HiLumi P1/P5, Cryogenic interfaces for sc links, DFX conceptual review

S. Claudet / A. Perin, 31Jan'19

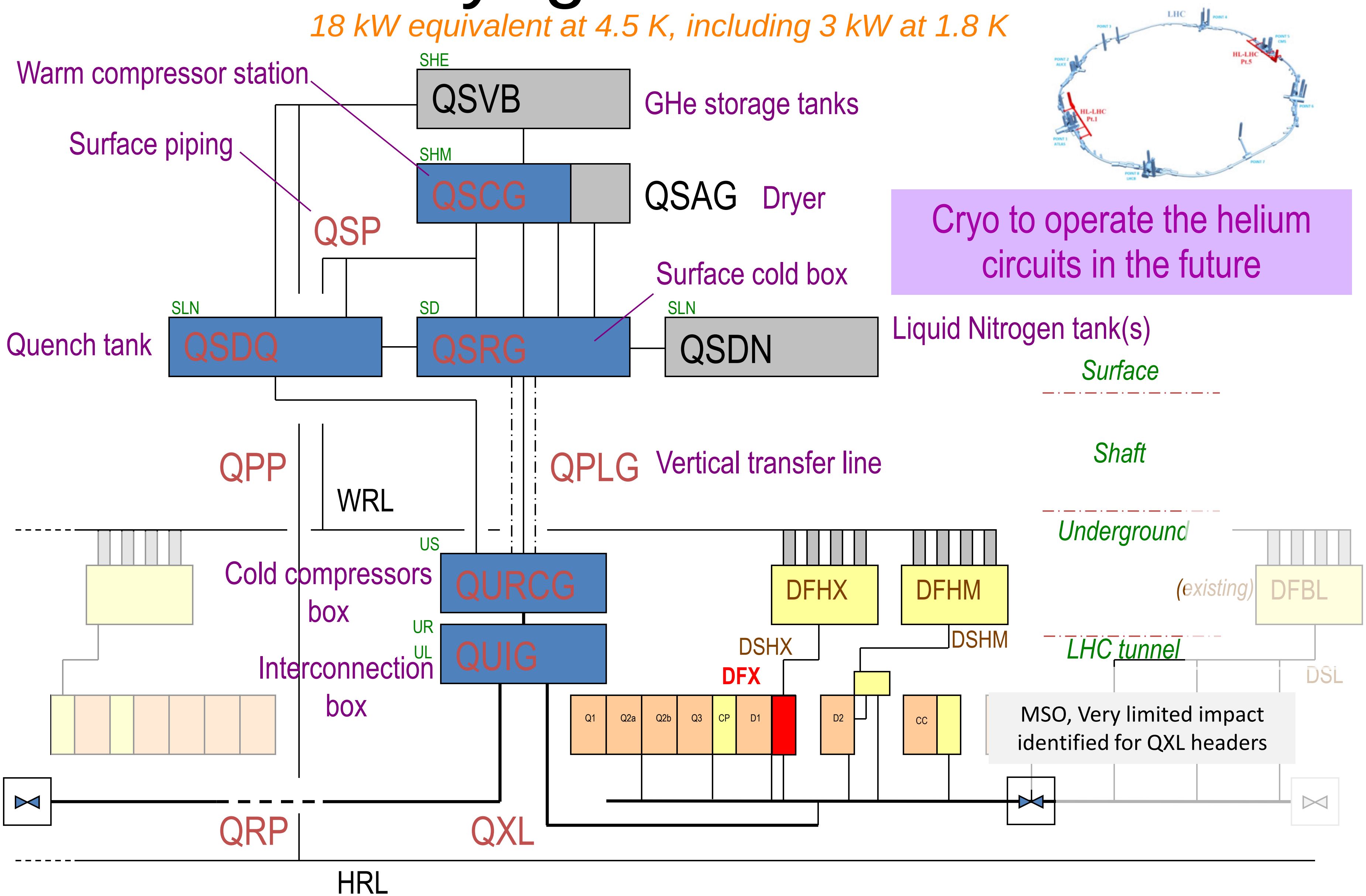
With contribution from: Michele Sisti, Jos Metselaar
(and before D. Berkowitz, U. Wagner)

Content

- Introduction (HiLumi cryogenics and sc_link cooling)
- Flow schemes
- Mechanical interfaces
- Instrumentation & controls
- Other cryogenic considerations
- Summary

P1/P5 Cryogenic architecture

18 kW equivalent at 4.5 K, including 3 kW at 1.8 K



HL-LHC refrigeration capacity at Points 1 & 5

About 18kW eq. @ 4.5K, including 3kW @ 1.8K

Preliminary global values, being revised

Temperature level	Cooling circuit	Specific heat load [W/m] (Static)	Capacity* / Point		Dynamic range
40-60 K	IT beam screen	16 (0)	3.2 kW	13 kW	~1.3
	Thermal shield	6 (6)	3.6 kW		
	Crab cavity	-	6 kW		
20-300 K	Current lead & SC link	-	40 g/s	40 g/s	~2
4.5-20 K	MS beam screen	2 (0.1)	0.1 kW	0.1 kW	~20
1.9 – 2 K	Cold-mass (1.9 K)	14 (0.35)	2.6 kW	3 kW	~10
	Crab-cavity (2 K)	-	0.4 kW		

**: Including uncertainty and design capacity factor*

HL-LHC refrigeration capacity at Points 1 & 5

Preliminary global values, being revised

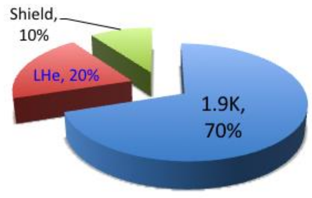
About ~~18kW~~ eq. @ 4.5K, including 3kW @ 1.8K

~12kW

Temperature level	Cooling circuit	Specific heat load [W/m] (Static)	Capacity* / Point		Dynamic range
40-60 K	IT beam screen	16 (0)	3.2 kW	13 kW	~1.3
	Thermal shield	6 (6)	3.6 kW		
	Crab cavity	-	6 kW		
~~20-300 K~~ 4.5-300K	Current lead & SC link	-	~~40 g/s~~ 20 g/s	~~40 g/s~~	~2
4.5-20 K	MS beam screen	2 (0.1)	0.1 kW	0.1 kW	~20
1.9 – 2 K	Cold-mass (1.9 K)	14 (0.35)	2.6 kW	3 kW	~10
	Crab-cavity (2 K)	-	0.4 kW		

**: Including uncertainty and design capacity factor*

The liquefaction load is the 2nd largest cooling capacity requirement (only for sc links + leads)

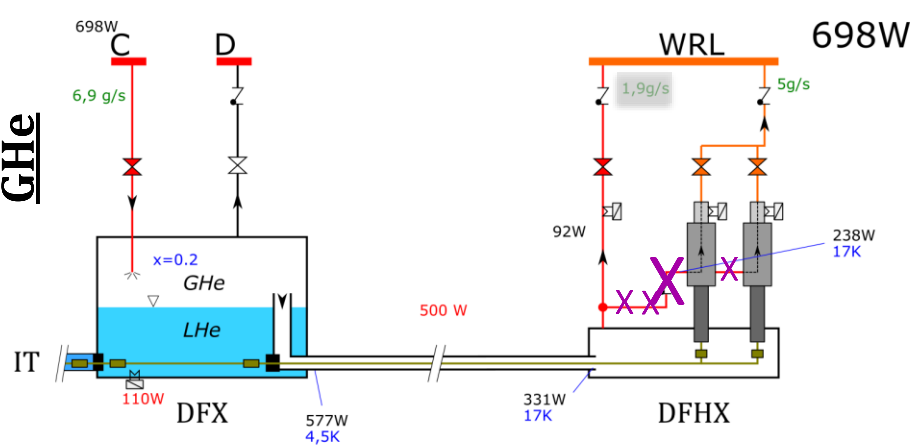


Cooling Variants

(without Thermal Shield)

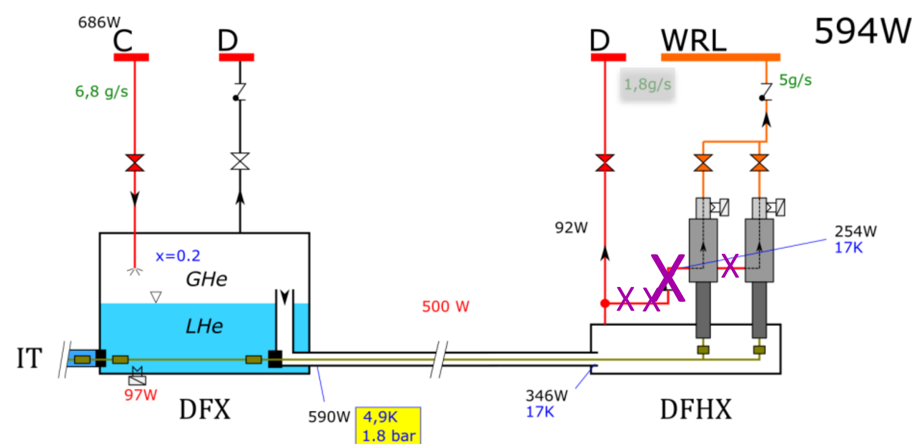
Legend:
[W@4.5]
[W]
T [K]
[g/s]

#3 **WRL only**



#4 **Extra Line D**

(for transients or specific needs)



HiLumi P1/P5, Cryo interfaces for sc links, DFX

Without thermal shield *(validated approach after successful tests at SM18 during 2018),*
the mass flow in the sc-link should only be driven by the current lead cooling flow,
For HiLumi configuration it will induce pure liquefaction load 4.5-300K

DFX requirements:

- MgB2-NbTi splices in LHe bath
- Generation of GHe mass-flow (for current leads)

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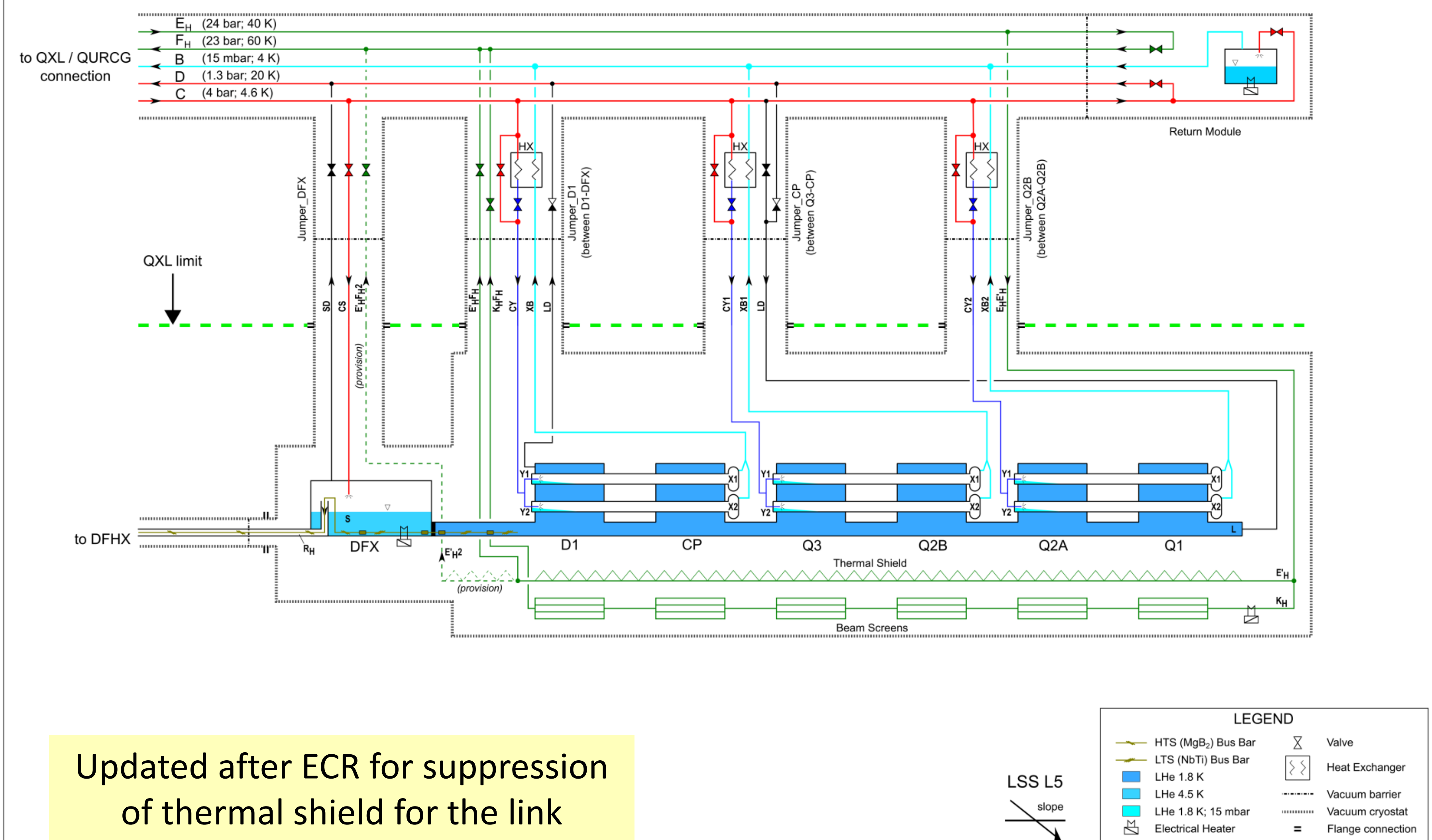
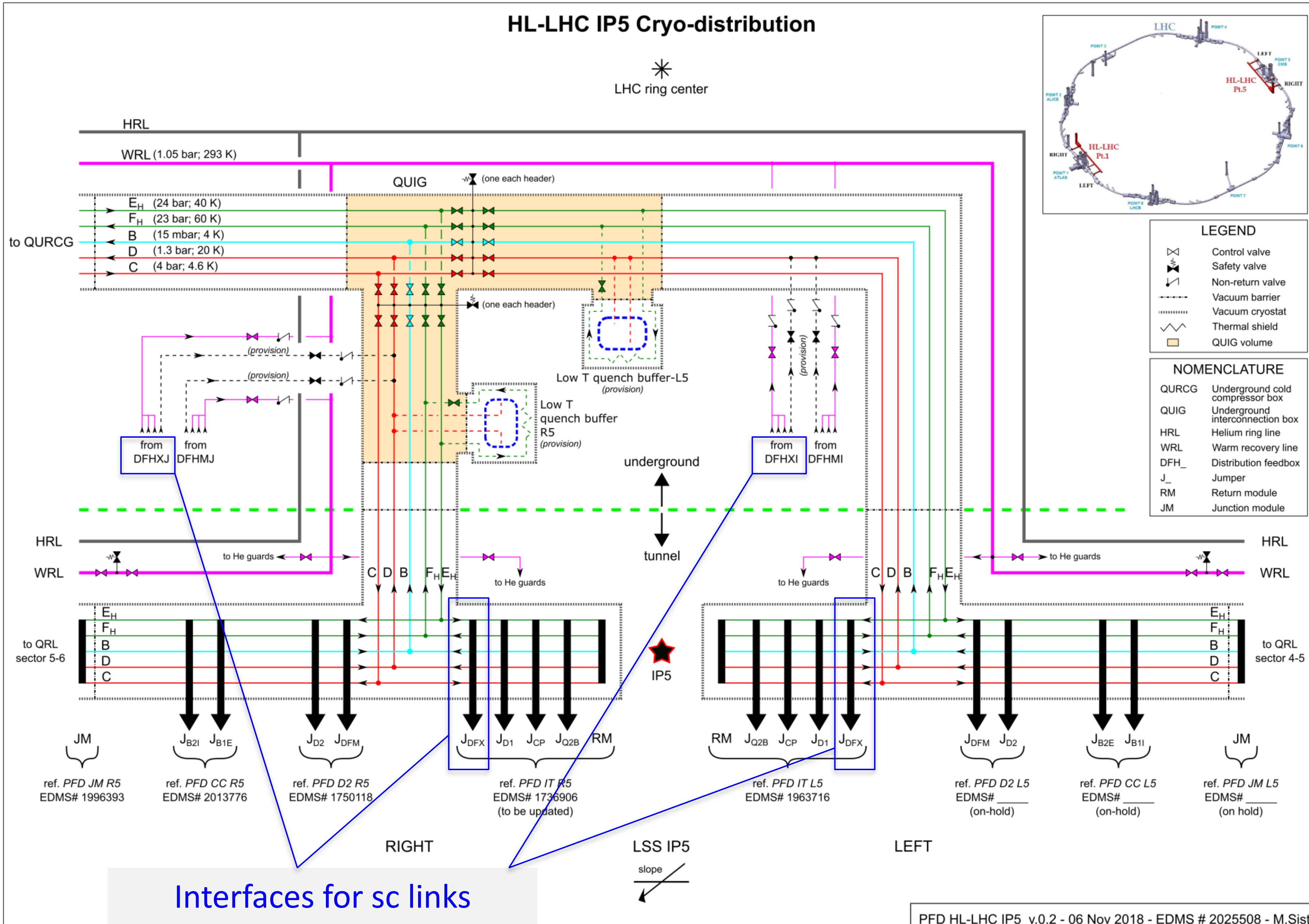
HL-LHC IT L5



Updated after ECR for suppression of thermal shield for the link

PFD HL-LHC IT L5_v.1.3 - 27 Aug 2018 - EDMS # 1963716 - M.Sisti


HL-LHC IP5 Cryo-distribution
LHC ring center
HRL
WRL (1.05 bar; 293 K)
QUIG
(one each header)
to QURCG
E_H (24 bar; 40 K)
F_H (23 bar; 60 K)
B (15 mbar; 4 K)
D (1.3 bar; 20 K)
C (4 bar; 4.6 K)
Low T quench buffer-L5
(provision)
Low T quench buffer R5
(provision)
from DFHXJ
from DFHMJ
from DFHXI
from DFHMI
underground
tunnel
to He guards
to QRL sector 5-6
to QRL sector 4-5
IP5
JM
RM
ref. PFD JM R5 EDMS# 1996393
ref. PFD CC R5 EDMS# 2013776
ref. PFD D2 R5 EDMS# 1750118
ref. PFD IT R5 EDMS# 1736906 (to be updated)
ref. PFD IT L5 EDMS# 1963716
ref. PFD D2 L5 EDMS# _____ (on-hold)
ref. PFD CC L5 EDMS# _____ (on-hold)
ref. PFD JM L5 EDMS# _____ (on hold)
RIGHT
LSS IP5
LEFT
slope
Interfaces for sc links
LEGEND
Control valve
Safety valve
Non-return valve
Vacuum barrier
Vacuum cryostat
Thermal shield
QUIG volume
NOMENCLATURE
QURCG Underground cold compressor box
QUIG Underground interconnection box
HRL Helium ring line
WRL Warm recovery line
DFH_ Distribution feedbox
J_ Jumper
RM Return module
JM Junction module
PFD HL-LHC IP5_v.0.2 - 06 Nov 2018 - EDMS # 2025508 - M.Sisti

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Cryogenic interfaces with DFX

Conceptual aspects – Boundary condition – Design input constraints

- Jumper interface (vacuum barrier at QXL side)

Not yet studied,
Should not be critical

=> Consideration of thermal contraction of cold tubes entering a user to be clarified and validated with concerned user

- Cable extremity as it would arrive to DFX, with in particular:

- Flange/weld/free, need for a fixed point or for a Vacuum barrier ?

- Positioning of splices in vertical axis as a reference for LHe control ?

- Need to protect splices with a priori a cylindrical shape (cross section holes for GHe escape to link to be checked for hydraulic impedance)

- Distance between MgB2/NbTi splices and sc-link He jacket extremity: to be minimised or could be extended (sizing t.b.c)?

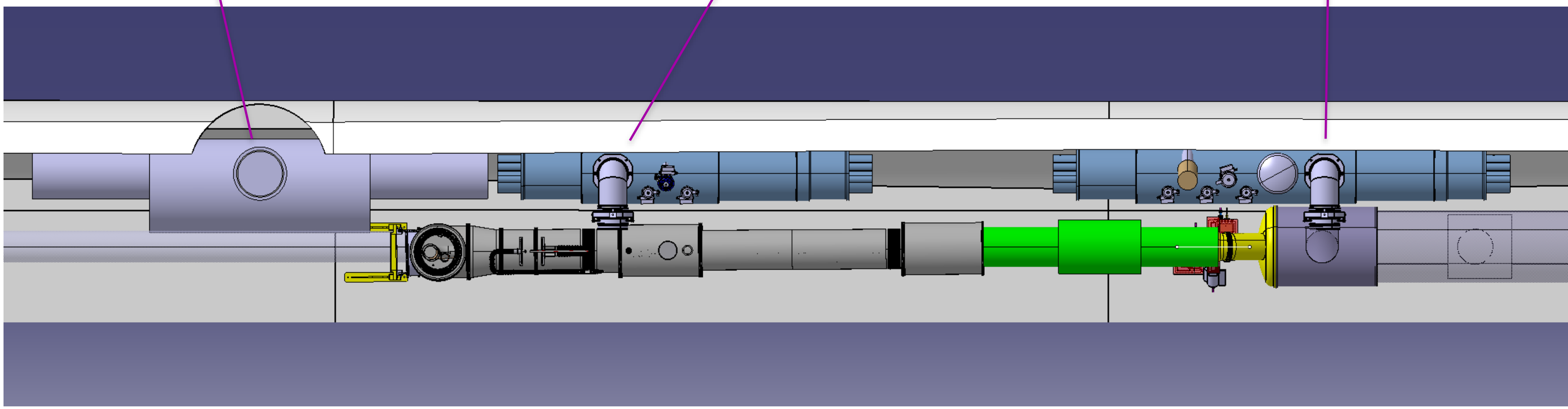
LHe-GHe zone being formalised,
should not be critical

Conceptual 3D models

T piece
(from gallery above)

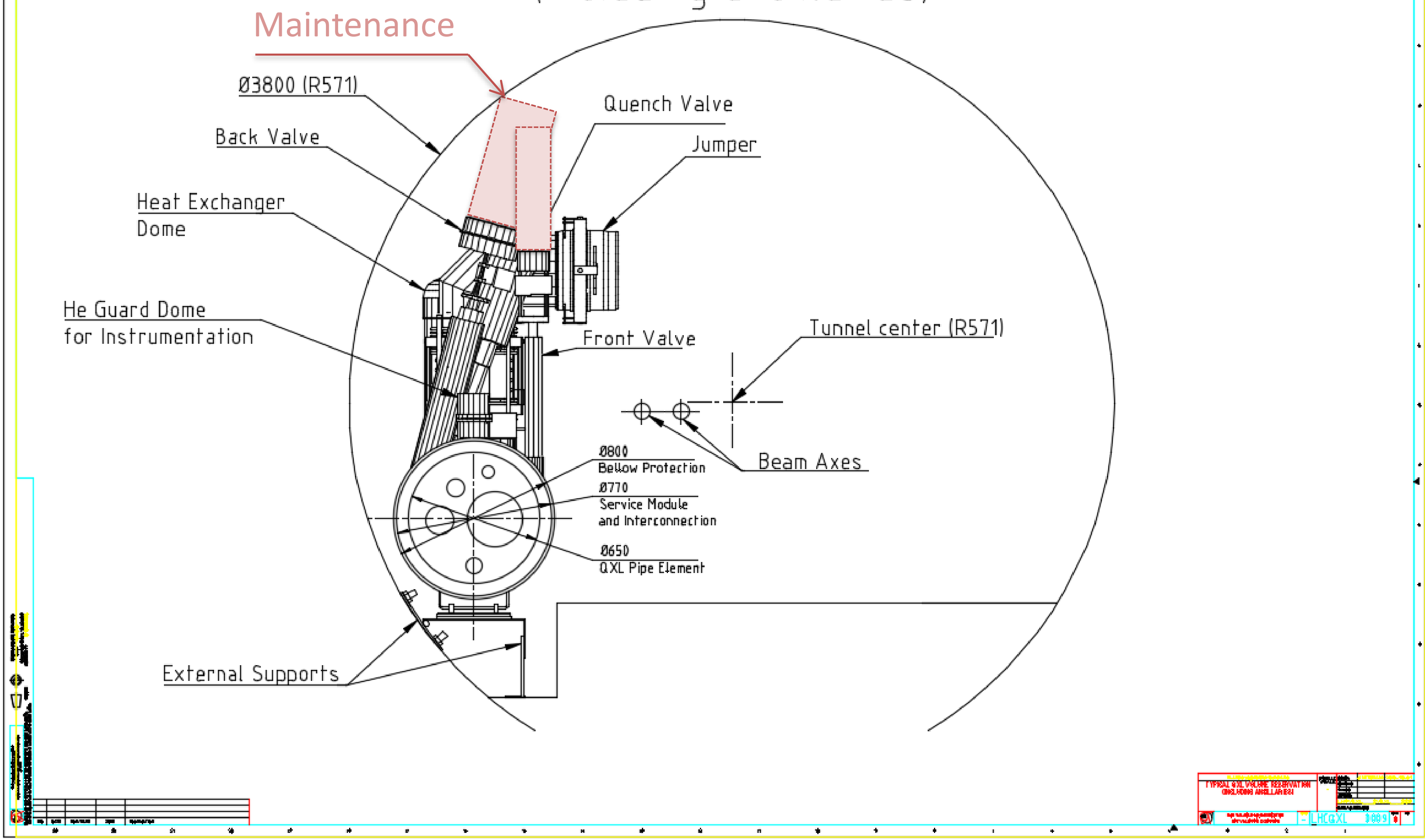
Service Module for DFX
(2.5m freedom longitudinally)

Service Module for D1
(Perpendicular to beam axis)



Complete integration studies on-going, considering as well:
- Access for interventions/maintenance
- Doses for material
- Doses for personnel *(for some pre-defined scenarii)*

Typical QXL Volume Reservation (including ancillaries)



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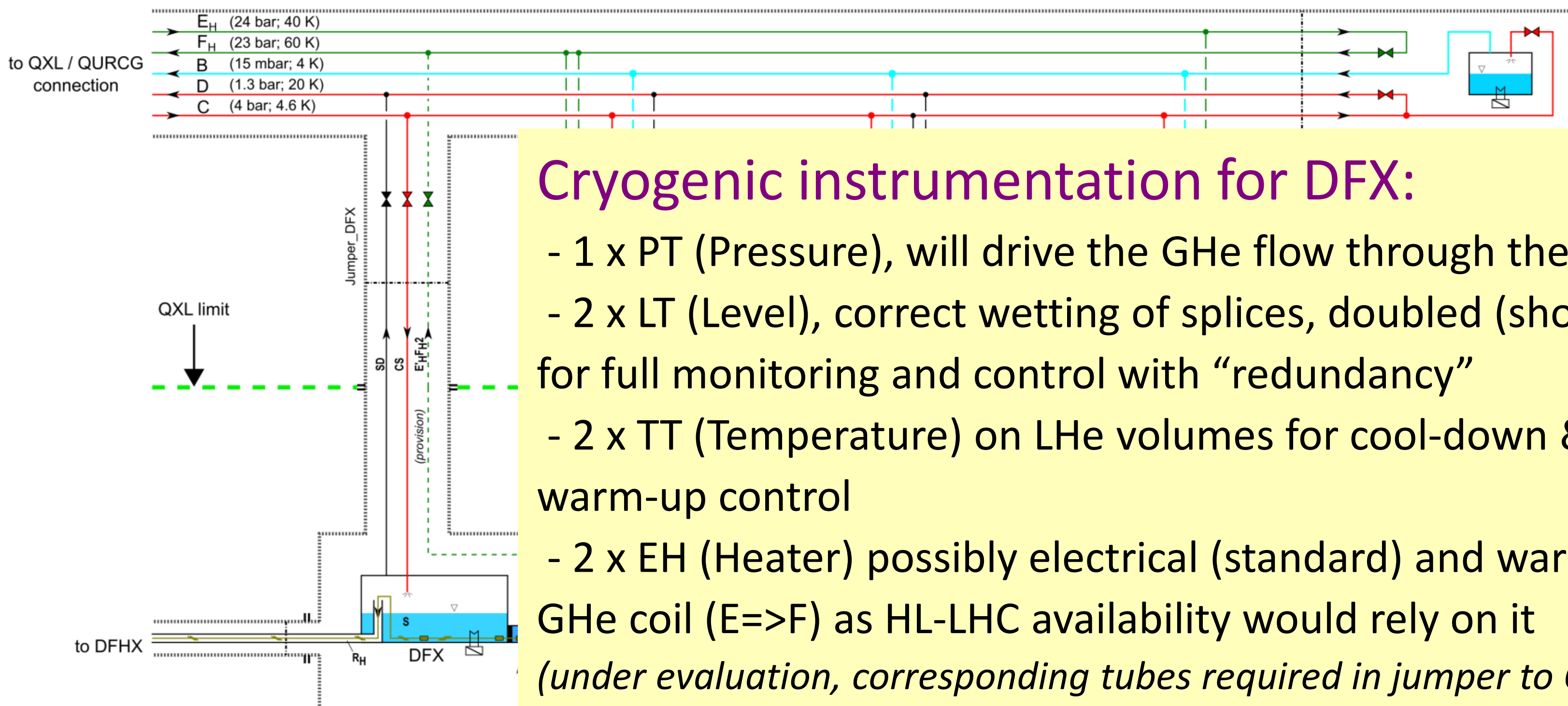
HL-LHC IT L5

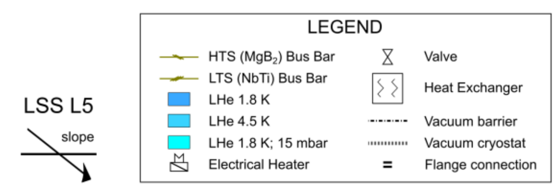


Cryogenic instrumentation for DFX:

- 1 x PT (Pressure), will drive the GHe flow through the link
- 2 x LT (Level), correct wetting of splices, doubled (short-long) for full monitoring and control with "redundancy"
- 2 x TT (Temperature) on LHe volumes for cool-down & warm-up control
- 2 x EH (Heater) possibly electrical (standard) and warmer GHe coil (E=>F) as HL-LHC availability would rely on it *(under evaluation, corresponding tubes required in jumper to QXL)*

To be clarified/confirmed:

+ 1-2 x TT (Temperature) for splice block
+ conduction of heat on lowest point for LHe emptying
+ WHAT COULD BE REQUIRED FOR GLOBAL CONTROL OF ENTIRE SUB-SYSTEM DFX-DSHX-DFHX *(dedicated CRG-wg for functional analysis of all users to be launched)*



PFD HL-LHC IT L5_v.1.3 - 27 Aug 2018 - EDMS # 1963716 - M.Sisti

Baseline as presented in "HILUMILHC-Del-D6-2-V0"

Schematic & work by Udo Wagner, 2014

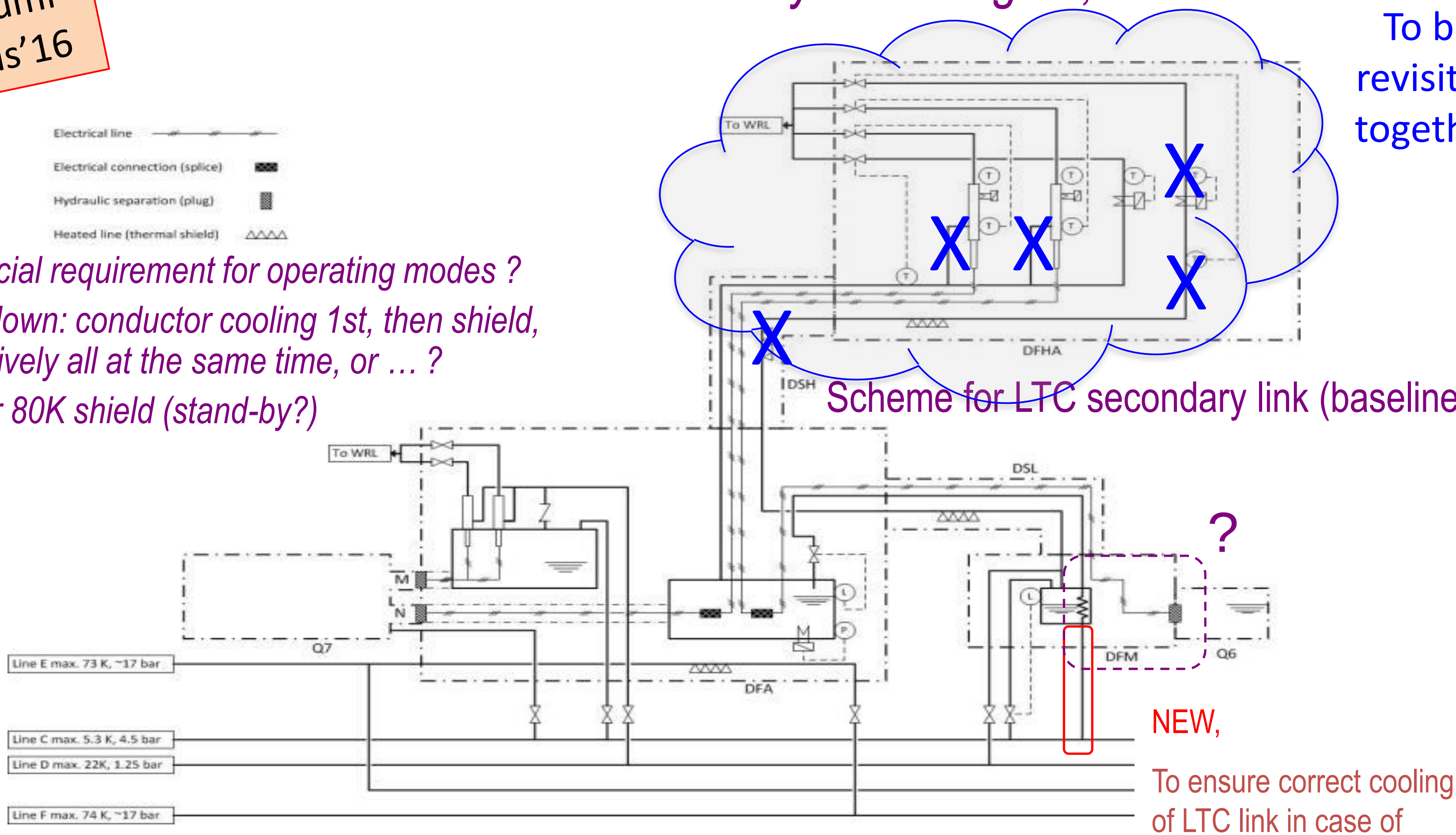
HiLumi Paris'16

To be revisited together

Any special requirement for operating modes ?

- Cool-down: conductor cooling 1st, then shield, or tentatively all at the same time, or … ?

- 20K or 80K shield (stand-by?)



Some of the concerns (shield, transients, local heat loads) are still present and should be studied and treated in 2017

Arc feed box

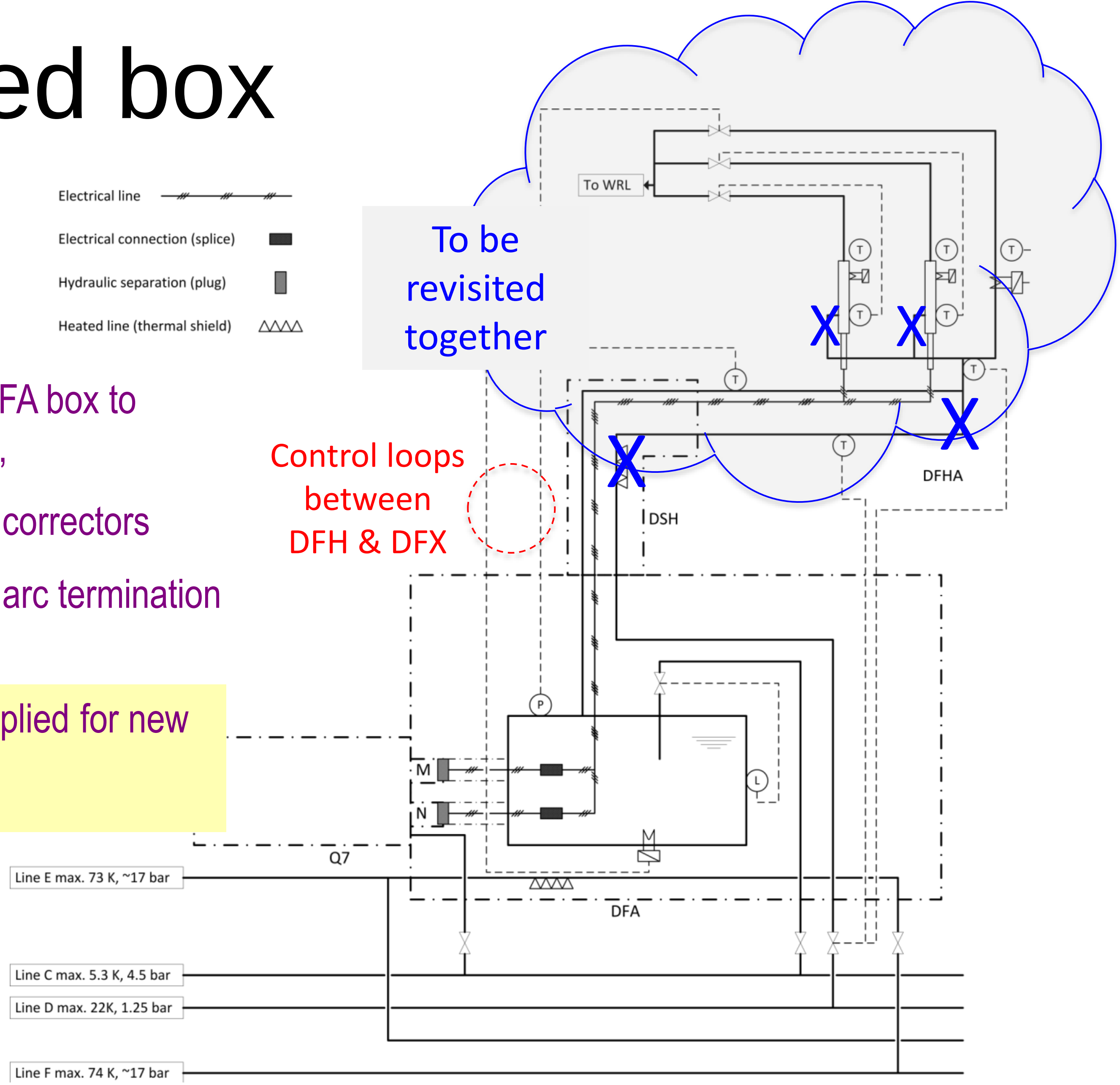
HiLumi
Paris'16

Simplified scheme of a DFA box to replace DFBA next to Q7,

+ Many circuits RB, IPQ, correctors

+ Delicate interface with arc termination module to be looked at

Same principle to be applied for new triplets



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Other CRYO considerations (1/2)

Besides basic general considerations (similar approaches for triplets and for D2 as done so far, installation sequence and operation/maintenance scenarii), below few points to be considered for cryogenic design of HiLumi sc links and extremity boxes.

<u>Major conceptual considerations for sc-link cryogenic interfaces:</u>

- Mechanical behaviour and thermal contraction: how is this considered for th… li…

  => impact and interface with extremity boxes

> Fixed at extremities + "snake", should be OK

- Cooling for nominal case: shielded for 1.8K volumes, possible unshielded for 4.5K if h… t load acceptable for specific configuration

> No shield for DFX, should be OK

- Transient modes: specific considerations to be identified (maxi flow, velocity, DT, …)

  => for proper sizing of pipe work

> To be done, should be OK

- Abnormal cases (degraded vacuum, temperature control if issues): margin in cooling capacity (mass-flow) to be foreseen locally (moderate impact globally)

> To be done, should be OK

Other CRYO considerations (2/2)

- Geometrical configuration: For saturated LHe volumes, constant increasing slope between coldest point (plug to 1.9K) and Liq/Gas interface

  (high points could be sensitive to gradients or GHe pockets, low points and/or risk of 2 phase flow with GHe to be evacuated)

  Considered now, Should be OK

- For GHe extremity at 17K, identification of volume with temperature to be contr

  DFH …

- Tolerance to transients: something like 5 min. autonomy before reaching lowe threshold, impact on GHe extremity to be evaluated

  Considered, to be clarified, Should be OK

- Valves & instrumentation: access for debugging, and for operation/maintenance doubling (for cross-check and continuity of operation) with in-situ replacement possib required for operation/control, less strict for global diagnostics)

  Considered, should be OK

This is just normal standard practice, no big scientific work required, but helps to start in the good direction. Then it is much easier to design and comment variants.

Summary

- The present conceptual design should enable:
  - to control LHe level above the MgB2-NbTi splices with enough stability, inertia and correct maintainability of cryo instrumentation
  - The generation of GHe flow to cool the sc-link and DFH (more elaborated design to be done)

$\Rightarrow$ We are confident that we should be able to operate reliably such a device

- Global considerations for control as well as for safety and off-design conditions to be conducted to consolidate the approach

Thank you for your attention !

HiLumi LSS overview

A large variety of cold masses, beam-screens and sc-links

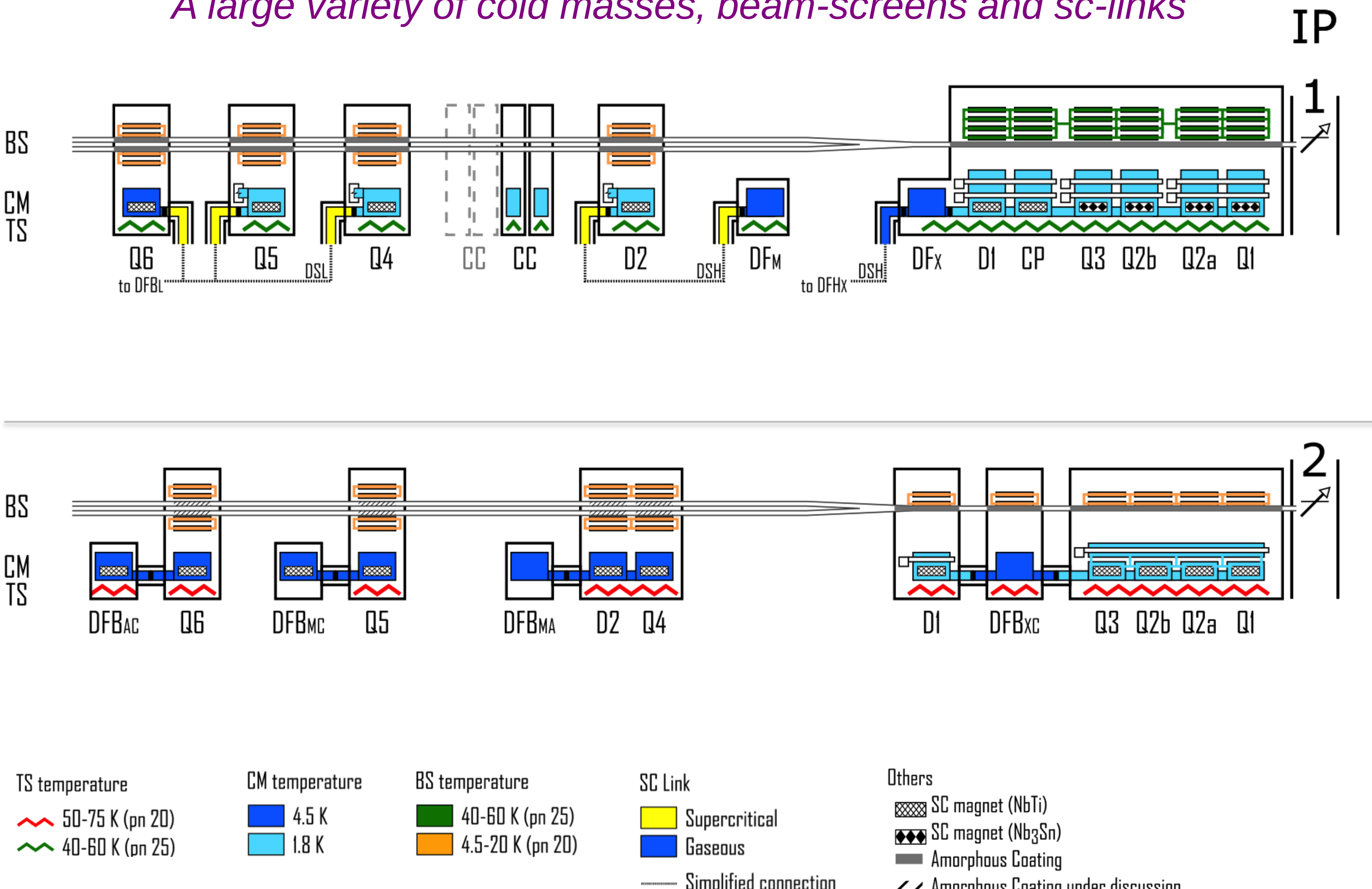


Table 3. Heat load table for mayor components on the magnet side of HL-LHC LSS.R5.

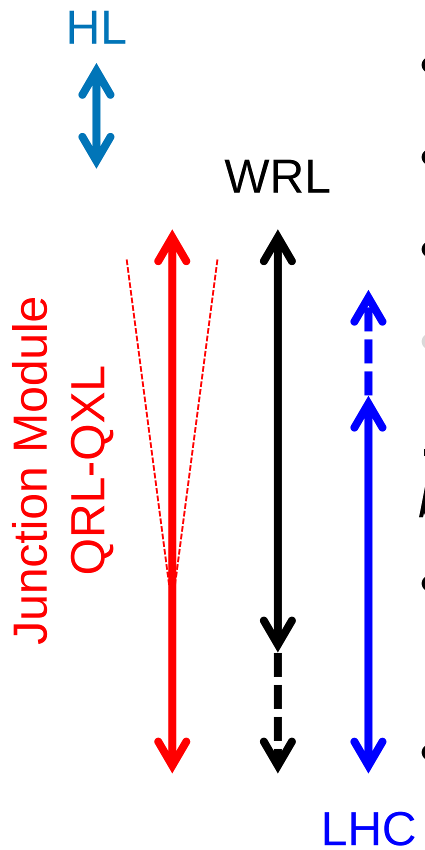
	Component Length [m] (thermal shield)	Q1 10.140 (10.640)	Q2A 9.785	Q2B 9.785	Q3 10.140	CP 6.016	D1 7.370	Intercon. 5.800 (5 units *)	DFX 2.435 (2.935)	DFM 4.000	D2 13.025 (14.025)	CC 4 module units †	Q4 9.062 (10.062)	Q5 8.010 (9.010)	Q6 6.610 (7.610)
	Cold Mass														
	Temperature [K]	1.9	1.9	1.9	1.9	1.9	1.9	1.9	4.5	4.5	1.9	2	1.9	1.9	1.9
	Total Heat Load [W]	185.9	147.6	186.7	195.4	90.2	120.4	65.5	1.7	tbd	55.0	123.8	14.4	11.3	4.0
	Avg. Heat Load [W/m]	18.34	15.08	19.08	19.27	15.00	16.33	6.13	0.72	tbd	4.22	30.94 W pu	1.59	1.42	0.60
Data	Static [W/m]	*0.82*	*0.83*	*0.83*	*0.82*	*0.87*	*0.83*	*0.13*	*0.72*	tbd	*0.28*	12.5 W pu	*0.29*	*0.32*	*0.36*
	Resistive [W/m]	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	-	tbd	tbd	tbd
	Beam Induced [W/m]	*0.16*	*0.05*	*0.06*	*0.11*	tbd	*0.17*	tbd	tbd	-	*0.10*	0.5 W pu	*0.19*	*0.23*	*0.24*
	Collision Induced [W/m]	*17.36*	*14.21*	*18.19*	*18.34*	*14.13*	*15.33*	*6 W pu*	tbd	tbd	*3.84*	0.34 W pu	*1.10*	*0.87*	tbd
	RF Induced [W/m]	-	-	-	-	-	-	-	-	-	-	17.6 W pu	-	-	-
	Beam Screen														
	Temperature [K]	40-60	40-60	40-60	40-60	40-60	40-60	40-60	tbd	-	4.5-20	-	4.5-20	4.5-20	4.5-20
	Total Heat Load [W]	271.1	118.9	158.2	161.2	107.4	117.9	110.0	1.3	-	16.7	-	21.7	14.3	3.0
	Avg. Heat Load [W/m]	26.74	12.15	16.17	15.90	17.85	16.00	22 W pu	0.55	-	1.28	-	2.40	1.79	0.45
Data	Static [W/m]	*0.14*	*0.14*	*0.14*	*0.14*	*0.23*	*0.19*	-	*0.55*	-	*0.00*	-	*0.15*	*0.17*	*0.21*
	Resistive [W/m]	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	-	tbd	-	tbd	tbd	tbd
	Beam Induced [W/m]	*1.25*	*0.25*	*0.39*	*0.67*	*tbd*	*1.29*	*tbd*	tbd	-	*1.08*	-	*2.08*	*1.60*	*0.24*
	Collision Induced [W/m]	*25.35*	*11.75*	*15.64*	*15.09*	*17.62*	*14.52*	*22 W pu*	tbd	-	*0.20*	-	*0.17*	*0.02*	tbd
	Thermal Shield														
	Temperature [K]	40-60	40-60	40-60	40-60	40-60	40-60	40-60	40-60	40-60	40-60	80	40-60	40-60	40-60
	Total Heat Load [W]	56.6	53.2	53.2	54.3	33.8	38.2	18.6	24.1	tbd	68.1	1528.0	48.1	44.7	40.2
	Avg. Heat Load [W/m]	5.32	5.44	5.44	5.36	5.63	5.18	3.21	8.21	tbd	4.85	382 W pu	4.78	4.96	5.28
Data	Static [W/m]	*5.32*	*5.44*	*5.44*	*5.36*	*5.63*	*5.18*	*3.21*	*8.21*	tbd	*4.85*	252 W pu	*4.78*	*4.96*	*5.28*
	RF Induced [W/m]	-	-	-	-	-	-	-	-	-	-	130 W pu	-	-	-

Maturity level of the source data: estimated = *italic*; calculated = normal; measured = underlined.
tbd = to be defined; "-" = not applicable; W pu = Watts per unit.
* Length of each interconnection unit is 1 m, except between Q3-CP which is 1.8 m.
† A module unit contains 2 crab cavities.

Direct conversion of heat loads into mass-flow for HiLumi at this stage and for QXL header sizing
(much more simple flow distribution scheme than for LHC, cf PN140)

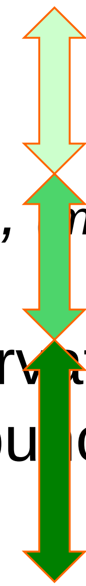
Possible modes and implications, as identified so far for HiLumi

Decreasing requirements in cooling capacity



- Ultimate Luminosity (HL)
- Nominal Luminosity (HL)
- Nominal Luminosity (LHC)
- Low Luminosity / Intensity
- . Powering conditions to 7TeV, (*maybe pilots or few bunches)*
- Injection stand-by (He preservation in magnets, ELQA, maybe pilots or few bunches at injection)
- Magnets @20K

=> The maximum reasonably possible



Bonus *(only 1st year)*

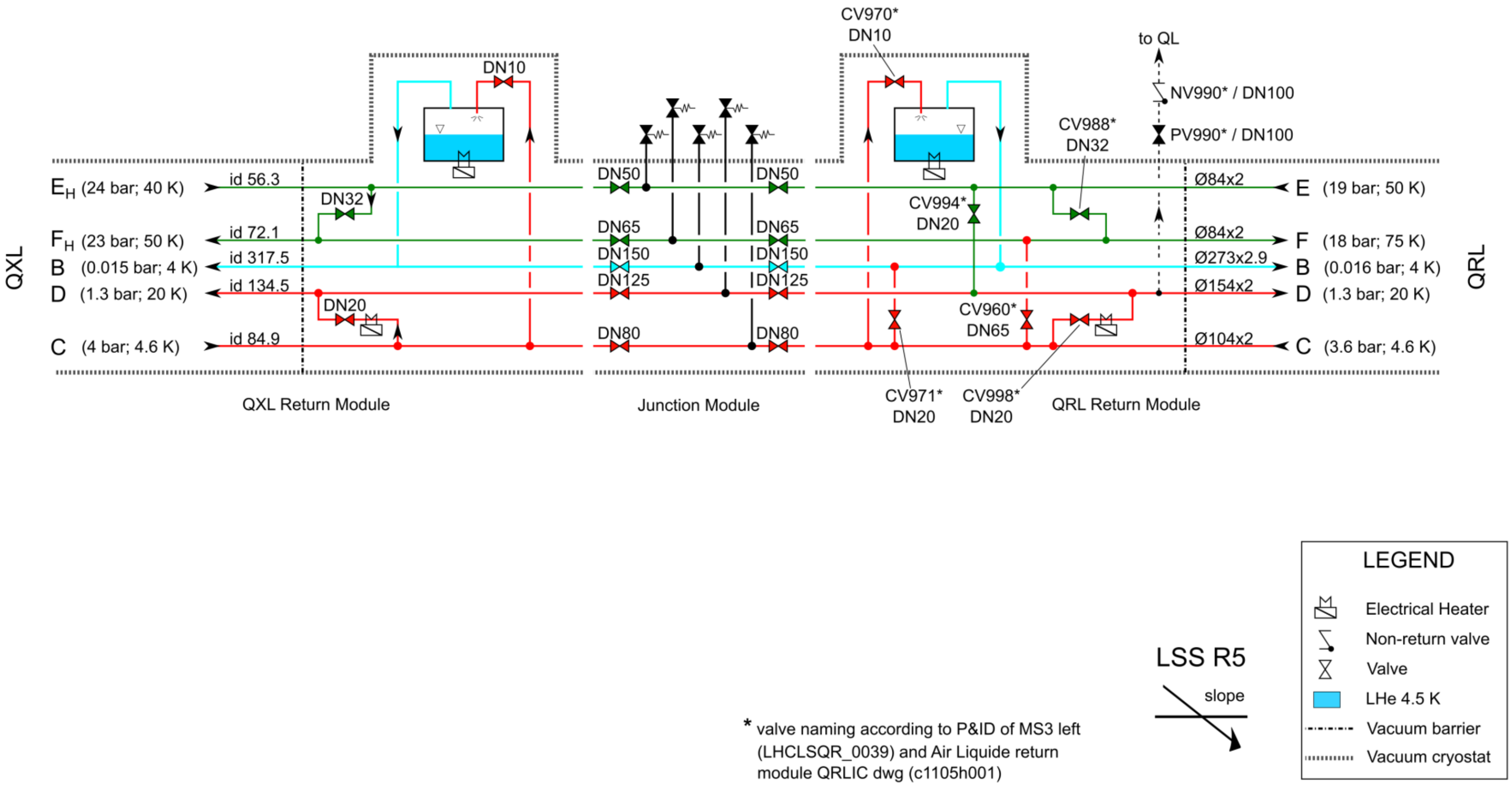
Desired *(1 wk)*

Mandatory *(few wks)*

=> Junction Module and bridge between WRL's recommended

=> Corresponding cooling capacities and impact on size/cost/volume to be further investigated

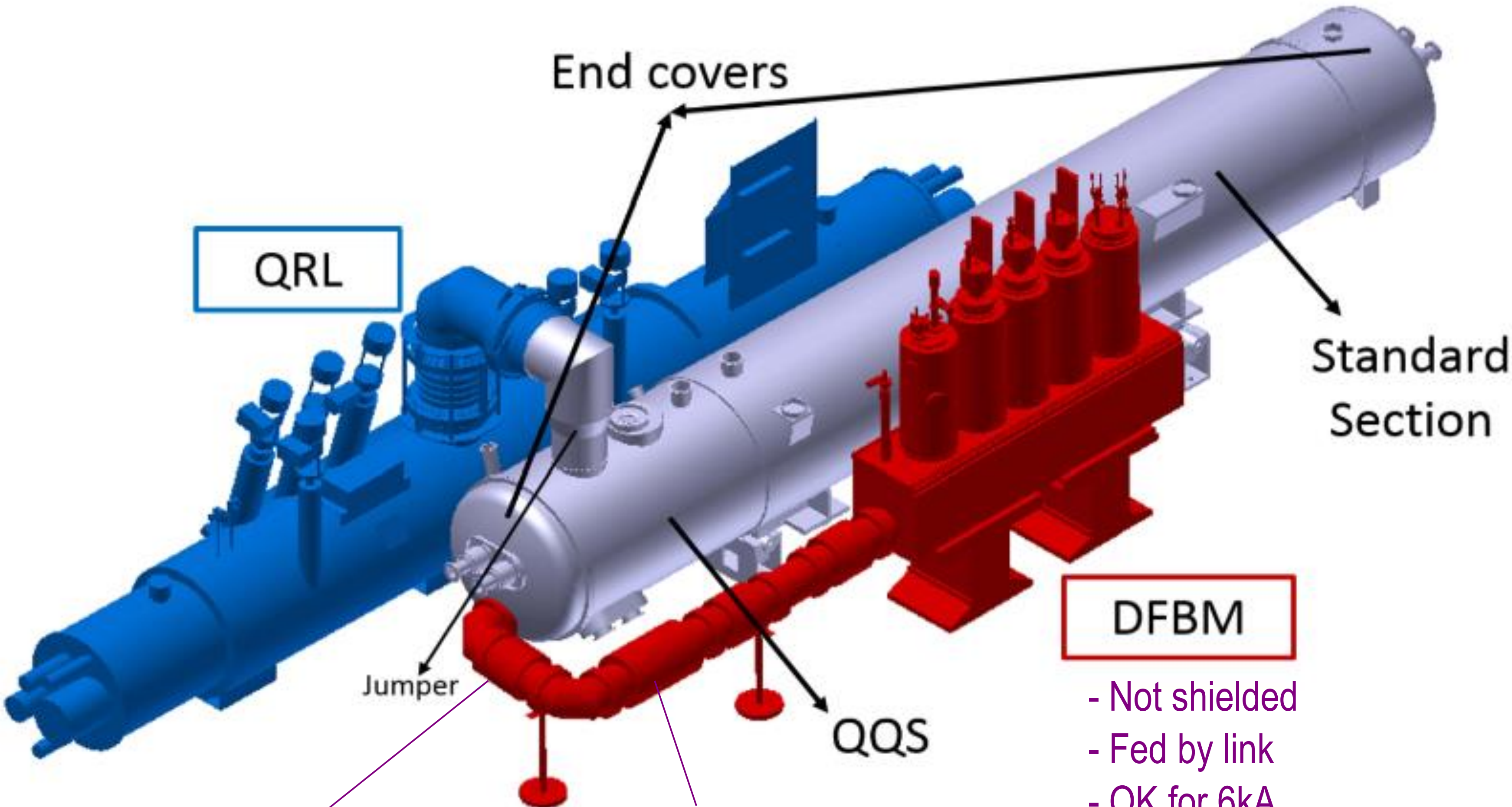
Junction module QRL-QXL



* valve naming according to P&ID of MS3 left (LHCLSQR_0039) and Air Liquide return module QRLIC dwg (c1105h001)

PFD HL-LHC QXL-QRL Junction module @ R5_v.1- EDMS # 1996393 - M.Sisti

LHC - Existing solutions

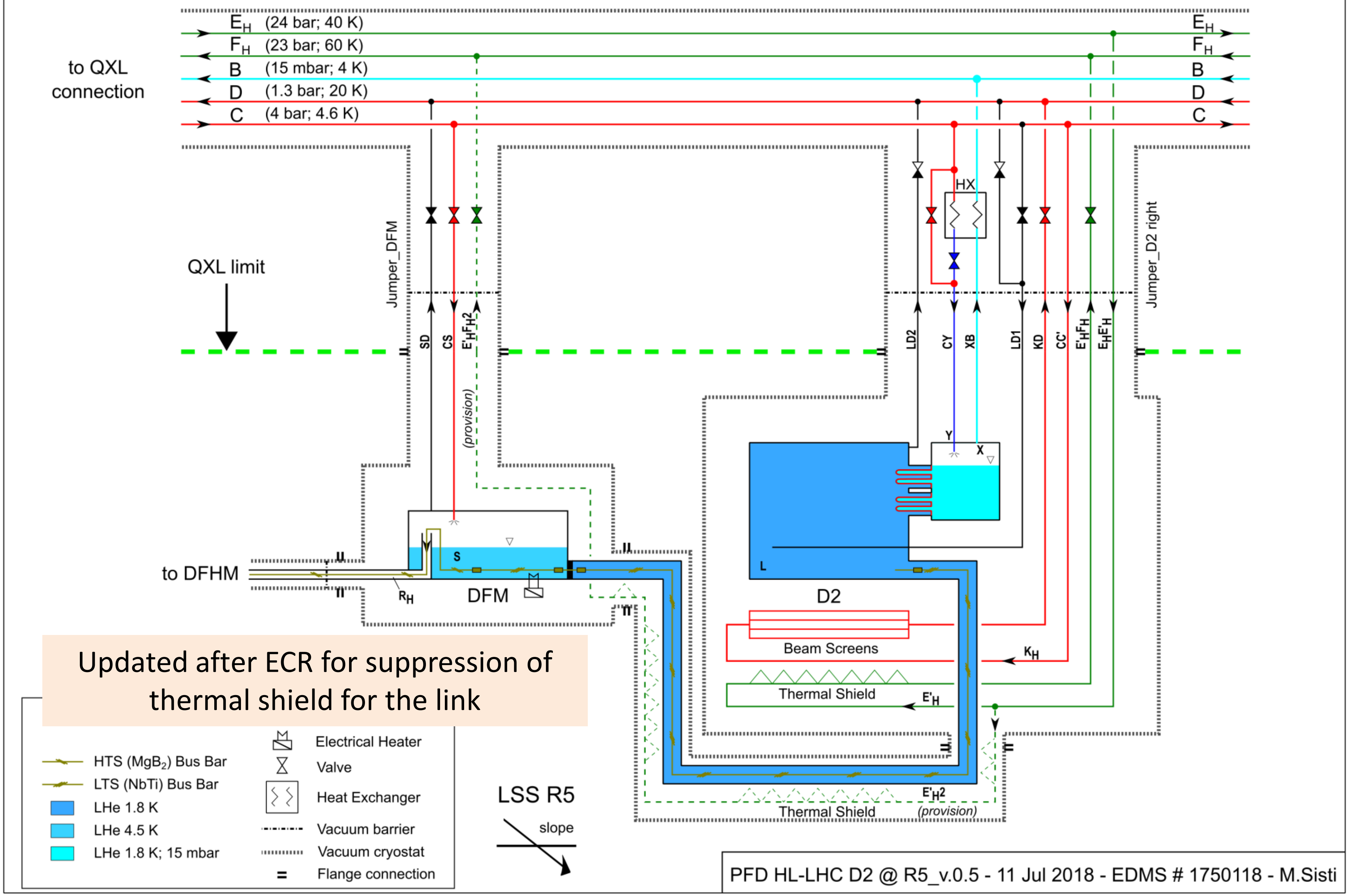


- Not shielded
- Fed by link
- OK for 6kA

- Not shielded
- 3 circuits (bus, LHe-GHe)
- Low point with splice & plug (as for DFBA's)

- Adapted to magnet operation @ 1.9K
- Need for thermal shied to be evaluated

HL-LHC D2 R5



Updated after ECR for suppression of thermal shield for the link

Quick illustration of DFX-cable interface as understood so far

Views to illustrate principles that would be specified, not of selected supplier!

Vertical distance for LHe control, And GHe passage