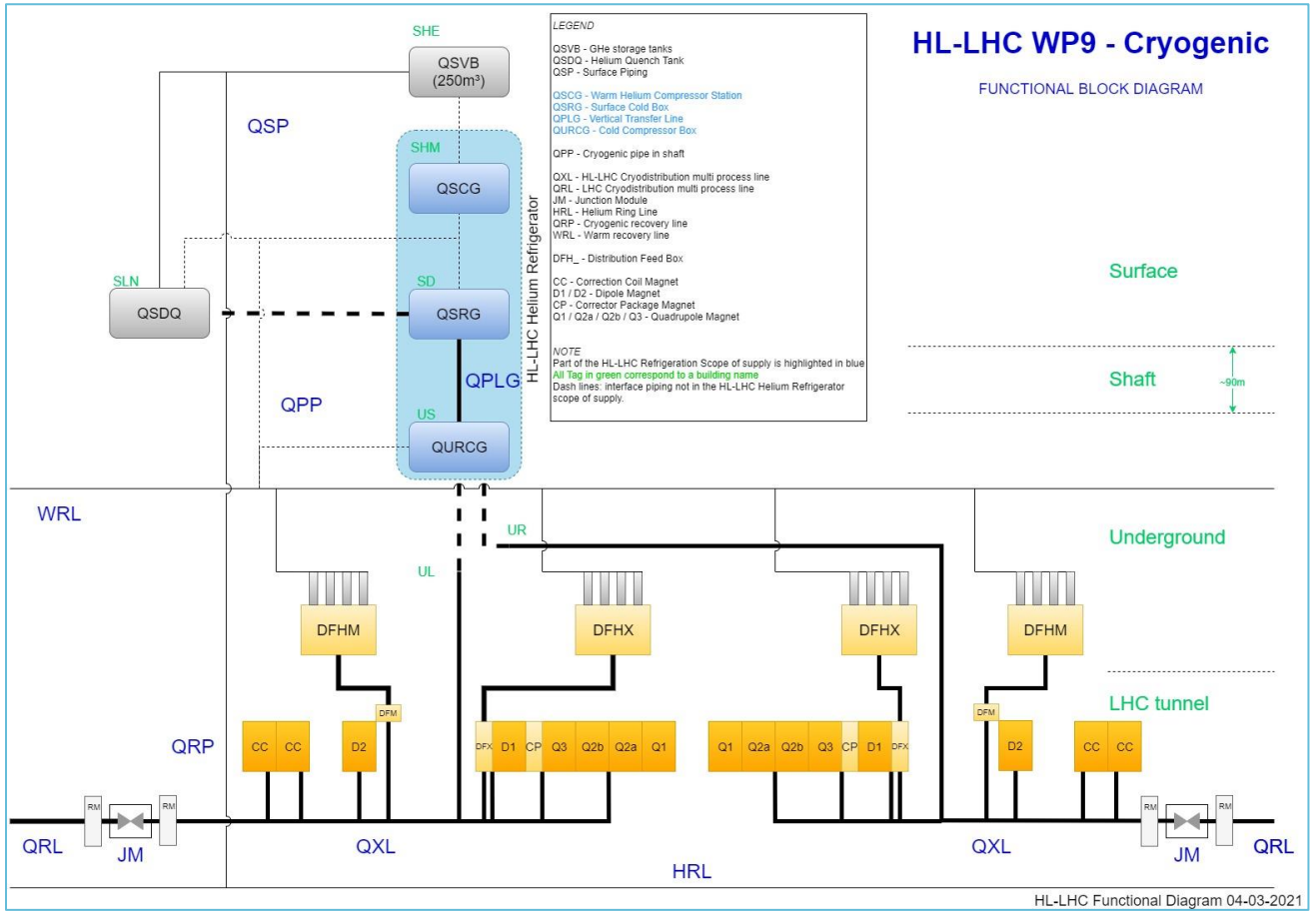
QSCG : Compressor station → gaseous helium **20 bara**

QSRG : 4.5K refrigerator→ supercritical helium at **3 bara and 4.6 K**

QPLG : Vertical transfer line (~100 m height)

QURCG : Cold compressor cooling capacity at **1.8 K**

Machine Components at tunnel level



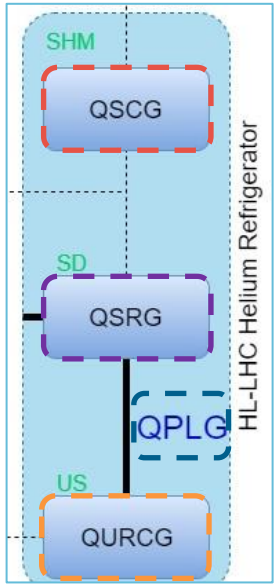
QXL : Distribution line distributing C,E and returning B,D,F

RM/JM : Return module and junction module at extremities for transient handling and back-up

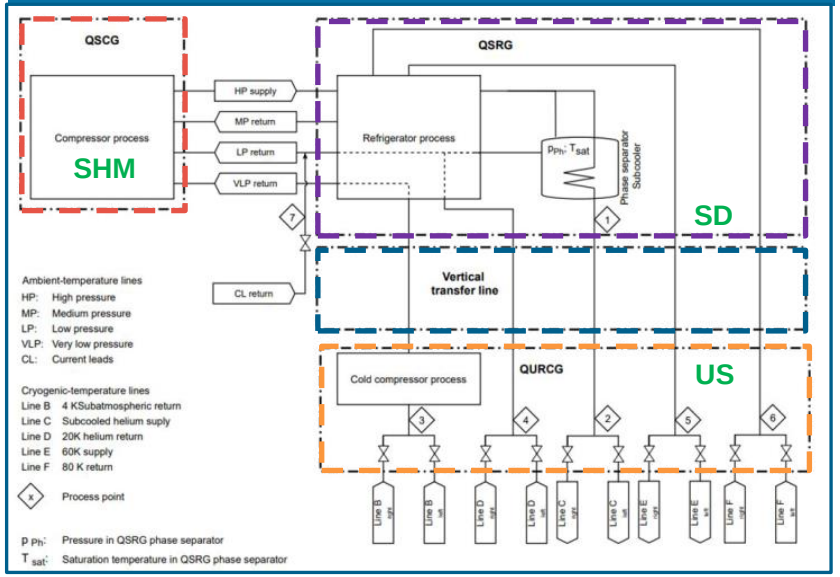
Refrigerator concept reminder

- Each P1 and P5 Refrigerators are designed for **14 kW at 4.5 K eq., including 3.25 kW@1.9 K**, based on the machine components and cryogenic distribution heat loads with a limited overcapacity.

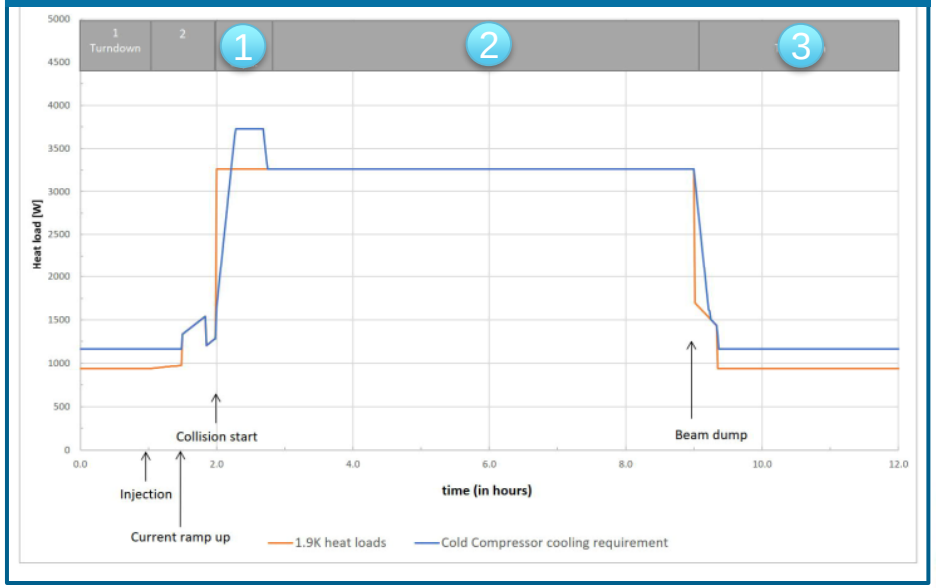
- Three main steady-state operating cases were considered for the Refrigerator design :
  1) The **Maximum Capacity mode**, corresponding to the moment when collision occurs. A **fast transient** occurs when collisions start.
  2) The **Design Capacity mode**, covering a steady state operating mode when the design heat load is extracted at the HL-LHC machine component level.
  3) The **Turndown mode**, characterized by minimum helium cooling before beam injection and after beam dump.



Simplified Block diagram for the refrigerator



Heat loads at 1.9 K profile during a typical fill



Refrigerator project Status

✓ Main Achievements

- **Contract Award to LKT (CH) in Dec 2022.**
- **Preliminary design review :**
  - PDR-1 : Process and Compressor Station;
  - PDR-2: CC; Cryo heat exchangers; Turbines;
  - PDR-3: Cryo valve; Pressure and vacuum vessel.
- Final design review split in two :

→ **FDR-1 "Mechanical – Main components" – Sep 24**

- **Manufacturing of components** in progress :
  - ~50% for Compressor Station (QSCG)
  - ~60% for 4.5 K Cold Box (QSRG)
  - ~15% for Cold Compressor Cold box (QURCG)
- **Factory acceptance for key components**:
  - PHFE,
  - Warm compressors and 3.3 kV Motors.

Equipment Status	Procurement	Preliminary Design	Detail Design	Manufacturing	FAT	Delivery
Cold Box Assembly	☑					
Dryer	☑					
Cryogenic Heat Exchangers (PFHX)	☑					
Cold compressor wheel and cold housing	☑					
Cryogenic Valves	☑					
QPLG – Cryogenic Vertical Transfer Line	☑					

Equipment Status	Procurement	Preliminary Design	Detail Design	Manufacturing	FAT	Delivery
Compressor Skids	☑					
Compressor	☑					
Motors	☑					

➢ Next steps

- **Finalize FDR-2** "Electrical / Control and secondary components" – Dec 2024.
- **Continue** with **manufacturing** and factory acceptance tests.
- **Prepare** the **installation** in SHM from Q1 2025.

Refrigerator Manufacturing

Valve Plate RefCbx @ Schalchen workshop

Valve Plate Refrigerator Coldbox @ Streicher worksh

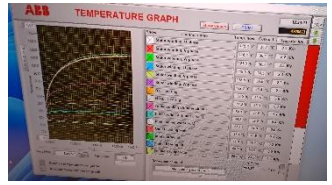
PFHE testing

Warm compressor testing

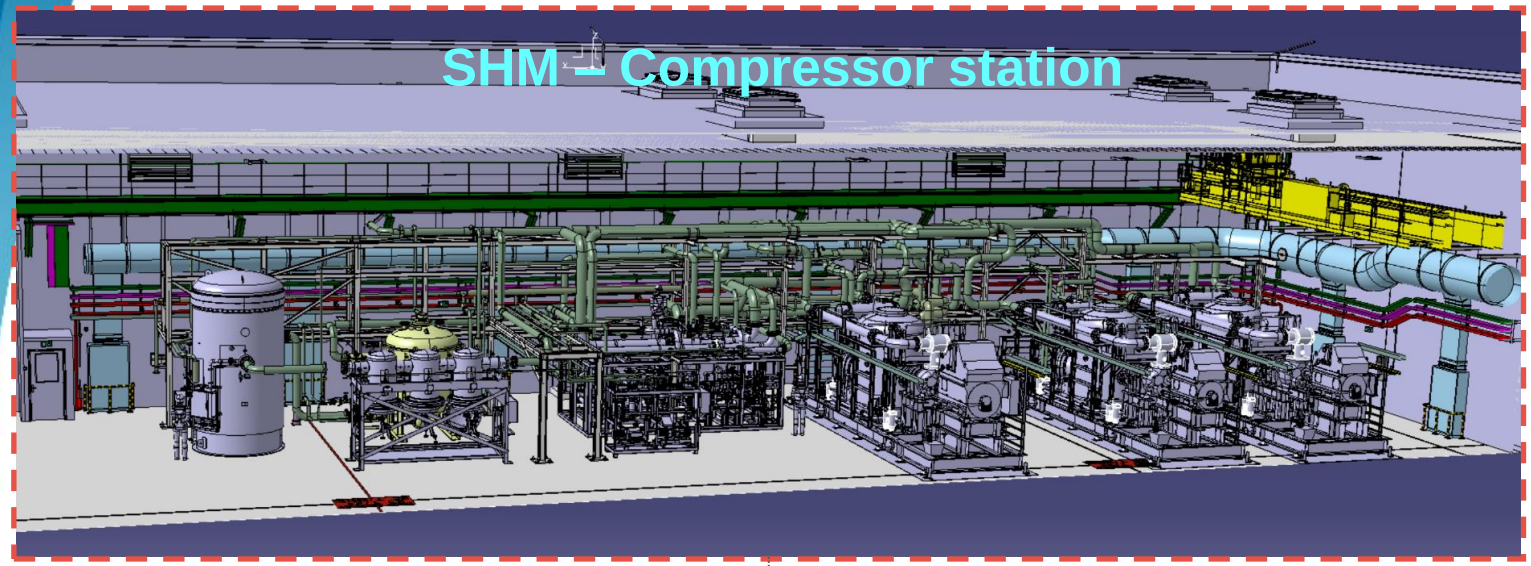
80K Adsorber @ Kasag workshop

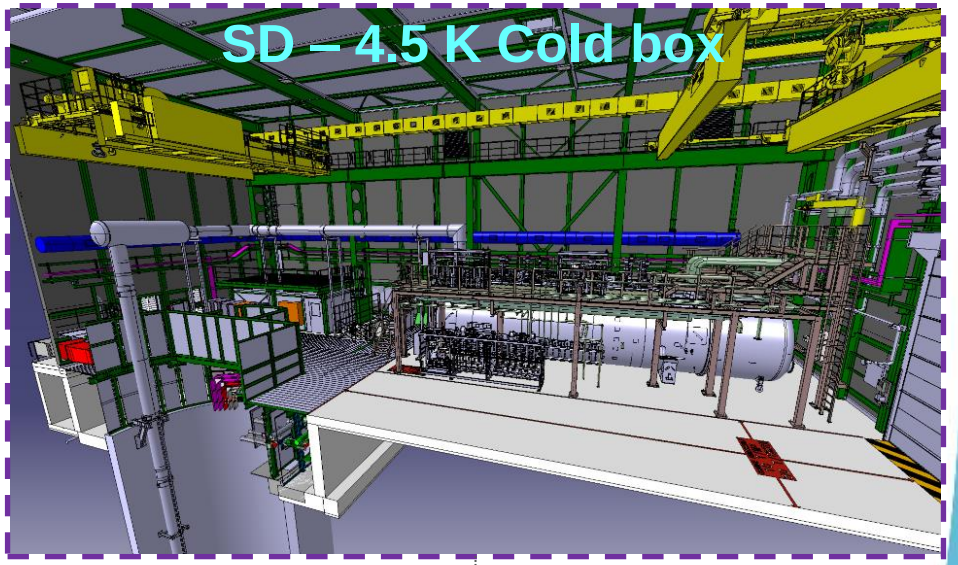
Oil Coalescer Vessel @ Kasag workshop

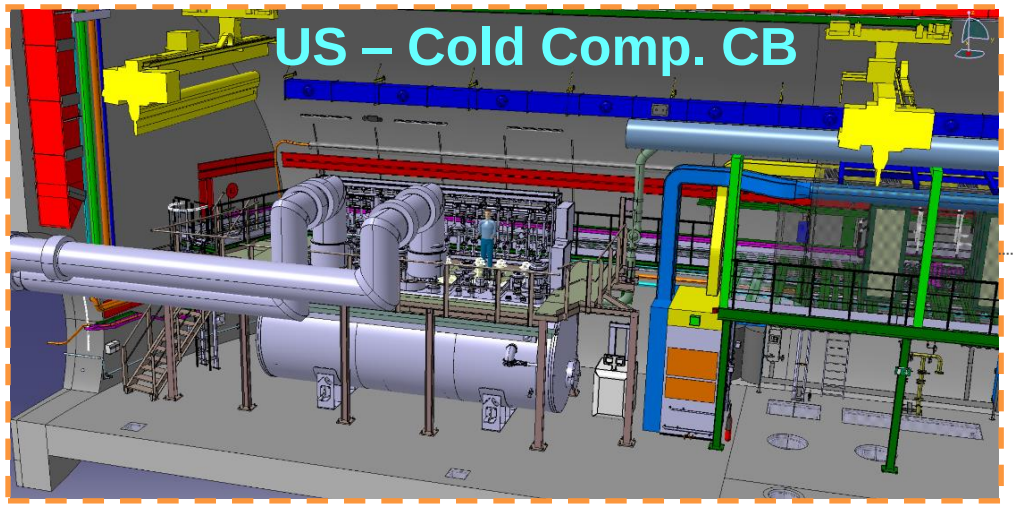
Motor testing

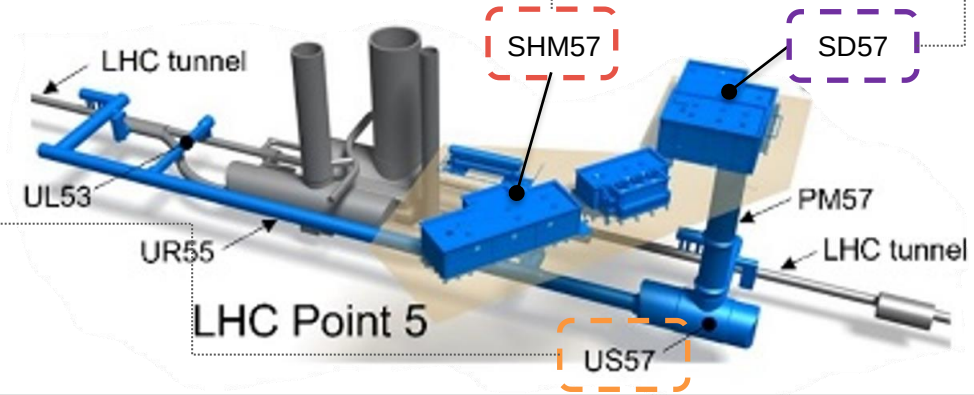


Integration view of the Refrigerator







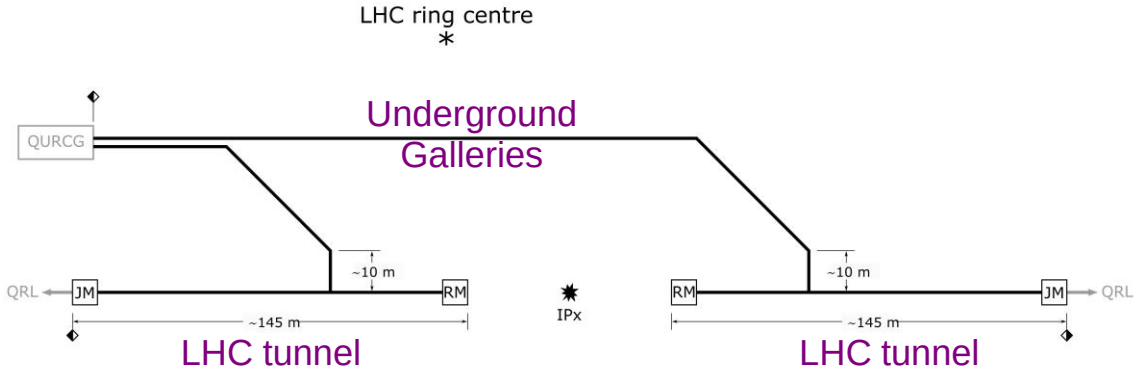


Close to 90% 3D model completion

Cryogenic distribution system

The cryogenic distribution system includes :

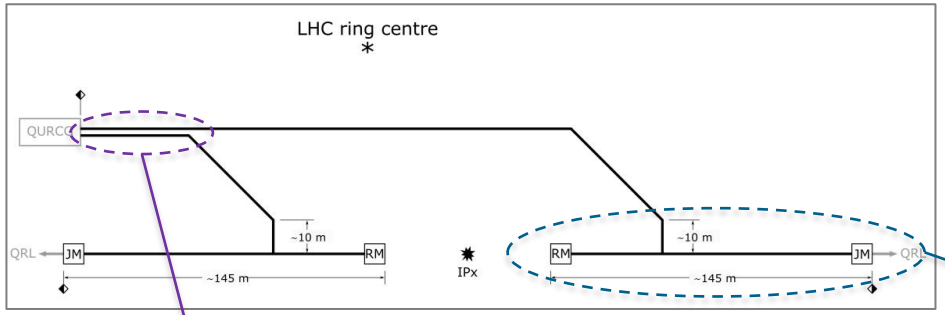
- **Five process pipes ISO DN 40-250** in a single **vacuum envelope (660-900 mm),** thermally shielded by an actively cooled thermal shield.
- **Service modules** including valves and sub-cooling heat exchangers to connect the insertion elements.
- **Return modules**, located close to the interaction point (IP), including valves, heaters, and a phase separator.
- **Junction modules**, located at the junction to the LHC distribution (QRL), including valves, heaters and a phase separator.



Installation strategy in two steps:

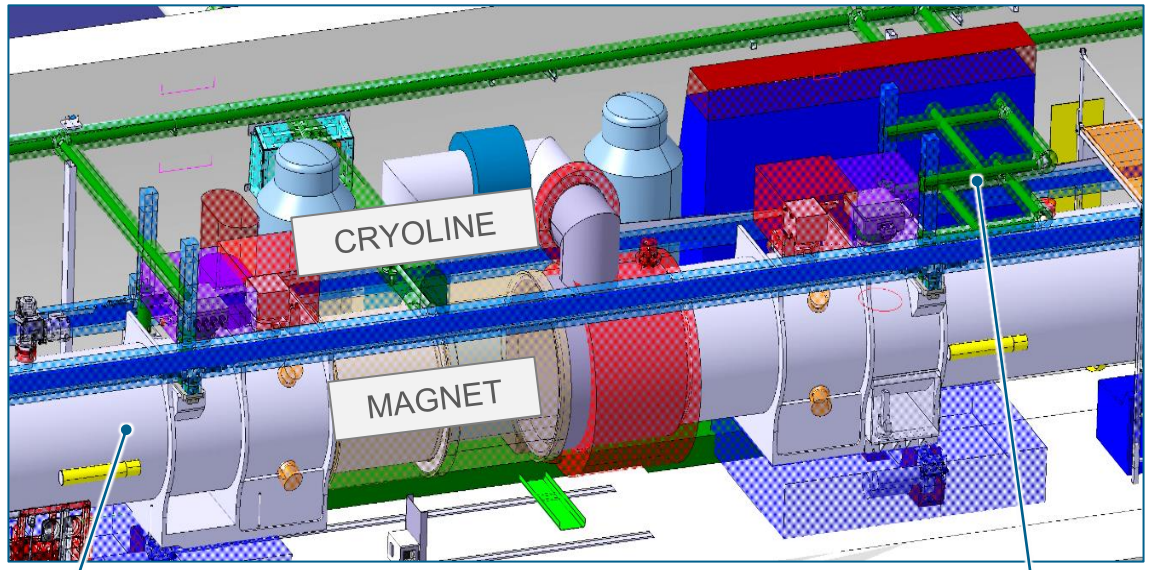
- Phase 1: in the underground galleries, independent from LHC machine operation
- Phase 2: in the LHC tunnel, after when the machine dismounting during Long Shutdown 3

Cryogenic distribution system Integration



Ph 1

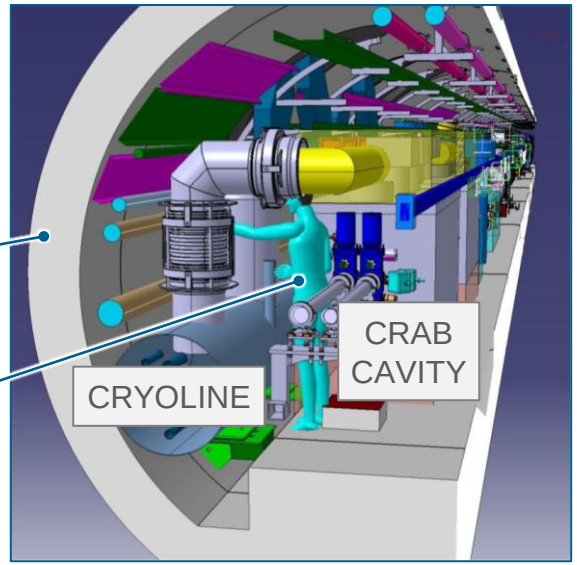
Ph 2



LHC machine components (Q1 magnet cryostat $Ø_{MAX}$ 1 m)

Civil infrastructures (LHC tunnel Ø3.8 m in P5)

Accessibility for maintenance



New HL-LHC equipment (e.g., remote alignment system of magnets)

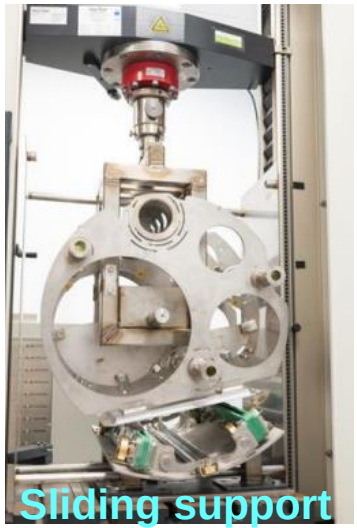
Radiation environment (dose from 100 kGy to 1 MGy)

Final Detailed 3D models pending from Contractor

Cryogenic distribution system– Status and Schedule

✓ Main Achievements

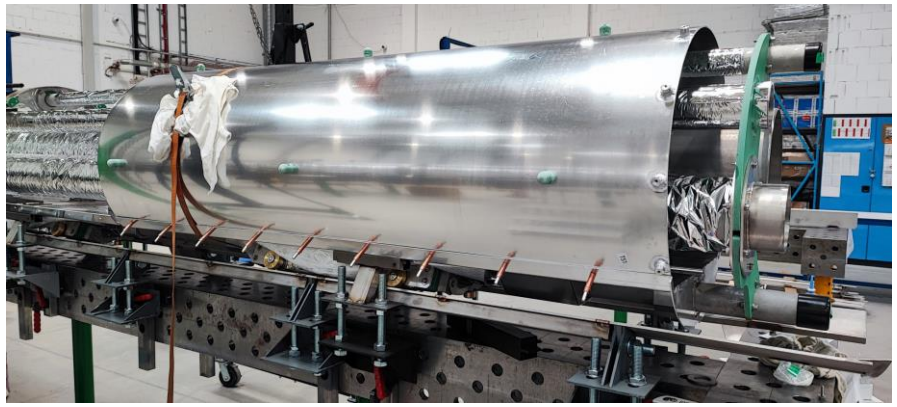
- **Contract Award** to KrioSystem (PL) in Dec 2022.
- Preliminary design review for Phase 1.
- Final design review Phase 1 split following main sub-components → **FDR for Pipe Elements.**
- **Manufacturing** in progress :
  - ~120 m of pipe elements delivered in SHM17
  - ~120 m of pipe elements to be delivered before year end.

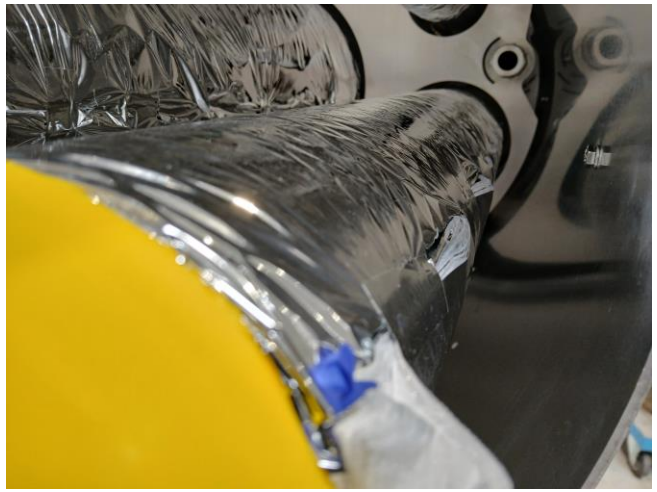


➢ Next steps

- **Phase 1 remaining sub-components :** Finalize FDR and continue with manufacturing.
- Prepare **installation in the Service Galleries** in sequence P1 then P5.
  - Installation strategy with detailed execution list under development.
  - Assistance from **EN-MME** for interconnects welds NDT.
  - Assistance from **TE-VSC** for leak tests and procedure.
- **Phase 2**
  - Finalize Junction Module region change.
  - **Preliminary / Final design** staggered in several steps for continuous manufacture.
  - **LS3 shift** to be considered for **installation.**

Some progress in pictures – QXL Ph1A





Warm piping and storage tanks

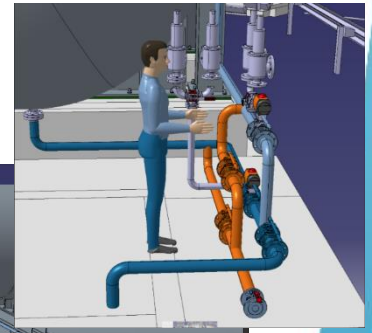
- **Warm piping** installed by EN-CV contractors
  - ✓ In the shaft P1 / P5
  - ✓ In the surface in P1
  - In the surface in P5
  - In the Cavern / Service Galleries in P1
  - In the Cavern / Service Galleries in P5
  - In the Tunnel in P1
  - In the Tunnel in P5

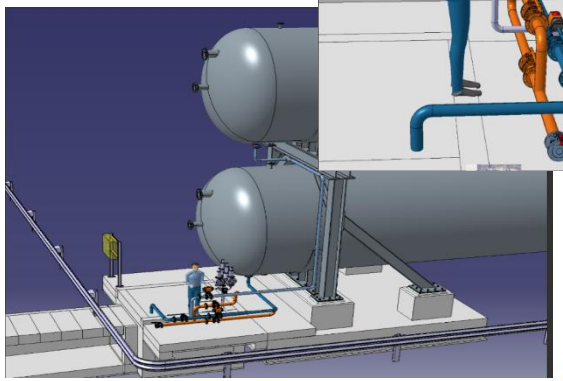
- **Helium buffers :**
  - ✓ 2 x 250 m3 in P1/P5 by *Silvia Matos*
  - 80 m3 vertical storage to be moved /refurbished to P1 and P5
  - Proximity equipment (valves panel) in design ph.

- **Nitrogen storage and lines connection**
  - Requirements defined
  - DO to be launched

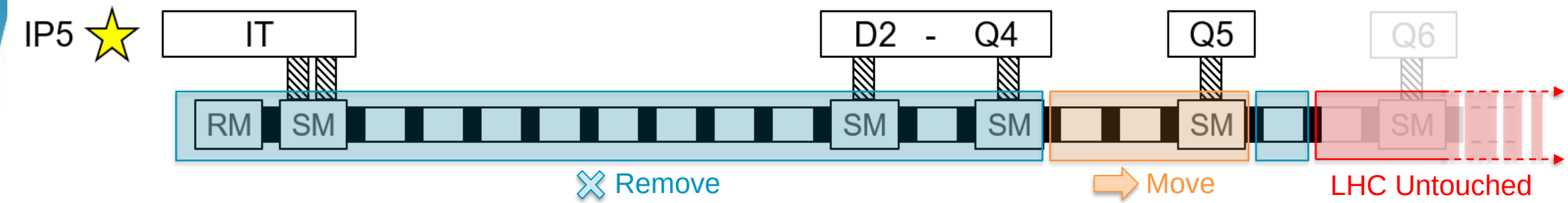








QRL Dismantling

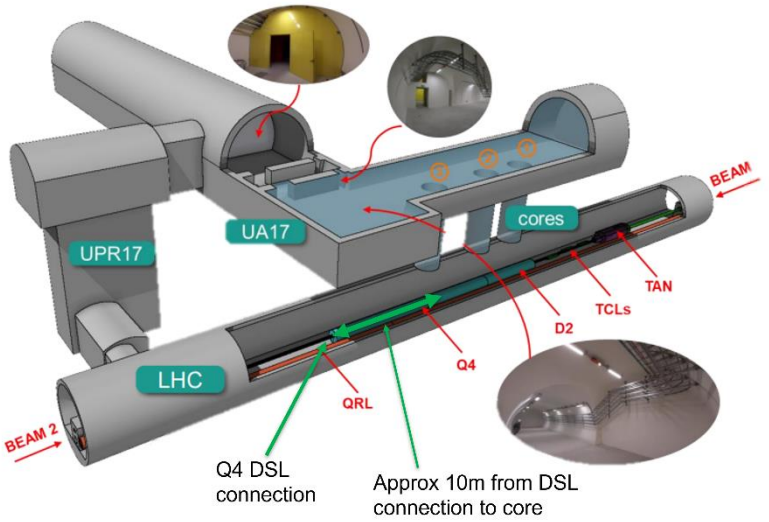


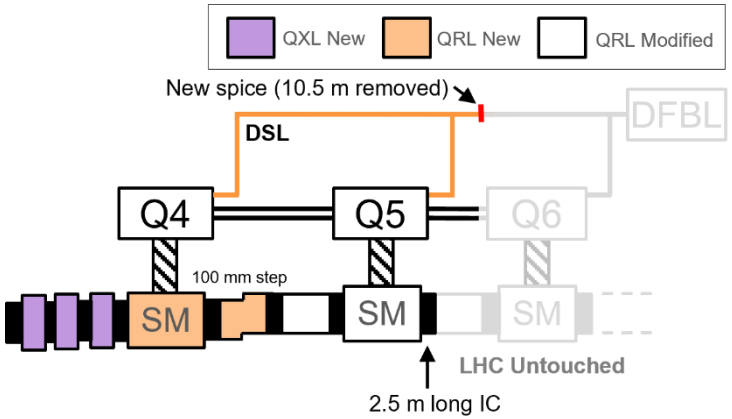
LS3 requirement	Estimated Mass	Sub-assemblies	RP Action	Storage Required
Move	~ 20 ton.	4 x SM 6 x PE	Temporary storage	Modification underground in UX65 before reinstallation in tunnel
Spares	Up to ~ 10 ton.	2 x RM 2 x SM 1 x PE	Long term storage	1000 m² storage above ground to manage removal from tunnel 100 m² long term spares storage
Remove	Up to 110 ton.	2 x RM 10 x SM 43 x PE Warm pipes	Disposal	1000 m² storage above ground to manage removal from tunnel 900 m² RP waste: - Short term ≈ 800 m² PE's awaiting destruction - Long term ≈ 100 m² SM's awaiting reduced radioactivity before destruction

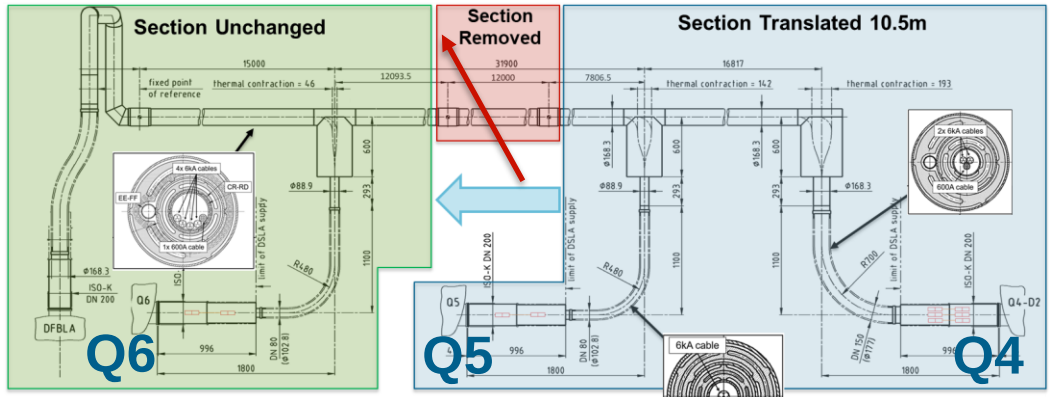
Dismantling resourcing strategy during LS3 to be frozen : functional specification ready to be sent to partners.

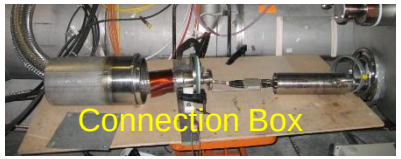
DSL dismantling / re-installation

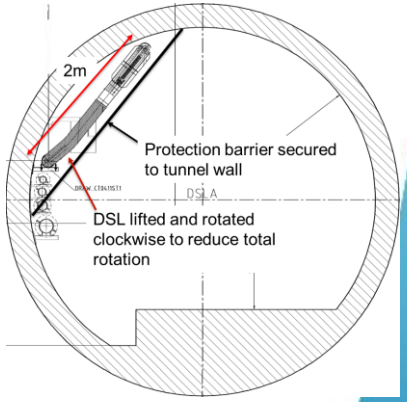
- **One new splice box** required : Mechanical design of splice box in collaboration with TE-MSC-LMF.
- **Store** the superconducting link in the tunnel during LS3 : require a DSL protection and tooling to rotate the DSL.
- **Translate DSL** to final location and **reconnection**.





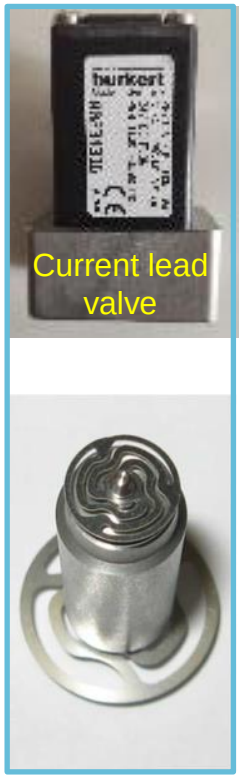


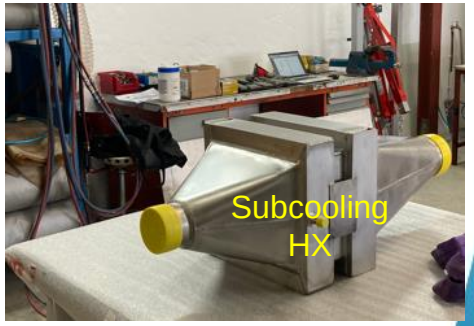




CERN Supplied items

Components	Function	Supplier	Quantity *(spare included)*	Status
Sub-cooling HEX	to minimize the helium vapour fraction produced in the final expansion of the 1.9 K loop	D.A.T.E high-end heat exchangers	25 HXI @ 25 g/s 15 HXD @ 7 g/s	**Delivered**
Quench valves	Protection of magnets against overpressure	VELAN	22 units	**10 units in testing** 10 in manufacture 2 + 3 spares to be ordered
Current Lead control valves	Compact frictionless solenoid valves controlling the current lead flow.	bürkert Fluid Control Systems	75 valves – 3 mm 56 valves – 8 mm 40 valves – 2 mm	**Delivered**





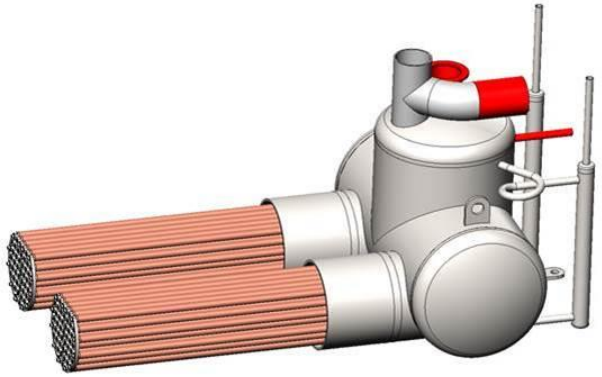
Contribution to D2 magnets (WP3)

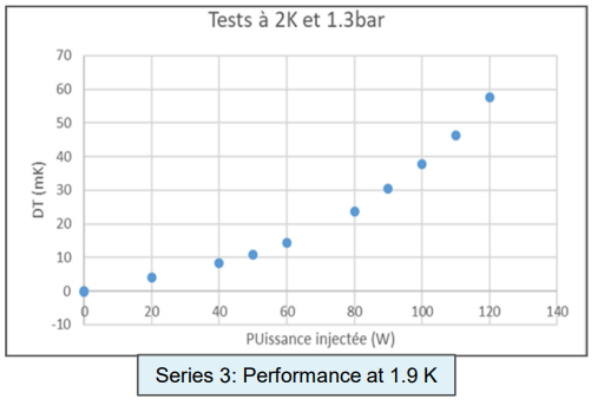
- **D2 finger heat exchangers** designed by **CEA** and manufactured by **Ravanat**
  - ✓ All HXs are ready and tested (cycling and performance tests)
    - ✓ 1 Prototype
    - ✓ 1 Pre-series
    - ✓ 4+1 series
  - ✓ Several NCs detected (rust, cleanliness, particles,…) which were remediated.
  - ✓ 2 Series HX delivered to MSC with installation of first HX planned for Oct'24.

- **D2 helium guard for level sensor** designed and manufactured by **TE-CRG**
  - ✓ Manufacture of 2 first units completed
  - ✓ Leak and Pressure testing underway

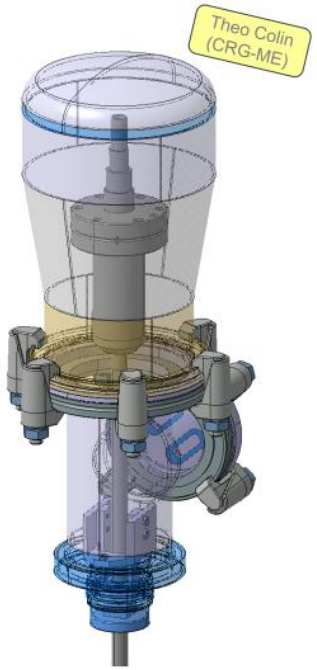
- Supply of Cryogenic instrumentation.

- Follow-up with WPE of the thermal tests in test bench





Series 3: Performance at 1.9 K



Instrumentation / Control / Database

- Development of an HL-LHC **Instrumentation standard** for **sensors, feedthroughs and connectors**.

→ All **CERNox sensors procured** – last batch expected beginning of 2025.

→ **DO for feedthroughs** issued Sep'24.

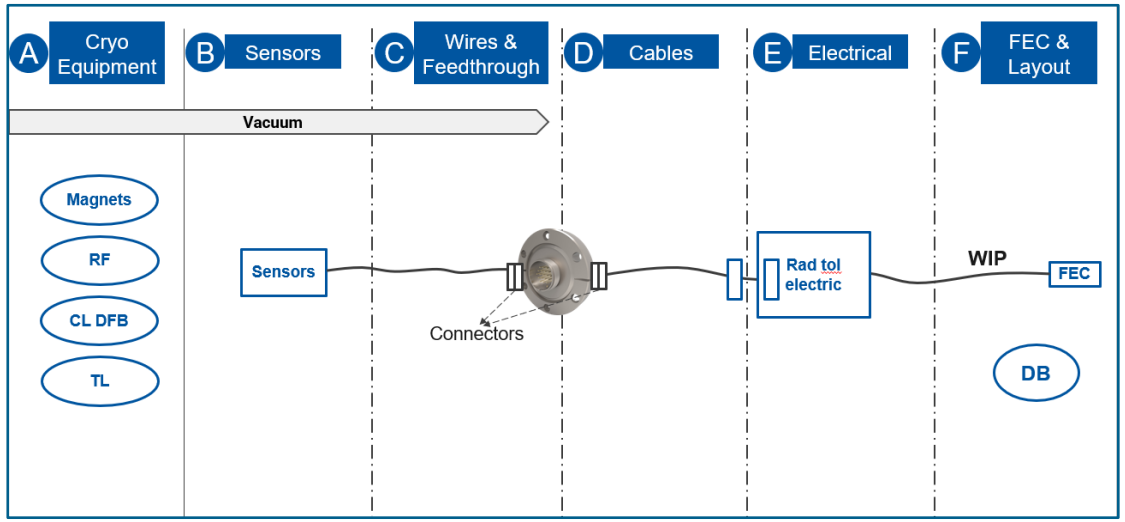
- Cryogenic instrumentation requirement followed-up in **P&ID component list**.

→ Development of Layout Database in progress.

- **Cables requirement refined** for the last revision of the DIC.

- **Development Radtol electronic** conditioning card.

- **Hardware control** for Refrigerator being **purchased.**

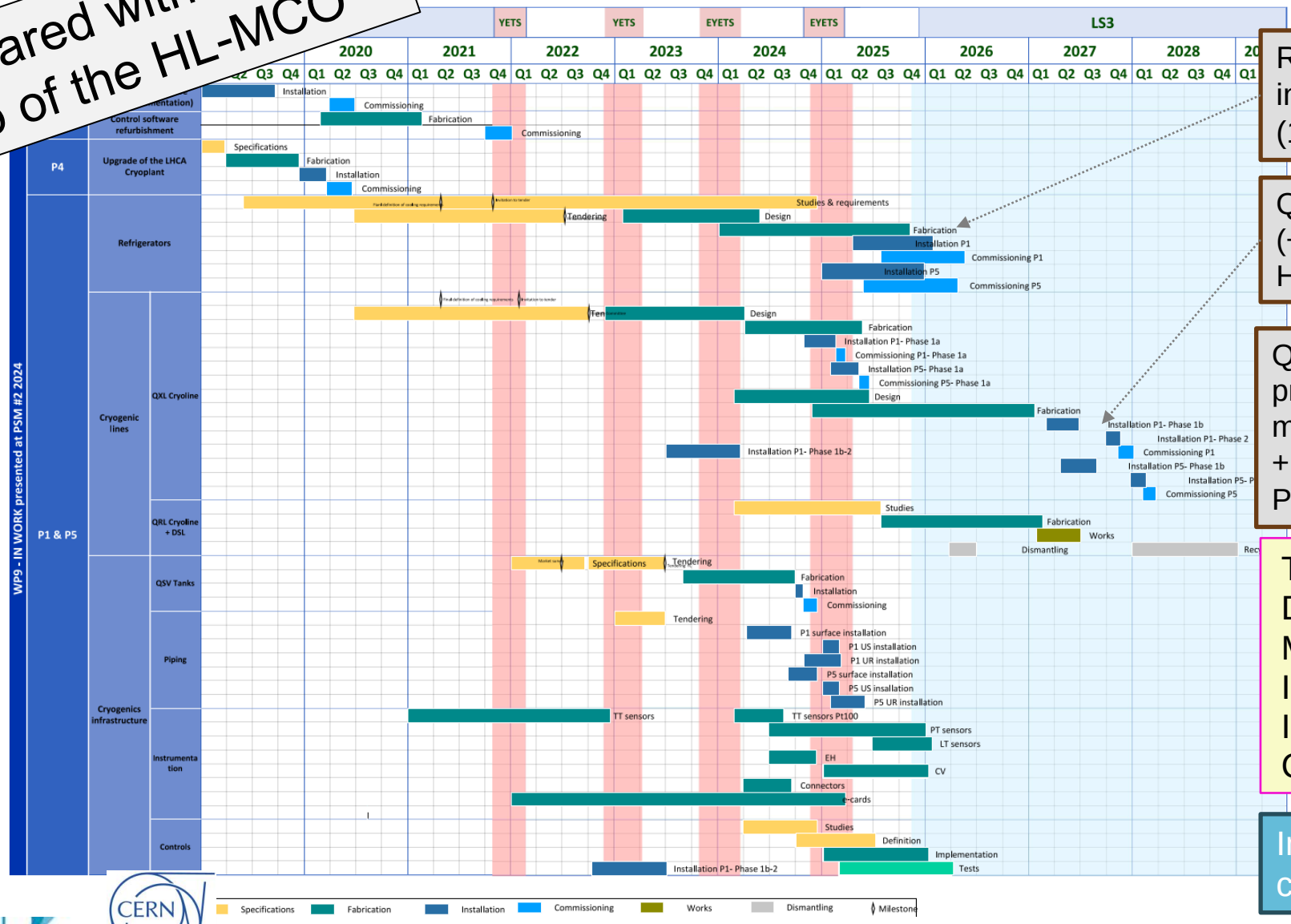


Next steps :

- Continue with the procurement of remaining instrumentation and supply to work packages.

Masterplan of WP9

Prepared with the help of the HL-MCO



Ref : marginal delay expected on installation of compressor station (1.5-3 months)

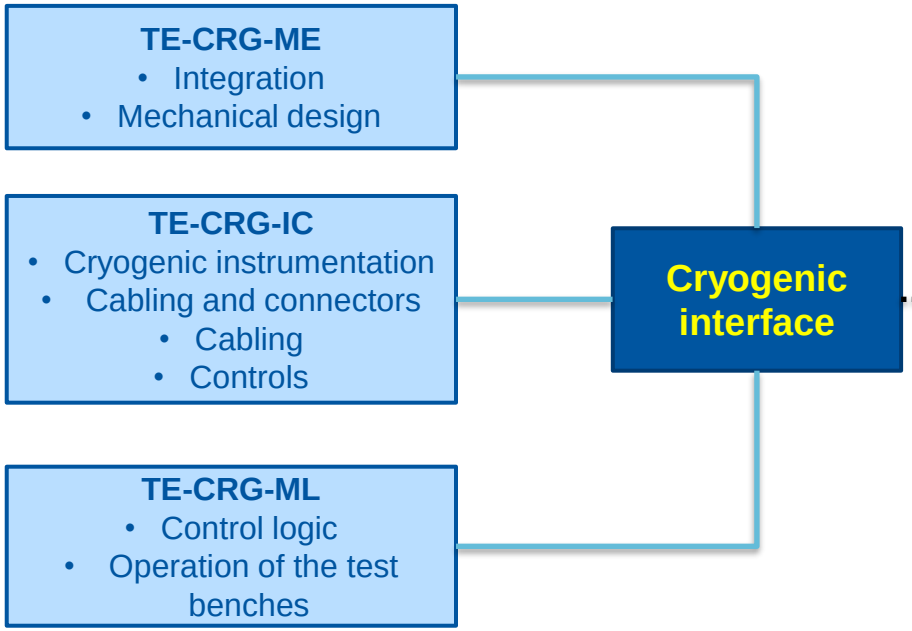
QXL Ph1b/2 : delay expected (+4 months) due to the vertical cores HL-LHC

QRL rework / DSL : studies still in progress – co-activity foreseen with magnet for dismantling.
+ 2 weeks float on the LS3 critical path.
Priority given to QXL Ph2 installation.

Tendering: mid20-21-22-23
Design: 2023-24-25
Manufacturing: 2024-25-26
Instrumentation: 2024 -25
Installation: 2025-26-27
Commissioning: 2026-27

Impact of LS3 delay not considered here

Contribution to other WPs



Cryogenic interfaces

WP3 - IT+D1 cooling: R. v Weelderen + P. Tavares
WP3 - IT+D1 techno: M. Sisti
WP3 - D2: A. Lees
WP4 - Crab Cavities: L. Delprat + *K. Brodzinski*
WP6a - Cold Powering: V. Gahier

- Example of achievements :
  - WP6A : Follow-up with WPE of Test Bench F2 Cold Powering thermal tests with comparison with expected performances and way forward on splices TT value engineering (197th HL-LHC TCC (13 June 2024) · Indico (cern.ch))
  - CC : follow-up of SM18 M7 - RFD prototype operation, support in Cryomodule design , preparation of SPS BA6 operation of the RFD prototype (Refer to 08.10.24 talk for more details - 14th HL-LHC Collaboration Meeting, Genoa (Italy), 7-10 October 2024 (7-10 October 2024): Crab cavities cryogenics – status and perspective · Indico (cern.ch))

Also with WP15 and WP17 for integration, coordination and interfaces

WP9 organization and main contacts

WP leadership
V. Gahier / S. Claudet

Refrigerator
E. Monneret / G. Zoglami

QXL
M. Sisti / F. Merli

Tanks and Warm Piping
A. Suraci / O. Pirotte

QRL/DSL works
A. Lees / J. McAnervey

Support / Coordination

QA, documentation
Heat loads - Process - Cooling Req.
3D models - Integration
Mechanical expertise
Contract – Technical
Instrumentation – Controls – Data Bases
Dismantling - Scheduling

Cryogenic interfaces

WP3 - IT+D1 cooling: R. v Weelderen + P. Tavares
WP3 - IT+D1 techno: M. Sisti
WP3 - D2: A. Lees
WP4 - Crab Cavities: L. Delprat + *K. Brodzinski*
WP6a - Cold Powering: V. Gahier

Conclusion

- **Refrigerator contract** is in the end of design phase and are currently **under manufacturing phase.** The **next phase** to come will be the **installation in SHM** from Q1 2025.

- **Cryogenic distribution** contract organized in two phases.
  - **Phase 1** in **manufacturing** for Pipe elements and **final design** for the remaining sub-components. Installation details in discussion with Contractor.
  - **Phase 2** design phase started, with effort to take the lesson learnt of phase 1. **LS3 shift** to be considered by Contractor for **installation.**

- **Warm piping** in **installation phase**. **Helium tanks** (2x250m3/point) installed.

- **Installation phase** will require the support of several groups (EN-HH for transport /handling, BE-GM (Marking), EN-MME (NDT) ; TE-VSC (leak tests) and coordination with WP15 /WP17.

- **QRL dismantling resourcing** strategy to be frozen before year end.

- Continue with the **procurement and supply of instrumentation** to WP3, WP4 and WP6a and with follow-up of thermal tests when applicable.

Installation of gaseous storage tank

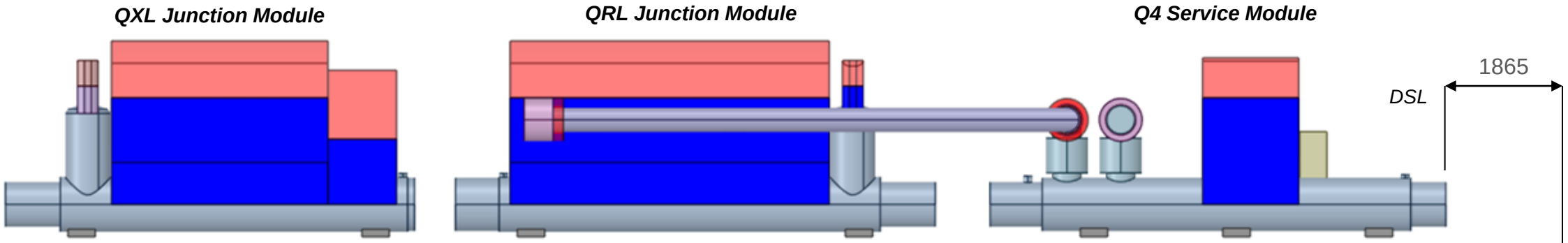
PFHE test at Linde premises

Vacuum vessel in stock at KrioSystem

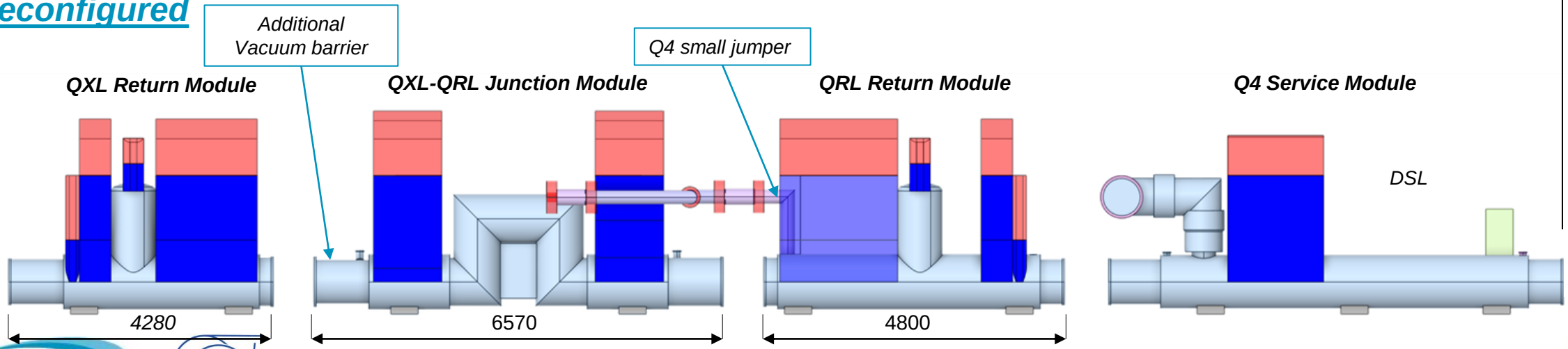
Bonus slides

Reconfigured equipment layout (5R)

Baseline

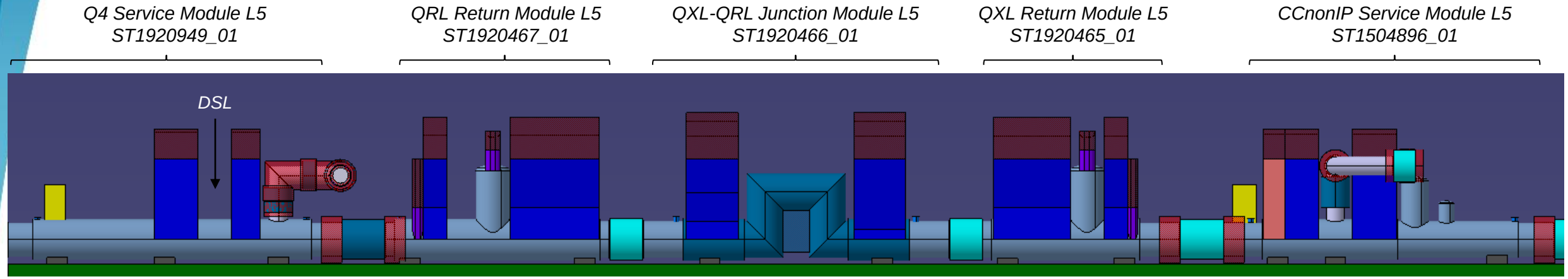


Reconfigured

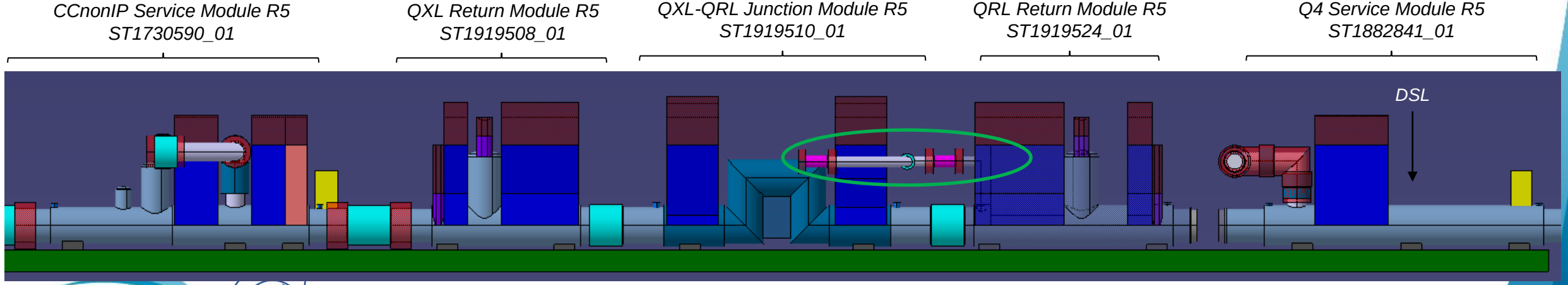


Reconfigured equipment layout

L5 layout *(ST1712228_01)*



R5 layout *(ST1675921_01)*



QSV, Warm Helium Storage Tanks at P1 & P5






Installation at P1 done June 12th

Installation at P5 scheduled July 2nd

Thanks to all involved for the smooth implementation of this spectacular activity !!!