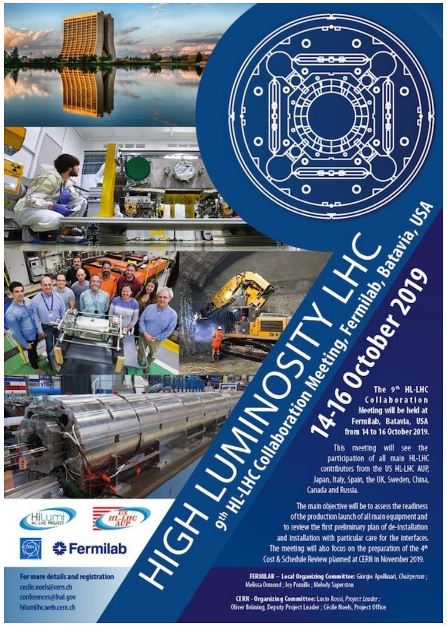

HiLumi Cryogenics, Progress highlights and perspectives

Serge Claudet,

On behalf of the Cryogenic project team

October 14th 2019

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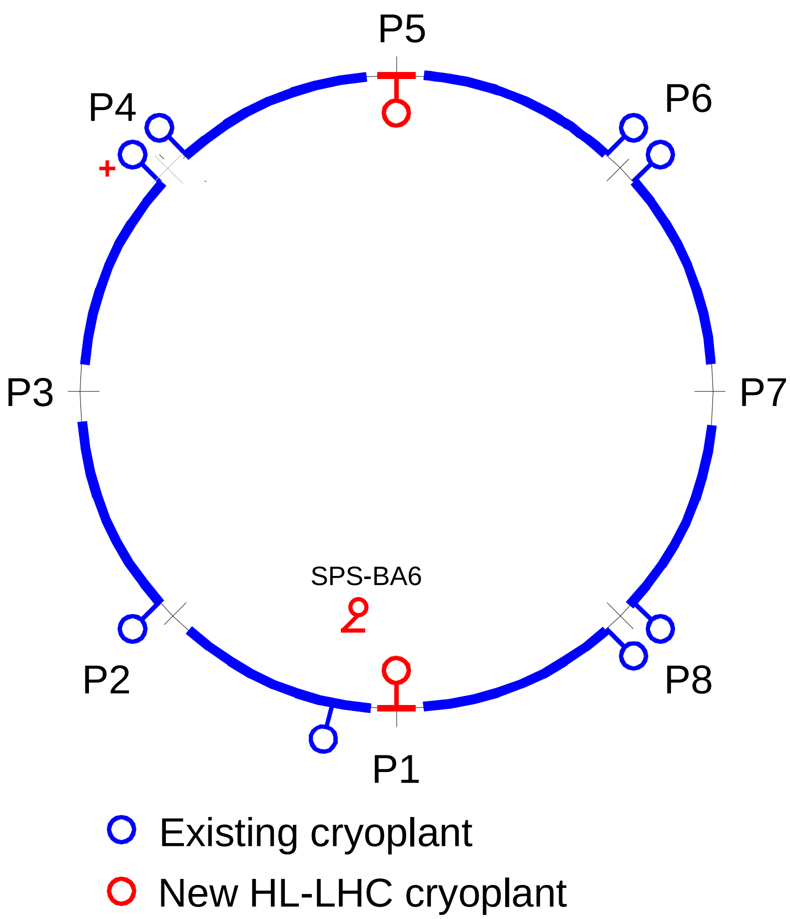
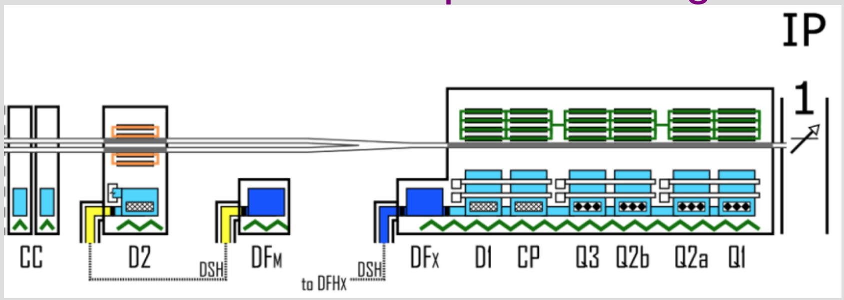
- Introduction
- P1/P5, interfaces revisited (IT, D2, DF's, CC)
- P1/P5, QXL cryoline integrated
- P1/P5, process studies – controls architecture
- P4 upgrade
- Summary

HL-LHC cryogenic upgrade



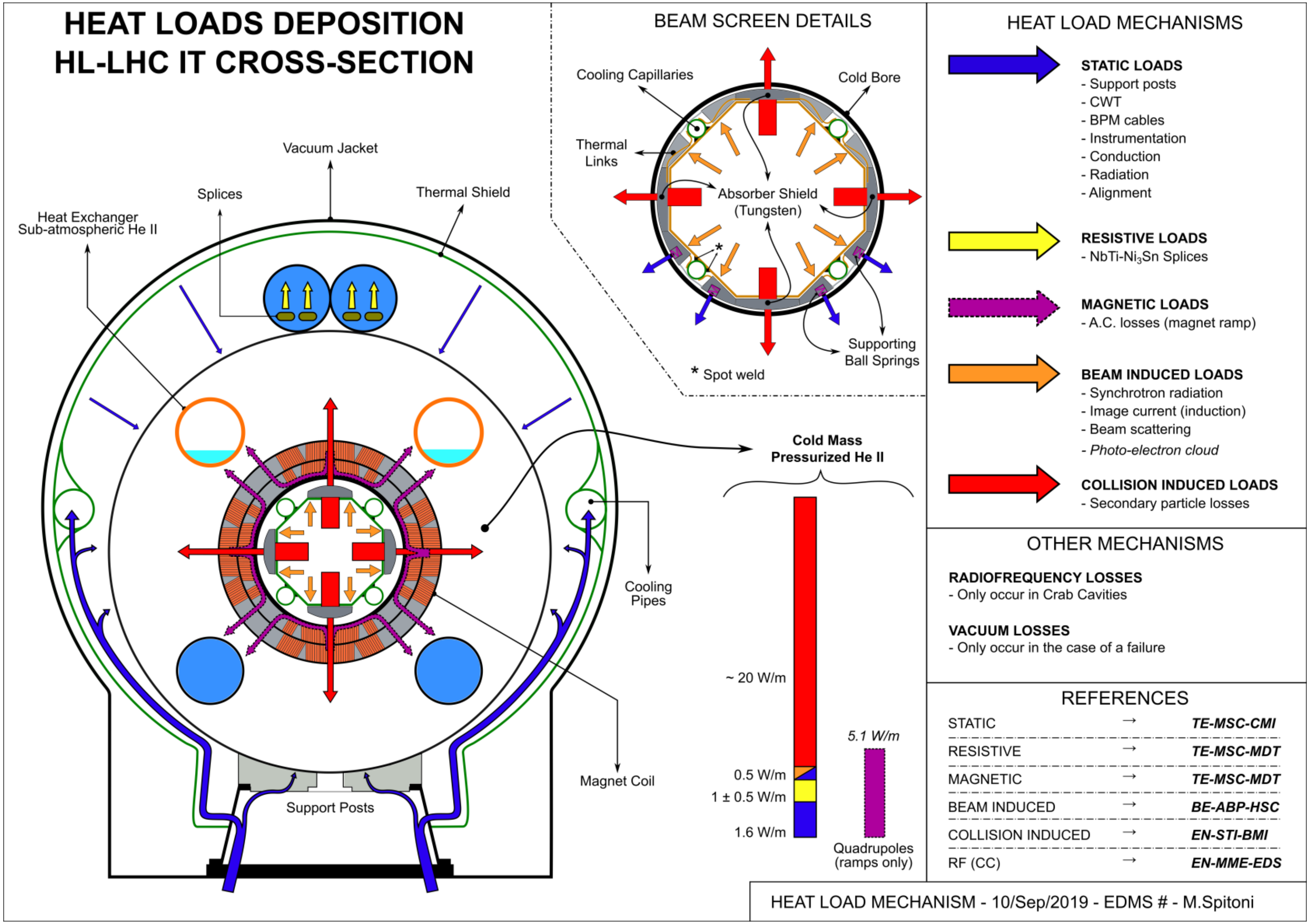
- P1-P5: 2 new cryoplants (~15 kW @ 4.5 K incl. ~3 kW @ 1.8 K) and 2 x 750m cryo-distribution for high-luminosity insertions
- P4: upgrade (+2 kW @ 4.5 K) of an existing LHC 18 kW @ 4.5K cryoplant
- *SPS-BA6: SRF test facility with beam primarily for Crab-Cavities*

P1/P5: Provide adequate cooling for this

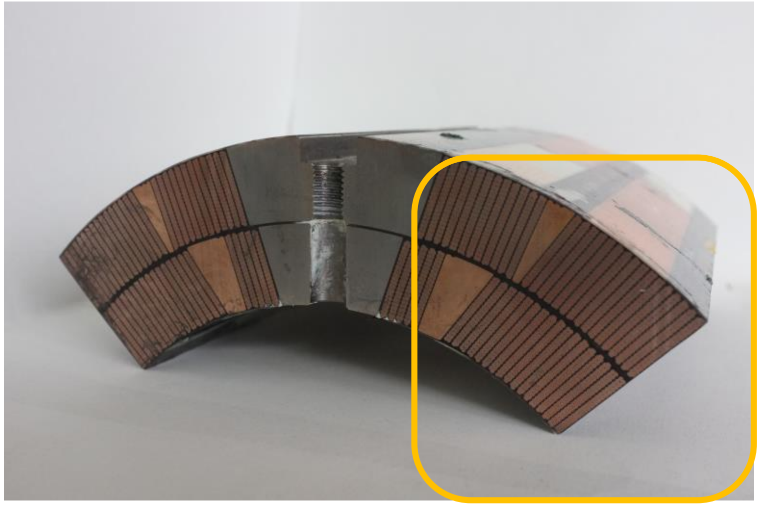


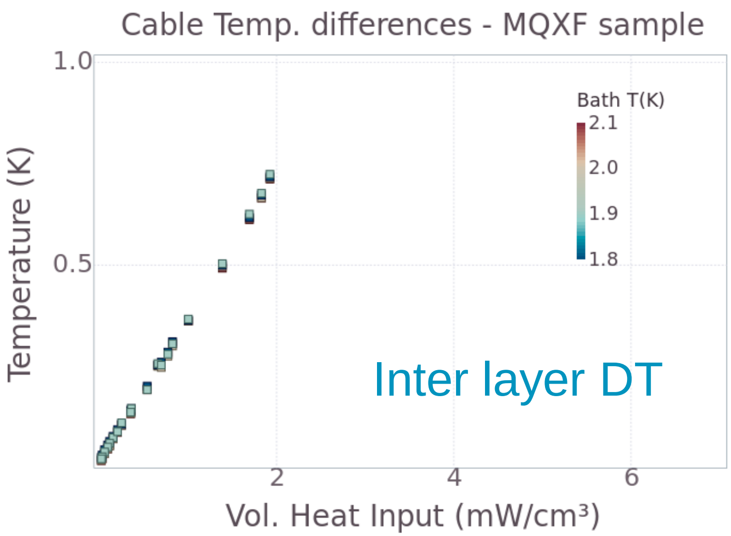
Other test facilities related activities not reported here

Heat loads mechanisms - Cross Section

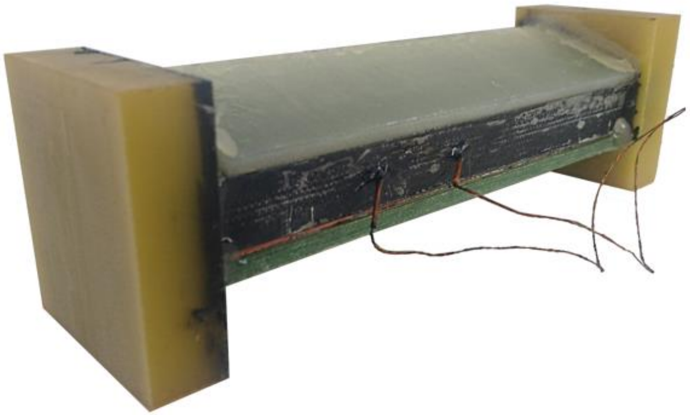


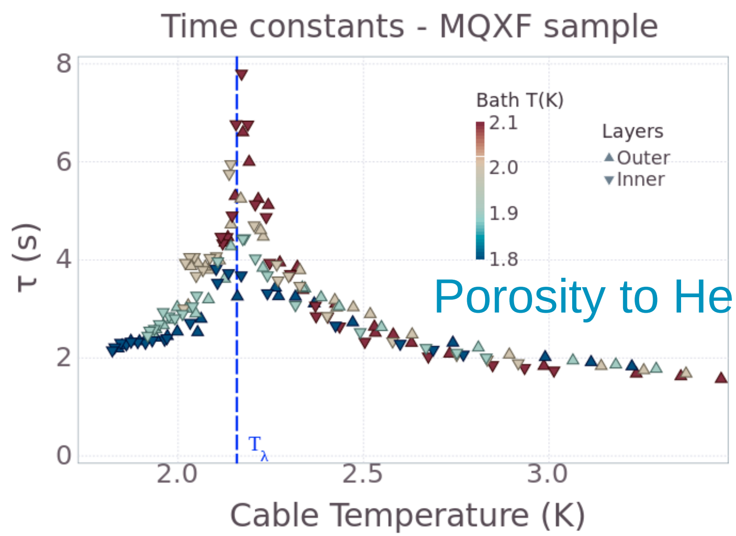
Heat transfer measurements in Nb3Sn stacks





Characterisation of material properties

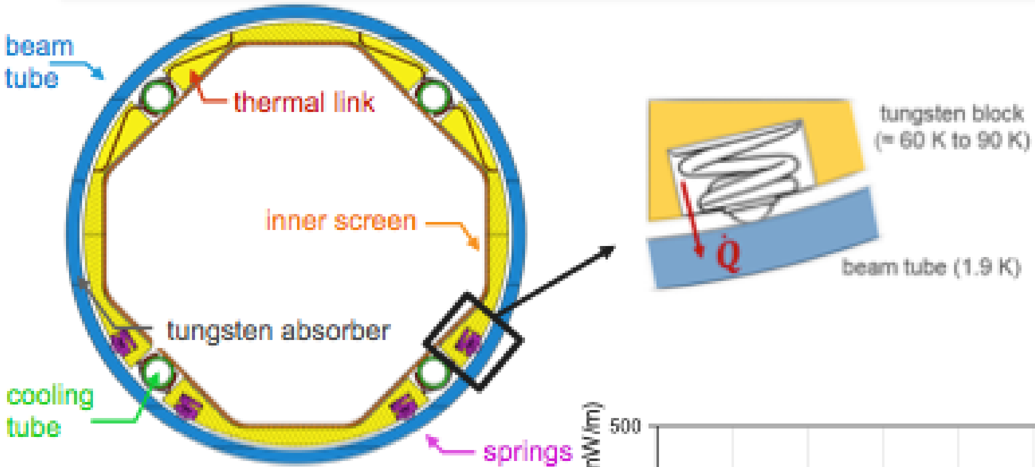




Beam-Screen thermal behaviour

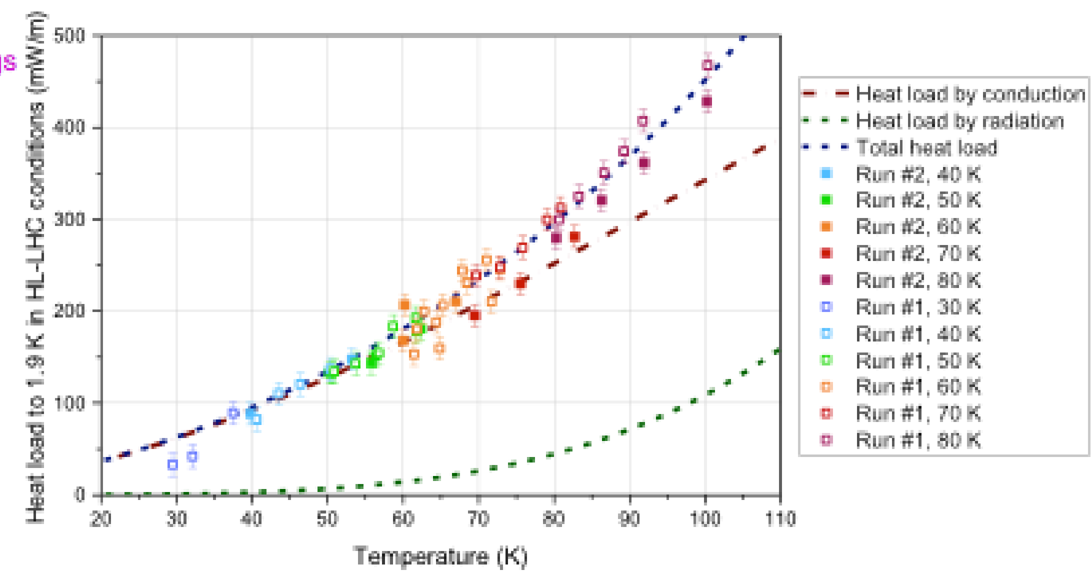
2+ years of elementary and complete tests done at cryolab, now completed

Results: heat load to the 1.9 K beam tube (both runs)

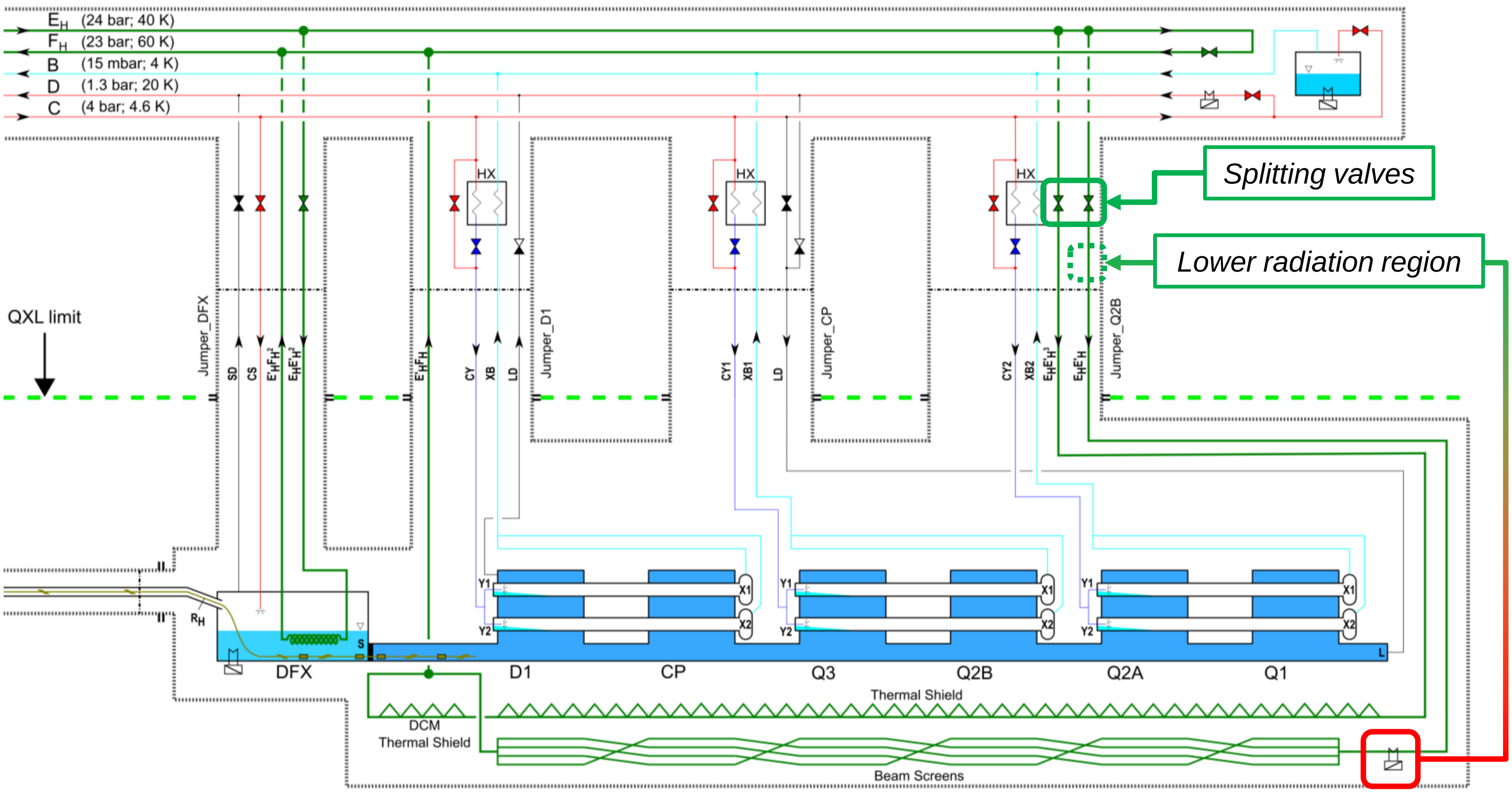


Tungsten block temperature
(base T of cooling tubes + ΔT due to heat load of 15 W/m)
drives heat load to 1.9 K

Fit curve:
Data from measured springs
Radiation with emissivity values of 0.10 and 75% of total beam screen area



Revised Process & Flow diagram

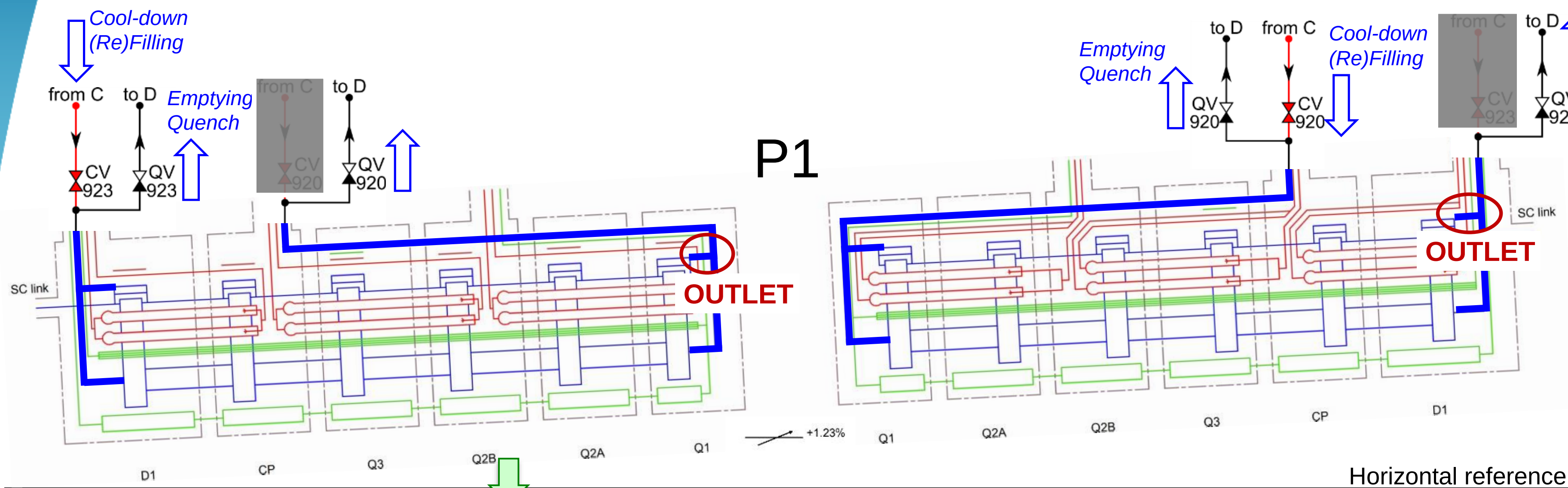


Reasons

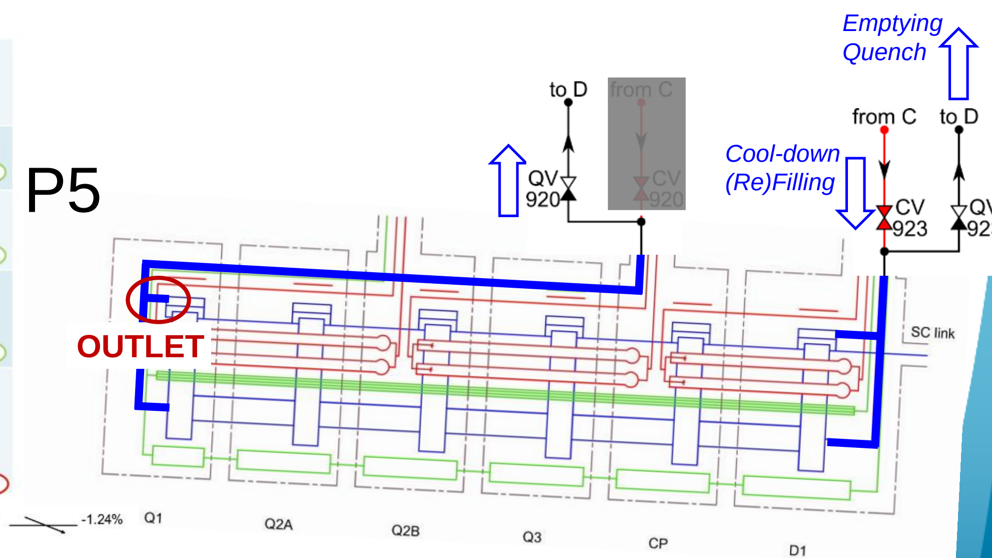
1) The electrical heater could be moved to a lower radiation area → ***main reason***

2) Separate supplies allow separate CV at inlet for better flow control → *positive effect*

IT+D1: LD' lines for transients



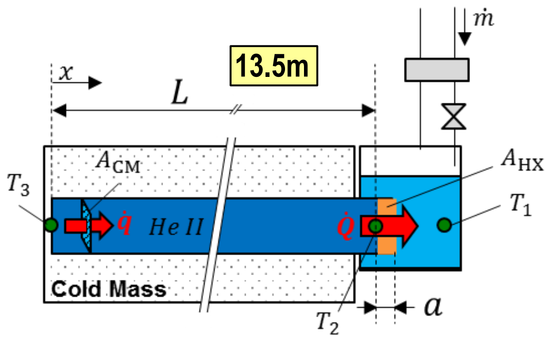
	Present (connections at the bottom) L1 & R5	Present (connections at the bottom) R1 & R5	Proposal #1 (double connections) All LSSs	Proposal #2 (connections at the top) All LSSs
Cool-down	Thermal gradient (vertical) --		Optimized thermal gradient ++	Optimized thermal gradient ++
(Re)Filling	Most of the volume shall be condensed via bayonet HX --	Limited -	Maximized ++	Maximized ++
Emptying	Most of the liquid He pushed out to header D by generated gas --		Small portion of liquid He pushed out ++	Small portion of liquid He pushed out ++
Quench	Nominal impedance (through L1 / L2 lines and then LD lines) ++		Nominal impedance (through L1 / L2 and then LD lines) ++	Reduced cross-section → higher speed (possible damages to cable insulation) --



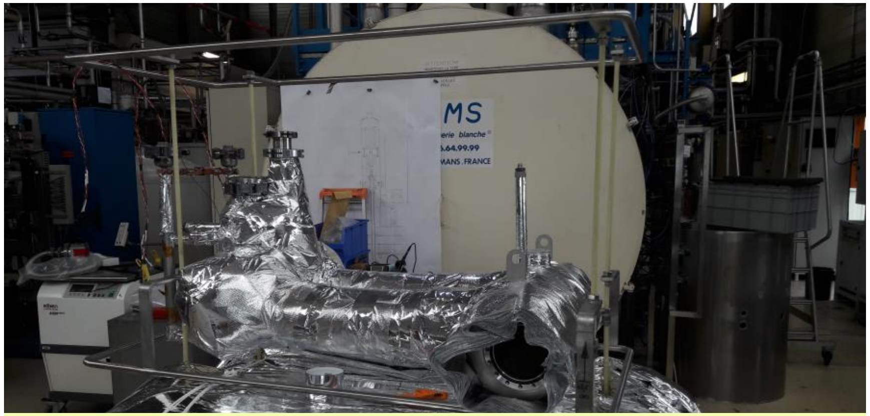
Horizontal reference

D2 heat exchanger

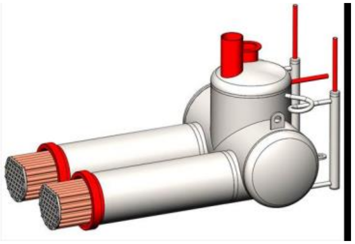
Studies, procurement and validations tests under collaboration with CEA-SBT Grenoble

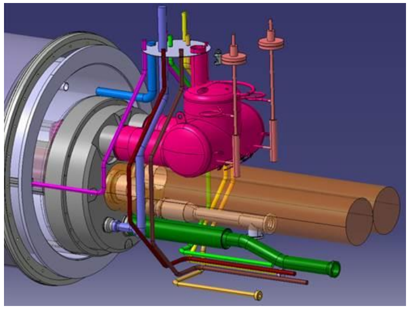


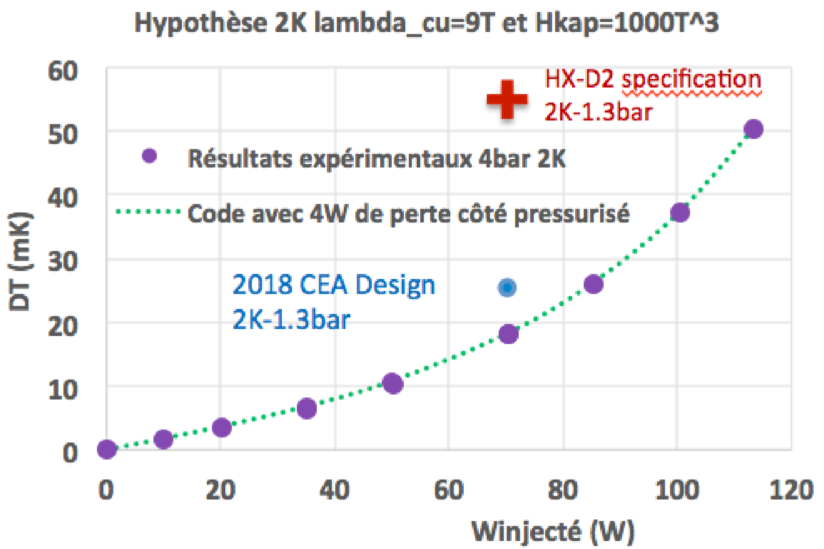
Not sensitive to slope, adapted for stand-alone magnets, up to 70W@2K ?



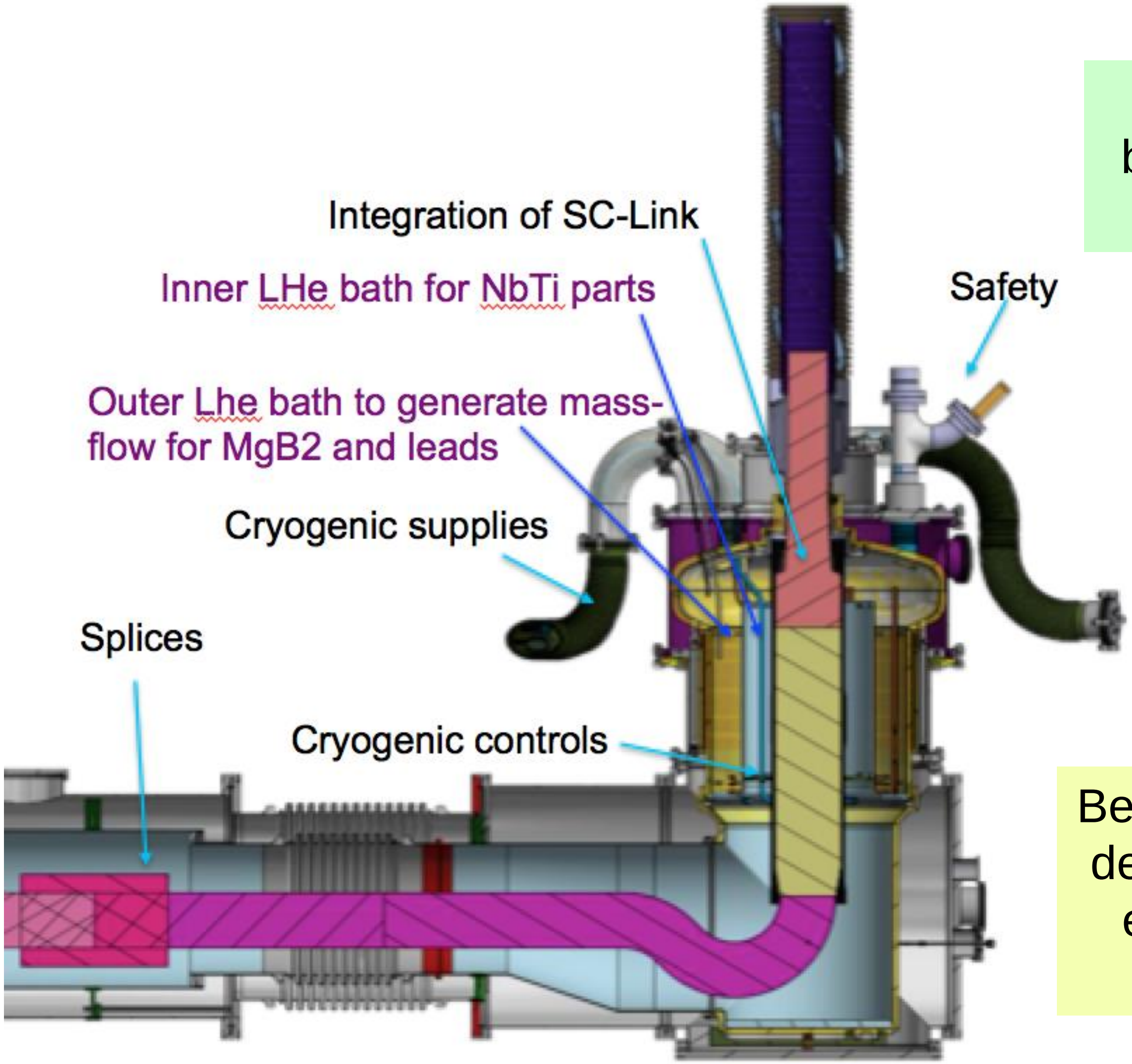
Performance validated @CEA Sept'19







Cold powering, cryogenic aspects



DFX Internal DDR 20 June 2019

Defined with a baseline for cold extremity,

Being studied and defined for warm extremity with leads

New CC warm-up proposal

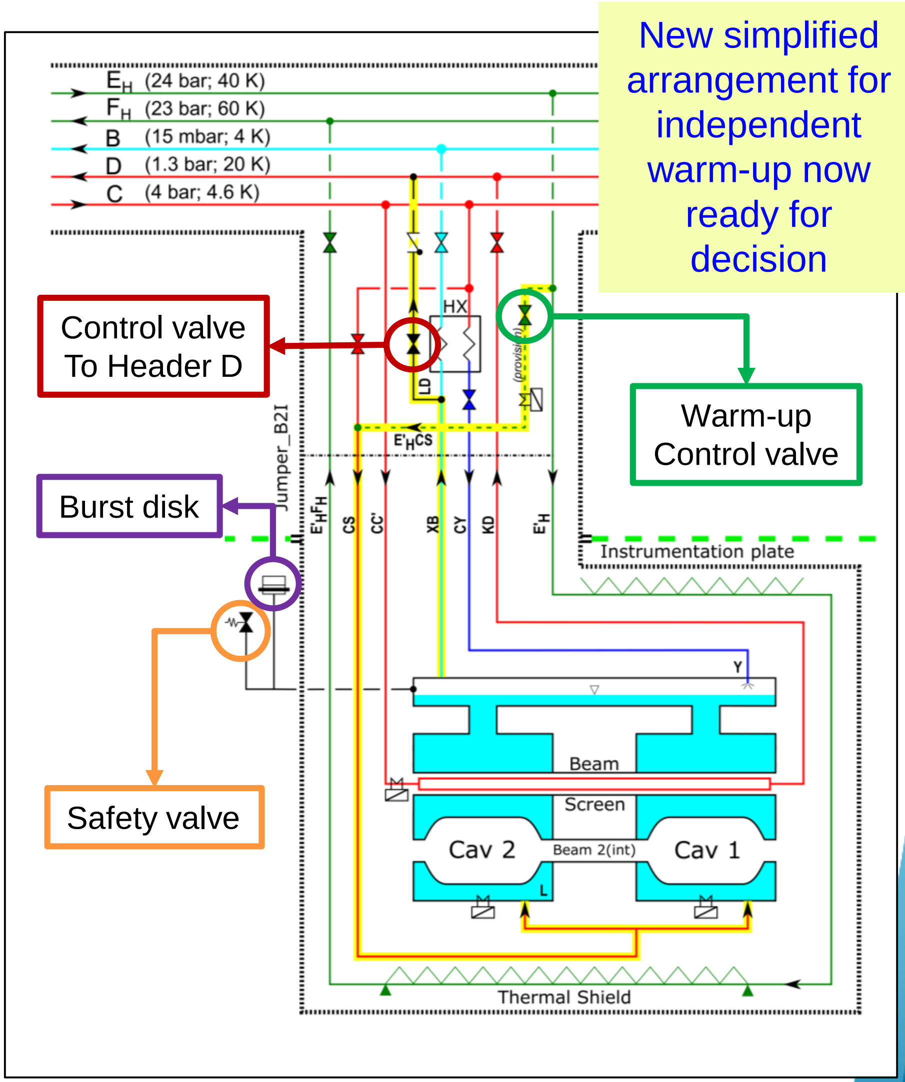
The objective is to warm-up the CC using warm helium from thermal shield at 60 K

The circuit to this purpose would be
Eh → E'h → CS → CC → XB → LD → D

The Warm-up control valve will regulate the flow in order to perform the **warm-**up in a controled way

The proposed warm-up configuration must cope with the **existing safety scheme**

Valve type	CV to Header D	SV to atmosphere	BD to atmosphere
Opening [bar a]	1.5	1.7	2.1
Kv [m3/h]	t.b.d.	-	-
Aperture [mm]	-	< 20	100
Tolerance [%]	+0% -10%	+10% -10%	+10% -0%
Remarks	Helium recovery	First protection	Extreme protection



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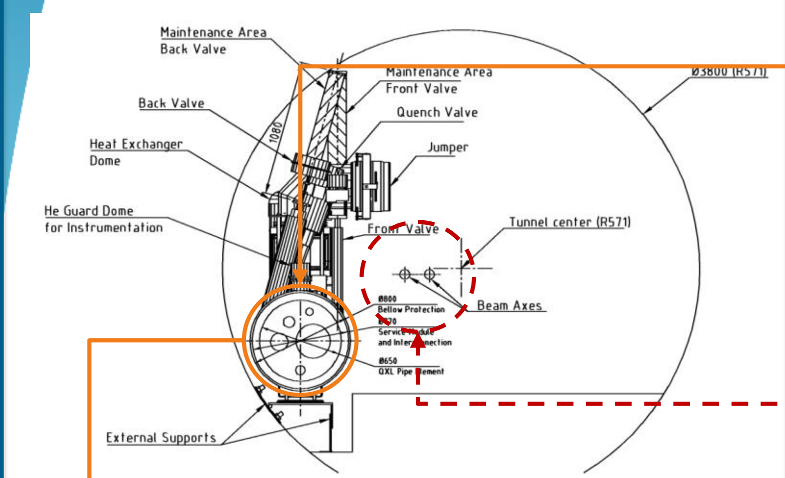
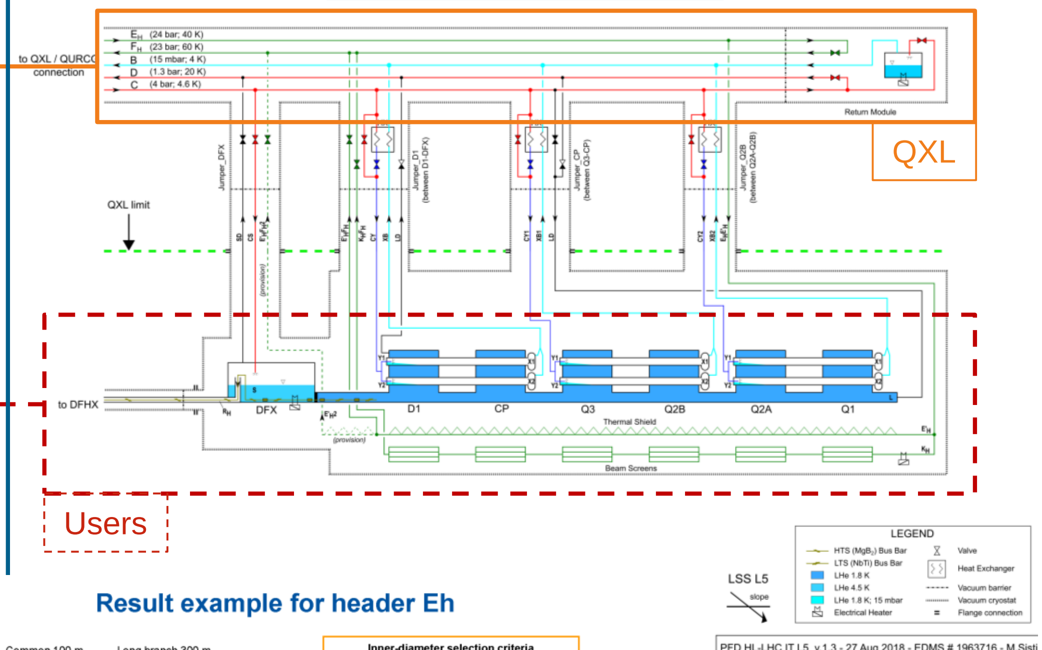
QXL cryoline headers

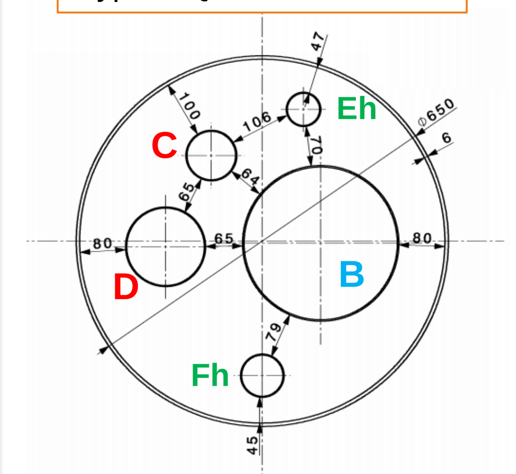
Typical Tunnel cross section



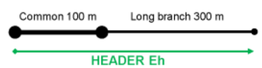
Inner Triplet flow scheme



Typical QXL cross section

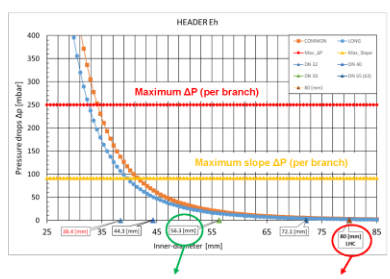


Result example for header Eh



Inner-diameter selection criteria

$$min\left(\left[\frac{d(\Delta P)}{dD} \leq \frac{\Delta P_{max}(branch)}{20}\right];\left[\frac{\Delta P_{max}(branch)}{2}\right]\right)$$



Property	Unit	Value
Temperature	K	40
Pressure	bar	21.5
Mass flow (common)	g/s	140
Mass flow (long)	g/s	70
Max ΔP (per branch)	mbar	250
Max slope ΔP (per branch)	mbar	91.2
Min inner-diameter (common)	mm	42
Min inner-diameter (long)	mm	39.5
Selected inner-diameter (overall)	mm	56.3
LHC Diameter	mm	84.9
Max flow velocity (overall)	m/s	2.3
Time of Flight (common + long)	min	4.2
Time of Flight (common + short)	min	1.3
Header total volume	m^3	0.94
Helium total mass	kg	23.1

HL-LHC diameters ≤ LHC diameters

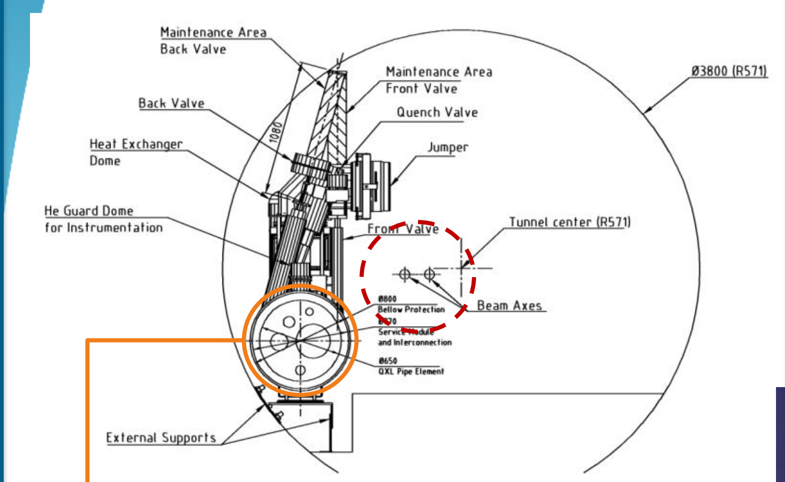
Same approach for each header

10/04/2019 Marco Spitoni HL-LHC / WP9 16

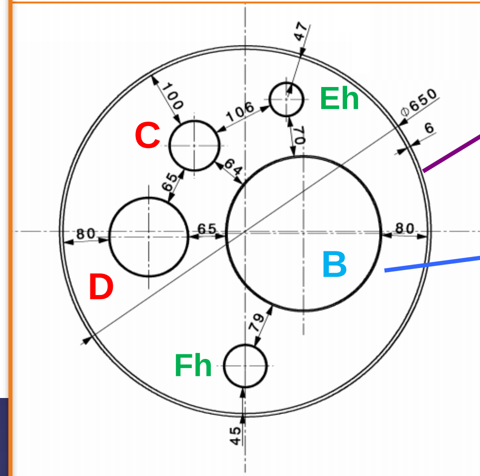
Various modes:
- Nominal
- Reduced capacity
- Cool-down
- Quench
- Other transients

QXL Cryoline sizing, and 3D model integrated !

Typical Tunnel cross section



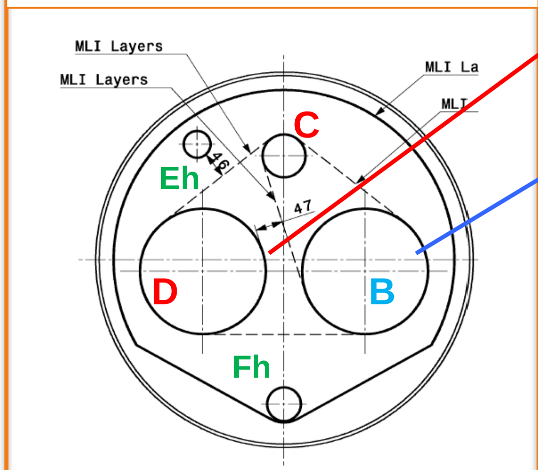
Typical QXL - Service Galleries



Constant outer diameter as boundary limit so far

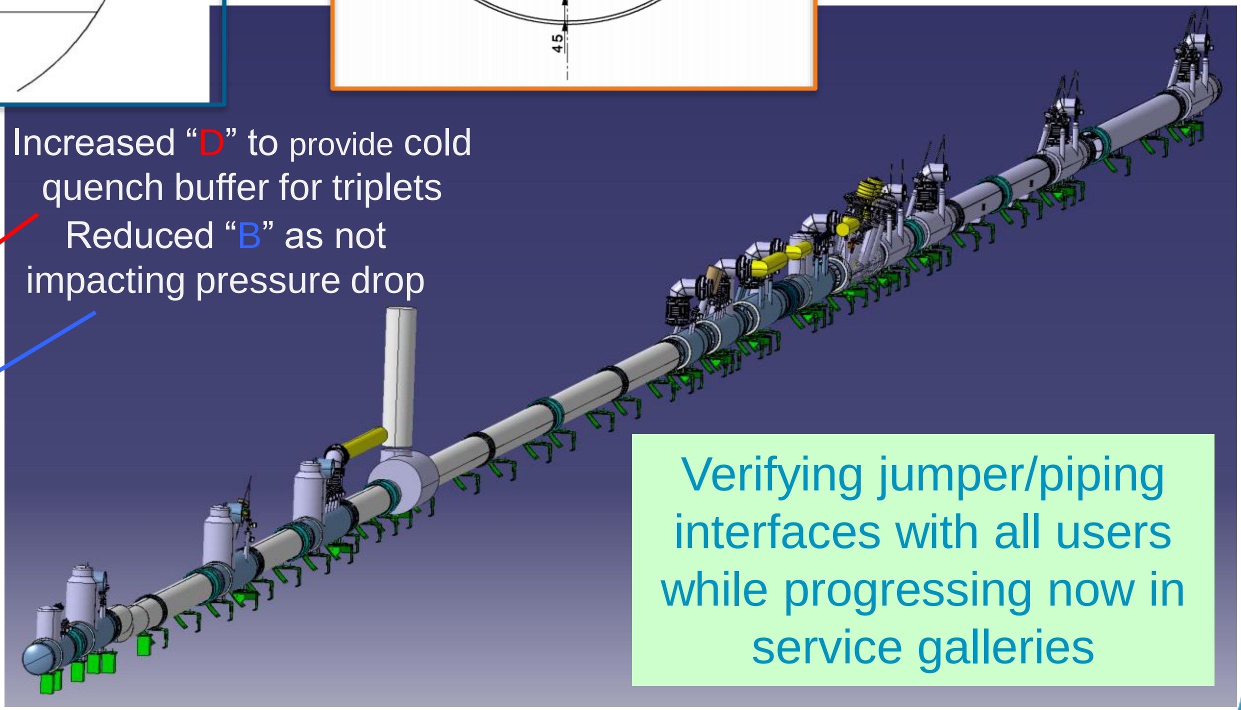
Large "B" to match pressure drop criteria

Typical QXL – LHC Tunnel



Increased "D" to provide cold quench buffer for triplets

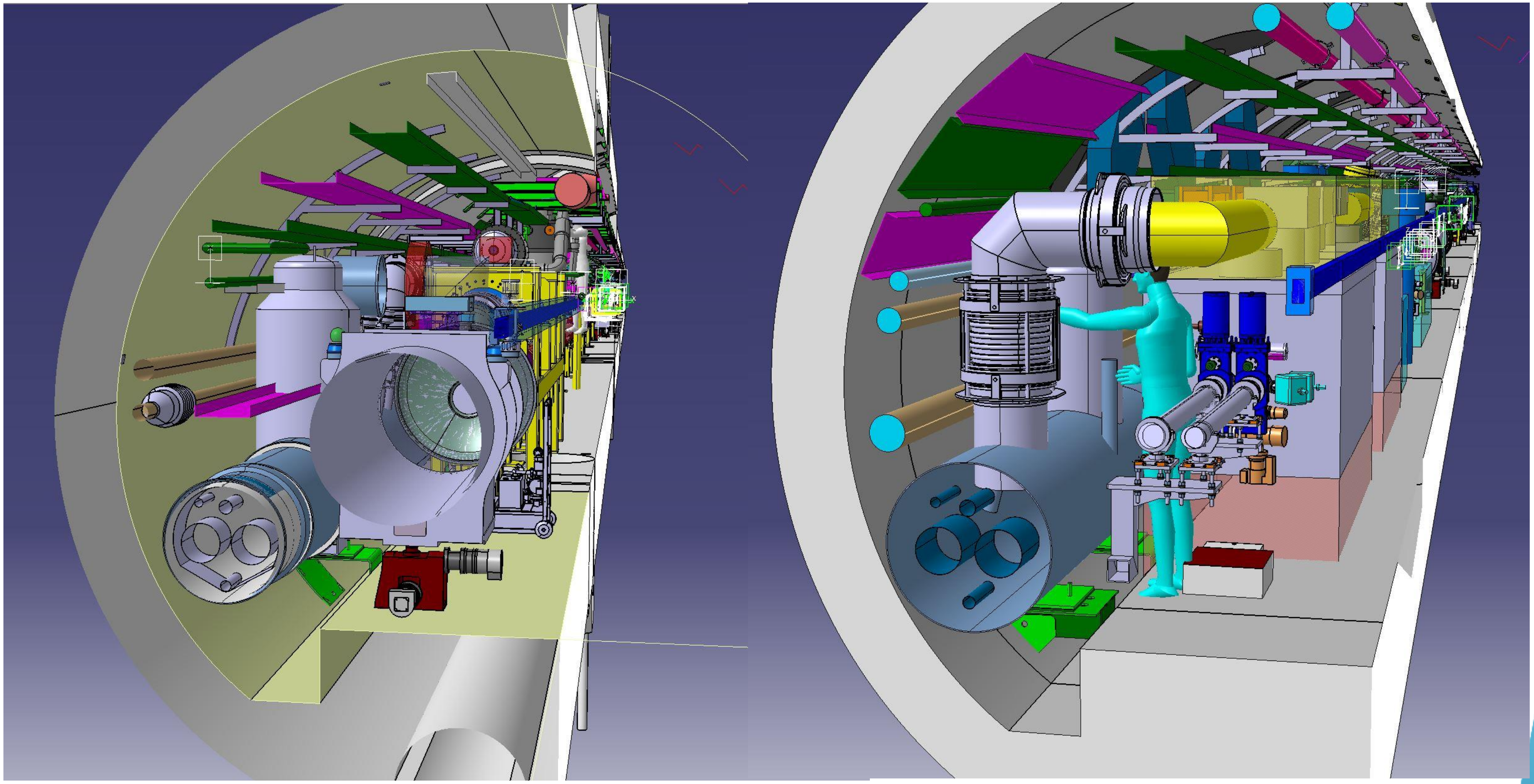
Reduced "B" as not impacting pressure drop



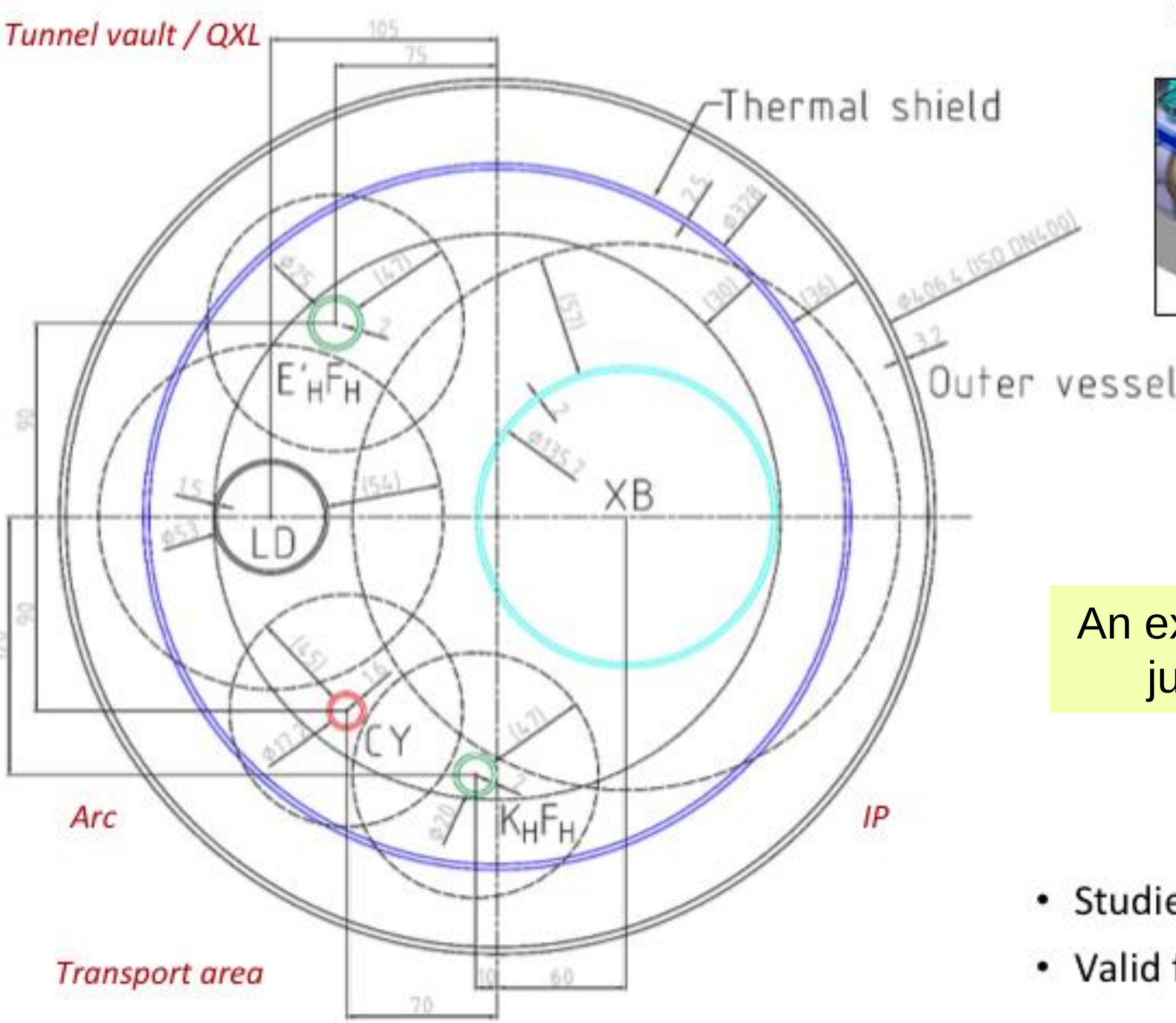
Verifying jumper/piping interfaces with all users while progressing now in service galleries

14Oct'19

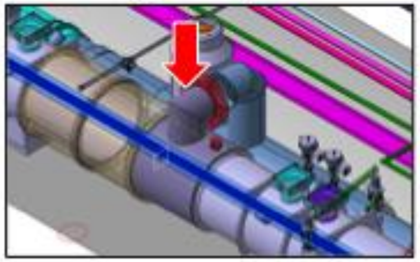
QXL cryoline, 3D models and integration



D1 jumper cross-section



View from the top of the magnet cryostat

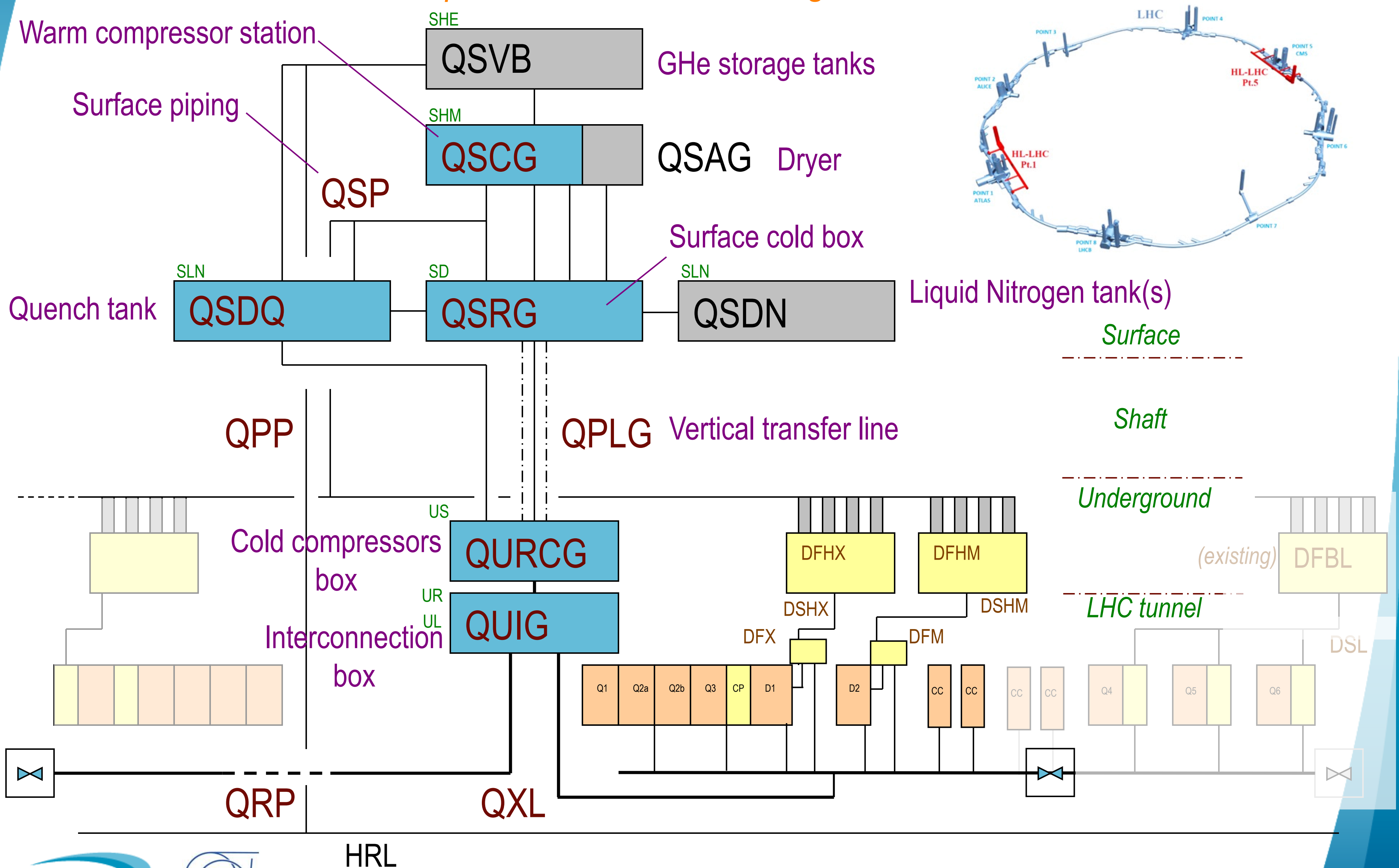


An example, done for all jumper interfaces

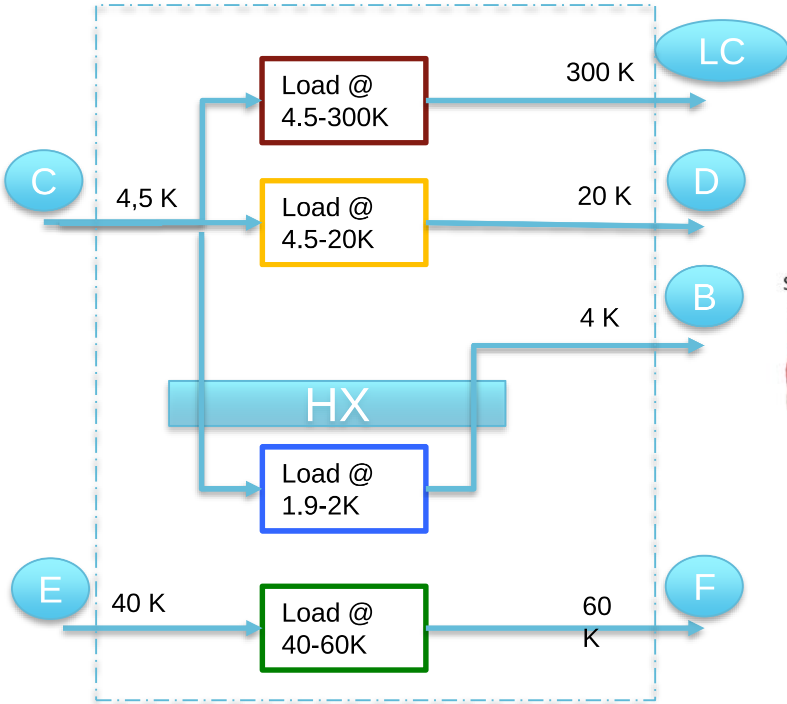
- Studied by TE-MSI
- Valid for the four LSSs

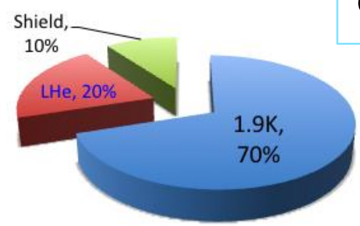
P1/P5 Cryogenic architecture

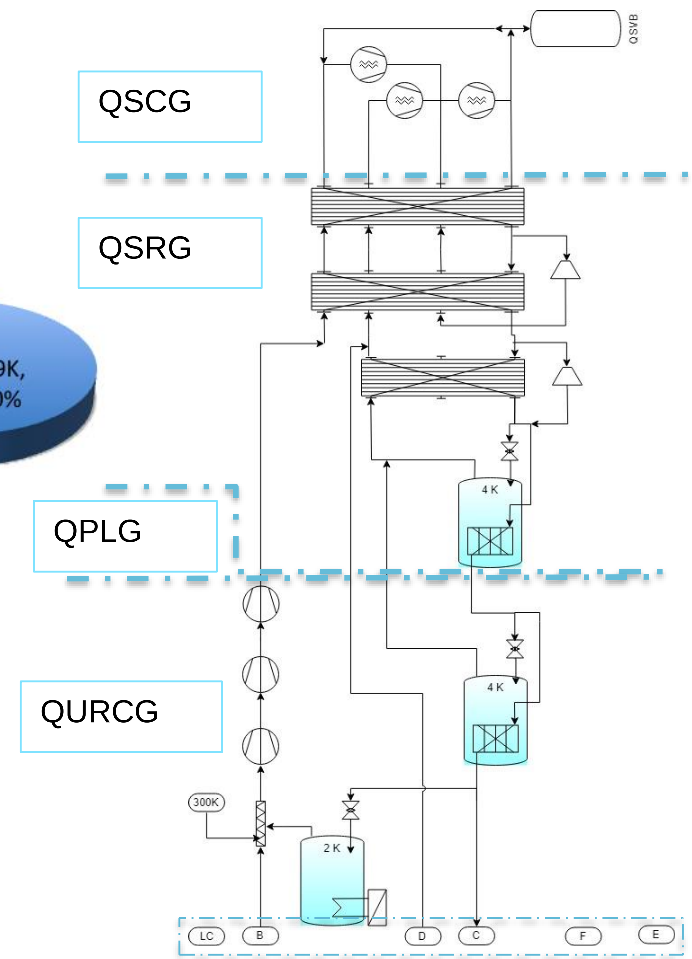
15 kW equivalent at 4.5 K, including 3 kW at 1.8 K



From cooling requirements to Refrigeration capacity and process



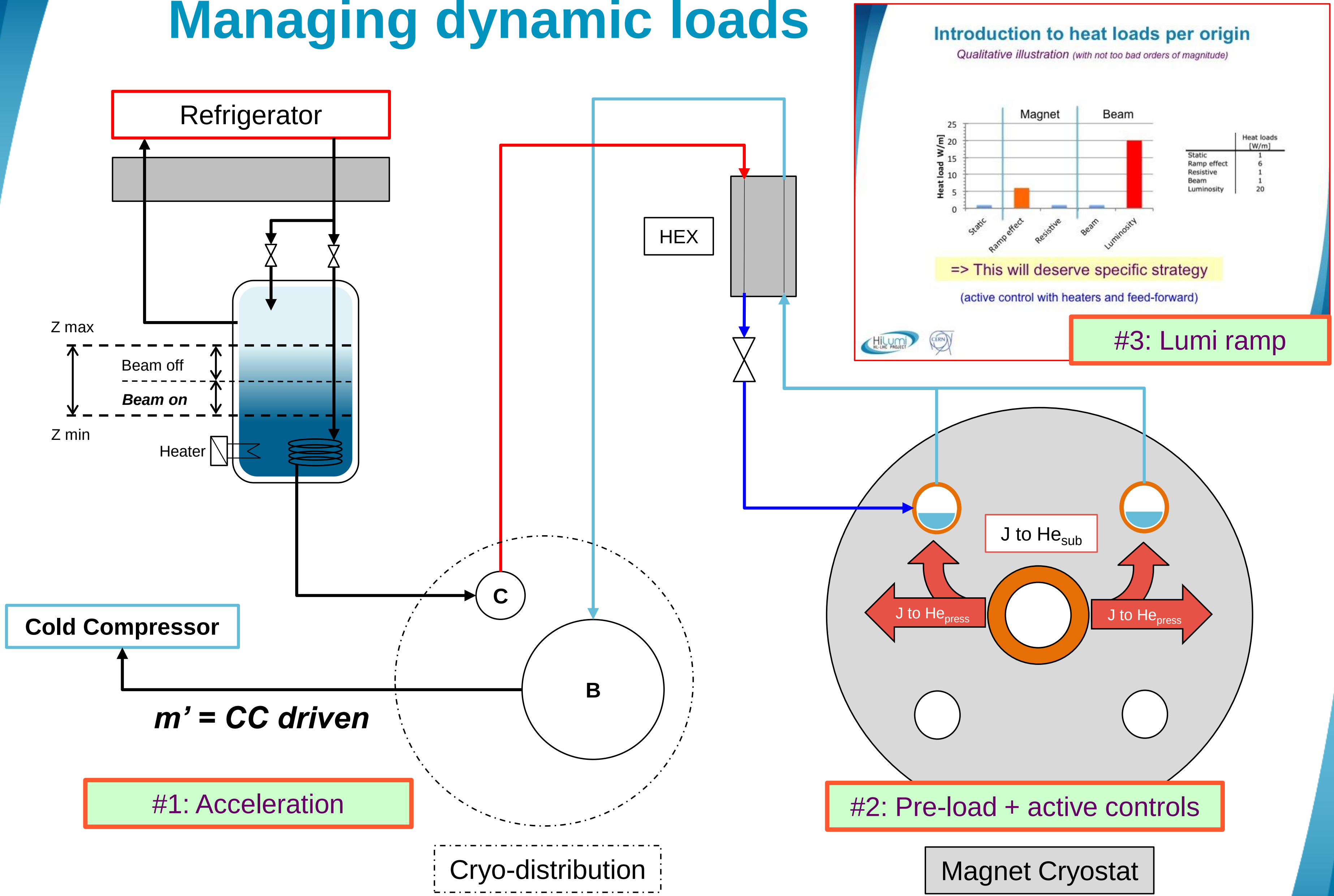




Obvious need for 15mbar header (1.8K cold source),
no special need for 4.5K loads

Process options now under study

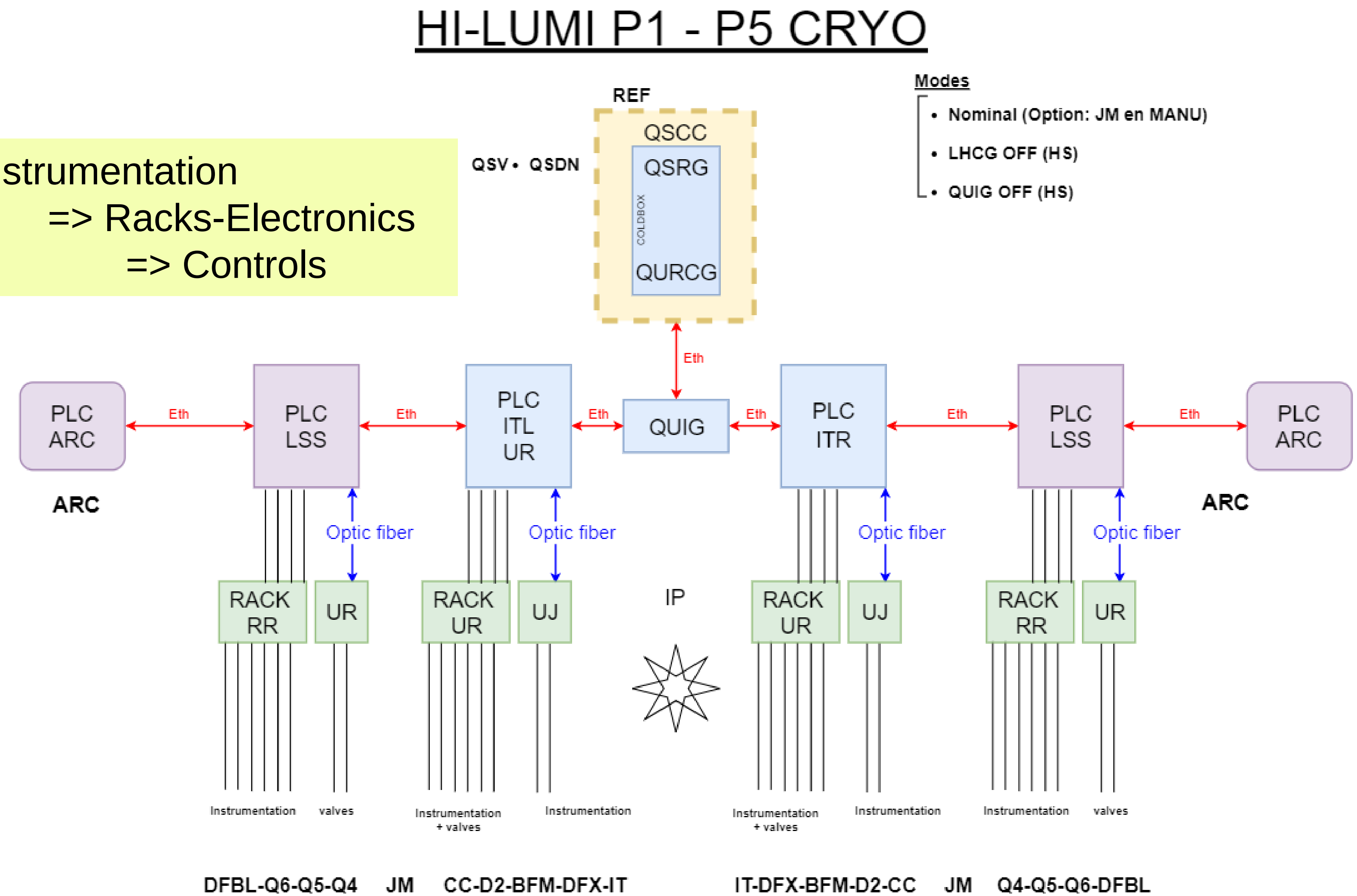
Managing dynamic loads



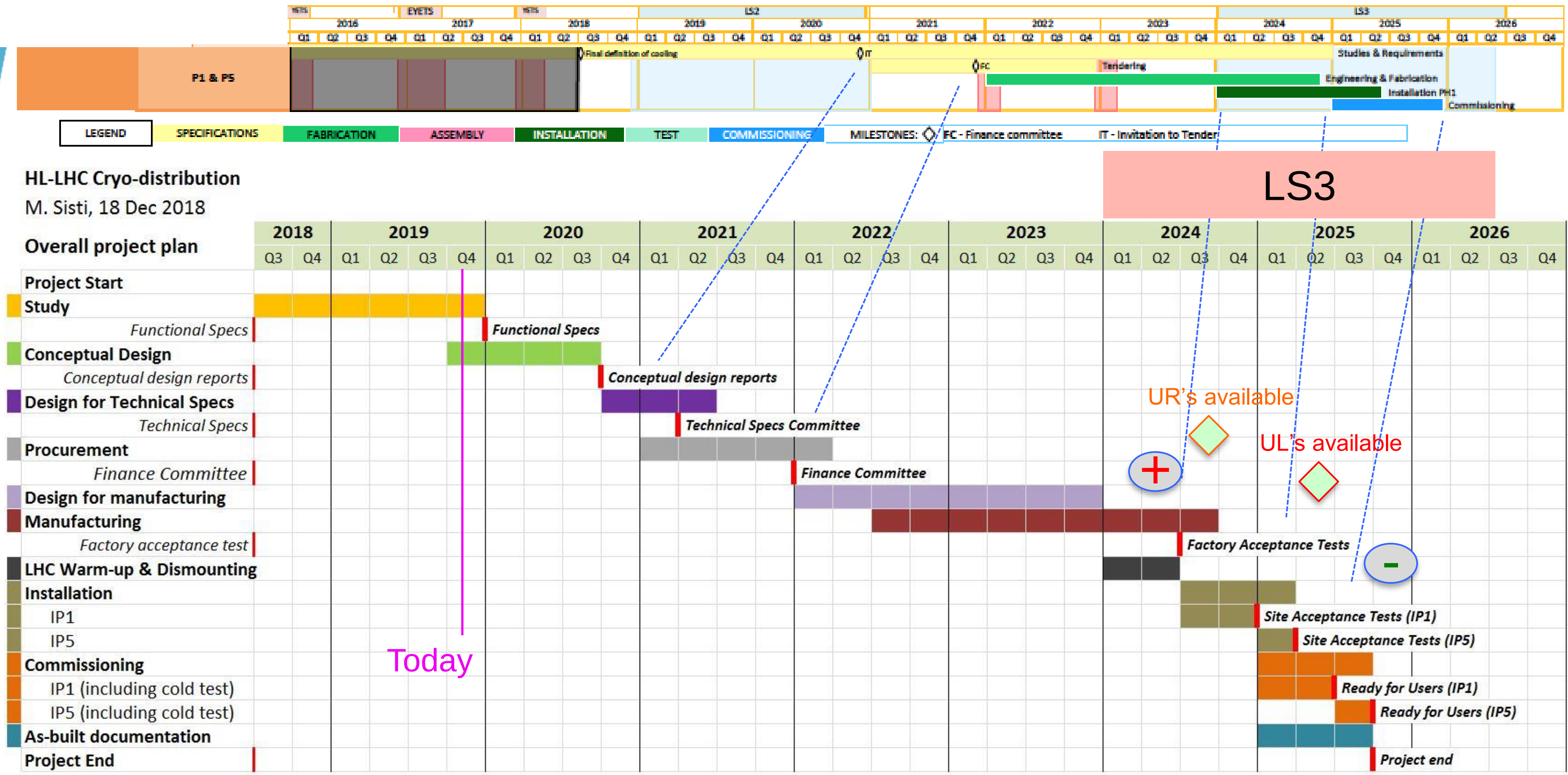
	Heat loads [W/m]
Static	1
Ramp effect	6
Resistive	1
Beam	1
Luminosity	20

HL-LHC cryogenic "control" principles

Instrumentation
=> Racks-Electronics
=> Controls



Project plans Refrigeration-Distribution



Interfaces to be frozen by end 2020

Used now to discuss for LS3 (ready to install, P1 w.r.t P5)

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Upgrade of Helium Refrigerator at LHC Point 4 for HL-LHC – Upper and Lower Cold Boxes

Principle of the capacity upgrade: to replace 8 turbines by new type (more efficient)
This requires exchange of turbine housings & instrumentation

(FC Dec'18)

Site works: Q4-2019
Commissioning: Q2-2020

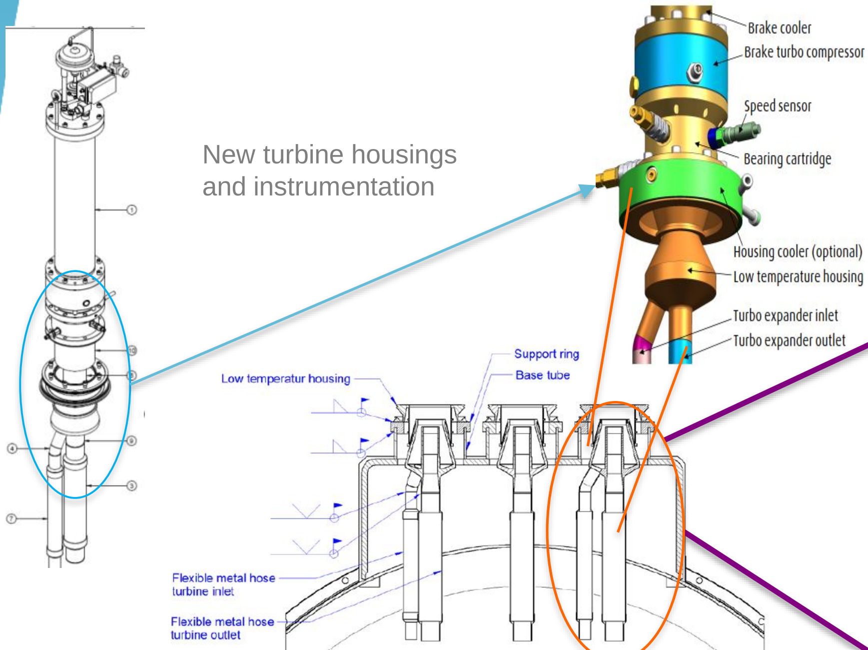
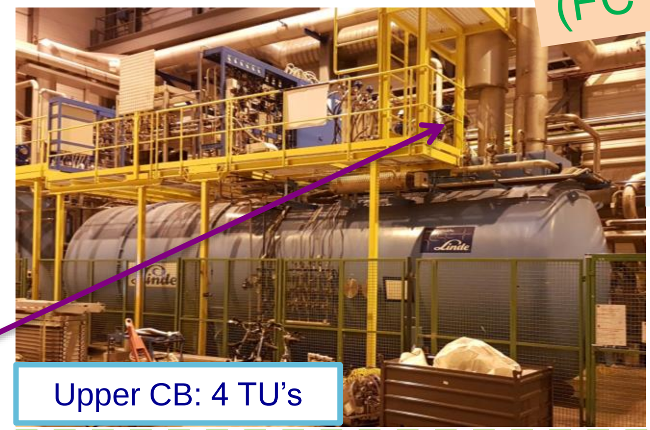


Figure 5: UCB, upgraded, TED45 low temperature housing placement and welding seams

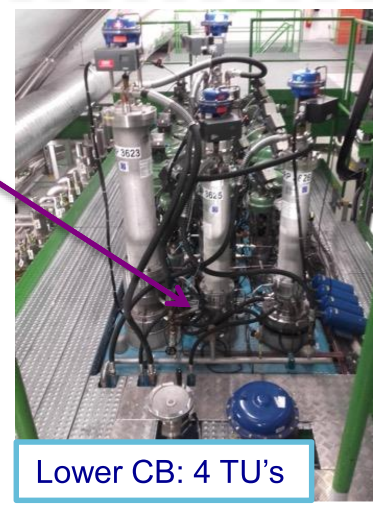
Cut view of existing cold box

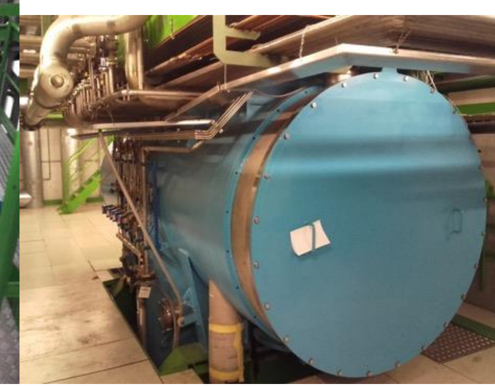


Surface

Shaft

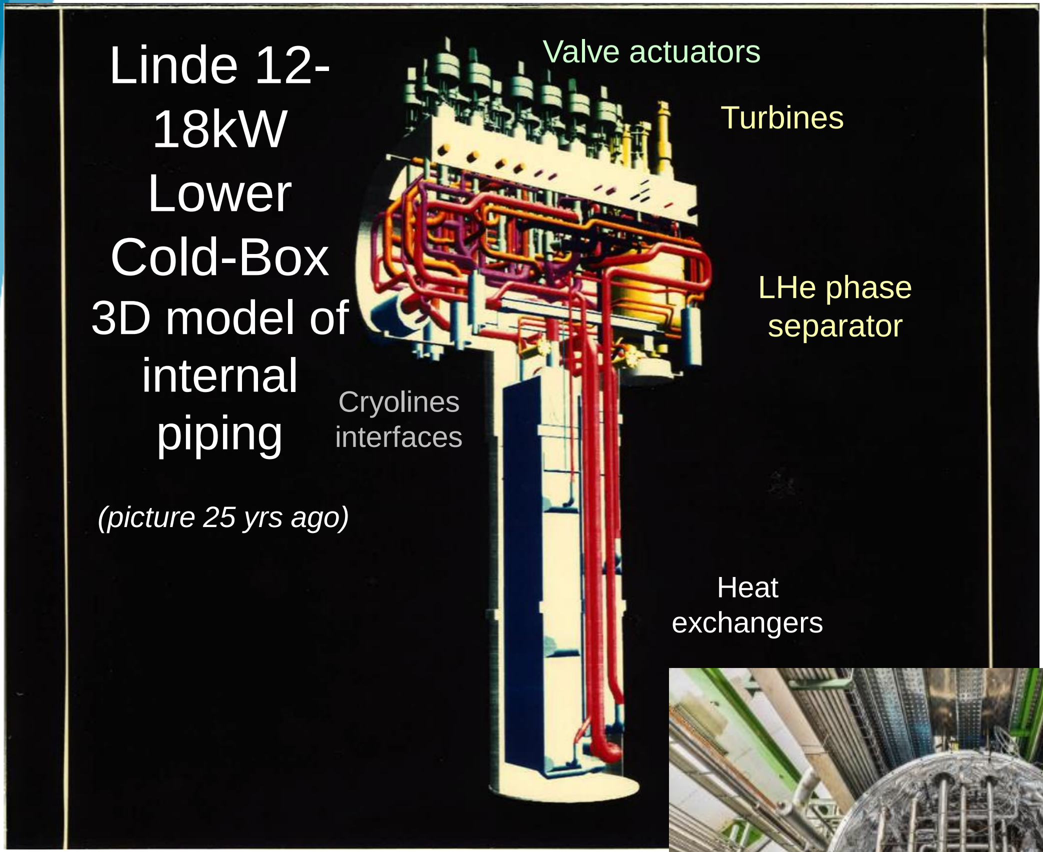
Cavern

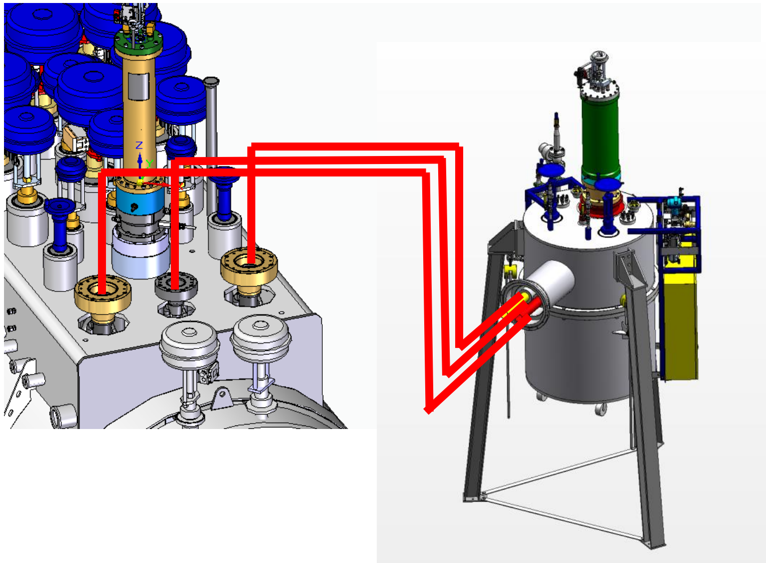




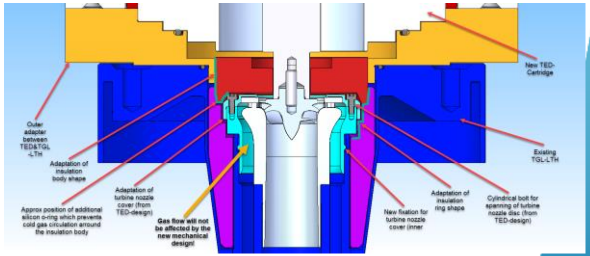
Spares and repairs: to ensure availability as for all helium refrigerators

P4 lower cold box, from inner piping to new turbine interface





Towards modified new inner parts into “old” housing



Next: work on-site to start end oct’19

Summary

- P1/P5 in 2019:
  - Final definition of interfaces with superconducting sub-systems
  - The HiLumi cryoline (QXL) has been sized and integrated
  - Process studies have started, together with management of dynamic heat loads
  - Instrumentation racks and controls architecture being studied

- 2020: Global review of heat loads foreseen to allow freezing requirements and proceed with procurement

- P4 upgrade is well advanced, on track for tests in Q2-2020

WP9 organisation and roles

Re-inforced 2019

- Coordination: Serge Claudet, Rob Van Weelderen
- Quality, documentation, project management: Antonio Perin + Sigrid Knoops*

- Magnet cooling requirements: Rob Van Weelderen + *K. Puthran*
- Crab cavities cooling requirements: Krzysztof Brodzinski

- Heat Load management: Antonio Perin + *M. Spitoni*
- General process overview: *Udo Wagner + Vanessa Gahier + Benjamin Bradu*
- 3D models and integration: Jos Metselaar *(+ designers)*
- Instrumentation & controls: so far CRG/CE-CI experts

- P4-RF and P1-P5
  - Refrigeration: Emmanuel Monneret (Sep'17)
  - Cryodistribution: Michele Sisti (Jun'17)
  - Cryogenic infrastructure: Gérard Ferlin (Jul'19)

Part time contributors during LS2, but valuable help expected from experienced colleagues

- SPS-BA6:
  - Refrig… tion: Laurent Delpr…
  - …ributi… …dzinski + Hendrie Derking
  - Inf… …os Metselaar + O. Pirotte

Done!

Consolidations: S. Claudet + Jos Metselaar