Cryogenic functionalities of the Hollow Electron Lenses project

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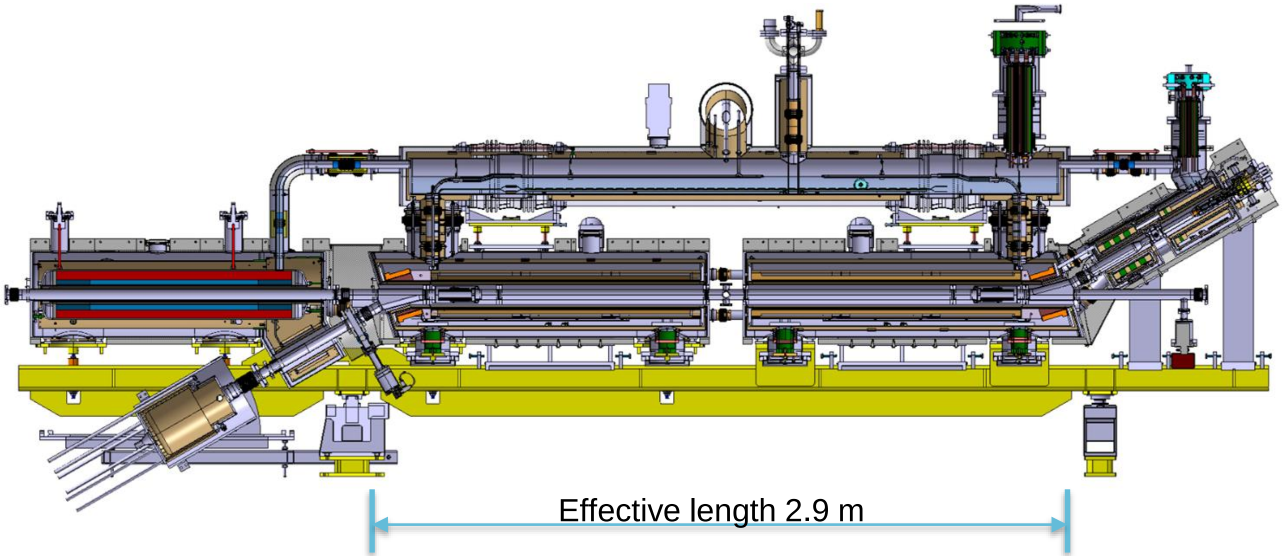
Agenda

The agenda will be:

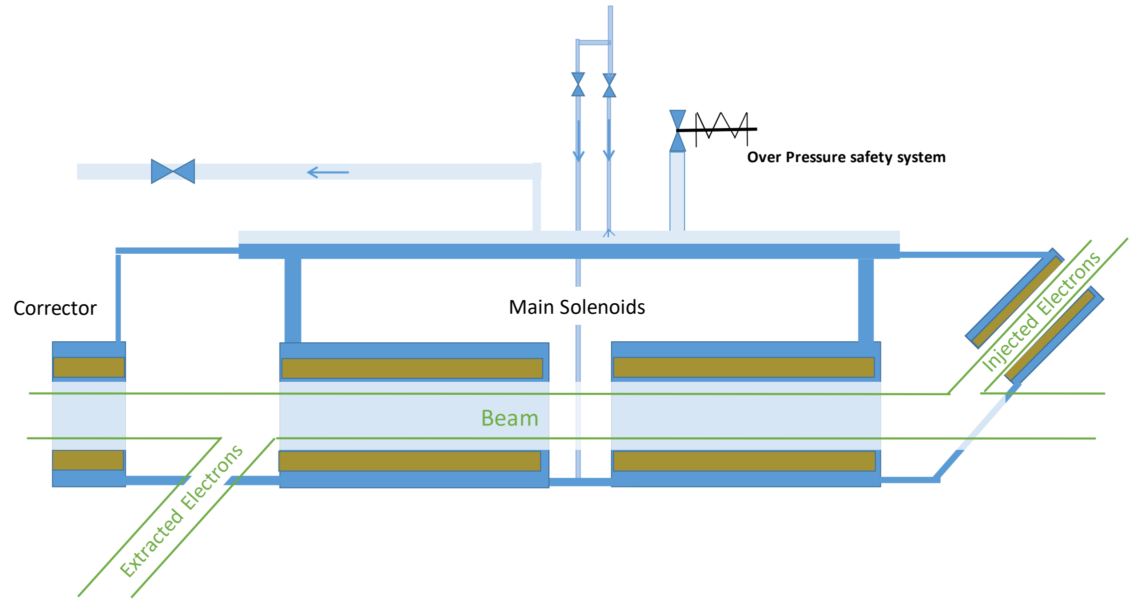
- Description, PFD
- Functional parameters of the supply lines
- Operating modes , functional parameters, hydraulic interfaces
- Protection against overpressure & ODH consideration
- Update of the feasibility study done for the SM at P4
- Pre-definition of the instrumentation
- Summary of the “Review of the HEL magnet system”

WP9 meeting, HEL project

The two HEL cryostats intend to be installed symmetrically at IP4, one per beam, in-between RF and D3 as shown in Figure 1-Location of the HEL, IP4



Cryogenic system is constituted of 4 individual cryostats associated by a phase separator link on the lower part and a gas collector at the upper part



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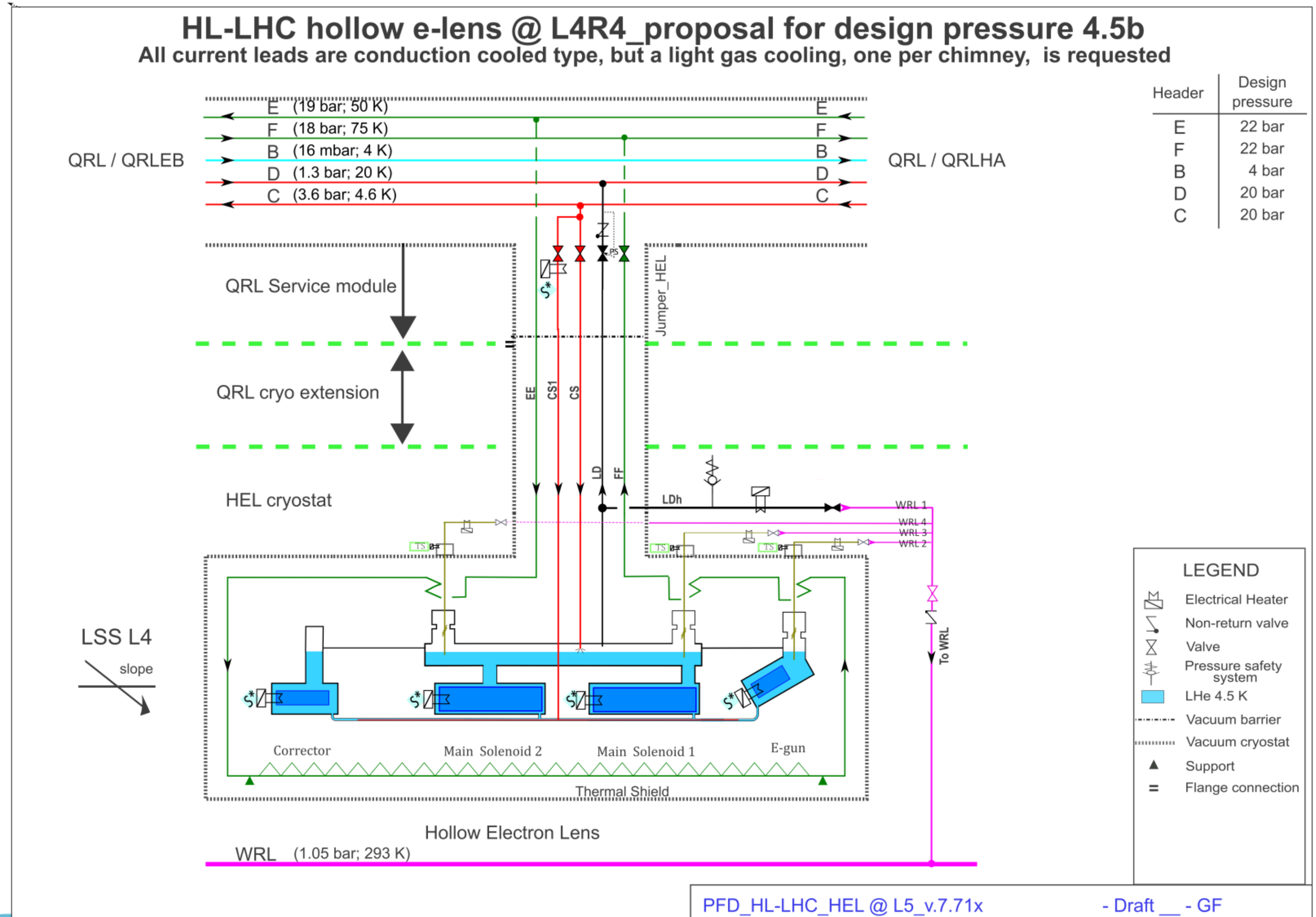
Process & Flow diagram of the HEL cryogenic system, last revision



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- The LHC QRL cryogenic line will supply the Hollow e-lens at IP4

Nominal parameters of the LHC QRL						
Line	Function	Nominal pressure [bar]	Nominal temperature [K]	Pressure range [bar]	Temperature range [K]	Design pressure [bar]
C	LHe supply	3.5	4.5	0-20	4.2-300	20
D	GHe return	1.25	20	0-20	4.2-300	20
E	Shielding supply	18.5	70	0-20	70-300	22
F	Shielding return	17.5	80	0-20	70-300	22

- The first baseline of the project HEL was to use PN20 as design pressure similar to the other 4.5 K cryostat installed in the LHC.
- For mechanical purpose, the project team has considered to decrease the 20 bar design pressure to PN 4.5 bars
- This PN 4.5 bars avoid helium spilling in the tunnel during quenching. Helium spilling in tunnel will exceptionally occur while a HEL quench or vacuum insulation incident happens in parallel with header D overpressure.

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The HEL system will have the following operating modes.

- Purging of the cryogenic circuits
- Cooling down
- Cold stand-by (magnets not powered) at 4.5 K
- Nominal operation at 4.5 K
- HEL Solenoid quench recovery
- HEL Solenoid quench & Major issue on LHC side
- LHC cryomagnets quench with back pressure of QRL line D
- Degraded cold stand-by at 20 K during technical stop
- Warming-up

The operation modes are summarise in the Operational modes table

mode	Cryostat parameter				Cold return parameter			Warm return parameter							Comments
	Pressure	Temperature	Mass flow	Heater line CS1	Pressure	Temperature	Mass flow	Pressure	Temperature	Mass flow	EH891	EH892	EH893	EH894	
	[bara]	[K]	[g/s]	[W]	[bara]	[K]	[g/s]	[bara]	[K]	[g/s]	[W]	[W]	[W]	[W]	
Cooling down 300/20 K	1.3	300/20	3	4500/0	1.25	300/20	0	1.25	293	3	< 4500	< 25	< 25	< 25	
Filling & Cold stand-by @ 4.5K	1.3	4.5	6	0	1.25	4.5	6	1.25	293	0	0	< 25	< 25	< 25	
Nominal operation 4.5K	1.3	4.5	1	0	1.25	4.5	0.7	1.25	293	0.3	< 4500	< 25	< 25	< 25	
HEL Solenoid quench recovery	1.3	4.5	6	0	1.25	4.5	6	1.25	293	0	0	< 25	< 25	< 25	
HEL Solenoid quench & no back pressure	4.8	7	0	0	4.8	7	2400	4.8	293	0	0	< 25	< 25	< 25	Safety valve openned
HEL Solenoid quench & back pressure	4.8	7	0	0	na	na	0	4.8	293	3	< 4500	< 25	< 25	< 25	WRL only, no flow to QRL
Operation with LH C quench	1.3	4.5	1	0	na	na	0	1.25	293	1	< 1500	< 25	< 25	< 25	WRL only, no flow to QRL
Degraded cold stand-by at 20 K	1.3	20	1	0	1.25	21	1	1.25	293	0	0	< 25	< 25	< 25	
Warming-up	1.3	20/300	3	0/4500	1.25	20/300	0	1.25	293	3	< 4500	< 25	< 25	< 25	

The functional parameters of the HEL cryostat are summarized in the table below

Functional parameters of the HEL cryostat								
Line	**Function**	**Nominal pressure [bar]**	**Nominal temperature [K]**	**Pressure range [bar]**	**Temperature range [K]**	**Design pressure [bar]**	**Nominal mass flow [g/s]**	**Maximum mass-flow [g/s]**
EE	Shielding supply	18.5	70	0-22	50-300	22	10	15
CS1	Cooling down supply	1.25	4.5-300	0-4.5	4.5-300	6	3	4
CS	Liquid supply	1.25	4.5	0-4.5	4.5-300	6	1.5	3
LD	Cold gas return	1.25	4.5-20	0-4.5	4.5-300	6	1.5-3	2400/3000
FF	Shielding return	17.5	80	0-22	50-300	22	10	15
LDh	Gas return to SV or WRL	1.25	4.5-300	0-5	4.5-300	6	0	2400/3000
WRL 1	Gas return to WRL from cyostat	1.25	293	0-4.5	250-300	6	0	10
WRL 2	Gas return to WRL from tower 2	1.25	293	0-4.5	250-300	6	0.1	1
WRL 3	Gas return to WRL from tower 3	1.25	293	0-4.5	250-300	6	0.1	1
WRL 4	Gas return to WRL from tower 4	1.25	293	0-4.5	250-300	6	0.1	1

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The piping interface of the HEL connection to QRL interface are summarized in this table.

QRL Service module							***Service module extension***			***Interface HEL cryostat***		
Valve			***other***				***Line***			***Line***		
Connexion to QRL header			other component to add									
Header	DN valve	Kv (estimation)		DN	Kv estimation	PN	Line	DN line	PN	Outer diam	Inner diam	DN
C	10	0.4	*na*			20	CS	10	20	17.2	14	10
C	15	2	Heater 5 KW	tbc	na	20	CS1	15	20	26.9	23.7	20
D	50	70	Check valve	50	100	20	LD	65	20	76.1	72.1	65
E	*na*	*na*	*na*			22	EE	15	22	*13.5*	*10.3*	*8*
F	15	5	*na*			22	FF	15	22	*13.5*	*10.3*	*8*

Subject to final configuration

To be adjusted

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Protection against overpressure considerations

- **Loss of vacuum insulation**

Parameters are: cold surface around 13 m^2 protected by a minimum of 15 MLI layers, with a safety valve set at 4.5 bara

According to ISO21013, the mass flow will be lower than 3 kg/s at a temperature of 7 K.

This mass flow match to a vacuum damage equivalent of Φ 30/35 mm in the vacuum envelope.

The flow will be evacuated to header D if the QRL is under nominal conditions **or** to the cryostat pressure relief devices. See ODH assessment

- **Back-filling of the cryostat**

In case of LHC cryomagnet multiple quenches, the QRL header D could be pressurised up to 6 bara. The HEL cryostat could not accept more than 4.5 bara and will be protected by a check valve and an automatic interlock on the valve CV935 (Pressure switch).

Protection against overpressure considerations

- **Quench**

According to the HEL_technical Note_13-09-2021 (P. Tavares), the maximum mass flow to treat will be 2.4 kg/s @ 4.85 bara /7 K

Most likely, the cryomagnet will quench with the cryostat connected to QRL-header D. The sizing of the line LD from HEL cryostat to QRL-header D is sufficient to keep the maximum pressure of the cryostat below 4.5 bara and consequently avoid helium release in the tunnel.

Least likely, the cryomagnet will quench with the cryostat not connected to QRL-header D. In this case, the pressure safety devices installed on the cryostat will extract the inventory to tunnel .

ODH assessment: The total helium inventory is in the range 40 kg of helium in the cryostat similar with neighbouring DFBA or one RF cryostat. Provided than HEL cryostat is used with DFBA like procedures, there will be no direct ODH risk linked to helium for a similar helium enclosure.

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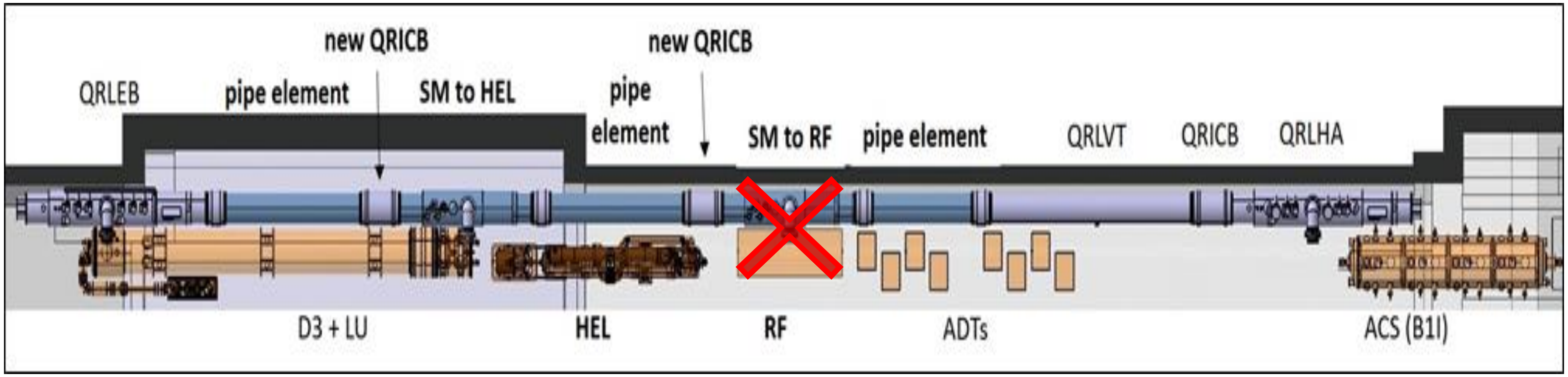
Update of the feasibility study done for the service modules at P4

We refer to the feasibility study done in 2018, solution 4 defined in chapter 5.6 of the document https://edms.cern.ch/document/2061800.

- The update incorporates the abandonment of the RF cryostat



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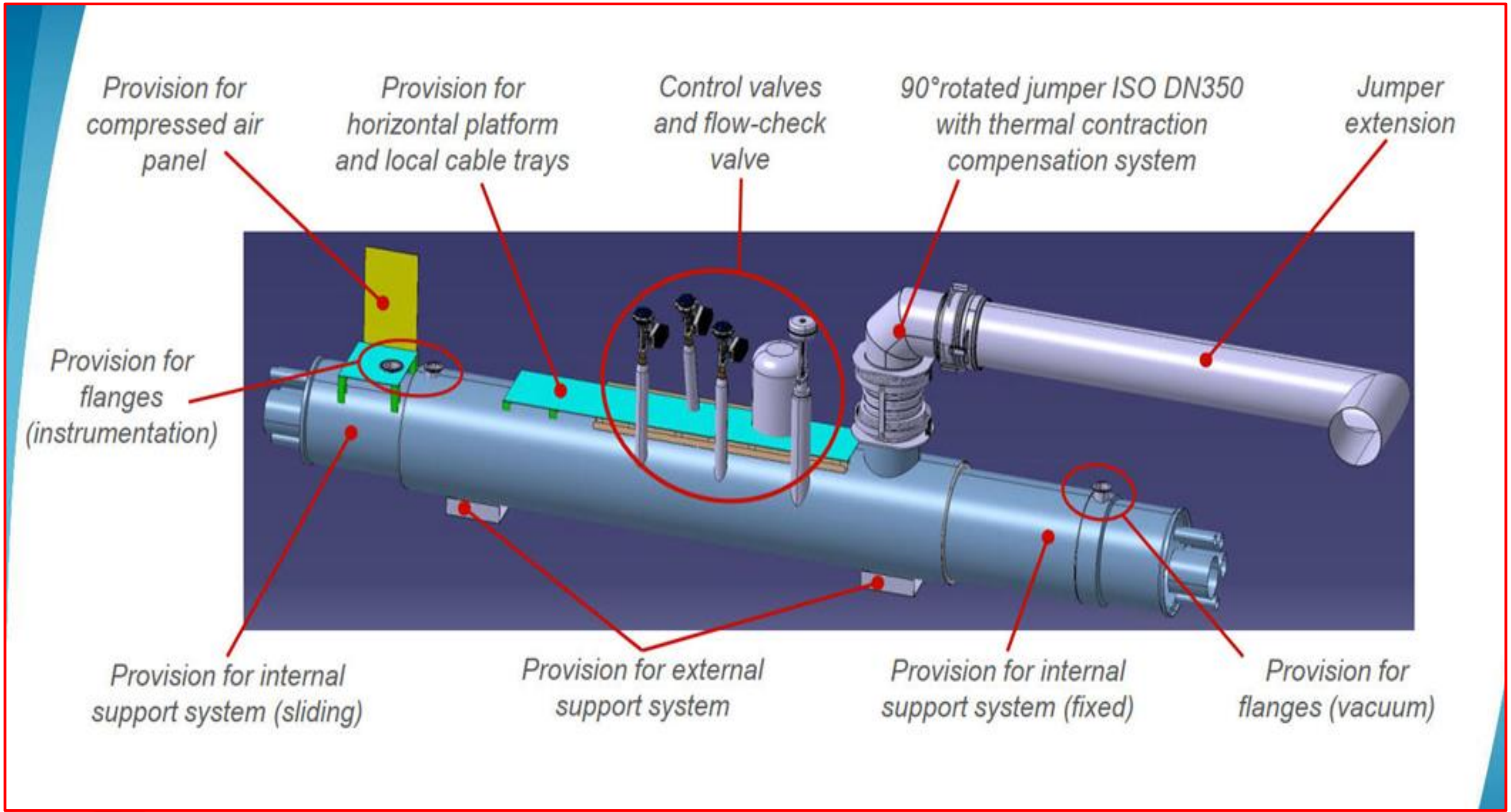
An updated feasibility study has been generated by TE-CRG design office with the same standard as used for P1-P5 QXL feasibility study, study including adequate sizing of the service module, 3D model & installation study. Please refer to (SISTI M.)



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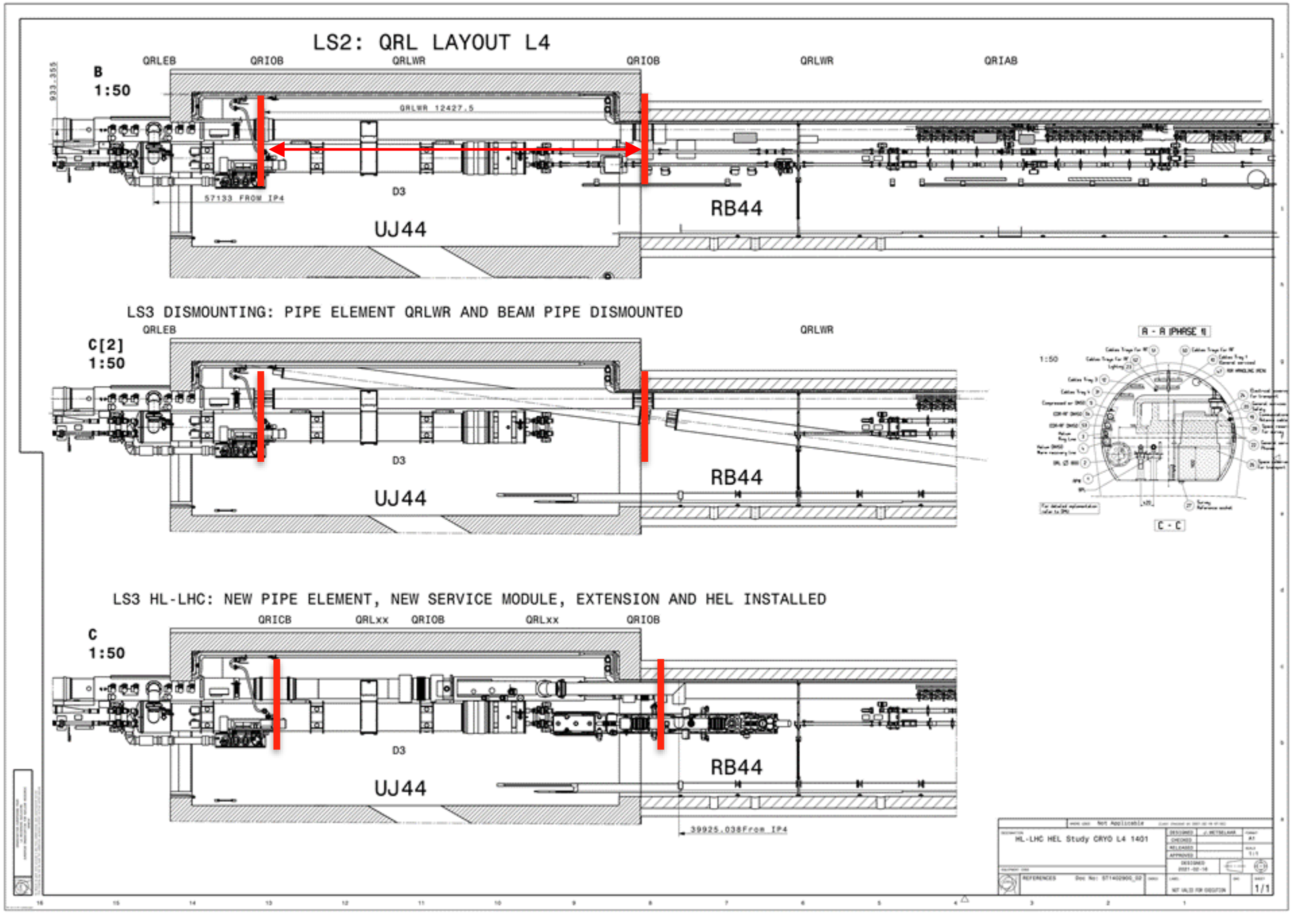
Cryo support team has launched a study to install service modules The Figure below (illustration for IP4L) validate the service module installation without displacing the D3 cryomagnet using the standard handling margins



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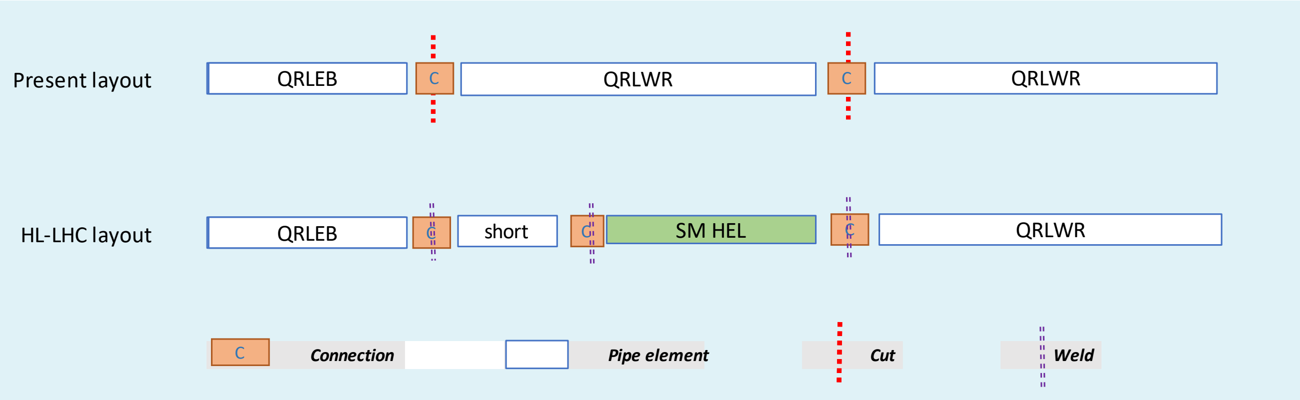
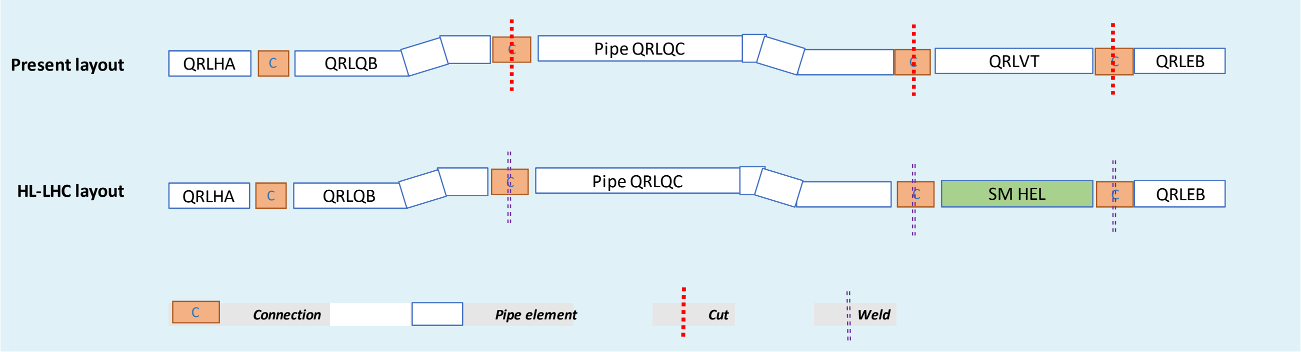
The above QRL IP4L layout shows the final configuration layout proposed with the new service module dedicated to the HEL cryostat and a new short pipe element needed to fit with the QRL hardware already installed.



A similar study has been created for the IP4R



The transport team has endorsed the method proposed for handling the QRL elements during the disassembly and for the reinstallation

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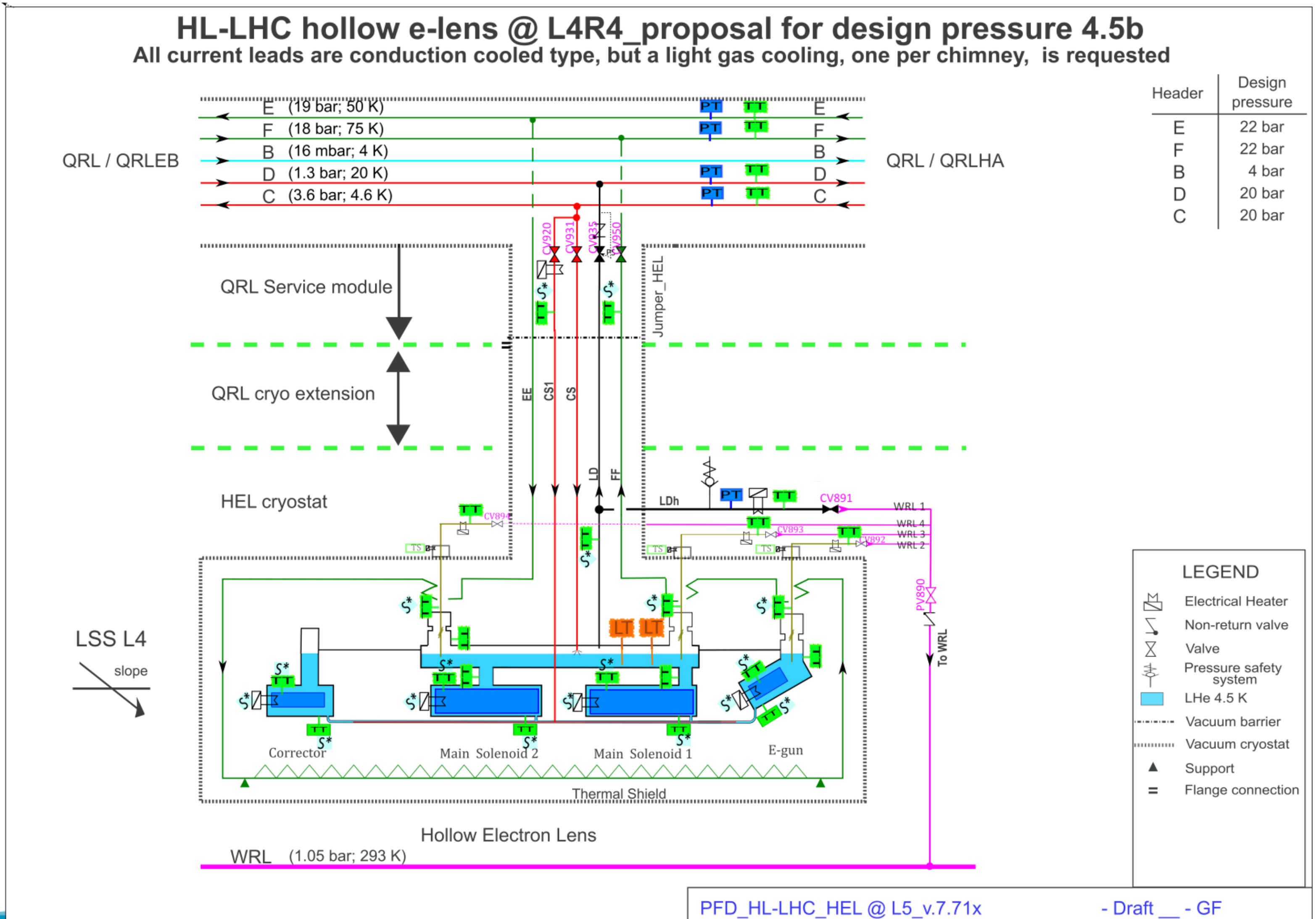
The cryogenic instrumentation necessary for the HEL project shown in PFD



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The pre-defined cryogenic instrumentation list necessary for the HEL

	Use	Abbreviation	Working range	Max range	Component considered	type of sensor	use foreseen	specific status	nominal Quantity for 1 system	measurement channels	nb active system	nb of spare system	Quantity components (spare included)	Quantity active channels
	Heater foils for cold mass	EH	50 W	50 W	50 W	Vacuum	Control, Wup		8	4	2	1	24	8
	Temperature sensor magnet	TT	4-300 K (Cernox)	330 K	Magnet	Liquid	Control, filling	not calibrated	8	4	2	1	24	8
	Temperature sensor for cryostat	TT	4-300 K (Cernox)	330 K	Cryostat	Gas	Control, filling	not calibrated	8	4	2	1	24	8
	Temp sensor for filling & lower level control	TT used also as LT	4-300 K (Cernox)	330 K	Cryostat	Liquid	Information	not calibrated	4	4	2	0	8	8
	Lhe level Sensor	LT	200 mm	200 mm	200 mm	immerged	Control		2	2	2	1	6	4
	Pressure Sensor	PT	0-5 b	25 b	25 b	surface, room temp	Control, Diag		1	1	2	1	3	2
	Temperature sensor cold end used for CL control temp	TT	4-300 K (Cernox)	330 K	cold end current lead	Gas	Control, interlock	not calibrated	6	3	2	0	12	6
	Temperature sensor return line D	TT	4-300 K (Cernox)	331 K	line D	Gas	Control, interlock	not calibrated	2	1	2	0	4	2
	Temperature sensor return shielding line F	TT	4-300 K (Cernox)	330 K	Shielding, Jumper side	Vacuum	Control, filling	not calibrated	2	1	2	0	4	2
	Heater for current lead tower	EH	Standard LHC	?	Current lead tower	Surface contact (air)	Control		3	3	2	1	9	6
	Tower Top flange Icing prevention temperature switch	TSL or TT	~ 0 Celsius	330 K	Current lead tower	Surface contact (air)	interlock		3	3	2	0	6	6
	Heater for current lead exhaust	EH	Standard LHC	500 W	500 W		Control		3	3	2	1	9	6
	gas exhaust current lead temperature sensor used for temp control	TT	80-350 K (PT100)	350 K	CL pipe upstrem heater	Surface contact (air)	Control, interlock	not calibrated	3	3	2	0	6	6
	Heater for WRL exhaust	EH	80-350 K	5 kW	5 kW	Gas	Control		1	1	2	1	3	2
	Temp control of WRL exhaust	TT	80-350 K (PT100)	350 K	WRL exhaust	Surface contact (air)	Control, interlock	not calibrated	1	1	2	0	2	2
	Service Module heater	EH	5 kW	5 kW	Service module	Gas	Control, cooling down/Wup	Heather exchangeable	1	1	2	0	2	2
	Temperature sensor cooling down circuit	TT	4-300 K (Cernox)	330 K	Cooling down circuit Jumper side	Vacuum	Control, filling	not calibrated	2	1	2	0	4	2

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Summary of the “Review of the HEL magnet system” held 06 October 2021

The detailed agenda and presentations are available in the following Indico link.

R9: The review panel recommends working out a detailed description of the operation modes from the cryogenic point of view. Done

R10: It is recommended to carry out a cost-to-benefit analysis of doubling the cryogenic valves to enable cryogenic separation for safe standalone interventions on the HEL magnetic system (and possible installation e.g. during EYETS). The impact of doubling the cryogenic valves on the integration of the HEL system in the tunnel should also be studied (refer to R12). To be done

R11: An interesting alternative to classical cryogenics with forced flow of liquid helium through the magnets seems to be cooling of the HEL magnets by thermal conduction to the flow of helium in dedicated pipes. An additional interesting option is the use of cryocoolers. …. The review panel recommends performing analysis of the applicability and feasibility of these options for cooling the HEL magnet system. May generate new tasks for TE-CRG

R12: The review panel recommends performing more detailed integration study, particularly around the area of the QRL, taking account of the equipment to be added in the vicinity according to the cryogenic interface specifications (refer to R4). The requirements for possible interventions for all types of equipment, facilities and infrastructure located in the HEL zone and the requirements for transport space should be taken into account. Mainly for integration team, may generate new task for TE-CRG

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Summary

- All functional parameters, operating modes and hydraulic interfaces are now in a stable status.
- Overpressure studies and ODH safety assessment of the project are completed.
- The Update of the feasibility study, included dismounting, handling and re-installation are done for the two SM at P4.
- The pre-definition of the instrumentation is completed.

- The design and mechanical studies of the HEL project is now in a stable condition to allows the hands-over.

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References

SISTI, M. (n.d.). *EDMS 2061800.*

SISTI, M. (n.d.). *QRL 3D modelling for the HEL hands-off, no edms reference.*

TAVARES, P. (n.d.). *EDMS 2647154 v.1.*

Spare slide

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IPR4 study for removal/installation