HL Heat load review for HL-LHC scope (P1/P5)

Cold powering Heat loads

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https://indico.cern.ch/event/1019569/
EDMS 2560551
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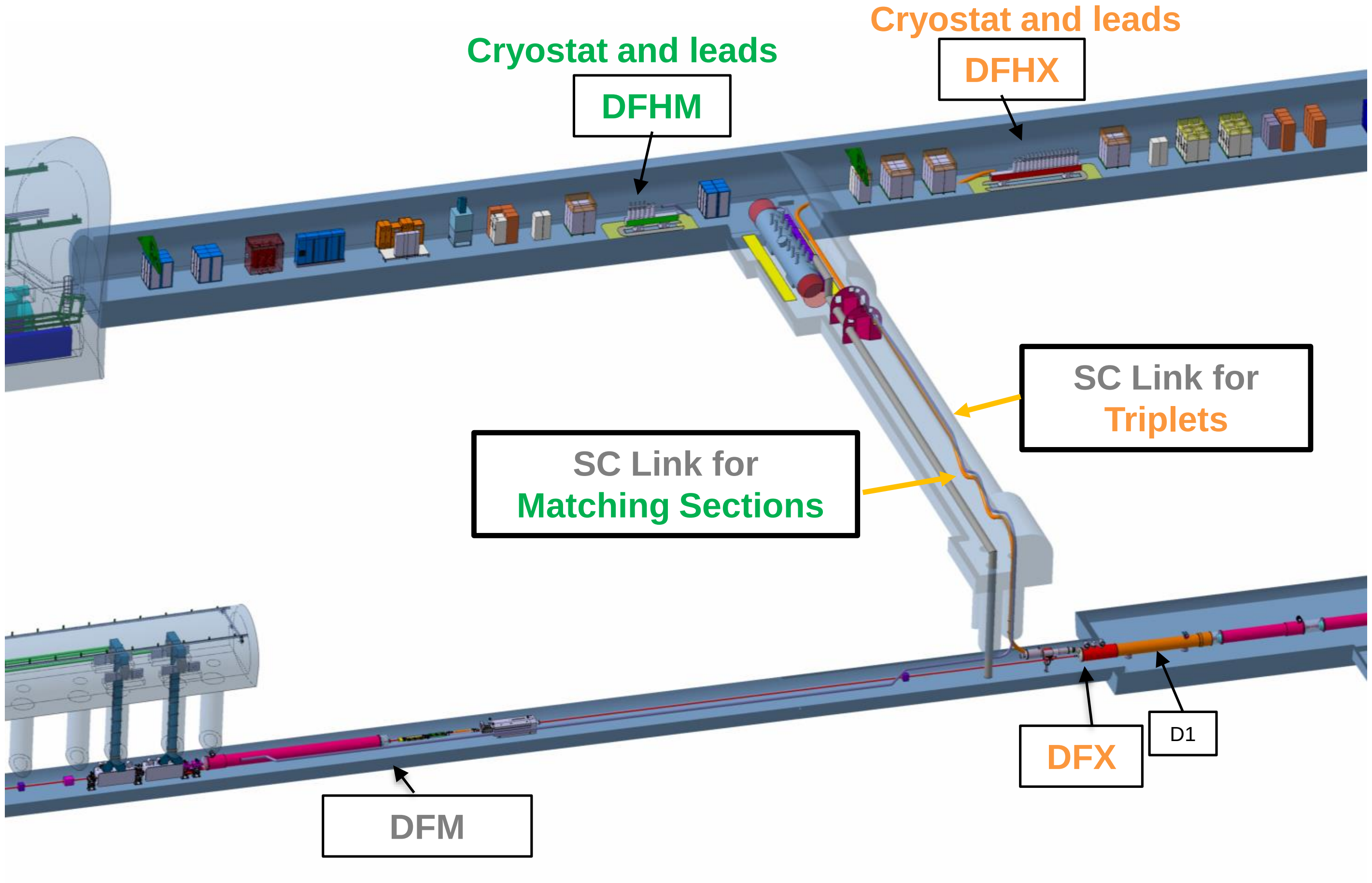
Outline

- DF/ SC link/ DFH location in the tunnel
- Zoom on Cold Powering cooling architecture
  - IT + D1
  - Matching section
- Heat loads Mechanisms
- Helium flow requirement
- Thermal design
  - DFHX
  - DFHM
- Conclusions

DF/ SC link/ DFH location in the tunnel



Courtesy from A. Ballarino
From Internal review of DFH detailed design

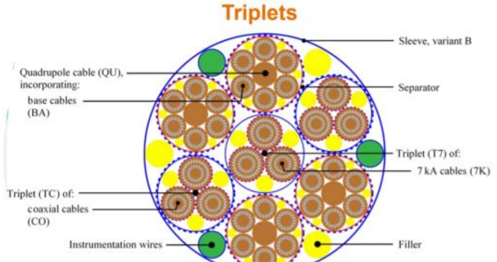
- ✓ One type of cold powering system to feed IT/D1 to be installed at **four** locations (5L,5R,1L,1R)
  →DF**X**/DSH**X**/DFH**X**
- ✓ One type of cold powering system to feed D2 to be installed at **four** locations (5L,5R,1L,1R)
  →DF**M**/DSH**M**/DFH**M**

Zoom on Cold Powering for IT cooling architecture

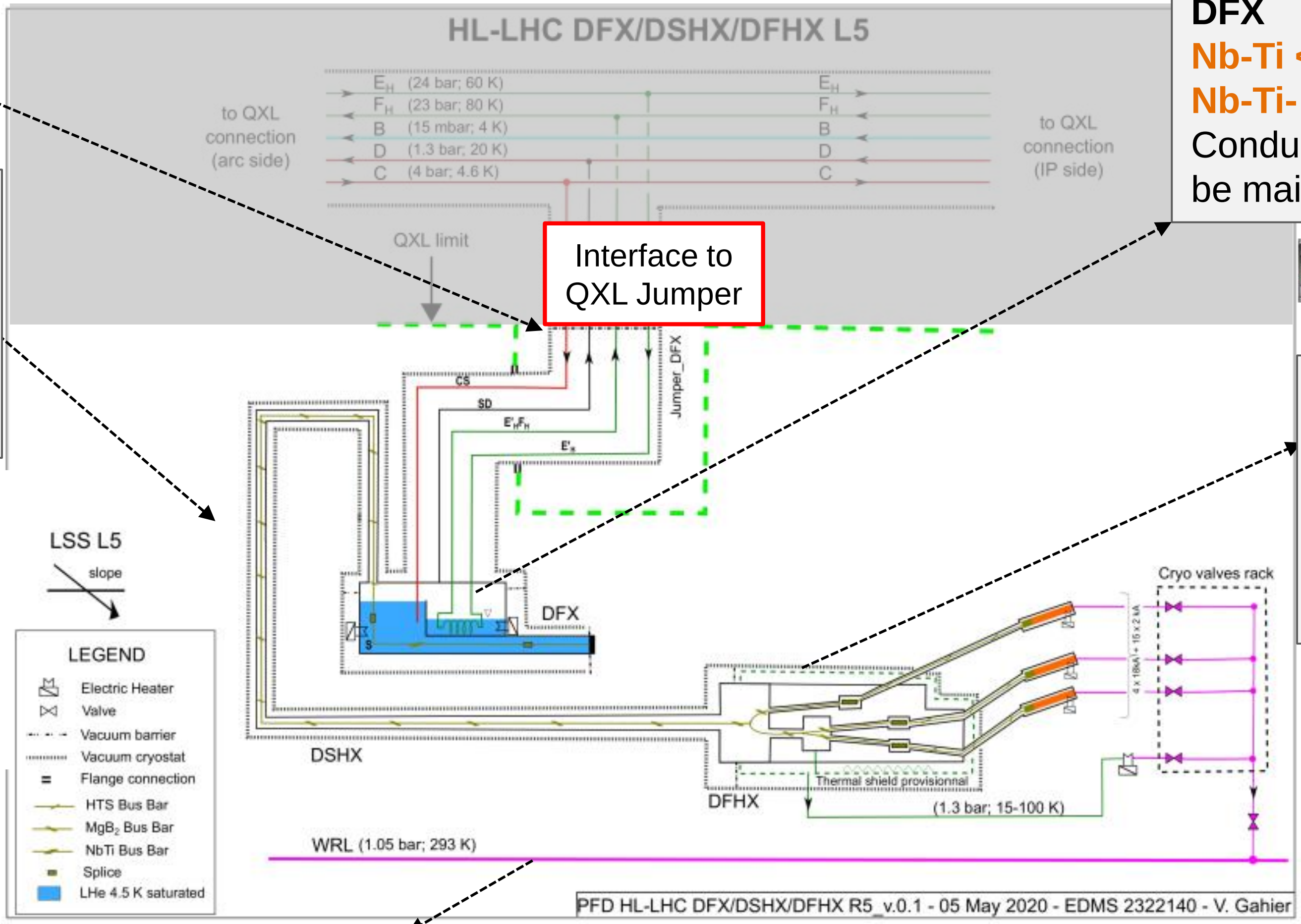
One cooling circuit from 4.5K to 300 K

One Service module feeding in particular supercritical helium to Cold Powering system.

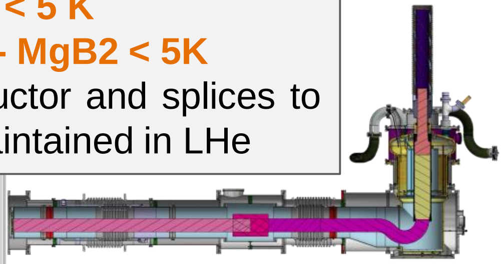
SC link (DSHX) ~ 72 m
19 cables cooled by gaseous helium (helium boiled from DFX)
Cryostat at **1.5 W/m**
MgB2 < 17 K



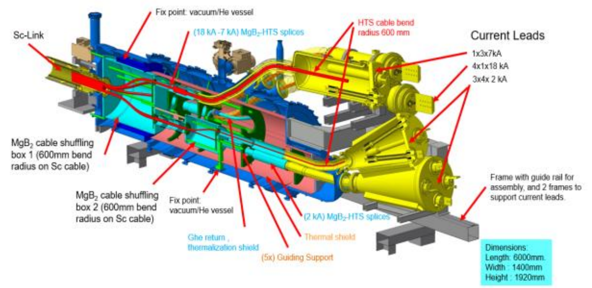
Courtesy from A. Ballarino
From 8th HL LHC collaboration meeting



DFX
Nb-Ti < 5 K
Nb-Ti- MgB2 < 5K
Conductor and splices to be maintained in LHe



DFHX
MgB2-HTS splice < 17 K by forced gaseous circulation
2 shuffling boxes
19 current leads :
- HTS- copper transition < 50 K



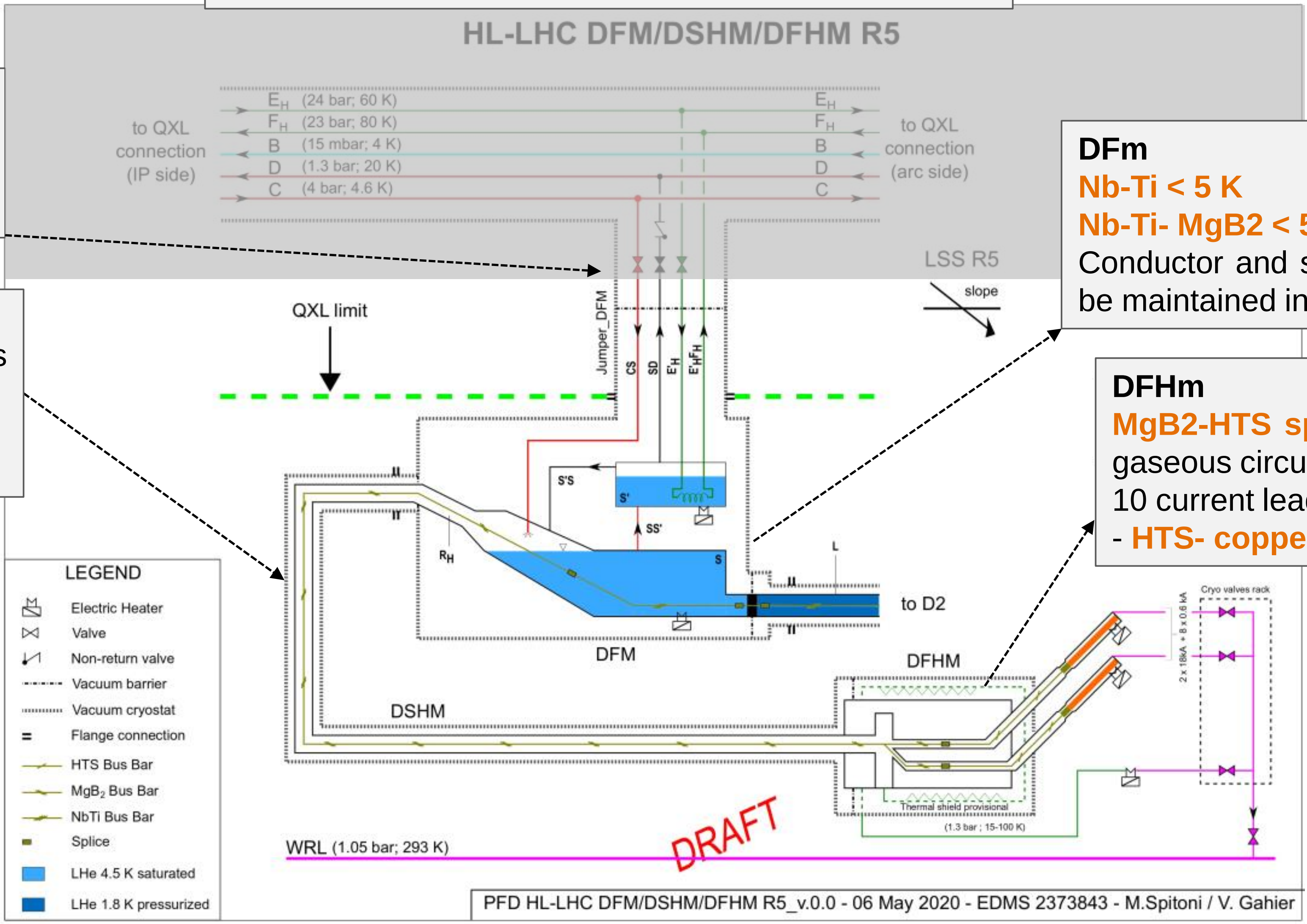
Return at 300 K and Low pressure → helium required is a **liquefaction** flow at refrigerator level

Zoom on Cold Powering for Matching section cooling architecture

One cooling circuit from 4.5K to 300 K

One Service module feeding in particular supercritical helium to Cold Powering system.

SC link (DSHm) ~ 117 m
15 cables cooled by gaseous helium
Cryostat at **1 W/m**
MgB2 < 17 K



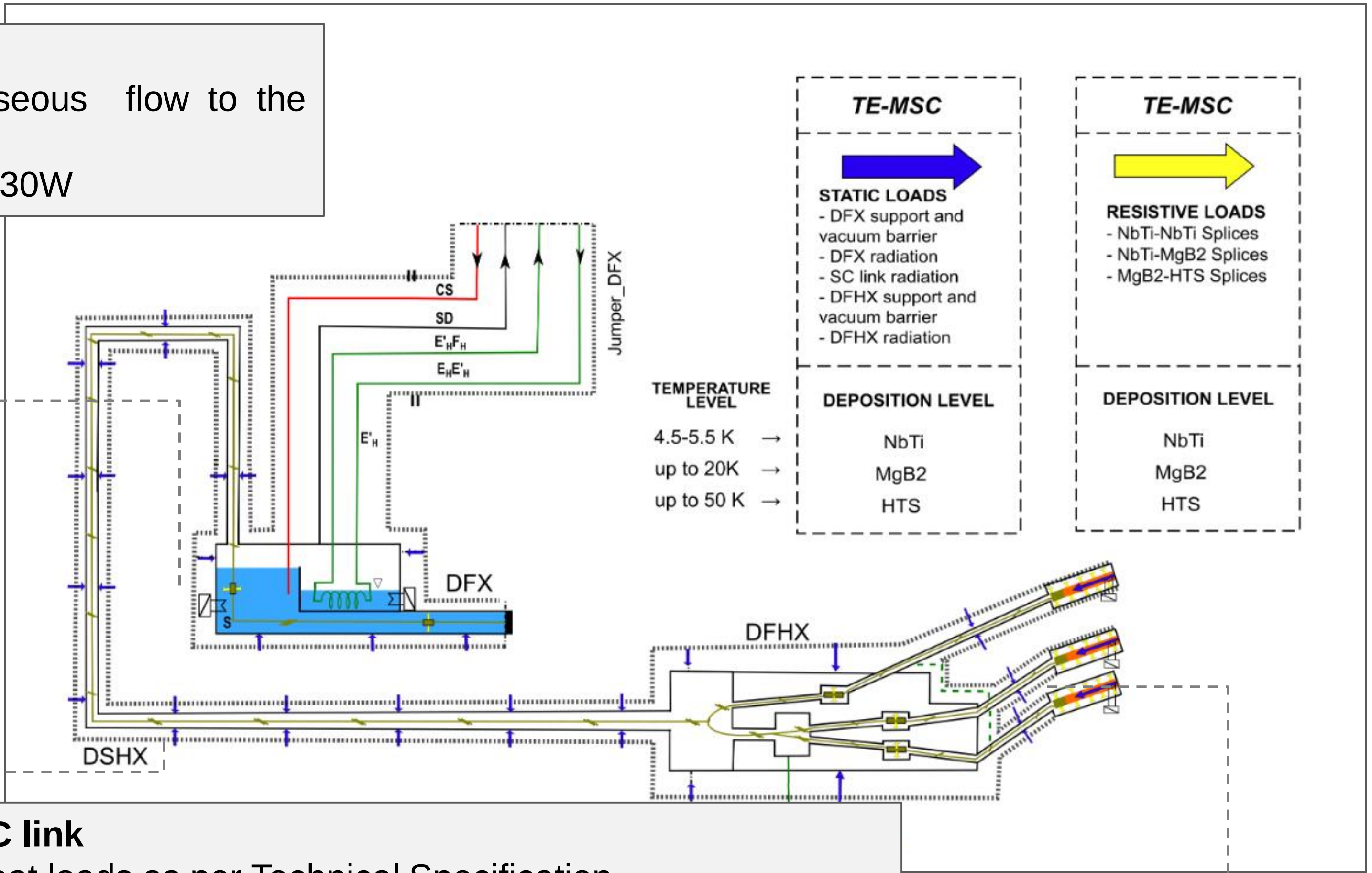
DFm
Nb-Ti < 5 K
Nb-Ti- MgB2 < 5K
Conductor and splices to be maintained in LHe

DFHm
MgB2-HTS splice < 17 K by forced gaseous circulation
10 current leads
- **HTS- copper transition < 50 K**

Heat load mechanisms for Cold Powering system

DFX /DFM

- Generates the gaseous flow to the link
- Local heat loads < 30W



SC link

Heat loads as per Technical Specification

https://edms.cern.ch/document/2435732/0.4

- **1.5 W/m** for Inner Triplet
- **1.0 W/m** for Matching section

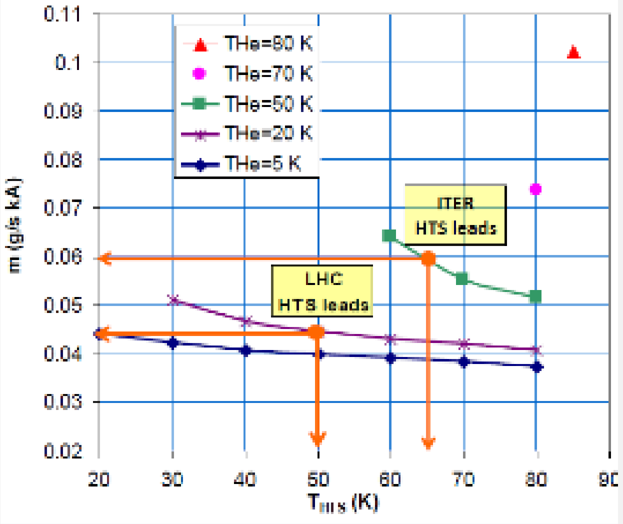
Based on measurements of Demo 2 !

For measurement of heat load, a tolerance of 0.5 W/m is permitted for acceptance

Current leads :

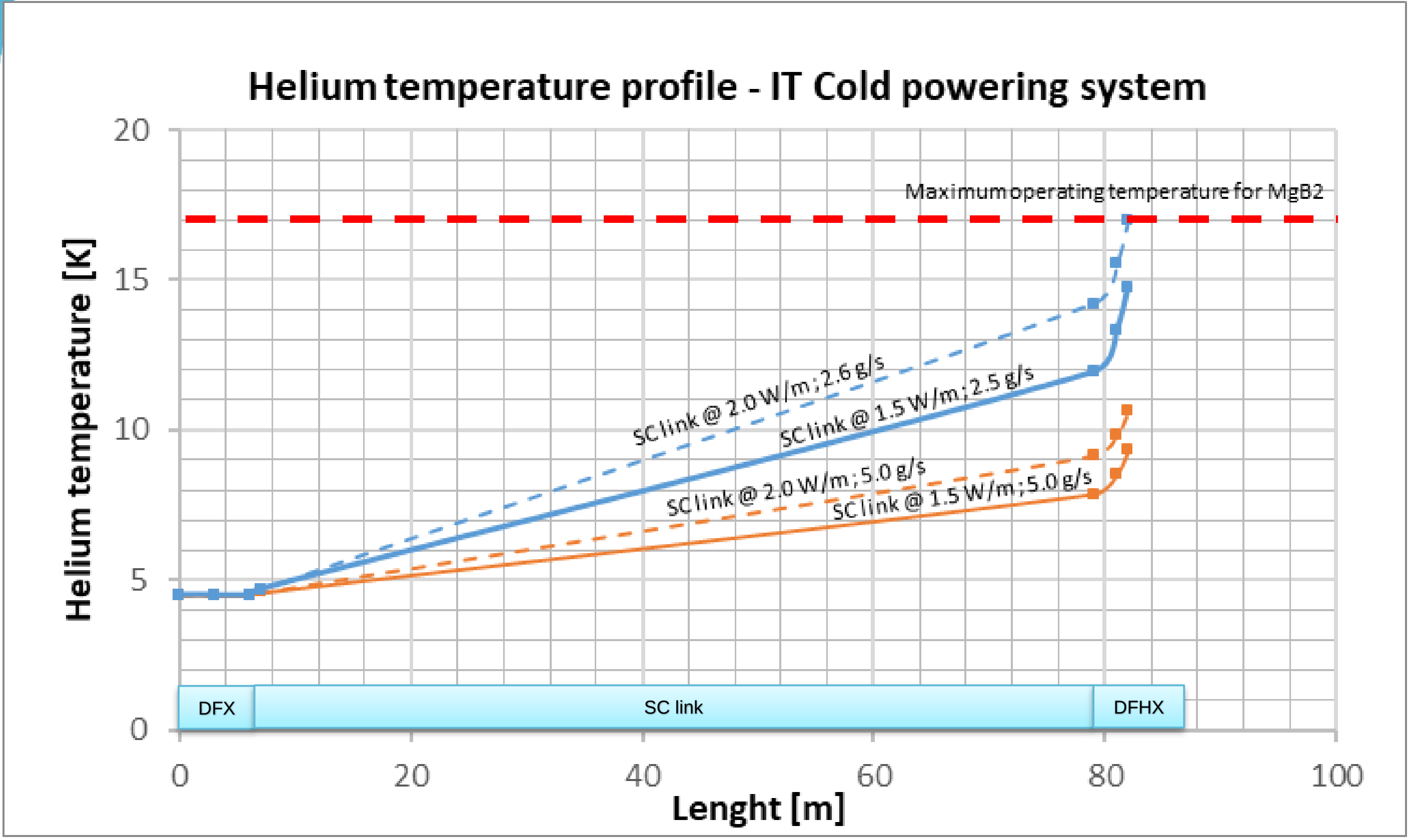
Required flow is proportional to current intensity – 0.05 g/s /kA

- 50% for conduction (no current case)
- 50% for Joule Effect (current case)



Courtesy from A. Ballarino

Helium temperature profile and Design flow along the Cold Powering system for IT



- Cold powering system for IT helium flow :
  - **Nominal at Ultimate current (raw): 5 g/s**
  - **Nominal with no current (raw): 2.5 g/s**
  - **Installed local capacity: 10 g/s**
- Installed local capacity is taken at twice the nominal flow at Ultimate current to cover any unforeseen event on DFX, SC link, DFHX.
- At nominal conditions and considering SC link at 1.5 W/m (as per specification), temperature in DFHX varies from 8 to 15 K
- Considering SC link tolerance of 0.5 W/m for acceptance, the helium flow for no current shall be increased from 2.5 g/s to 2.6 g/s to stay below 17 K in DFHX.

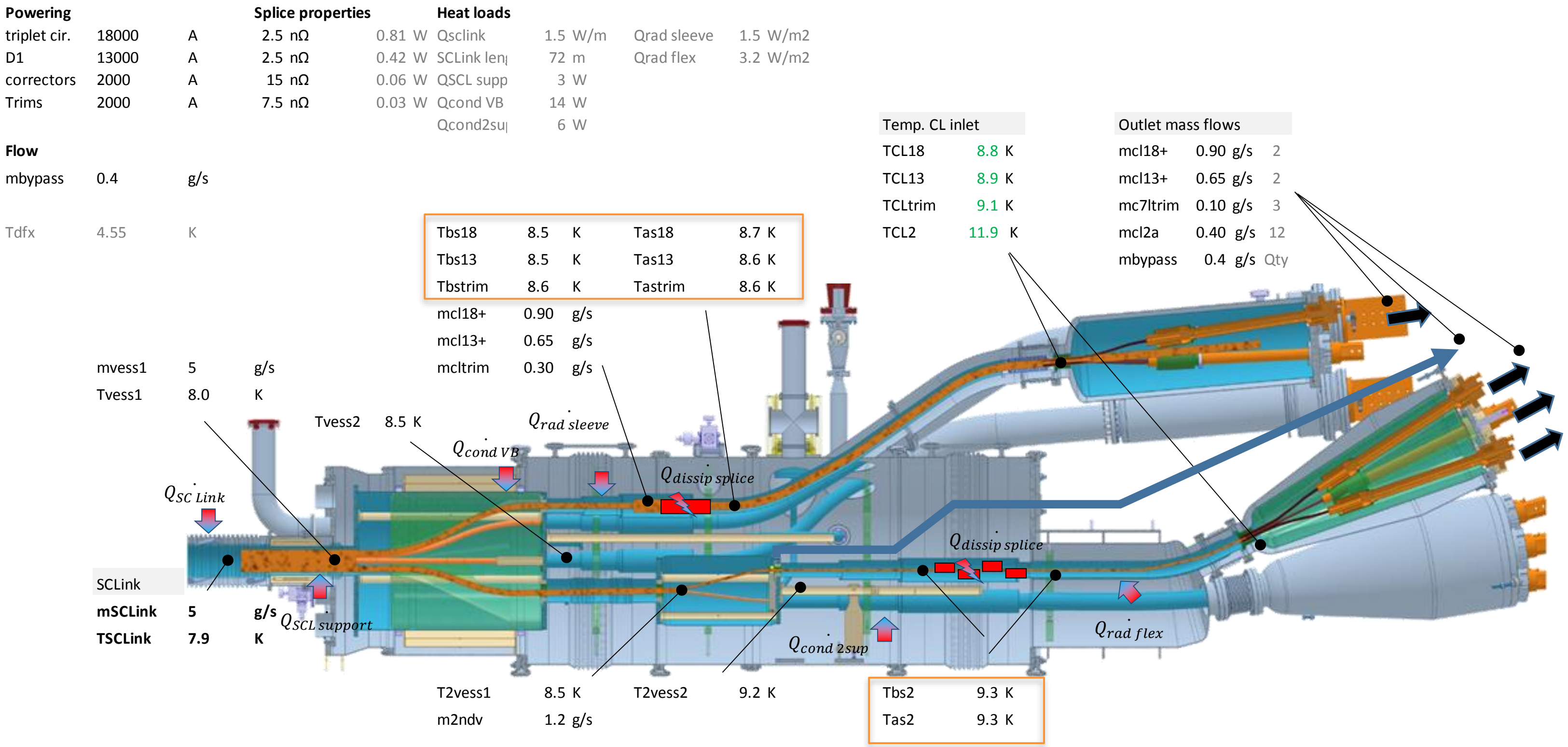
Zoom of DFHX
Thermal design thoroughly studied by design team

DFHX : Ultimate current

Thermal design of DHFX was thoroughly studied by WP6a design team.

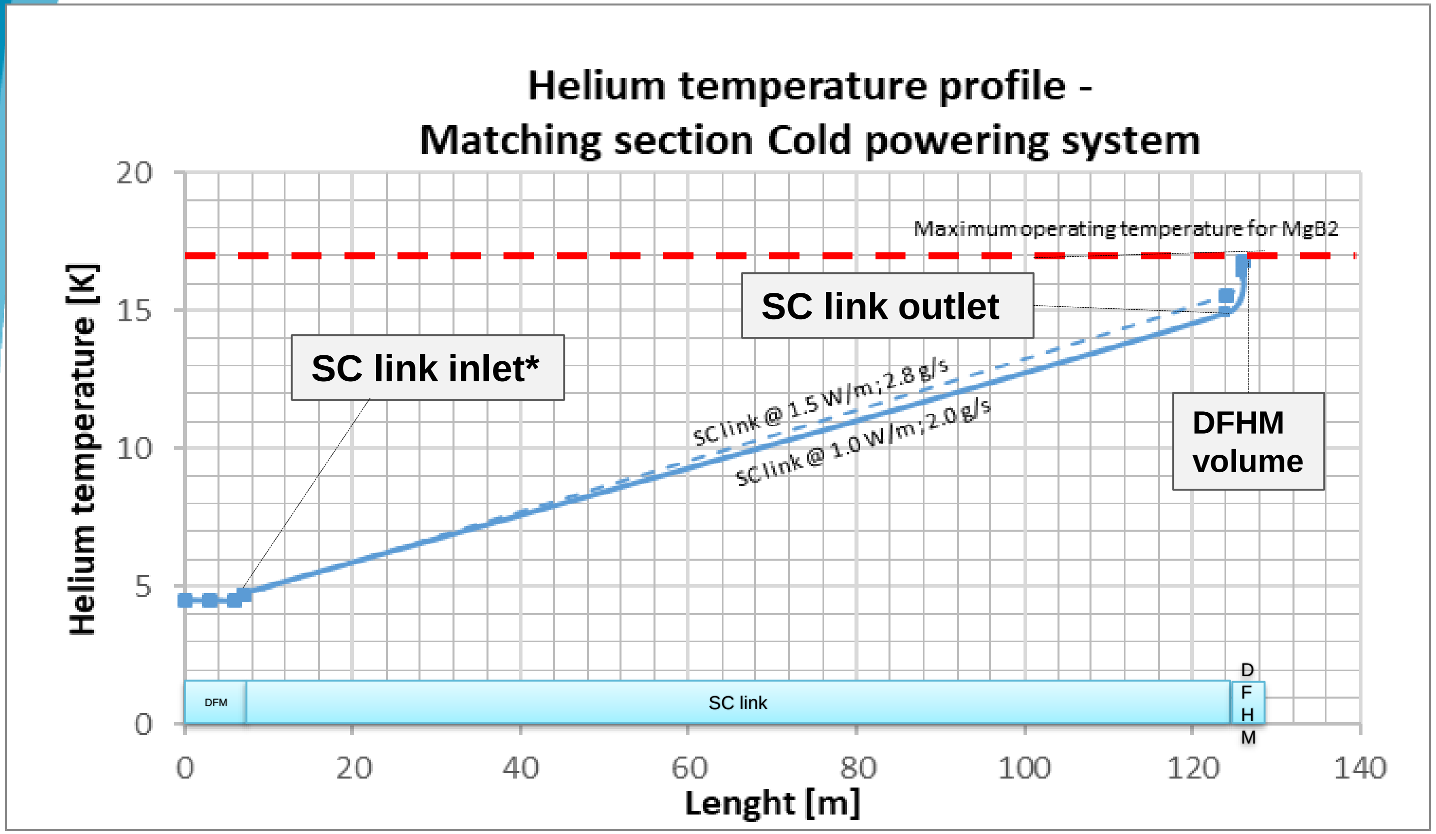
DFHX contains 2 shuffling modules and temperature ranges between 7.9 K and 9.3 K for the Ultimate current case (at 5 g/s)

Total Heat load on DFHX is estimated < 30 W as per specification.



Courtesy from Y. Leclercq

Helium temperature profile and Design flow along the Cold Powering system for Matching section



- Cold powering system for MS helium flow
  - **Nominal at Ultimate current: 2 g/s**
  - **Nominal with no current: 2 g/s**
  - **Installed local capacity : 5 g/s**
- Nominal flows defined by SC link flow requirement.
- At nominal conditions and considering SC link at 1.0 W/m (as per specification), flow with current and with no current at 2 g/s to stay below 17 K at MgB2-HTS splice.
- Considering SC link tolerance of 0.5 W/m for acceptance, the helium flow for no current shall be increased from 2.0 g/s to 2.8 g/s to stay below 17 K in DFHX.
- Installed local capacity is taken at 5 g/s to cover in particular **higher heat loads on the SC link.**

Thermal design DFHM
Thoroughly studied be design team

DFHM : Ultimate current

Powering			Splice properties			Heat loads				
D2 circuit	13000	A	2.5 nΩ eq	0.42	W	Qsclink	1 W/m	Qrad sleeve	1.5	W/m2
						SCLink leng	117 m	Qrad flex	3.2	W/m2
Correctors	600	A	15 nΩ	0.01	W	QSCL supp	3 W			
						Qcond VB	11 W			

Flow		
mbypass	0.3	g/s
Cp	5.3	J/g.K
Tdfm	4.5	K

Negligeable (IFS, safety interface, convection)

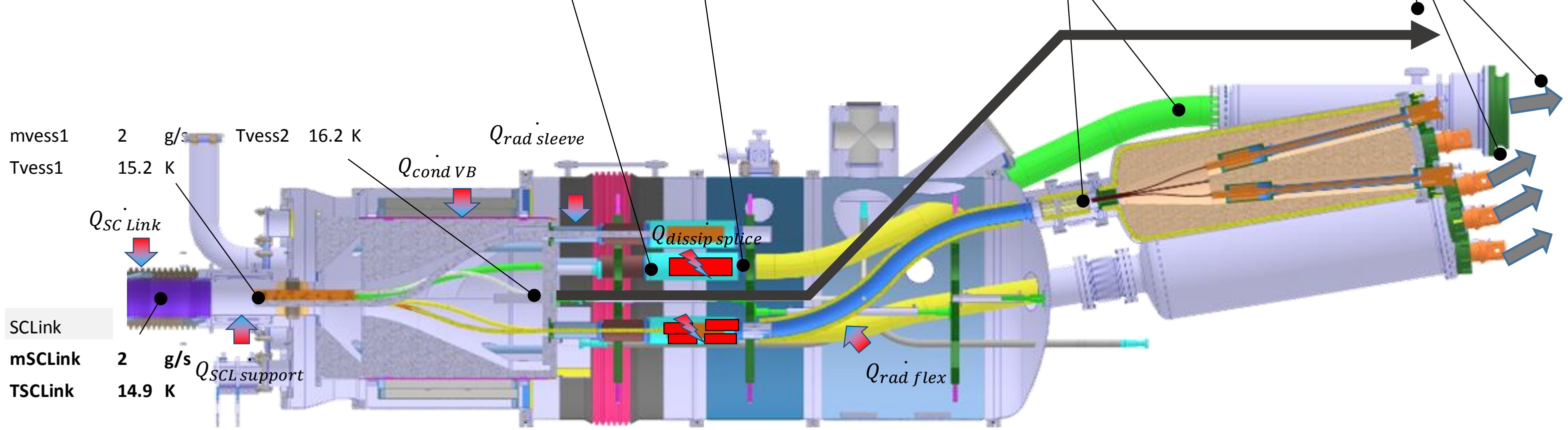
Upstream splice			Downstream splice		
Tbs13	16.3	K	Tas13	16.4	K
Tbs0.6	16.4	K	Tas0.6	16.4	K
mcl13+	0.65	g/s			

Temp. CL inlet		
Tcl13	16.6	K
Tcl0.6	17.2	K

Outlet mass flows			
mcl13+	0.65 g/s	2
mcl0.6	0.05 g/s	8
mbypass	0.3 g/s	Qty

Thermal design of DHFM was also thoroughly studied by WP6a design team.
Total Heat load on DFHM is estimated < 30 W as per specification.

Due to the temperature at inlet of DFHM, the temperature at splices close to 16 K.



Courtesy from Y. Leclercq

Conclusion

- Helium cooling flow required for the Cold powering system acts as liquefaction flow at refrigerator level : these requirements should not be overlooked.

- Design formula used for heat loads reminded (refer to Methodology talk)

$$Q_{design} = Max[\ F_{ov} * \left(F_{un} * Q_{static} + Q_{dynamic\ nominal}\right)\ ;\ F_{un} * Q_{static} + Q_{dynamic\ ultimate}\ ]^*$$

  - Uncertainty factor (F_{un}) taken at 1.25 since components were tested in Demo 2,
  - Overcapacity factor (F_{ov}) taken at 1.5 as per global approach,

	Design factor	DFX/DSHX/DFHX		DFM/DSHM/DFHM	
		Raw	Design	Raw	Design
Nominal flow at max Current	1.5	5 g/s	**8.4 g/s**	2 g/s	**3.8 g/s**
Nominal with no current	1.25	2.5 g/s	3.1 g/s	2 g/s	2.5 g/s
Installed local capacity	-	10 g/s		5 g/s	

- Refrigerator will be designed for 24.4 g/s liquefaction rate considering design factors.

Thanks for your time and answers

Helium requirement for Cold powering system

	Temperature level	DFX/DSHX/DFHX Helium flow (g/s)	DFM/DSHM/DFHM Helium flow (g/s)
DF static loads	4.5 K	1.5	1.5
Superconducting link	4.5 K → 15 K	1.8	2.0
Current leads (with Current)	20 K → 50 K	5.0	2.0
Current leads (with no Current)	20 K → 50 K	2.5	1.0

	DFHX	DFHM	Comment
18 kA Current leads (DFHLA)	4	2	Helium consumption : 0.9 g/s at maximum current
2 kA Current leads (DFHLB)	12	-	Helium consumption : 0.1 g/s at maximum current
2 kA Current leads (DFHLC)	3	-	Helium consumption : 0.1 g/s at maximum current Up to 7kA DC (one spare lead)
0.6 kA Current leads (DFHLD)	-	8	Helium consumption : 0.03 g/s at maximum current
Grand total	19		

Helium flow for Nominal current

Applying the design formula on the nominal current as defined in the MCF.

Flow requirement for	DFX/DSHX/DFHX		DFM/DSHM/DFHM	
	Raw	Design	Raw	Design
Current leads at Max current	5.0 g/s	8.4 g/s	2.0 g/s	3.4 g/s
Current leads at Nominal current	4.1 g/s	7.0 g/s	1.5 g/s	2.6 g/s
SC link at specified heat loads	1.8 g/s	3.4 g/s	2.0 g/s	3.8 g/s

		DFX/DSHX/DFHX		DFM/DSHM/DFHM	
		Raw	Design	Raw	Design
Nominal flow at Nominal Current	1.5	4.1 g/s	**7.0 g/s**	2 g/s*	**3.8 g/s**
Nominal with no current	1.25	2.5 g/s	3.1 g/s	2 g/s*	2.5 g/s
Installed local capacity	-	10 g/s		5 g/s	

* Requirement defined by SC link heat loads