Cryogenic design, including operational considerations

Review of the cryogenic by-pass for the LHC DS collimators, 26 May 2011.

- Cryogenic circuits
- Generic cryogenic requirements
- Heat loads
- Beam screens
- Instrumentation
- Conclusions

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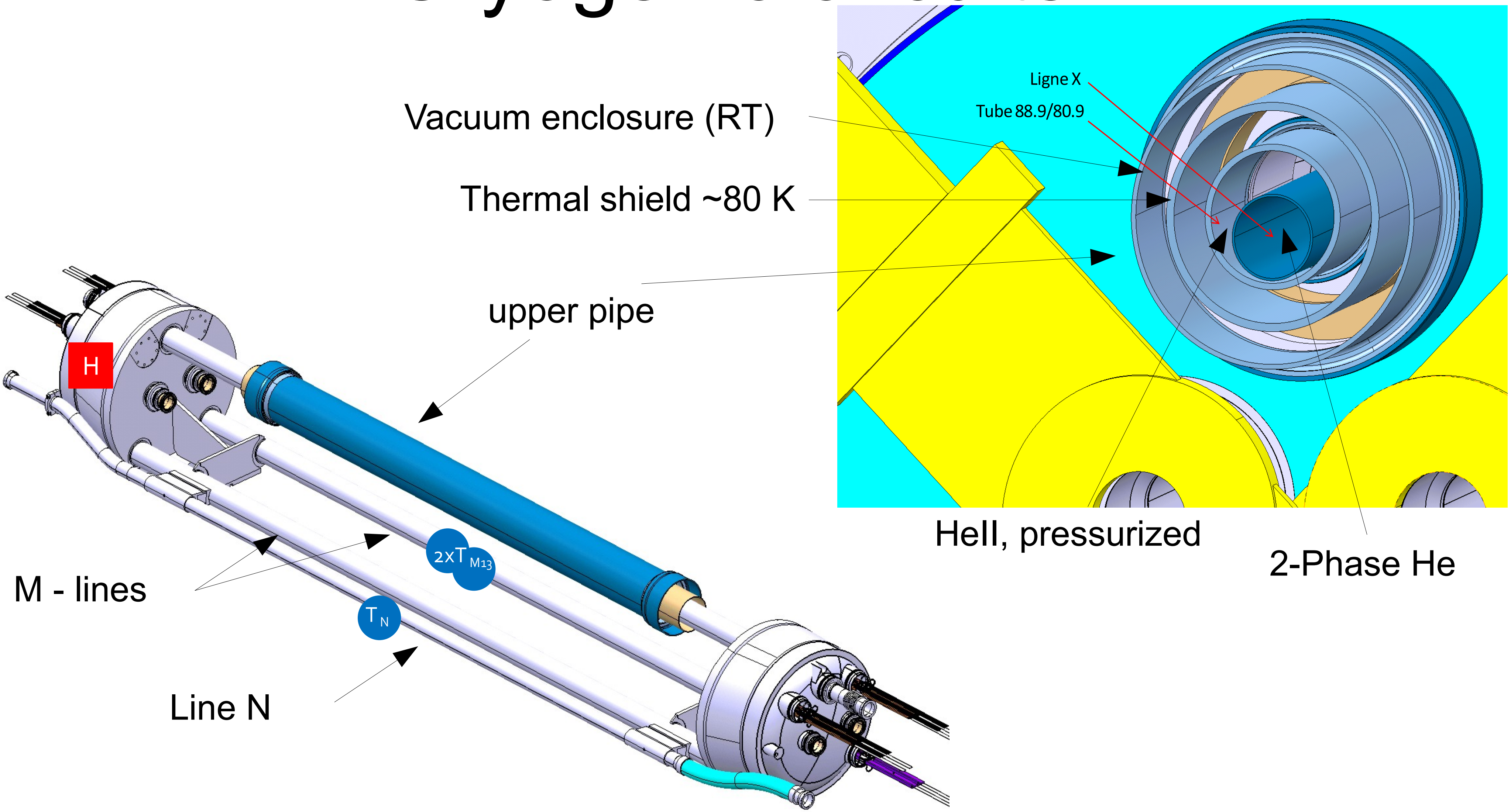
Cryogenic circuits



Vacuum enclosure (RT)

Thermal shield ~80 K

upper pipe

M - lines

Line N

HeII, pressurized

2-Phase He

The superfluid helium is contained inside an envelope made of 2 short vessels connected by 3 pipes:

- An upper pipe provides partial continuity of the He bath at the top level and surrounds the heat exchanger tube (line X).

- 2 pipes placed under the beam height allow to deviate the busbars, creating the space for the collimator. They provide the main continuity of the He bath. *With respect to the standard DS interconnects one of the M lines is suppressed and the other one displaced to the lower half of the cryostat*.

Generic cryogenic requirements : P & T

		Cool-down/Warm-up		Normal operation		Magnet Quench	
	d_i [mm]	T [K]	P [MPa]	T [K]	P [MPa]	T [K]	P [MPa]
1.9 K He vessel (and lines M)	(80)	293–1.9	1.2	1.9	0.13	30	2.0
Line N	50	293-1.9	1.2	1.9	0.13	30	2.0
Line X	54	293–1.9	IP = 0.2 OP = 1.2	1.8	IP = 0.0016 OP = 0.13	30	IP = 0.0016 OP = 2.0
Line Y	10	293–1.8	0.2	1.8	0.0016	30	0.0016
Line E	80	293–50	1.95	50 – 65	1.95	50-65	2.2
Line C′	15	293–4.6	1.65	4.6	0.36	4.6	0.36
Lines V1, V2	50	293–1.9	IP = vac. OP = 1.2	1.9	IP = vac. OP = 0.13	30	IP = vac. OP = 2.0
Lines K1, K2	3.7	293–4.6	1.65	4.6	0.36	4.6	0.36
Vacuum vessel W	890	293	vacuum	293	vacuum	293	vacuum

Pressure, temperature and sizing requirements are according to the LHC engineering specification LHC-Q-ES-0001 v1.1 applicable for the LHC continuous cryostat and long straight section cryomagnets.

Generic cryogenic requirements : thermal sections

The requirements applicable to the continuous LHC cryostat are to be satisfied, in particular:

- For reasons of cool-down / warm-up & quench discharge: *There must be a total of parallel free flow passages which together give rise to a frictional pressure drop less than, or at maximum equal, to the frictional pressure drop of a single smooth circular tube of 50 mm inner diameter.* Ok (see D. Duarte Ramos slide)
- To allow for efficient cooling and redundancy in case of neighbouring 2-phase heat exchanger failure: *There must be a total free cross section of at least 60 cm^2 to provide sufficient heat conductivity to homogenise the magnet temperatures over the cell length and allow for good temperature control.* Ok (see D. Duarte Ramos slide)

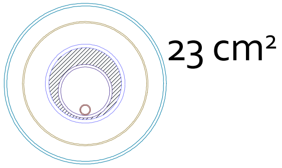
In addition:

- For reasons of cool-down continuity on the top half of the cold mass, and for assuring an undisturbed (no heating) passage for the 2-phase helium: *A free section of at least 15 cm^2 filled with liquid helium must be foreseen around the X line for heat exchange and continuity of the helium bath.* Ok (see D. Duarte Ramos slide)

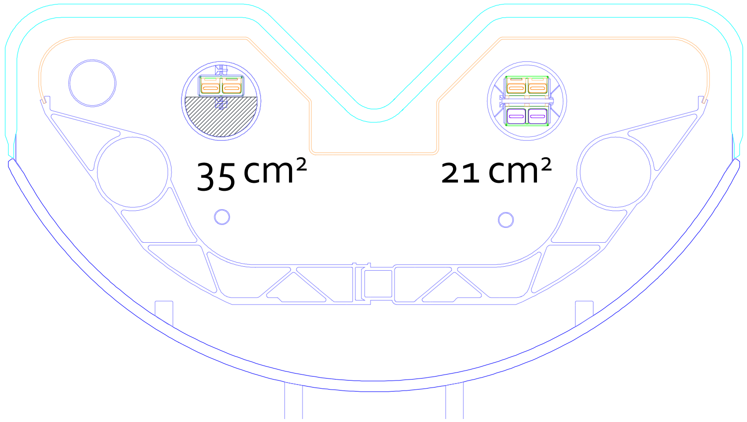
(The 15 cm^2 section guarantees that even in case the neighbouring magnets reach 2.0 K still 10 W (5 W to the left and 5 W to the right) can be evacuated by conduction. This provides ample margin with respect to the expected static heat loads and 0.42 W FLUKA estimates of the total (10 s duration) power on the liquid helium and piping.)

Hydraulic and thermal continuity

- Pressure drop analytical estimations:
  - He flow 6 kg/s, 6 K, 20 bar
  - Specification: Pressure drop of a 50 mm smooth pipe: **4.3 kPa/m**
  - Pressure drop QTC: **3.1 kPa/m** (ε=0.2 mm)
  - *Conservative results according to CFD analysis by H. Alain TE-CRG*

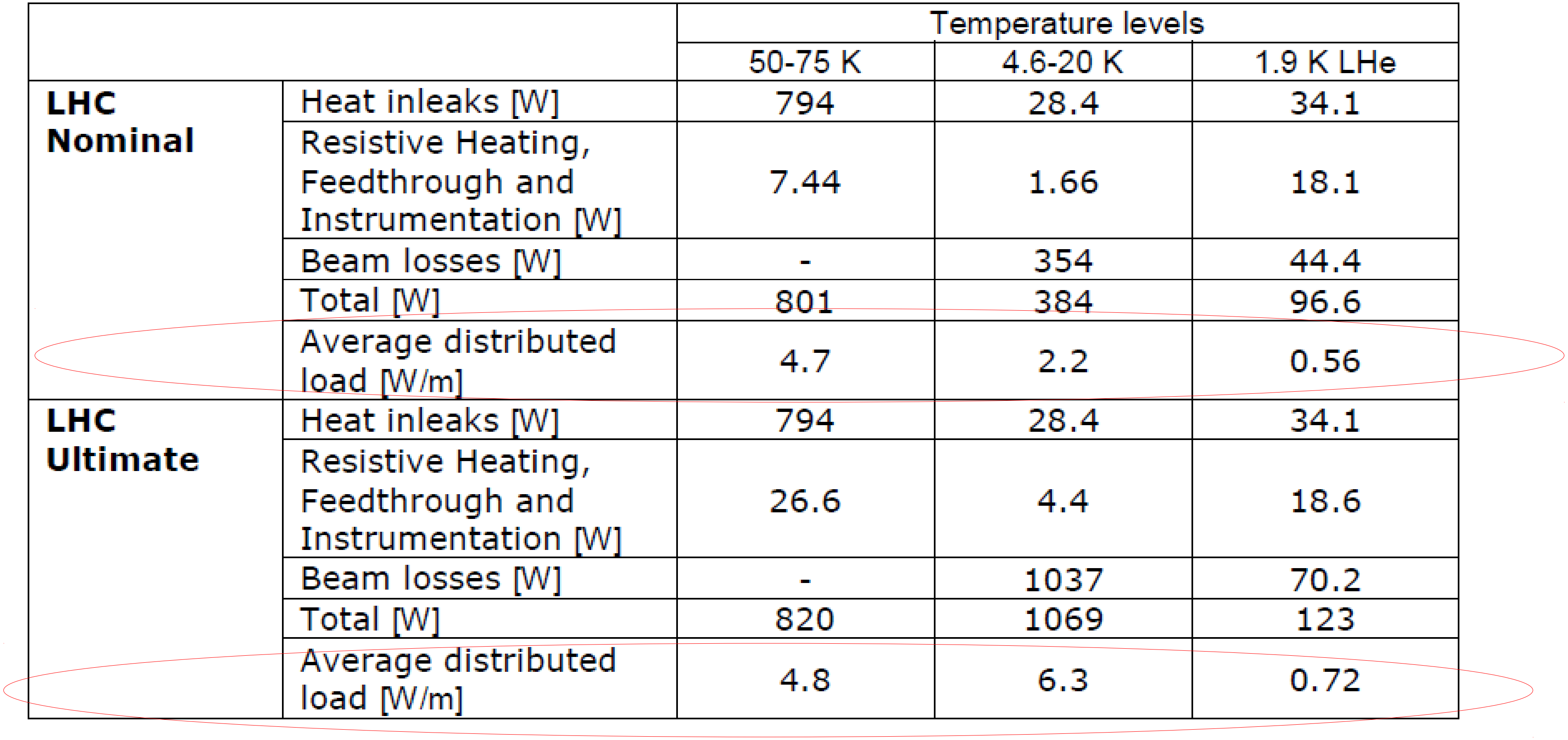


- He II free cross section:
  - **79 cm^2** > specification: **60 cm^2**

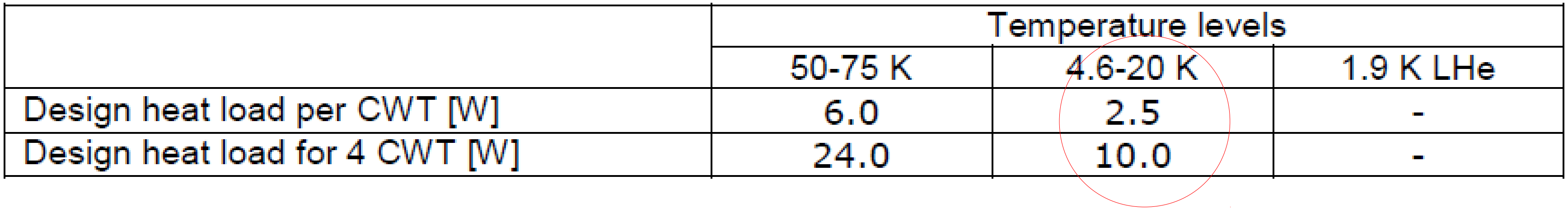


Courtesy D. Duarte Ramos

Heat loads: typical DS & CWT reference values



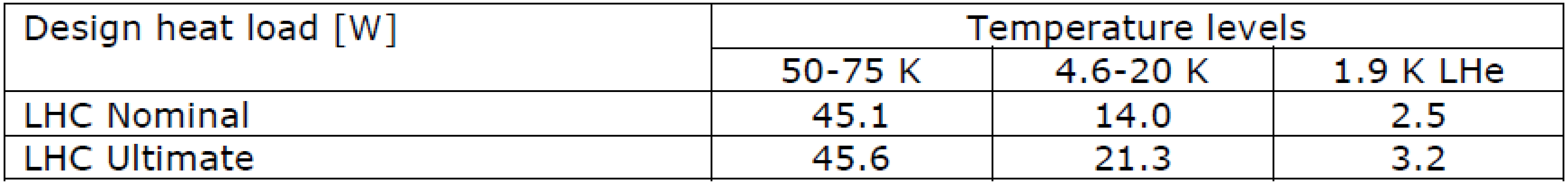
		Temperature levels		
		50-75 K	4.6-20 K	1.9 K LHe
LHC Nominal	Heat inleaks [W]	794	28.4	34.1
	Resistive Heating, Feedthrough and Instrumentation [W]	7.44	1.66	18.1
	Beam losses [W]	-	354	44.4
	Total [W]	801	384	96.6
	Average distributed load [W/m]	4.7	2.2	0.56
LHC Ultimate	Heat inleaks [W]	794	28.4	34.1
	Resistive Heating, Feedthrough and Instrumentation [W]	26.6	4.4	18.6
	Beam losses [W]	-	1037	70.2
	Total [W]	820	1069	123
	Average distributed load [W/m]	4.8	6.3	0.72



	Temperature levels		
	50-75 K	4.6-20 K	1.9 K LHe
Design heat load per CWT [W]	6.0	2.5	-
Design heat load for 4 CWT [W]	24.0	10.0	-

Heat loads: by-pass compared to DS

Design heat load budget for a 4.5 m long cryostat bypass with 1.8 m long beam screen, including the four cold to warm transitions



Design heat load [W]	Temperature levels		
	50-75 K	4.6-20 K	1.9 K LHe
LHC Nominal	45.1	14.0	2.5
LHC Ultimate	45.6	21.3	3.2

1.9 K : *no major deviation* from standard DS values foreseen : no effect on DS / ARC cryogenics (cooling loops remain shorter than standard ARC).

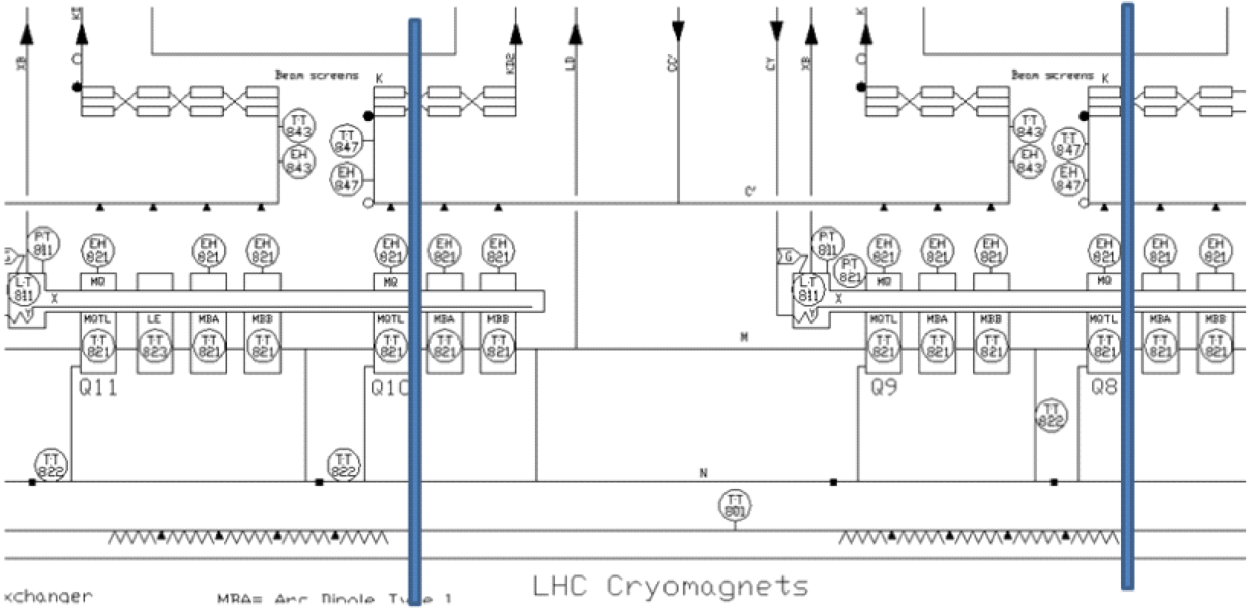
4.6 – 20 K: The by-pass has *extra thermal loads* mainly due to the 4 cold-to-warm transitions (CWTs). Dominated by CWTs in nominal and by CWTs + electron clouds in ultimate. Presently *no arguments for any imbalance in heat load*. Effect of collimator negligible :

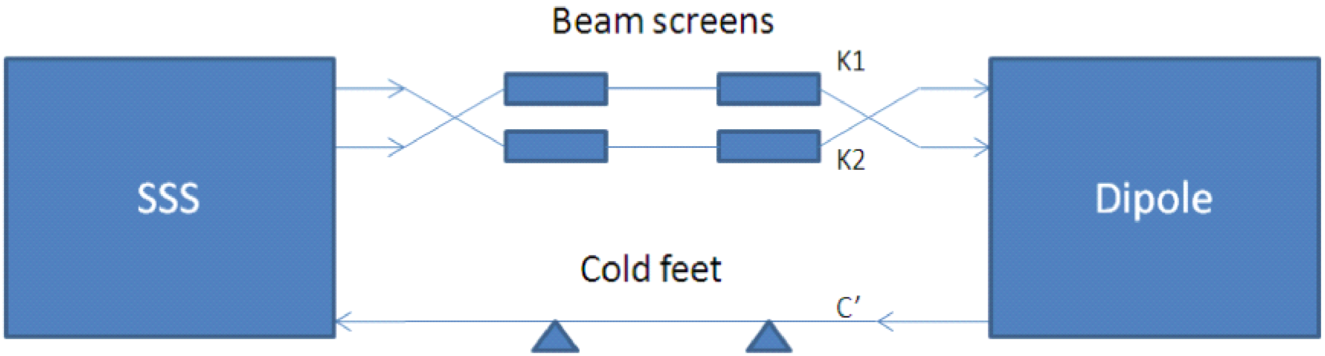
7.8 W/m w.r.t. 2.2 W/m for the DS in nominal (equivalent to 6.4 m long dipole)
11.8 W/m w.r.t. 6.3 W/m for the DS in ultimate (equivalent to 3.4 m long dipole)

The DS beam-screen cooling circuits concerned are shorter than their neighbouring cells and the standard 54 m ARC loops. There is therefore margin to absorb the maximum “6.4 m long dipole equivalent” heat load : no effect on cryo functionality, small (16 - 9 %) extra load to beam-screen loops, but still only 86 – 80 % of neighbouring cell's capacity

50 – 75 K : The by-pass has about *twice the thermal loads* compared to a DS cryostat due to the 4 cold-to-warm transitions (CWTs) : no effect on ARC cryogenics.

Beam screens : DS3 Left variant



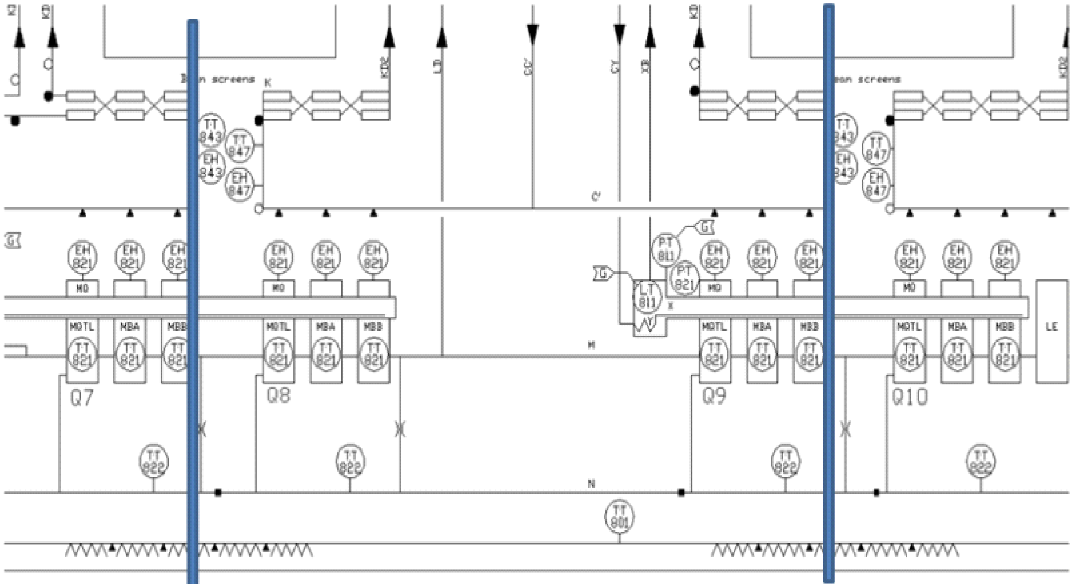


Courtesy D. Duarte Ramos

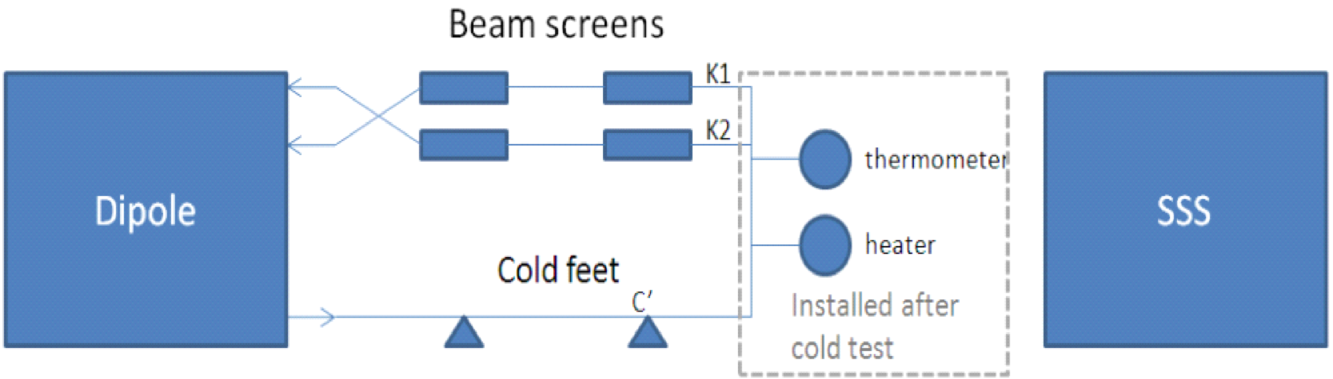
The cryo by-pass beam screen lines will be interconnected like in standard interconnects, with crossing of the cooling pipes.

Since no imbalance in heat load over the 4 beam screen sections is identified, no beam screen cooling pipes crossing in the collimator region is envisaged.

Beam screens : DS3 Right variant



LHC Cryomagnets



Courtesy D. Duarte Ramos

The cryo by-pass beam screen lines will be interconnected like in standard interconnects, with crossing of the cooling pipes.

Since no imbalance in heat load over the 4 beam screen sections is identified, no beam screen cooling pipes crossing in the collimator region is envisaged.

Instrumentation

The following instrumentation shall be integrated in the cryostat for monitoring of the temperature at the 1.9 K level during LHC warm-up, cool-down and temperature drift. *It will provide info for the necessity of having to do an ELQA :*

1. Drift tube with busbars M1 and M3: *1 thermometer*

2. Drift tube with busbar M2: *1 thermometer*

3. Line N: *1 thermometer*

The M-lines will be below the nominal level of the neighbouring cold-masses.

4. *A heater* to provide a means to evacuate liquid has to be foreseen at the lowest point (left side of by-pass).

5. The DS3 right cryostats shall also be equipped with: *one heater* followed by *one thermometer* at the inlet of the K lines

Conclusions

- No risks for the cryogenics functionality have been identified.
- Small , 16 % (nominal) - 9 % (ultimate), extra load to beam-screen loops. But still only 86 % (nominal) – 80 % (ultimate) of neighbouring cells (which are longer)

  No visible degradation in cryogenic performance identified.
- Room temperature beam vacuum exposure to neighbouring cold beam vacuum sections necessitates specific coordination between vacuum and cryogenics systems for opening / closing of vacuum valves.