HiLumi HL-LHC PROJECT

UPPSALA UNIVERSITET

12th HL-LHC Collaboration Meeting Uppsala - Sweden

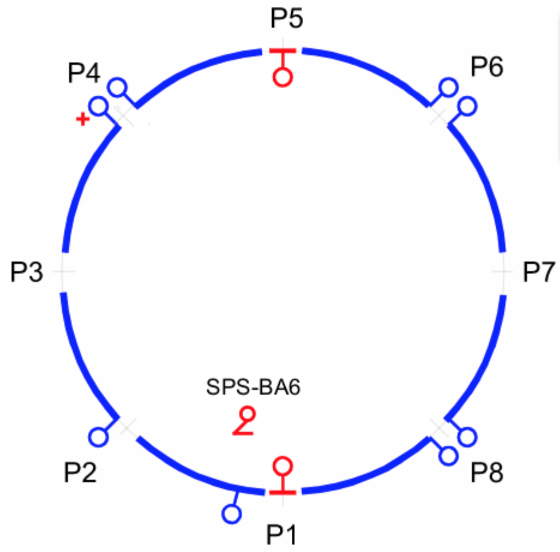
HL-LHC Status and Perspectives WP9 Cryogenics

S. Claudet, *on behalf of WP9-Cryo project team*

19th Sept 2022

indico#1161569

HiLumi-WP9-Cryogenics, Global scope overview



- Existing cryoplant
- New HL-LHC cryoplant

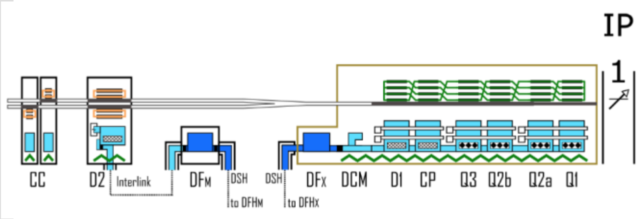
P1-P5: 2 new cryoplants (~14 kW @ 4.5 K incl. 3.25 kW @ 1.9 K) and 2 x 750m cryo-distribution for high-luminosity insertions

To provide adequate cooling for:

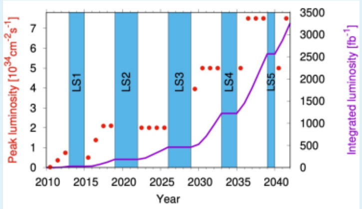
P4: upgrade (+2 kW @ 4.5 K) of an existing LHC 18 kW @ 4.5K cryoplant

SPS-BA6: SRF test facility with beam primarily for Crab-Cavities

P1-P5 machine devices



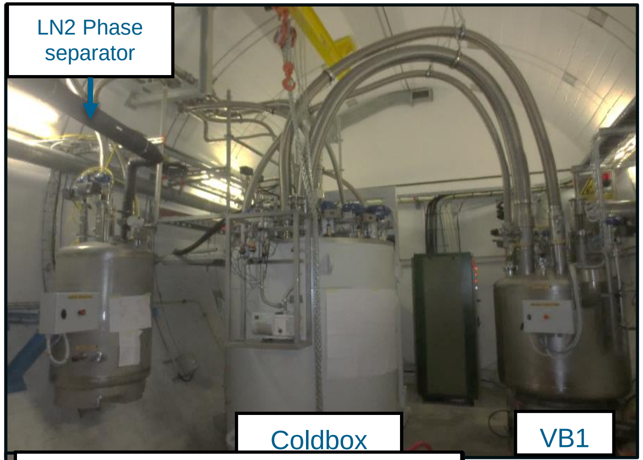
HL-LHC performance



Other test facilities related activities are not part of this WP9-Cryogenics

Cryogenics for HL IT String part of WP16, See talk by A. Perin

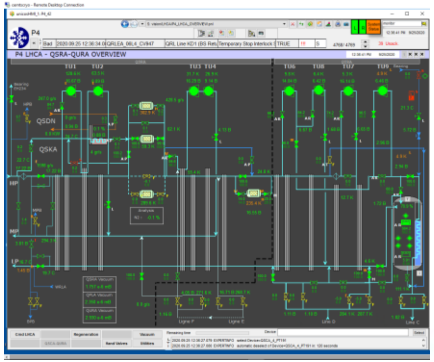
Deliveries completed up to now



SPS BA6

SPS-BA6, see talk by K. Brodzinski

QURA – Lower Cold Box at LHC P4



=> Equipment in operation, working as expected, available for support if needed

Agenda for Cryogenic scope at P1-P5

- Review of cooling requirements & global scheme
- Refrigerators and Cryogenic distribution line
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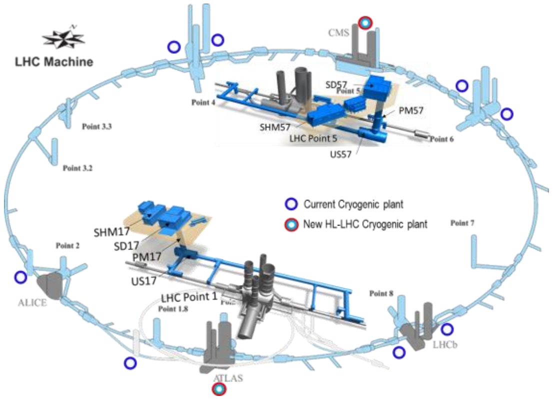
- Summary



HL-LHC P1/P5 Cryogenic architecture

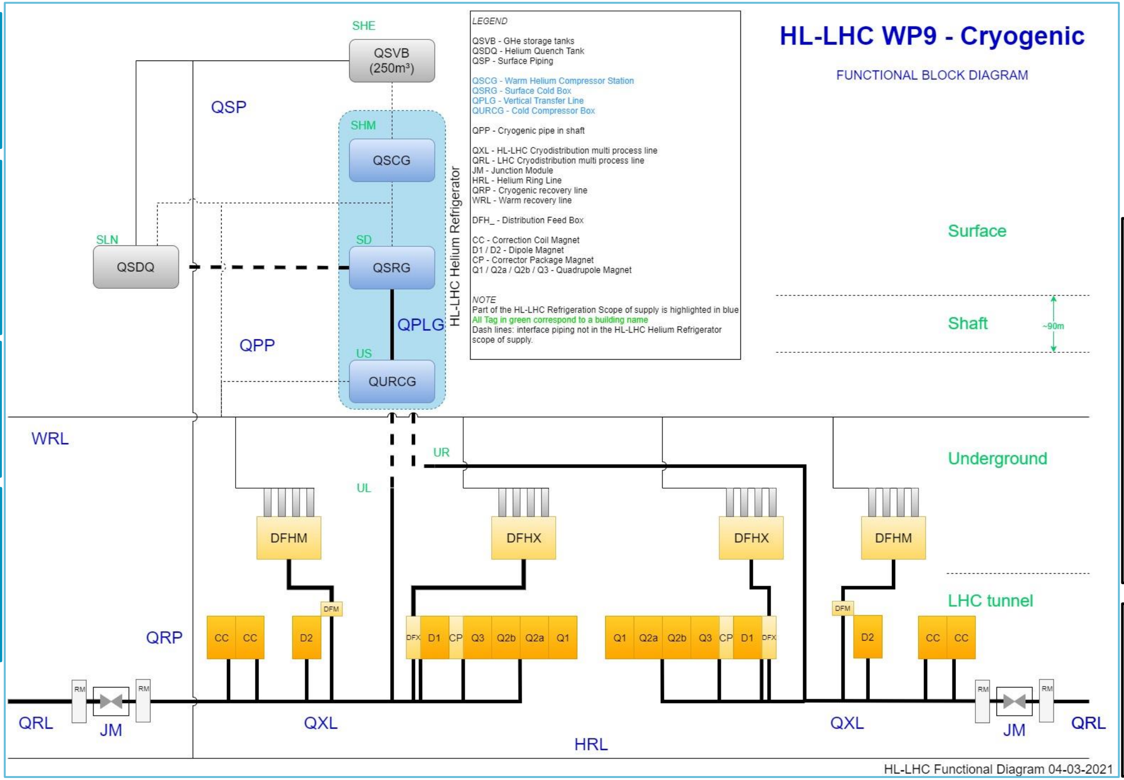
QSRG : Compressor station providing gaseous helium **20 B**

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

QPLG : Vertical transfer line (~100 m height)

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

Users at tunnel level

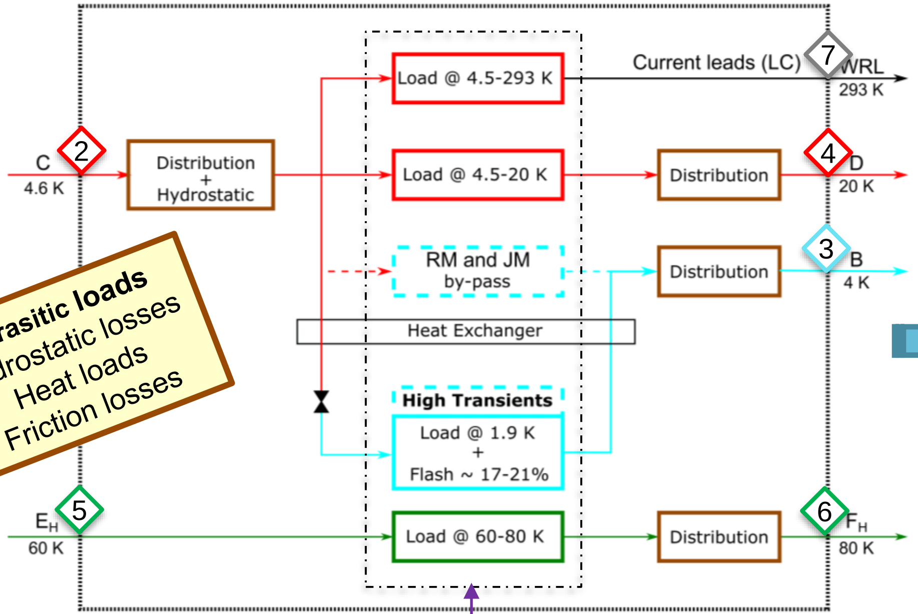


QXL : Distribution line distributing C,E and returning B,D,F

- 70 m for the common branch
- 270 m for the long branch
- 60 m for the short branch

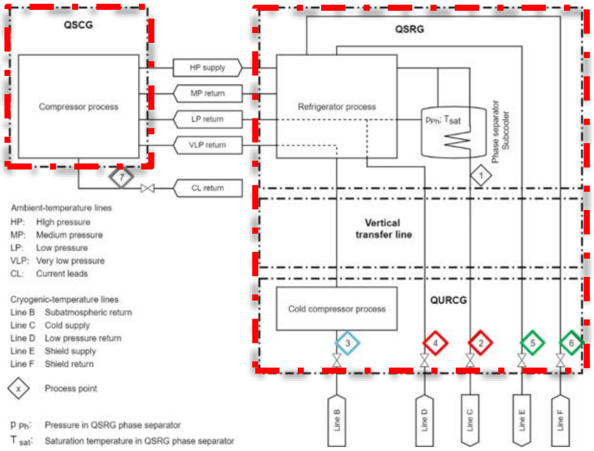
RM/JM : Return module and junction module at extremities for transient handling and back-up

From cooling requirements to refrigeration capacity



Parasitic loads
Hydrostatic losses
Heat loads
Friction losses

Limits of supply for Refrigerator delivery

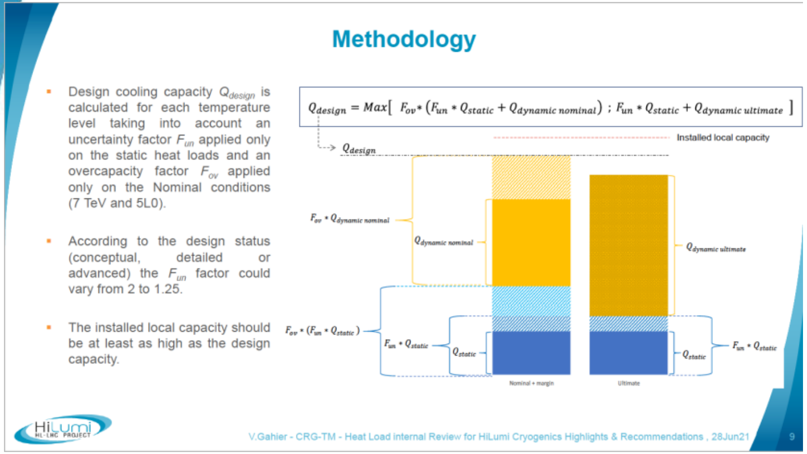


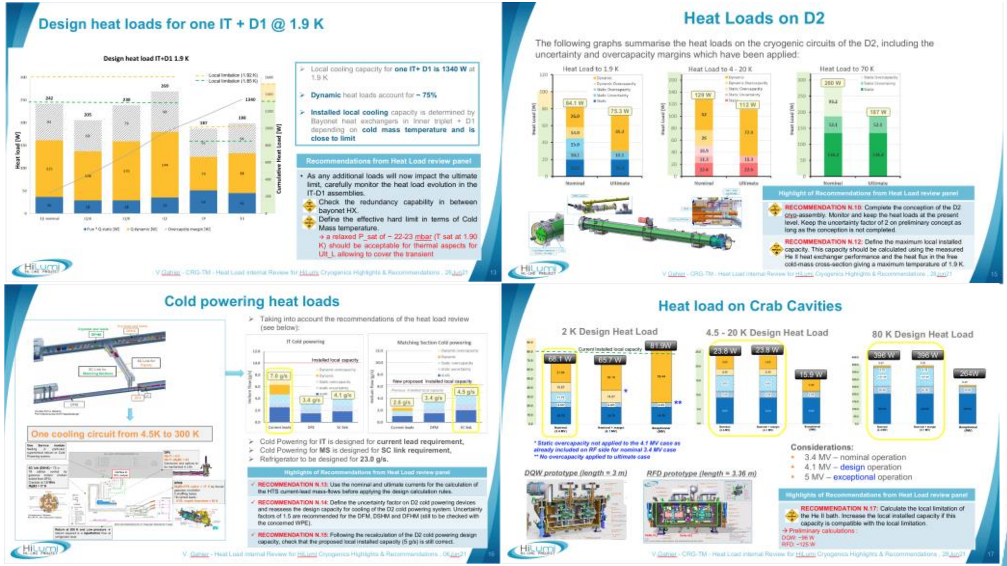
1 Evaluation of Heat loads at User level **considering**

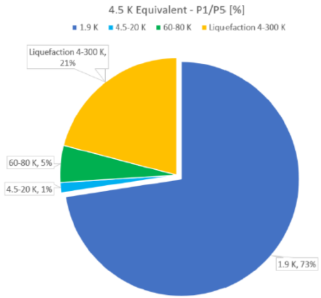
2 Parasitic loads from distribution to be taken into account

3 Proper evaluation of Refrigerator supply to proceed with Call for Tender.

Heat Load Review, major outcome







The total design heat load at 1.9 K is very close to the limit of the installed local cooling capacity for all users

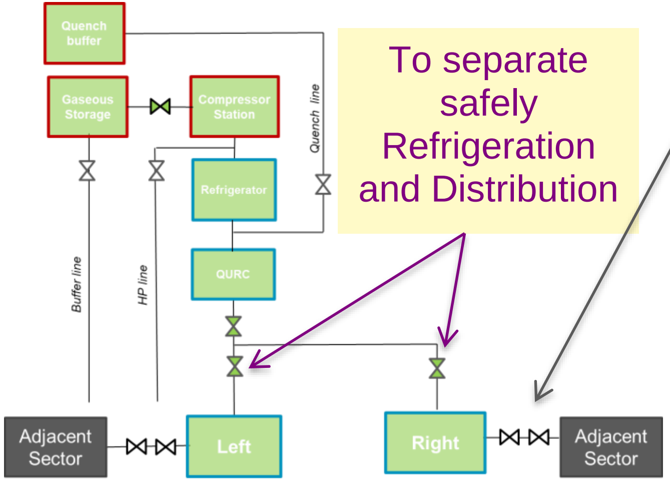
All parties involved shall be aware of the situation

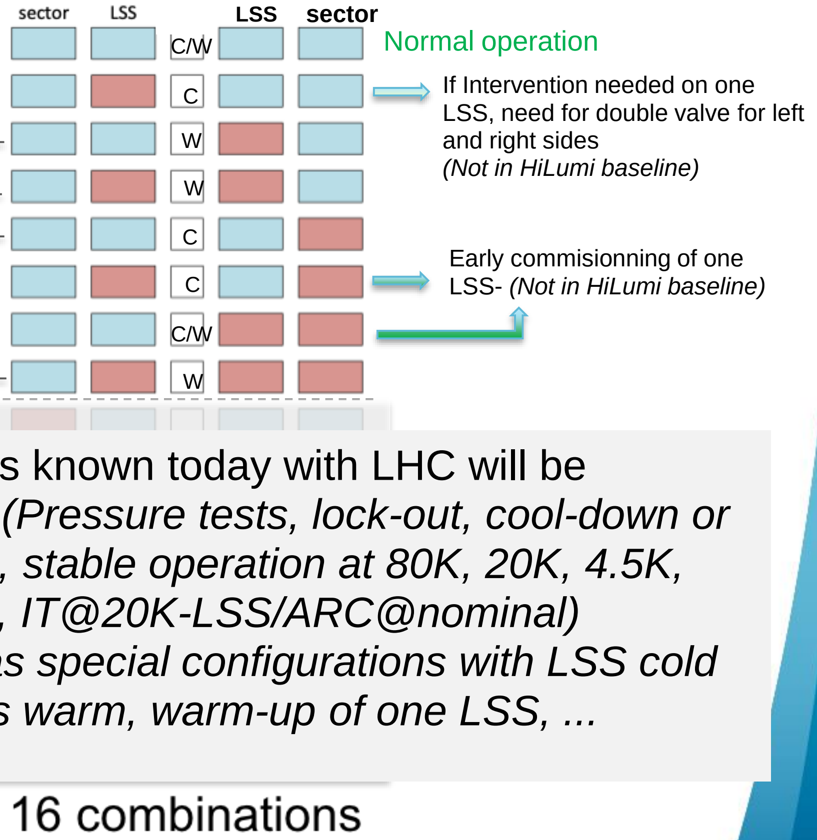
➡ It is time to freeze the configuration and commit on these figures considering fabrication and installation phase

=> 2 x 14kW@4.5K, including 3.25kW@1.9K

Sectorisation: safety and operation modes

- HiLumi magnets/users can be cooled by :
  - Adjacent sectors
  - New Refrigerators which will be installed
- Several considerations :
  - *HiLumi baseline is to cool-down both LSS at the same time*
  - *Due to access constraints during cooldown,* ***at this stage****, LSS/sector have to be in same state.*
  - *Periodic testing configuration shall be covered*





All modes known today with LHC will be possible *(Pressure tests, lock-out, cool-down or warm-up, stable operation at 80K, 20K, 4.5K, 3K, 1.9K, IT@20K-LSS/ARC@nominal)*
As well as special configurations with LSS cold & sectors warm, warm-up of one LSS, ...

Agenda for Cryogenic scope at P1-P5

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- Refrigerators and Cryogenic distribution line
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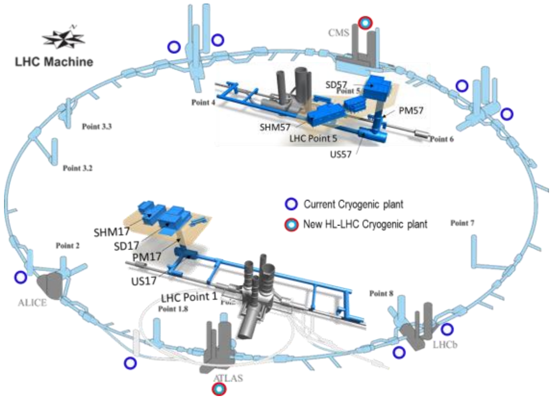
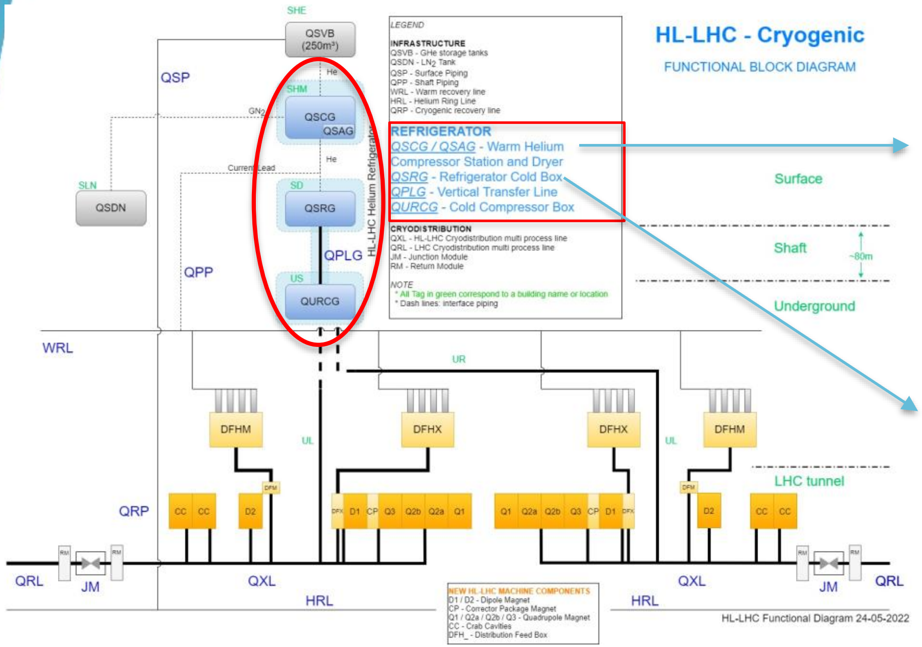


Helium Refrigerators at LHC P1 and P5 for HL-LHC

P1-P5 Cryogenic Architecture



Helium Refrigerators

2 x 14kW@4.5K, including 3.25kW@1.9K

LHC Helium Refrigerators

similar capacity required for P1 and for P5, in addition to 8 existing

Compressor station
(100t, 4MW input power)

Cold boxes from world wide leading industries
(>100t, Heat exchangers, expansion turbines, valves, controls)

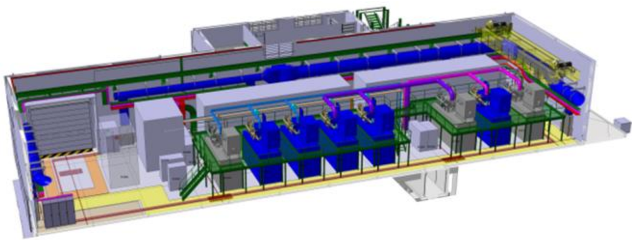
HL-LHC Helium Refrigerators

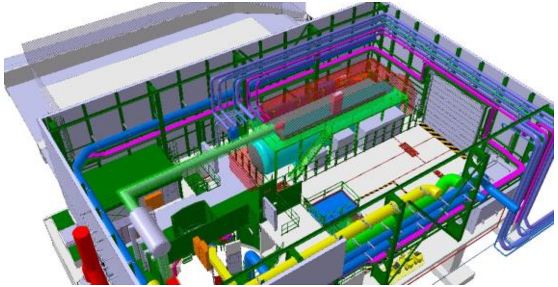
Civil Engineering @ LHC P1 Sept. 2022

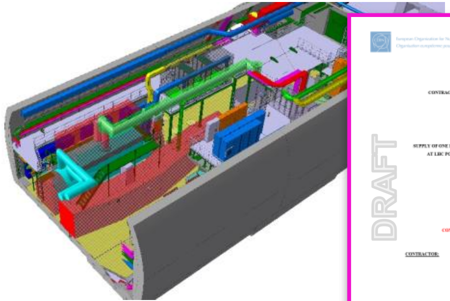
SHM – Compressor Station

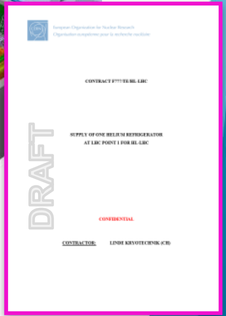
SD – Refrigerator Cold Box

US – Cold Compressors Box



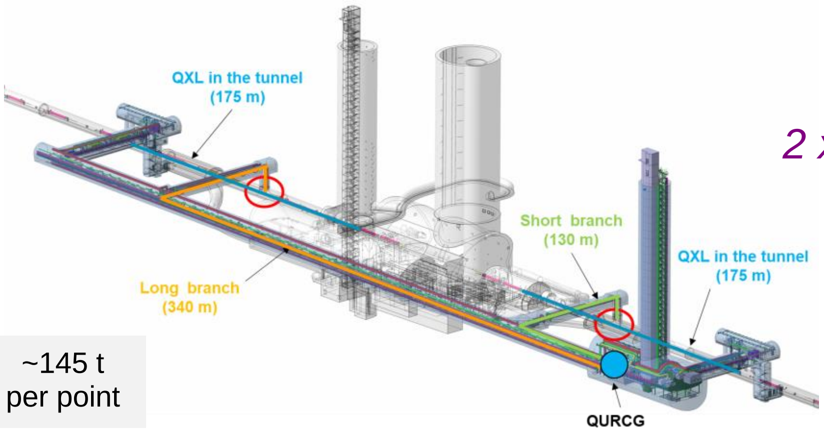




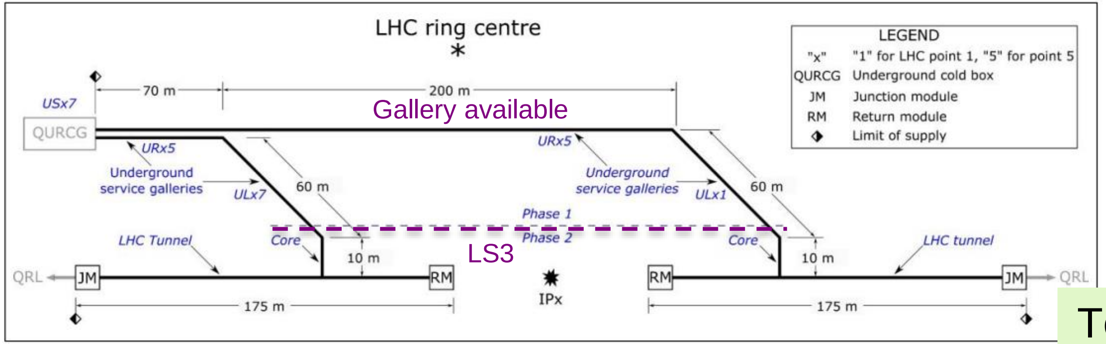


CERN HL-LHC Refrigerators Conceptual Design
14kW@4.5K including 3.25kW@1.9K

Cryogenic distribution line at P1 and P5



~145 t
per point



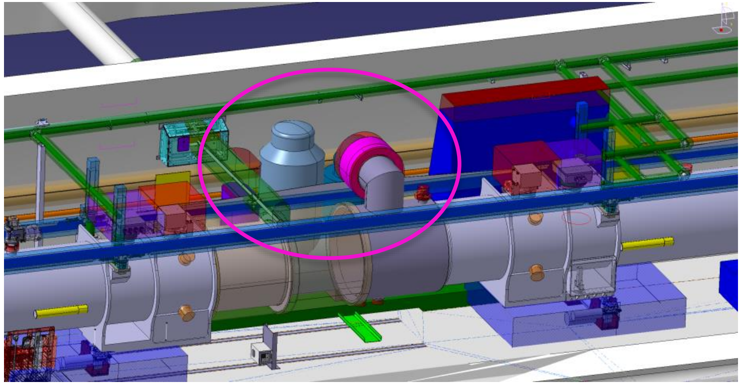
Cryogenic Distribution Lines

2 x 750 m, 5 process pipes, vacuum insulated
(Diam 40 to 273, 650 to 800mm)

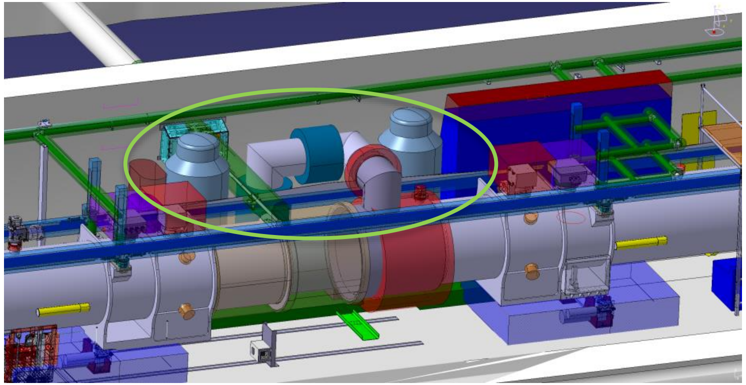
Tendering process Q1-Q2_2022,
Proposal for adjudication FC_Sept'22

Cryogenic line, integration & last interfaces

Baseline



Towards alternative proposal



Work on-going with WP3-Magnets & WP15-Integration for a solution solving identified issues

Global integration could look nice (and small!)

but issues identified for local cooling capacity, jumper mecanical design & interconnection

HiLumi HL-LHC PROJECT

CERN

Cryogenic line: CERN (to be) supplied items

Very specific items qualified for LHC following developments, qualification of alternatives & selection, working fine so far


~ 20 x 30 cm

- Sub-cooling heat exchangers for Cryogenic line (Very Low Pressure for return gas at 2K)
- Quench valves (protection of magnets against overpressure)
- Control valves for current leads (Gaseous helium at 300K, small flow)

=> Procurement (as LHC spares) to start early 2023

Collaborations with CEA-Grenoble for D2 heat exchangers

KE5016/TE/HL-LHC with CEA-Grenoble

On tracks !

WP1, Cu measurements (Kapitza resistance)

DIRECTION DE LA RECHERCHE FONDAMENTALE
Institut de Recherche Interdisciplinaire de Grenoble IRIG,
Unité mixte CEA–UGA
DEPARTEMENT des SYSTEMES BASSES TEMPÉRATURES

2021-12-15

Final Report on copper thermal properties and performance assessment of multi-tube He II/He II heat exchangers using a single tube sample

WP1 - Deliverable D1.2

KE5016/TE/HL-LHC - ADDENDUM No. 3
to FRAMEWORK COLLABORATION AGREEMENT KN3573

B. Rousset, F.Millet
SBT-CT-21-63_Final_Report_WP1-Kapitza_Measurements_V0.Docx
DSBT/CT/21-63 – Version 0.0

	NOM	SIGNATURE
Préparé par	**Bernard ROUSSET** Responsable scientifique HX-D2	
Vérifié par	**Francois MILLET** Chef de projet HX-D2	

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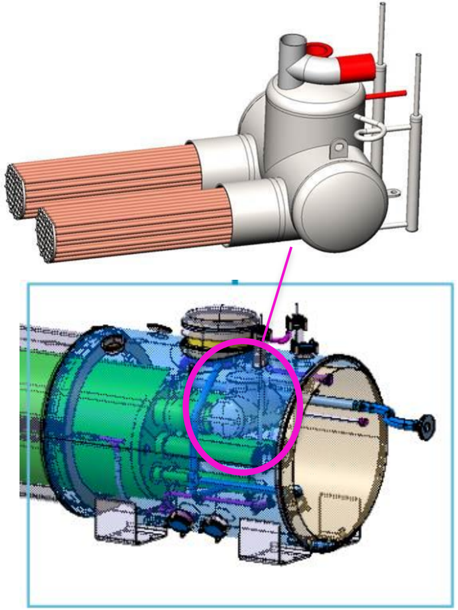
WP2, pre-series unit received series fabricated with one to be tested/measured at 1.9K Aut'22



Procurement of storage tanks and piping

Industrial sub-systems, illustrations from LHC existing similar equipment

GHe 250 m3

Market Survey

Technical Description

Supply of HL-LHC Gaseous Helium Vessels

Abstract

GHe 80 m3

Industrial stainless steel piping

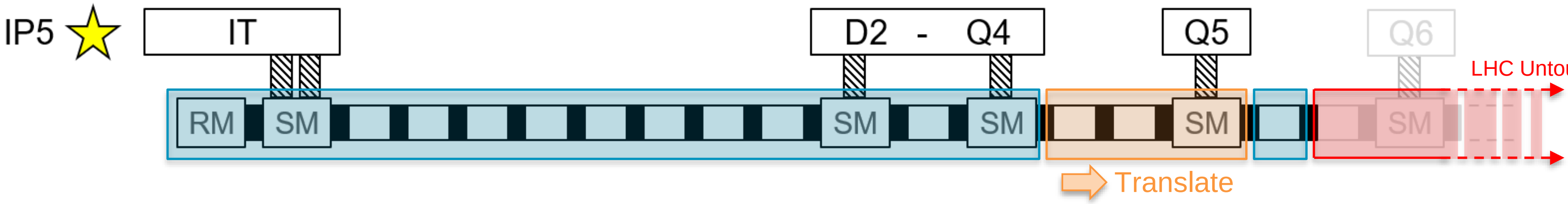
LN2 existing 50 m3

GHe storage tanks: Market Survey ready to be dispatched, tendering to follow end'22

Industrial piping: detailed interfaces to match referigerator needs, then MS - IT to follow

Usage of Dismantled QRL Sub-Assemblies

- ‘Reused’ sub-assemblies (HL-LHC total = 12) will be reinstalled in a new position.
- All other sub-assemblies (HL-LHC total = 58) will be substituted by new equipment.



QRL sub-assemblies

- **To be reinstalled**
  - Underground waiting area → Preferred solution, space to be found with EN-ACE.
  - Surface waiting area → To be used in case re-work is required.
- **Kept as spare** → Investigate within TE-CRG which spares are desired (DFBX, SM, RM, PE). Storage procedure must consider sub-assemblies' activation.
- **To be discarded** → Disposal procedure based on:
  - activation
  - materials
  - weight
  - volume

  To be defined with HSE-RP:
  - Discard as is
  - Cut in pieces, sort them, discard
  - Compact before discarding

Collaboration with EN-MME – Custom Cutter

Support wheels

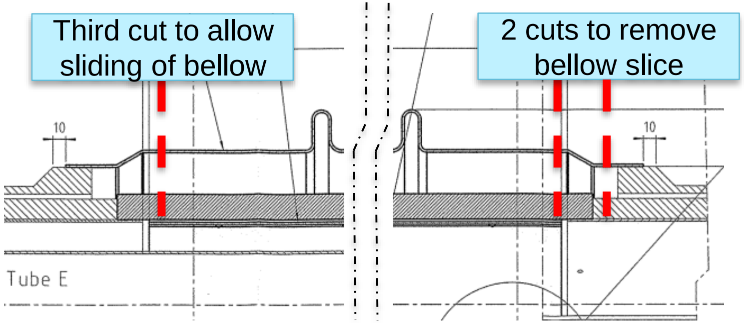
Cutter

Pipe cutter mounted on mockup

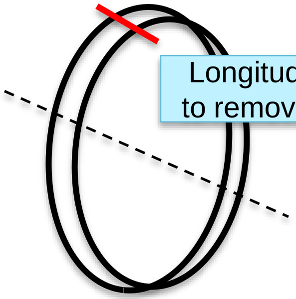
Back in timing allocated for QRL removal

Third cut to allow sliding of bellow

2 cuts to remove bellow slice

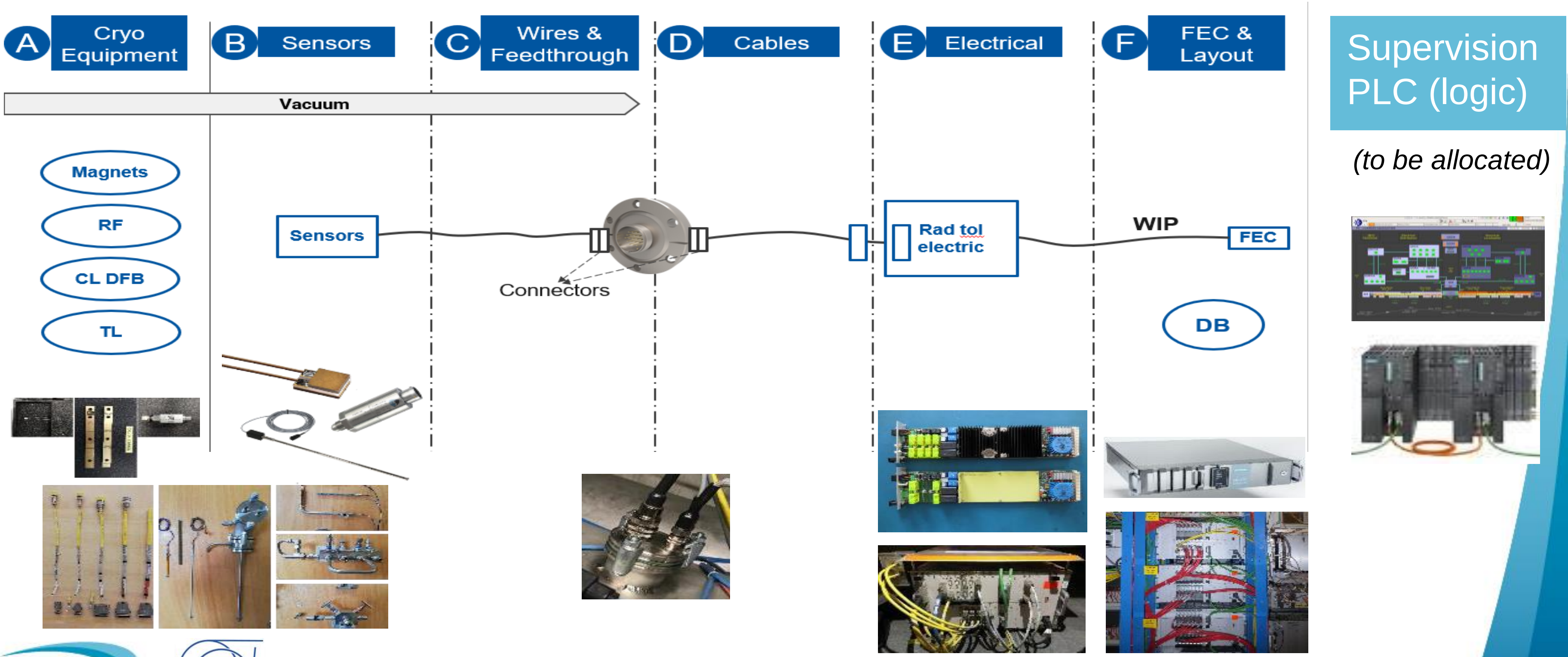


Pipe cutter before installation



Longitudinal cut to remove bellow

Cryogenic instrumentation & controls



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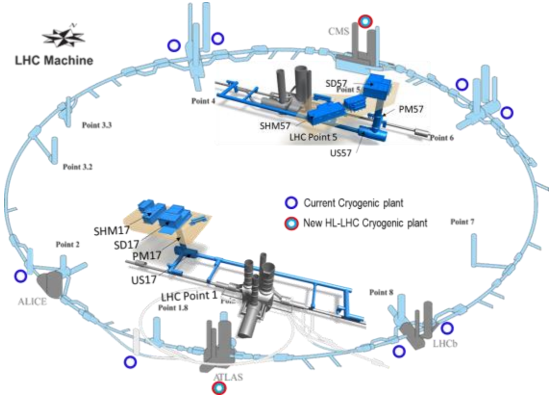
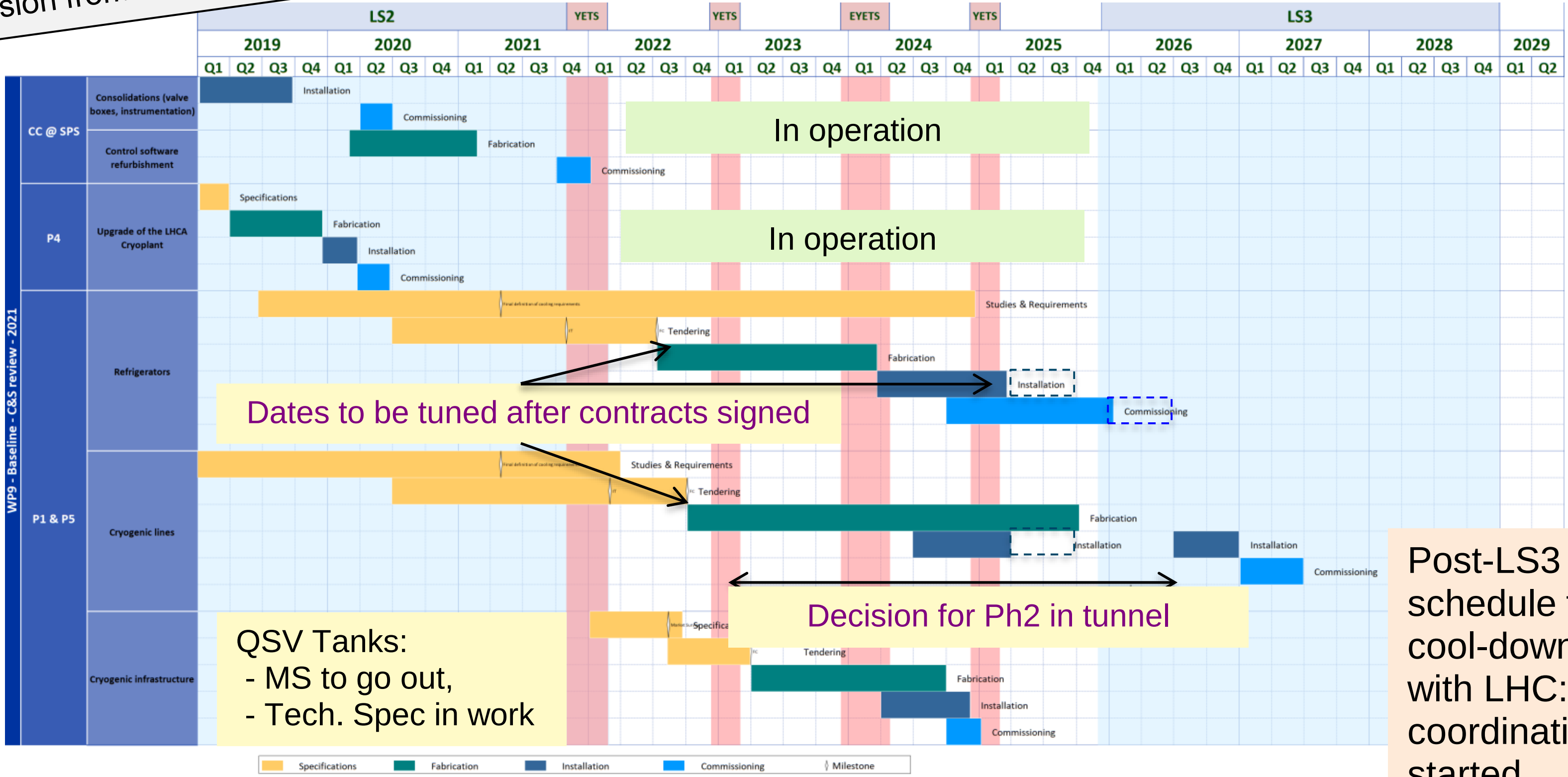


Prepared with the help of the HL-BSO
(Version from Feb'22)

Masterplan of WP9



Post-LS3 schedule for cool-down with LHC: coordination started

HL-WP9-Cryo organisation, Jan'22

WP leadership:
S. Claudet / A. Perin

Project Engineers for Cryo sub-systems
- Refrigerators: E. Monneret
- QXL Cryoline: M. Sisti
- Tanks: A. Suraci - O. Pirotte (G. Ferlin)
- Piping: G. Ferlin => O. Pirotte - A. Suraci
- QRL/DSL refurbishment: A. Lees

Re-inforced & stabilised team(s),
for WP9 proper,
as well as within TE-CRG ME & IC

Coordination:
QA, documentation: N. Grada => New graduate
Heat loads - Process - Cooling Req.
3D models - Integration
Mechanical experts: incl. F. Merli
Instrumentation – Controls – Data Bases
Dismantling - Scheduling

Interfaces:
- IT+D1 cooling: R. v Weelderen + P. Tavares
- IT+D1 techno: M. Sisti
- *11T - connection-cryostats: R.v.W*
- D2: A. Lees
- Crab Cavities: K. Brodzinski + L. Delprat
- Cold Powering: V. Gahier
- Hollow e- Lens: G. Ferlin + A. Lees

Summary

- Cooling requirements reviewed mid 2021, allowing to confirm the refrigeration capacity with final tuning of the global cryogenic architecture
- Major tenders (Refrigerators, cryogenic distribution line) done following process & technical feasibility studies with shared cost risks for post-covid & Ukraine impacts, with continued efforts to get industrial contracts signed in coming weeks and maintained on good tracks
- Few issues identified (at jumper interfaces) being solved with partners
- Procurement of complementary items (gaseous tanks, piping, items as LHC spares, existing QRL cryoline refurbishment) started, to be continued
- Instrumentation and controls activites now well structured and delivering
- Team in place to implement WP9 scope for LS3 to start in 2026

Complements

Possible

Some typical cases illustrated (4/4)

To be kept in mind: HL refrigerator will need 2-3 months maintenance as well (independant from the proposed simplification)

HL-LSS cold stand-by, arcs warm (LS?):

	ARC	LSS	Ref.	LSS	ARC
Cold stand-by of LSS			Cold Stand-by		
	(locked)			(locked)	

(and if later 1 LSS has to be warmed-up, 2nd will follow as 1 Ref. = 1 mode)

Intervention on 1 HL-LSS:

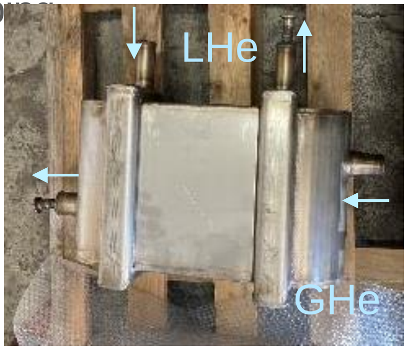
	ARC	LSS	Ref.	LSS	ARC
Nominal operation			Cold		
LSS warm-up for intervention			C -> W	C -> W	
			(C/W)		
LSS warm-up for intervention			Warm (locked)	Warm (free)	

(No need for QUIG for that, the 1+2 valves in QURCG could do the job)

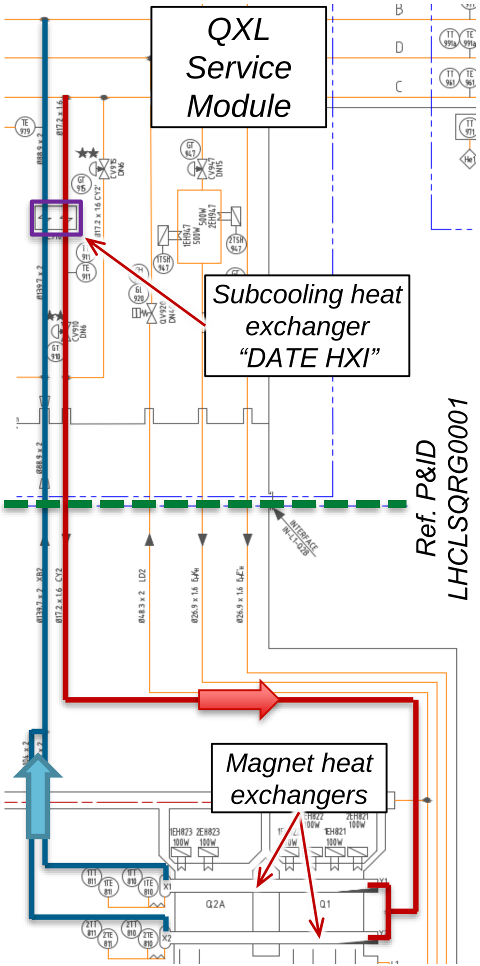
Tuning for technical solutions

1. Too high pressure drop measured in existing subcooling HXI [25 g/s]
2. Identified bottleneck for "installed local capacity" in cryogenic equipment rather than being higher than magnets proper
3. Possible distribution issue with supply lines for 2 bayonets
4. Some concerns with medium term quality control in case of change with the heat exchanger manufacturer from LHC (long qualification)

=> Evaluation of alternatives, from increased piping wherever possible, to parall[illegible]rn piping



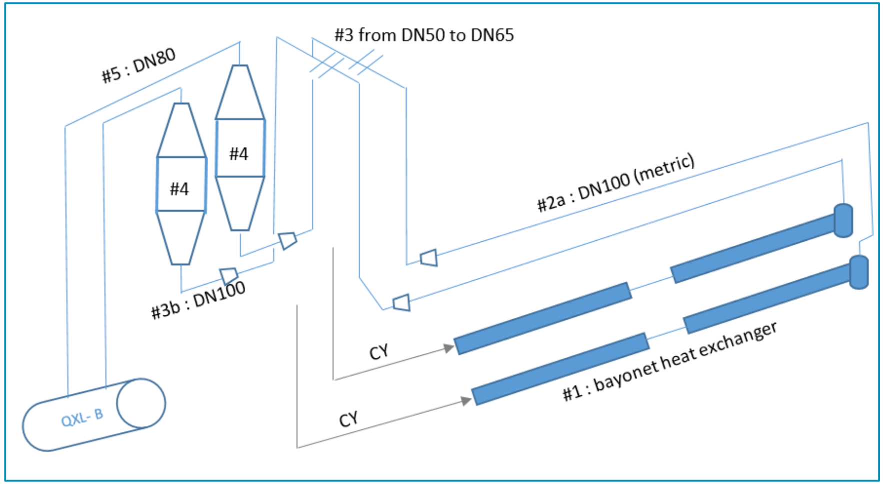
~ 20 x 30 cm

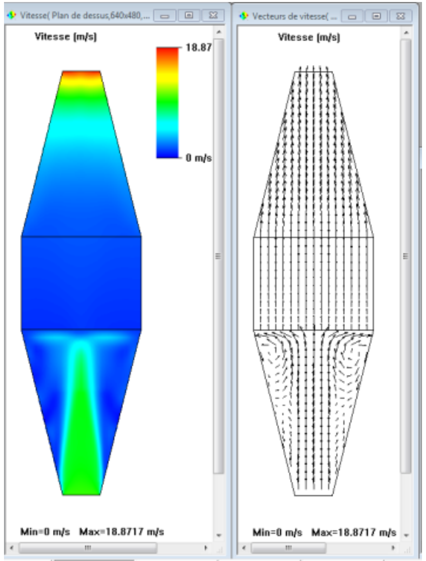


Recent progress & Perspectives

Revisiting distribution line & interfaces

Parallel HX scenario studied to overcome:
- pressure drop issue on VLP
- capacity of cooling loop (bayonets of the magnets and not cryo equipment)
- distribution (parallel CY-bayonets)

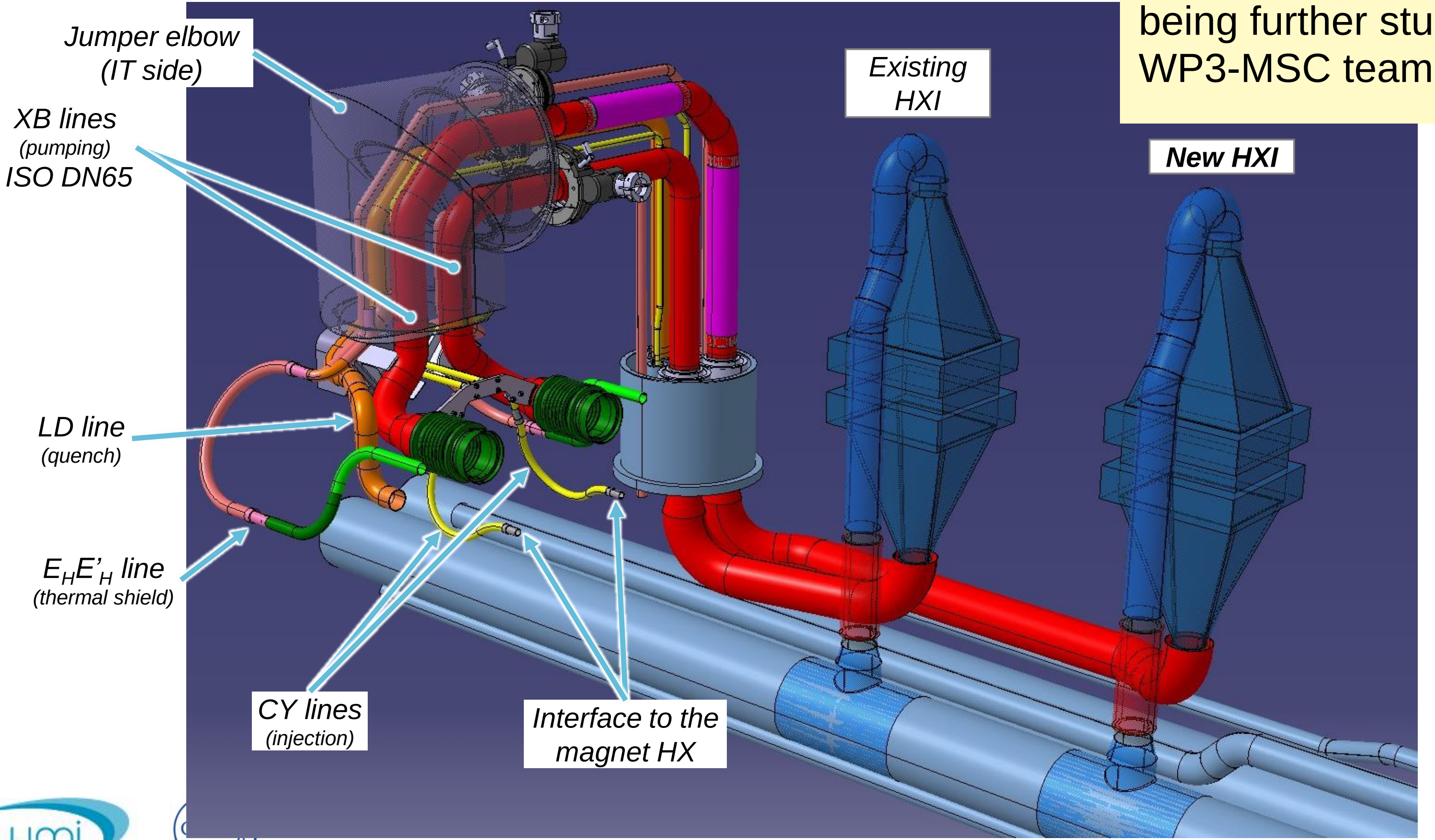




Study asked to original manufacturer (LHC, 20 yrs ago), now with modern numerical tools:
- Confirmed "jet" at inlet cone-HX
- possibility to shorten outlet cone

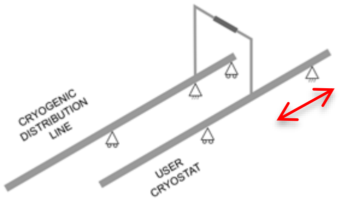
IT side: potential pipe routing

No show-stopper identified, being further studied with WP3-MSC team

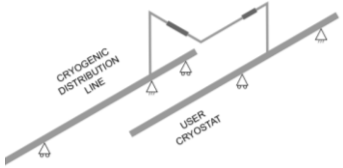


HL-LHC QXL Jumper Interfaces

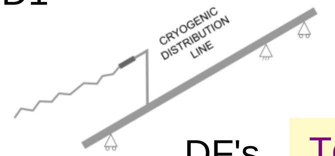
Baseline concepts



IT+D1



D2, CC

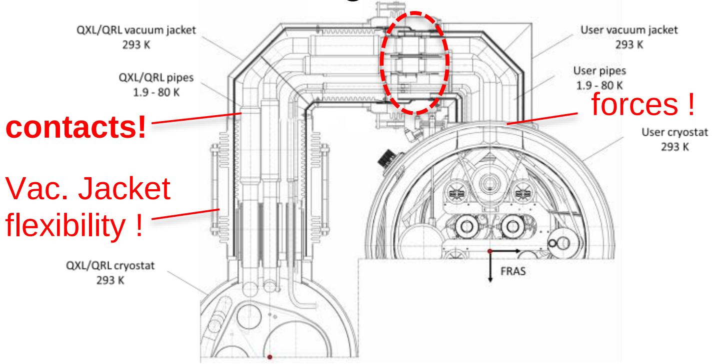


DF's

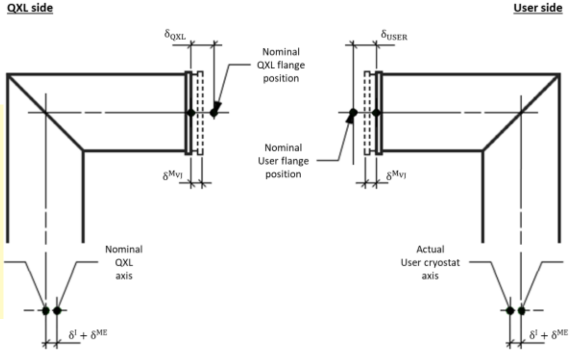
! thermal contractions !

Too many big pipes for required (longitudinal) adjustments,
+ Interconnection works?

Tentative design, **would not work !**



Tolerance & Alignment

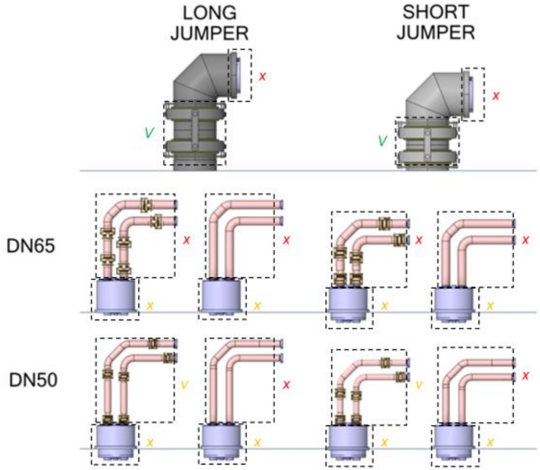


Current IT jumper design outcomes

- Pipes flexibility is a critical issue for all the configurations:
  - the use of DN65 lines does not allow to accommodate the design displacements.
  - the use of DN50 lines may allow to accommodate the design displacements using gimbals.
- Accessibility for the interconnection is a critical issue for all the configurations.
- Vacuum Barrier heat load is above the specification for all the configurations, but likely to be acceptable.
- VJ flexibility is not a critical aspect, but reaction forces are significantly above the specification:
  - review of margins with stakeholders is needed.
  - Could be mitigated using super soft bellows if needed.

ITEM	XB2 lines	VJ flexibility	Pipes flexibility		Vacuum barrier	Interconnection
			Hose	Gimbal		
Short Jumper	DN65	V[1]	X	X	V[3]	X
	DN50		X	V[2]		
Long Jumper	DN65	V[1]	X	X	V[3]	X
	DN50		X	V[2]		

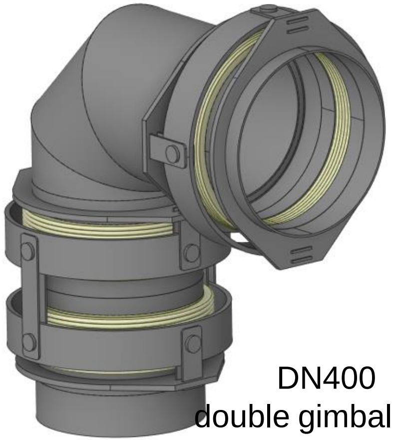
Notes:
1. Pending verification of acceptability of forces and moments on the magnet's cryostat
2. Very limited margins, high risk to loss margins with manufacturing tolerances.
3. Pending design optimization to avoid condensation. Design requirements to be confirmed.



New IT jumper design proposal

Baseline design

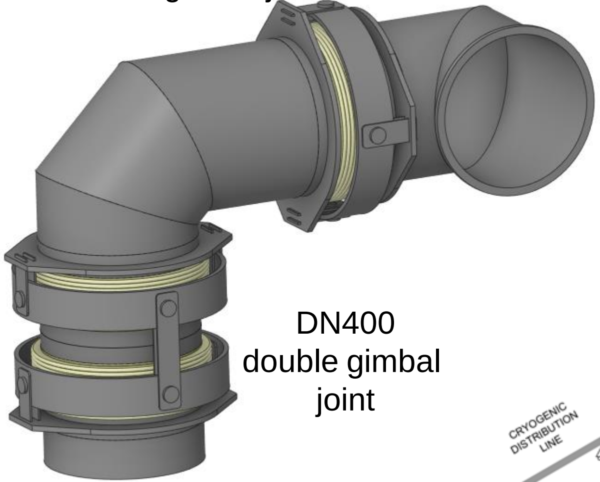
DN450
gimbal joint



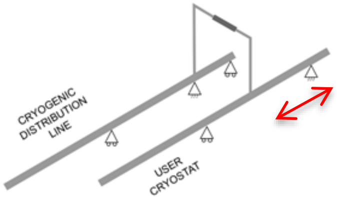
DN400
double gimbal joint

New design

DN400
gimbal joint



DN400
double gimbal
joint



IT+D1

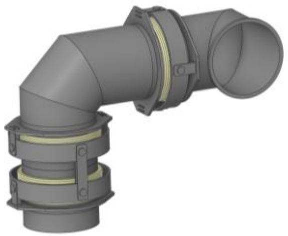
! thermal contractions !

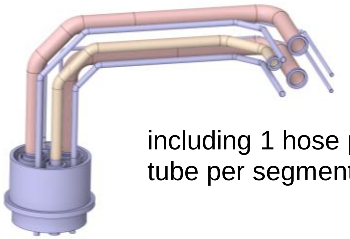
New IT jumper design outcomes

New design provides valuable solutions for:

- accessibility for the interconnection:
    - Different solutions can be envisaged
    - Final decision to be agreed with stakeholders
- pipes flexibility
    - Detailed verification to be performed

The design of the vacuum barrier is still to be optimized to meet the design requirements, but this is not considered a showstopper.





including 1 hose per tube per segment

ITEM	XB2 lines	VJ flexibility	Pipes flexibility	Vacuum barrier	Interconnection
Current Jumper	DN65	V[1]	X[2]	V[4]	X
New Jumper	DN65	V[1]	V[3]	V[4]	V

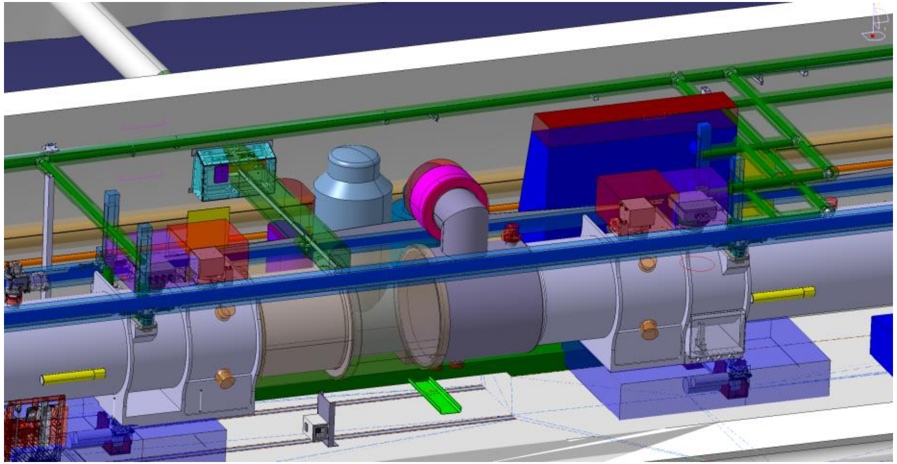
Notes:

1. Pending verification of acceptability of forces and moments on the magnet's cryostat.
2. Very limited margins, high risk to loss margins with manufacturing tolerances.
3. Pending detailed verification.
4. Pending design optimization to avoid condensation. Design requirements to be confirmed.

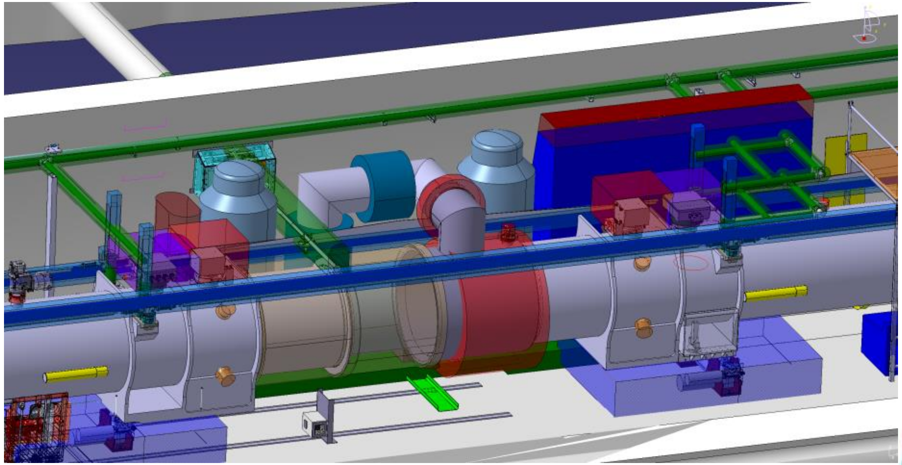
To be completely checked with WP3 team for feasibility & impact

QXL Service Module in front of Q2B example

Baseline



towards alternative proposal



Feasibility of integration probed, mostly impacts with survey tubes/wires, not easy but no serious showstopper so far

Technical interfaces, way forward

- An alternative design double HX and jumper identified in order to:
  - Avoid limitations in cryo circuits (capacity, pressure drop) to match "installed local capacity"
  - Ensure proper distribution of LHe in both bayonets in parallel
  - Allow mechanical design of process pipes and vacuum jacket in jumpers
  - Provide feasible volume for interconnection work (activity not yet allocated, or to be confirmed)

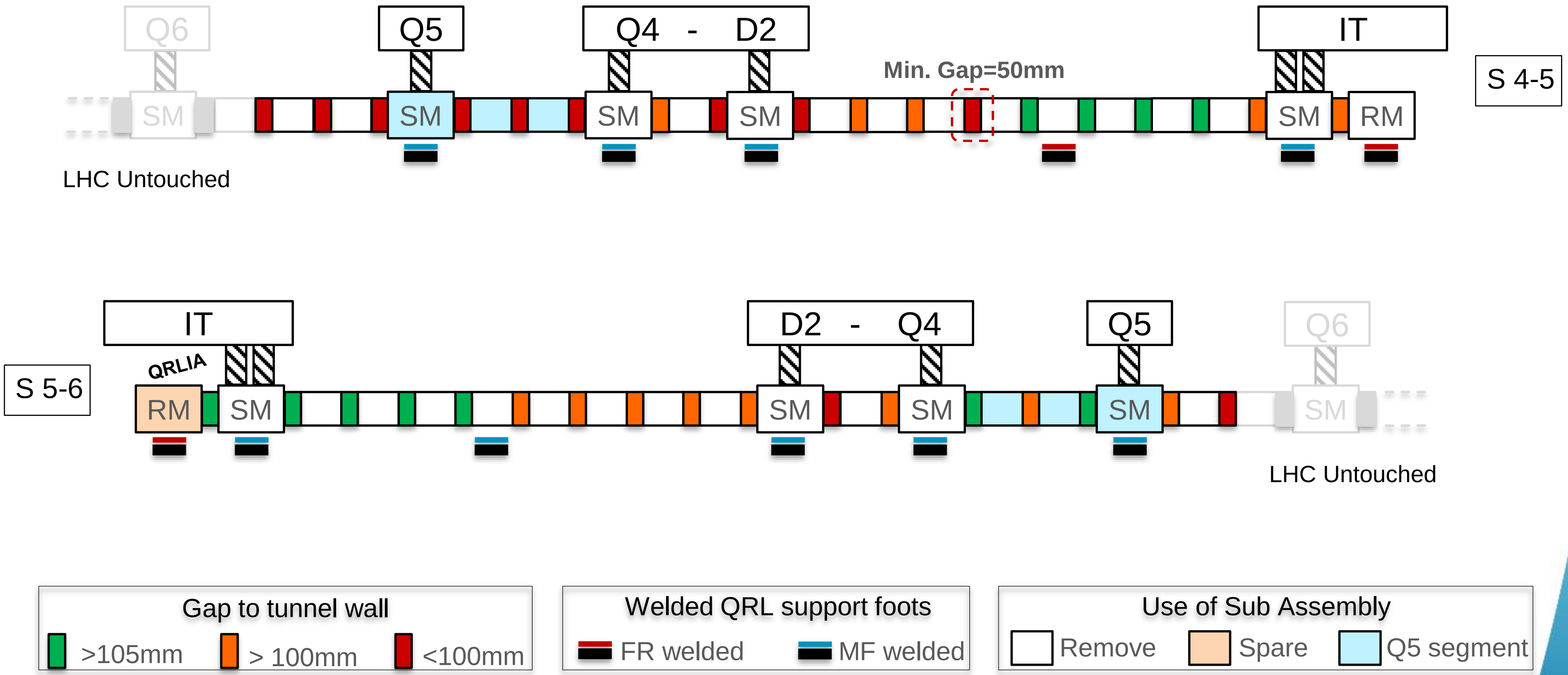
- If supported, to be further reviewed with WP3-cryostat and WP15-integration, to allow establishment of an ECR

  (for completeness, detailed study to be done for D2 and CC's,
  does not appear as critical due to extensions already in baseline)

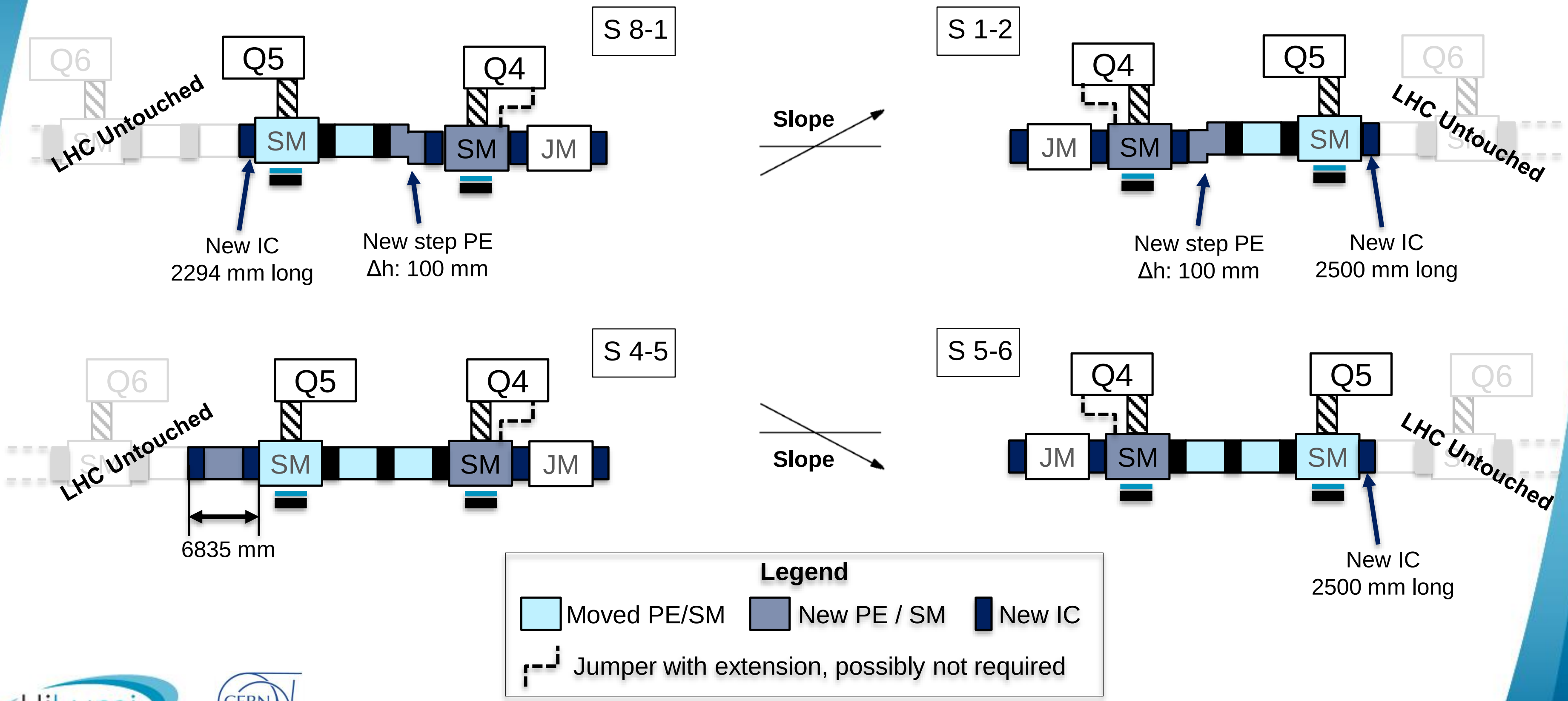
- DFX-DFM jumpers: request received to shorten-lower them: will be studied, with no assurance so far considering work done for IT+D1...

- Recent identification of a possible cooling limitation between D1 and DFX_plug area, being investigated

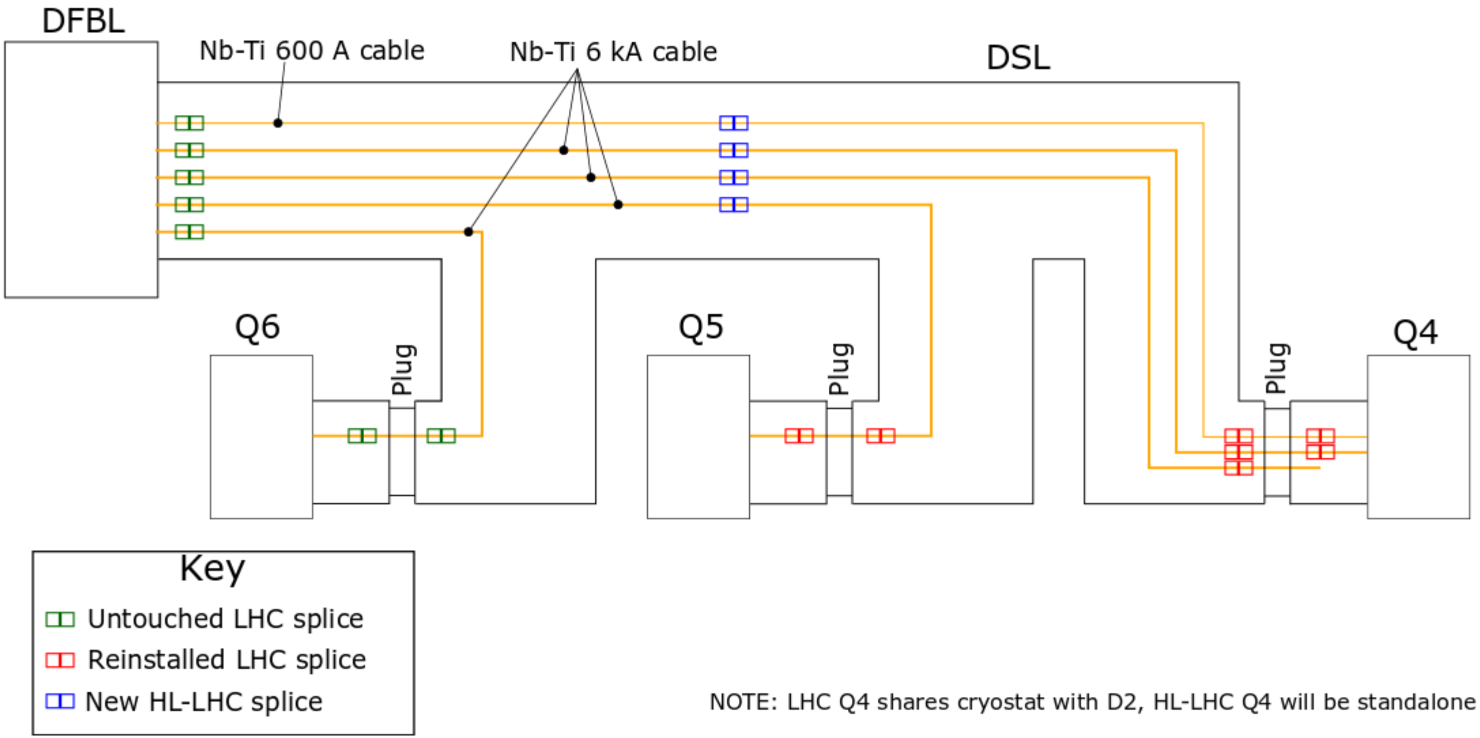
QRL Dismantling Constraints P5



QRL – HL-LHC Configuration



DSL Schematic

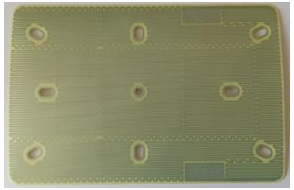


NOTE: LHC Q4 shares cryostat with D2, HL-LHC Q4 will be standalone

Radiation tests and check at cryolab, IFS (no) crosstalk verification, connector/pin count & list

Irradiation tests performed at external facility (Expected 1.5 MGy, tested OK up to 5 MGy)

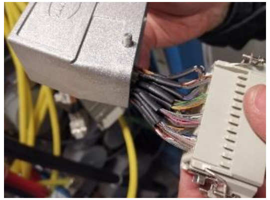
Industrial electrical heater



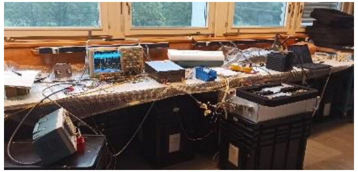
CERN designed flex heater

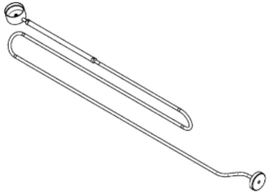
Connector bodies

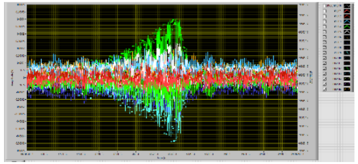
Electrical heaters tested with LN_2 before & after irradiation (>30 thermal cycles, 2 days testing)



~2500 connectors and 25000 pins needed to acquire the signals







Electronic cross-talk measurements inside IFS tubes (3403 mm) .
Impact of EH PWM mode on Voltage-taps

Instrumentation laboratory - Temperature sensors
Electronic designs and production

CERNOX instrument laboratory

CERNOX sensors
assembled and wired on blocks

Electronic cards production needs:

- 700 x Temperature/Pressure
- 130 x Electrical heater
- 100 x Liquid helium level
- 50 x Communication
- 40 x Power
- 50 x Regrouping cards
- 50 x Digital input/output cards
- 40 x Crates

140 kCHF of component have been ordered.
Dedicated storage area and database ongoing.

Long block

Short block

As defined Dec'21

WP9-Cryo Goals 2022

- BA6 & P4+: continued smooth operational results, performance & availability

- Heat extraction revisited, first lessons learned from prototype & pre-series (MAG, Cav, DF-DH)
- Dynamic simulations (CD, WUP, Qch, ...) revisited

- Refrigerators: Contract signed (mid'22) and PDR passed
- Distribution: Contract signed (mid'22) and PDR passed at least for Ph1 (UR's)

- QRL+DSL dismantling/refurbishment: From preliminary studies to Tech Specs for tender
- Piping and tanks: From studies to tendering in 2022, possibly FC passed

- CERN supplied items (Qch_V, QXL_HX, CL_V): From studies to tendering in 2022
- Instrumentation (tunnel): defined (sensors to feedthroughs), ready for batch deliveries
- Cabling & controls: From concept to preliminary studies with reinforced CRG-IC

Dynamic team fully committed, re-inforced for contract follow-up, with multi-years goals towards LS3!!!