Heat Loads for HL-LHC Internal Review Crab Cavities

K. Brodzinski, L. Delprat (TE-CRG)

O. Capatina, T. Capelli, F. Carra, and L. Dassa (EN-MME)

Heat loads for HL-LHC – Internal review – Crab Cavities – CERN – April, 27th 2021

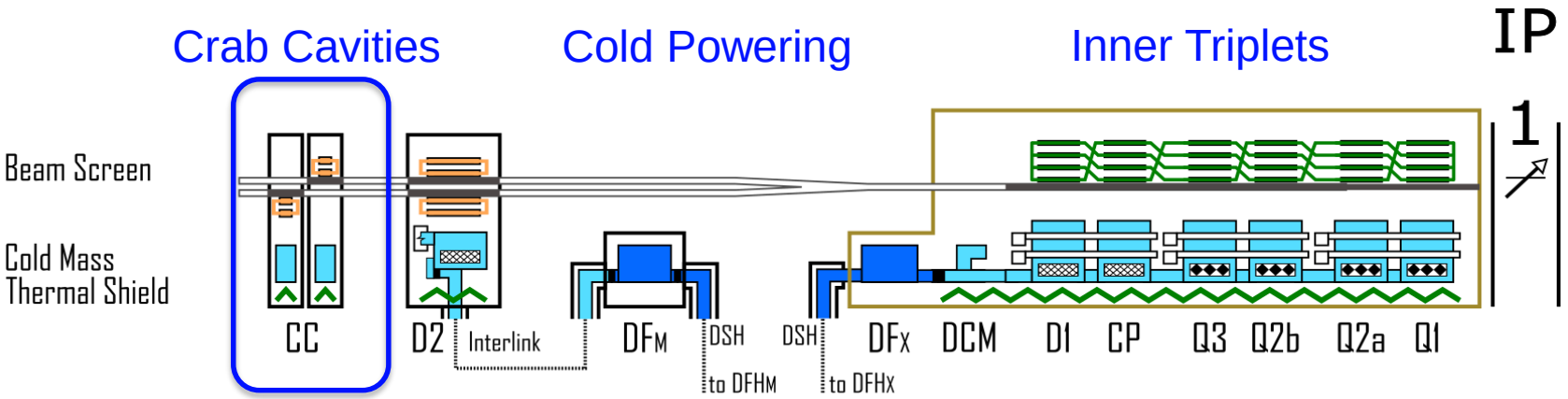
EDMS: 2566329

Indico: 1019569

Outlook

- Introduction and considerations
- Static heat load at 2 K
- Dynamic heat load at 2 K
- Thermal shield and beam screen circuits
- Conclusions

Introduction and considerations



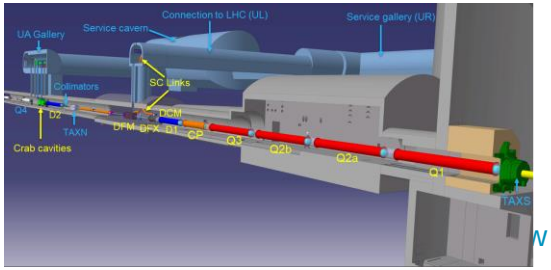
Thermal Shield temperature
- 60-80 K

Beam Screen temperature
- 60-80 K
- 4.5-20 K

Cold Mass temperature
- 4.5 K
- 1.9 K

Super Conducting Link
- Gaseous
- Simplified connection

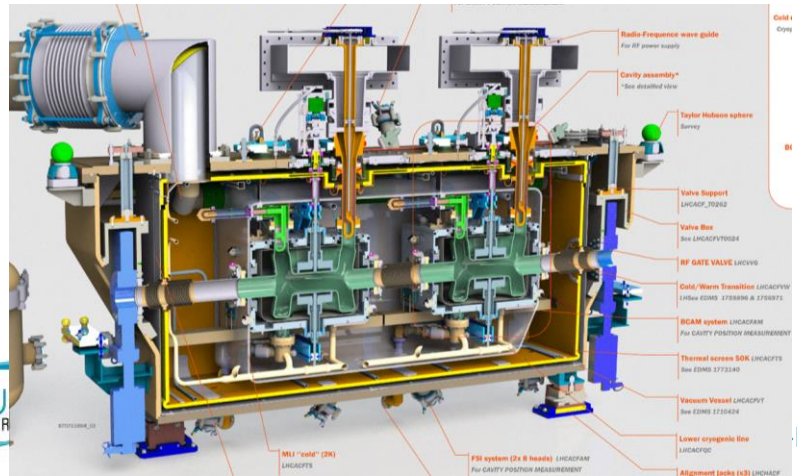
Others
- SC magnet (NbTi)
- SC magnet (Nb_3Sn)
- Amorphous Coating



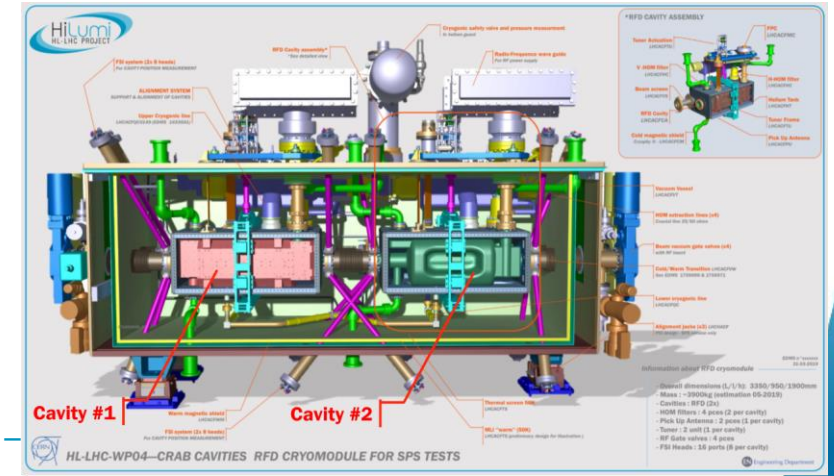
Introduction and considerations

- 8 crab cavities cryogenic modules will be installed in the HL-LHC
- Each cryogenic module will contain two cavities
- There are two types of the cavities: DQW and RFD
- 4 modules of one type will be installed at P1 and 4 modules of another type at P5
- There is a request to foresee the possibility to swap the modules between P1 and P5 and for this reason both HL-cryoplants shall cope with any of the module type

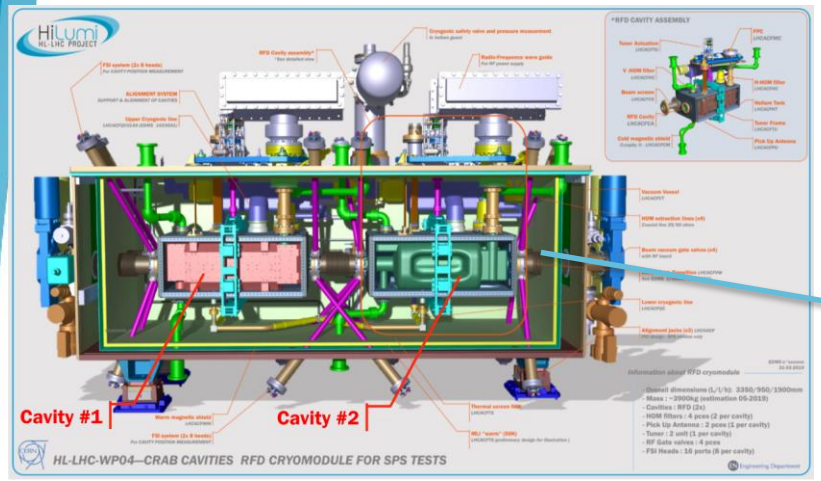
DQW prototype (length = 3 m)

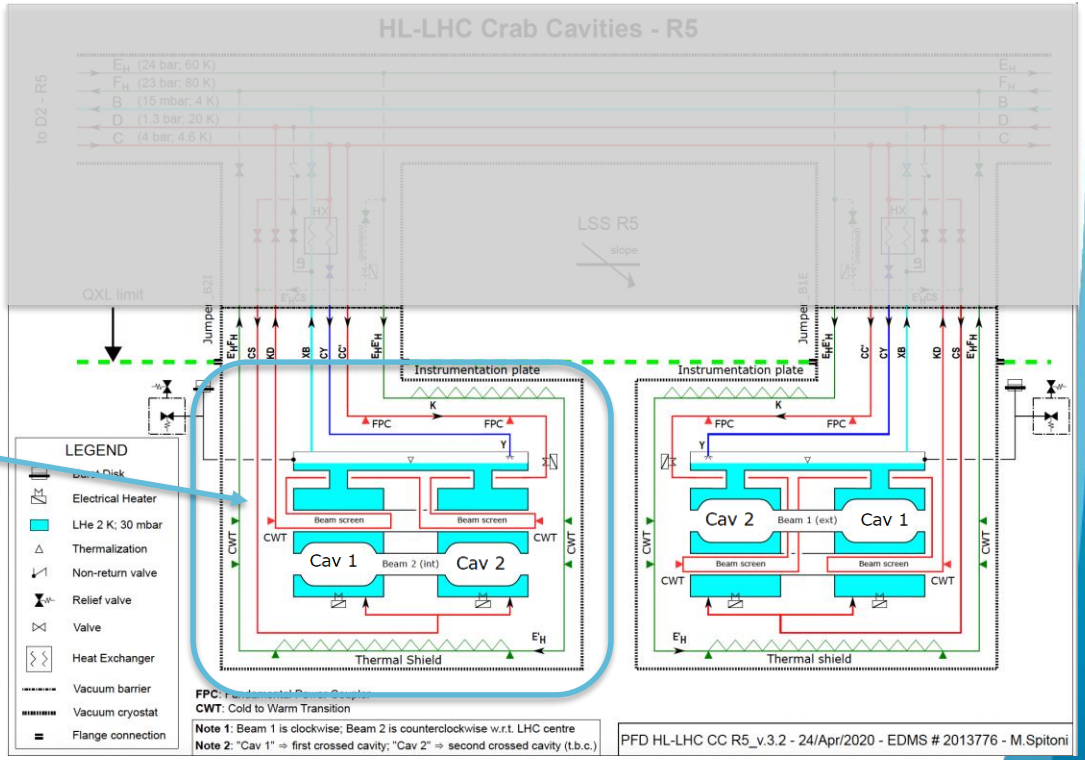


RFD prototype (length = 3.36 m)



3D model & PFD – RFD prototype





EDMS 2013776

Introduction and considerations

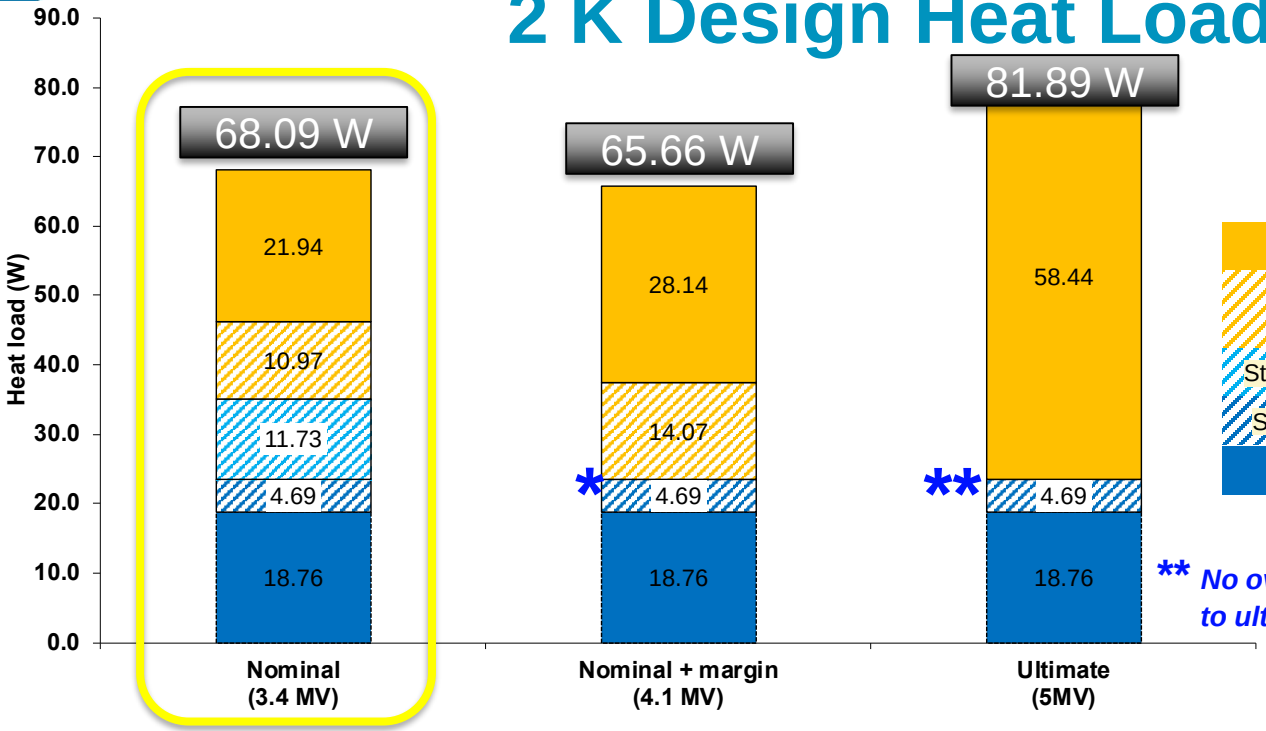
- As the final cryomodule design for DQW and RFD will base on the same technical solutions, the heat load of RFD (bigger cryostat) is selected as dimensional for the cryogenic infrastructure and needed cooling capacity.
- The below table presents available summary of the heat load analysis for RFD module.

	NOMINAL					DESIGN					EXCEPTIONAL				
	Static					Static + Dynamic 3.4 MV (40 kW FPC)					Static + Dynamic 4.1 MV (40 kW FPC)					Static + Dynamic 5 MV (40 kW FPC)				
	2 K bath	comments	10 K intercept	80 K intercept	comments	2 K bath	comments	10 K intercept *	80 K intercept	comments	2 K bath	comments	10 K intercept *	80 K intercept	comments	2 K bath	comments	10 K intercept *	80 K intercept	comments
Radiation	3.4	(from DQW)	-	30	(from DQW)	3.4		-	30	-	3.4		-	30	-	3.4		-	30	-
CWT [2]	5.8		-	41.2		5.8		-	41.2	-	5.8		-	41.2	-	5.8		-	41.2	-
Supports [3]	1.1 TBC	cavity support Cryomodule jumper	-	20 -	cavity support Cryomodule jumper	1.1		-	20 -	-	1.1		-	20 -	-	1.1		-	20 -	-
FPC [4]	1.3		6	55		2.3		7.8	56		2.3		7.8	56		2.3		7.8	56	
VHOM lines [5]	0.08		1.5	12.7		0.9		2.9	14.9		0.9		2.9	14.9		0.9		2.9	14.9	
VHOM antennas [6]	-		-	-		0.2		-	-	-	0.2		-	-	-	0.3		-	-	-
HHOM lines [5]	0.08		1.5	12.7		0.9		2.9	14.9		0.9		2.9	14.9		0.9		2.9	14.9	
HHOM antennas [6]	-		-	-		0.3		-	-	-	0.5		-	-	-	0.7		-	-	-
Pickup lines	2.7	(old value, desing ongoing)	TBC	7.8	(old value, desing ongoing)	7	(old value, desing ongoing)	TBC	11.8	(old value, desing ongoing)	7	(old value, desing ongoing)	TBC	11.8	(old value, desing ongoing)	7	(old value, desing ongoing)	TBC	11.8	(old value, desing ongoing)
Pickup antennas [6]	-		-	-		0	around 0	-	-	-	0	around 0	-	-	-	0	around 0	-	-	-
Tuner [7]	0.9		-	8.9		0.9		-	8.9	-	0.9		-	8.9	-	0.9		-	8.9	-
Instrumentation	2.3	(from DQW)	-	10	(from DQW)	2.3		-	10	-	2.3		-	10	-	2.3		-	10	-
He level sensor [8]	0.4		-	0.8	most conservative	0.4		-	0.8	-	0.4		-	0.8	-	0.4		-	0.8	-
Cryo safety device [9]	0.7		-	4.5		0.7		-	4.5	-	0.7		-	4.5	-	0.7		-	4.5	-
Beam screen	-	TBC	TBC	TBC		TBC		TBC	TBC	TBC	TBC		TBC	TBC	TBC	TBC		TBC	TBC	TBC
Beam	-		-	-		0.5		-	-	-	0.5		-	-	-	0.5		-	-	-
Cavity [10]	-		-	-		14		-	-	-	20		-	-	-	50		-	-	-
	Static					Static + Dynamic					Static + Dynamic					Static + Dynamic				
TOTAL (temporary)	18.76		9	203.6		40.7		13.6	213		46.9		13.6	213		77.2		13.6	213	

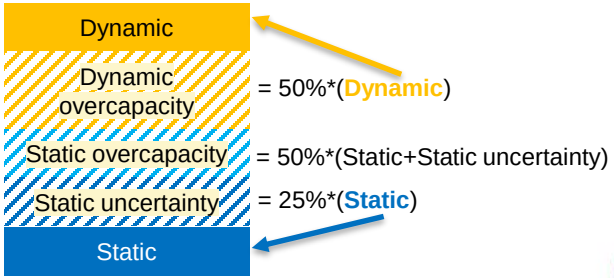
** 10 K intercept refers to het load taken by 4.5 – 20 K BS circuit*

Courtesy of EN-MME; EDMS 2310389

2 K Design Heat Load



For 1 cryomodule!



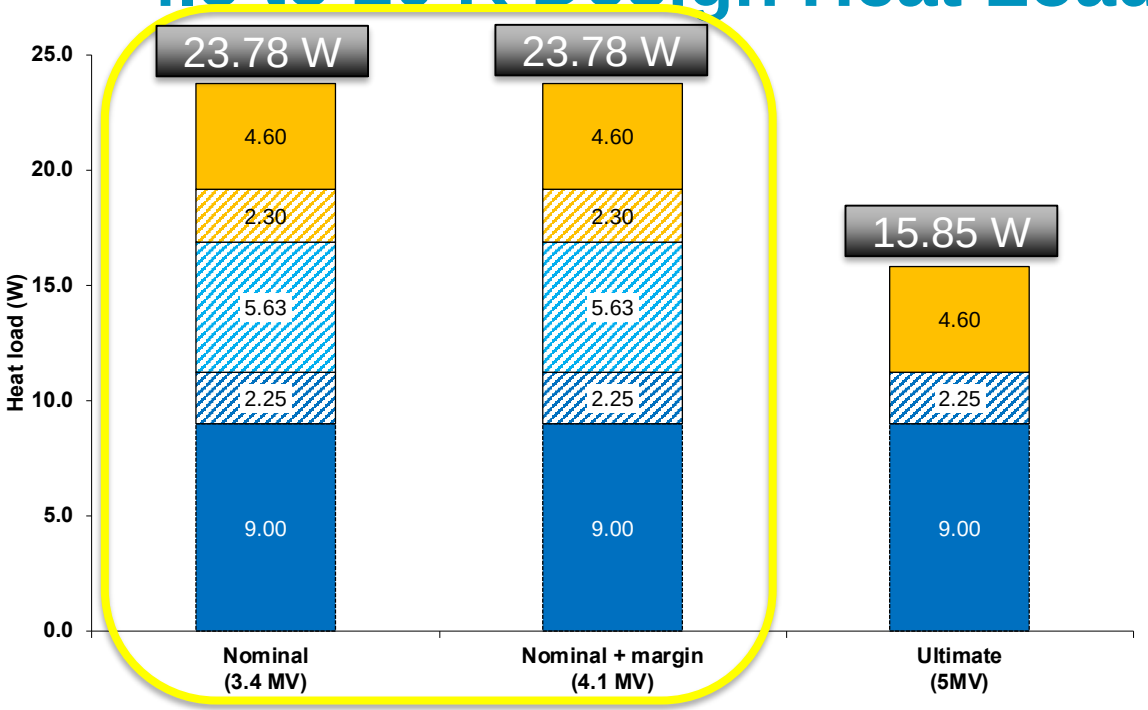
** *No overcapacity applied to ultimate case*

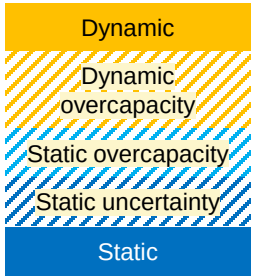
	3.4 MV	4.1 MV	5 MV
Comments	Heat load @ 2 K (W)		
Dynamic	21.94	28.14	58.44
Dynamic overcapacity	10.97	14.07	-
Static overcapacity	11.73	- *	-
Static uncertainty	4.69	4.69	4.69
Static	18.76	18.76	18.76
TOTAL	**68.09**	**65.66**	**81.89**

*** Static overcapacity not applied to the 4.1 MV case as already included on RF side for nominal 3.4 MV case***

4.5 to 20 K Design Heat Load

For 1 cryomodule!

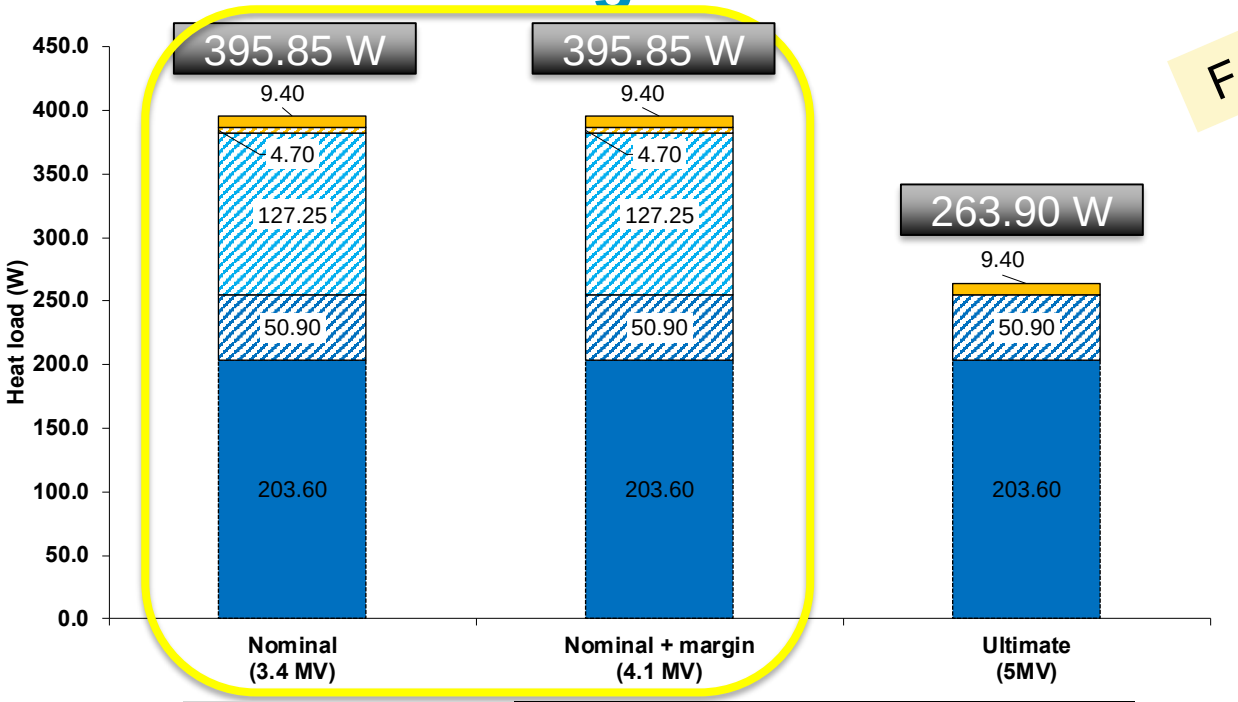




	3.4 MV	4.1 MV	5 MV
Comments	**Heat load @ 4.5-20 K (W)**		
Dynamic	4.60	4.60	4.60
Dynamic overcapacity	2.30	2.30	-
Static overcapacity	5.63	5.63	-
Static uncertainty	2.25	2.25	2.25
Static	9.00	9.00	9.00
TOTAL	**23.78**	**23.78**	**15.85**

80 K Design Heat Load

For 1 cryomodule!



	3.4 MV	4.1 MV	5 MV
Comments	Heat load @ 80 K (W)		
Dynamic	9.40	9.40	9.40
Dynamic overcapacity	4.70	4.70	-
Static overcapacity	127.25	127.25	-
Static uncertainty	50.90	50.90	50.90
Static	203.60	203.60	203.60
TOTAL	**395.85**	**395.85**	**263.90**

Static heat load at 2 K – "*Bravi Fede!*"

- Static heat load of the first prototype cryomodule (DQW) was calculated by Federico Carra as 17 W and measured in SPS with boil-off method by CRG as 18 W (details below).

Extract from Krzysztof e-mail to MME Colleagues on 20.12.2017:

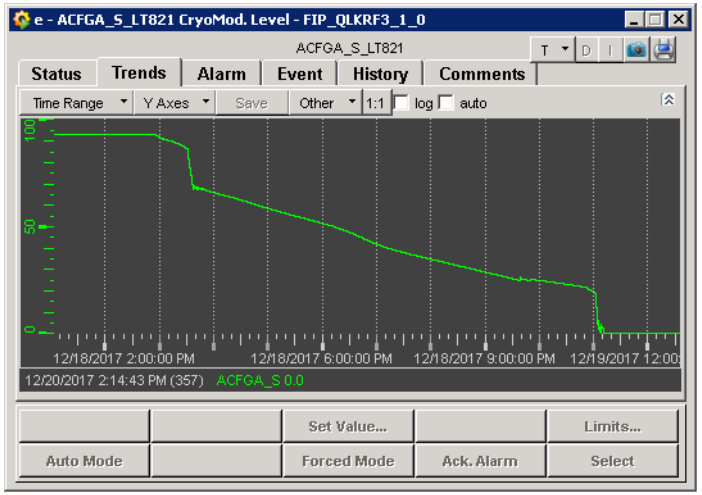
Thanks Teddy for the volumes. I made the calculation with the following results:

- Between 93% and 50 % = **70.08L (+/-0.88L), evap. time: 198 min, heat load = 19.8 W**
- Between 93 % and 30 % = **113.83L (+/-1.42L), evap. time 353 min, heat load = 18.0 W**
- Between 93% and 0 % = **133.6L (+/-1.67L), evap. time 493 min (not precise in my opinion for last evaporation stage from 25 % to 0%, see curve below), heat load = 15.1 W**
- Between 87% and 74.3% (connection pipes) = **2.24L (+/-0.03L), evap. time 7 min, heat load = 17.9 W**

The evaporation was done with constant aspiration at 20 mbar -> He latent heat = 23.04 J/g.
The thermal shield/intercepts were stably adjusted with TTin=50 K resulting with TT out=75 K.

In conclusion:
Let us do not consider both extreme values, then the heat load to 2 K is measured at level of **18 W** and in my opinion it is the right value, additionally in very good agreement with theoretical calculation of 17 W **(BRAVI FEDE !!!).**
However, the most of the intercepts on the top plate were thermalized between ~50 … ~70 K i.e. colder than considered for theoretical calculation.

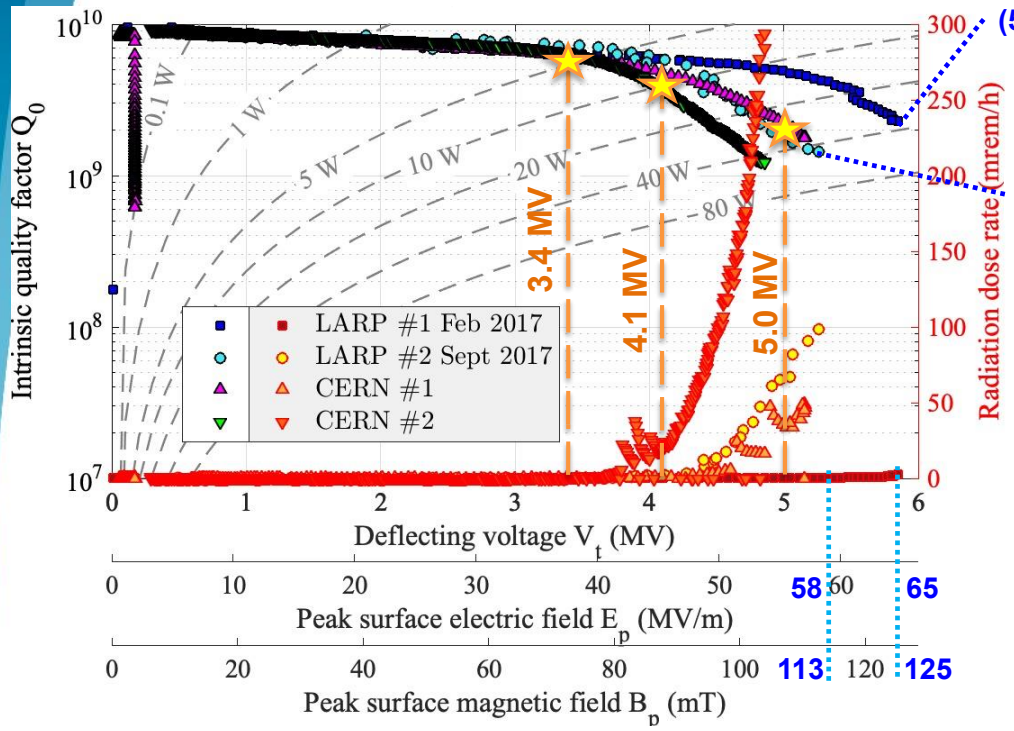
The main conclusion is that the measurement gives good confidence for SPS operation.



- Considering good agreement between calculated and measured values for the first prototype, we consider that static heat load calculated for RFD as ~19 W will also reflect reality(*). It will be confirmed by measurement during the SM18/SPS test in 2022/23.

Some contributions at 2 K are still to be completed in the MME table (previous slide) e.g. contribution from BS, supports or antennas, however they will stay relatively small and level of 19 W with a few % of margin should reflect the reality.

Dynamic heat load at 2 K (data for 1 cavity)



Considerations:

- 3.4 MV – nominal operation
- 4.1 MV – design operation
- 5 MV – exceptional operation
- Data coming from DQW bare cavities testing, RFD data not available yet
- Both types are suspected to perform similarly

S. Verdú-Andrés, 9th HL-LHC Collaboration Meeting, FNAL 2019

Conclusions

- Thermal load related to 3.4 MV is considered as nominal value and all related contingency is applied for this case;
- The static heat load: calculations and measurement done on first prototype gives high confidence to calculated value;
- The dynamic heat load will depend on Q factor and global cavity, FPC and HOM performances (no reliable measurements available on assembly of the cryomodule yet).

- The total design value of 2 K heat load for 3.4 MV with applied contingency is 68 W, which covers operation at 4.1 MV with overcapacity on dynamic but no overcapacity on static HL;

- The ultimate value is calculated at the level of ~80 W for 5 MV. The recommended value for local installed capacity to cool down one cryomodule will be at the level of 80 W at 2 K.

Thank you for your attention!
Questions?

Spares

Thermal shield and beam screen

- The thermal shield load comes from two sources: thermal intercepts of main equipment (e.g. FPC, HOMs, CWT, Safety port, instrumentation etc.) and from the shielding function. The total calculated value for RFD is 213 W for 4.1 MV and 213 W for 5 MV to be re-checked). The design of the circuit allows for maximum heat extraction of 400 W (limited by the heat transfer coefficient).
- The Beam Screen cooling loop will be loaded similarly to the thermal shield circuit by the intercepts and from shielding function. The load is not calculated precisely yet but it should be at the level of ~20..25 W to be extracted between 4.5 – 20 K (contribution from intercepts 13.6 W + tbd and from the circulated beam estimated at max. 2 W/m on non crabbed line i.e. ~6 W on 3 m module length).