HL-LHC
Cryogenics
Required Clarifications (1/2)

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On behalf of WP9 team and Cryogenic group

Chamonix workshop 31 Jan. 2018

Clarification on the e-cloud heat load and spare capacities in the triplet and arc magnets

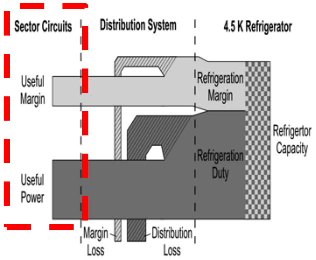
Available capacity for all beam screens is to be shared between Arcs, IT, SAM's,

This global capacity will be reduced from ~6kW (LHC) to 3kW (HL)

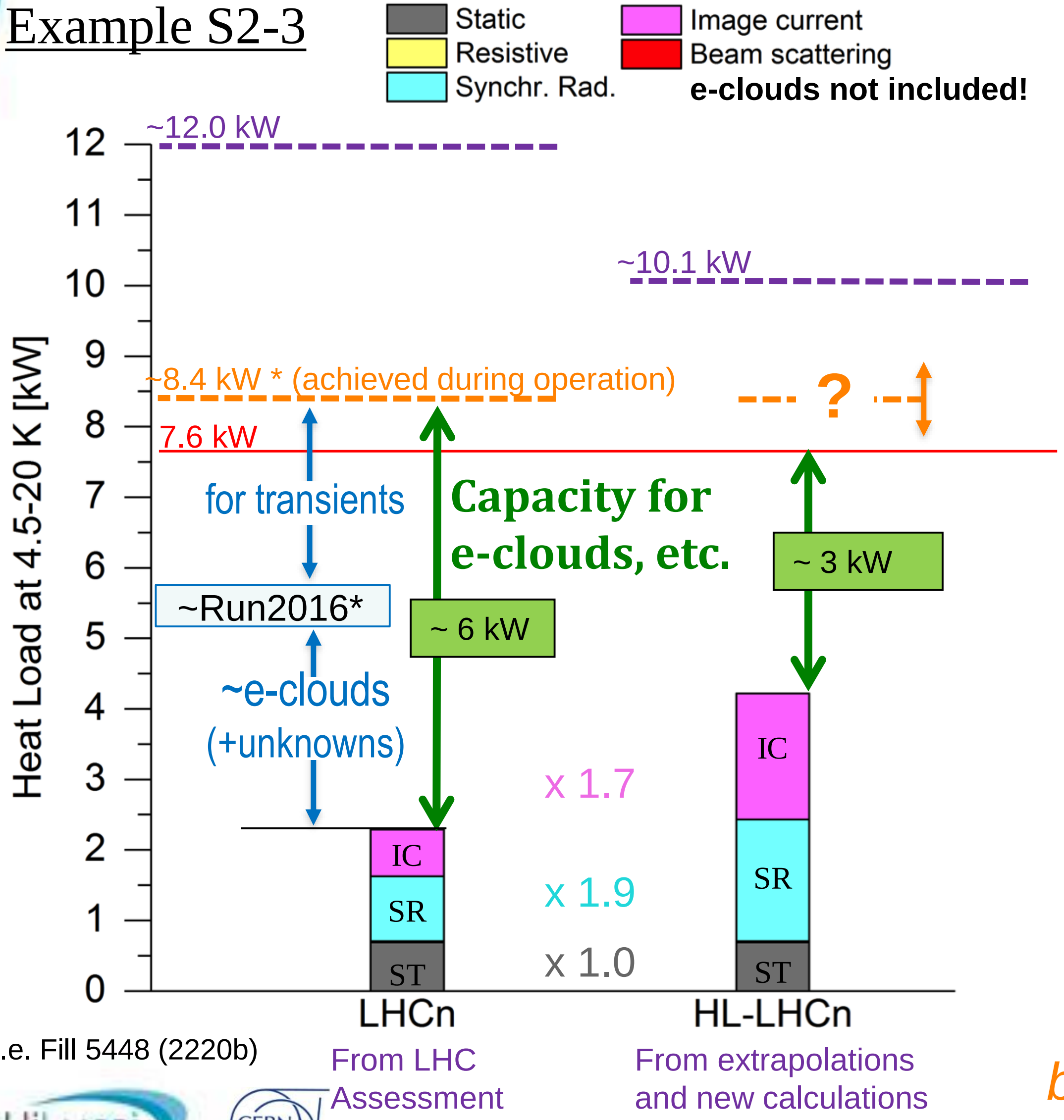
This is valid until a local capacity is reached (size of capillaries, valve body)

w/o e-clouds!

Evolution of the beam-screen heat loads from LHC to HL-LHC



Example S2-3



* i.e. Fill 5448 (2220b)

Highest theoretical** limit achievable with a «capacity transfer» from 1.8 K.

** assumes design values and constant hardware performance despite the change in working conditions.

Increased capacity thanks to «capacity transfer» (mainly from 1.8 K circuits)

Installed capacity for the BS circuit

Less available capacity for e-clouds, transients and unknowns:

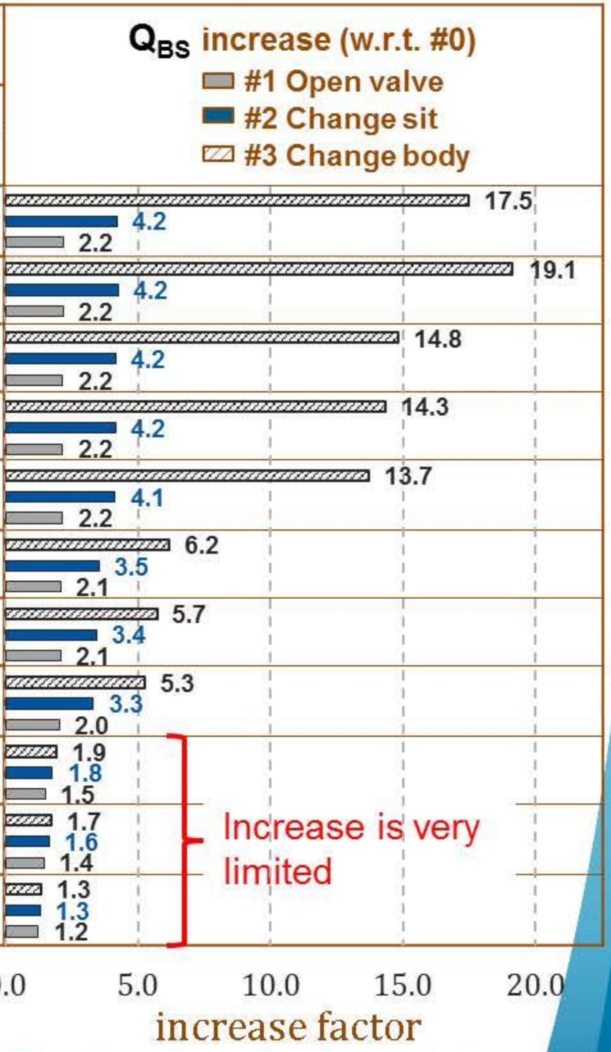
- LHC ~ 6 kW
- HL-LHC ~ 3 kW

The assessment of mitigation measures for e-clouds is needed to anticipate "bottlenecks".

Complete status update by D. Berkowitz in // session

Limitations – e-cloud – Straight Sections

Type	Inventory				Length [m]	Q_{BS} [W/m per aperture] #0 Op80%	#1 Op100%	#2 Change sit	#3 Change body
SAM Type 1	Q5 L/R1	Q5 L/R5	Q6 L/R1	Q6 L/R5	8.2	3.5	7.7	14.9	61.9
SAM Type 2	Q6 L/R4	Q4 L/R6	Q5 L/R6		6.9	4.2	9.1	17.9	80.5
	D3 L/R4				11.2	2.6	5.6	10.8	38.4
	Q6 L/R2	Q6 L/R3	Q6 L/R7	Q6 L/R8	12	2.4	5.2	10.0	34.6
	Q5L2	Q5R2	Q5L8	Q5R8	13	2.2	4.8	9.2	30.6
Semi-SAM	Q5D4L4	D4Q5R4			16.7	3.4	7.1	11.9	20.9
	Q4D2L1	D2Q4R1	Q4D2L5	D2Q4R5	19.4	2.9	6.0	10.0	16.6
	Q4D2L2	Q4D2R2	Q4D2L8	Q4D2R8	22.8	2.5	5.0	8.2	13.0
IT	IT L/R1	IT L/R5			35	3.5	5.3	6.2	6.7
	IT L/R2	IT L/R8			45	2.6	3.8	4.3	4.6
Arc half cell	all sectors				53.5	2.6	3.2	3.4	3.5



Increase is very limited

LSS2 & LSS8

Global limit given by installed refrigeration capacity 1.5 W/m/aperture

D. Berkowitz, S. Claudet

Limitations – e-cloud - Triplets

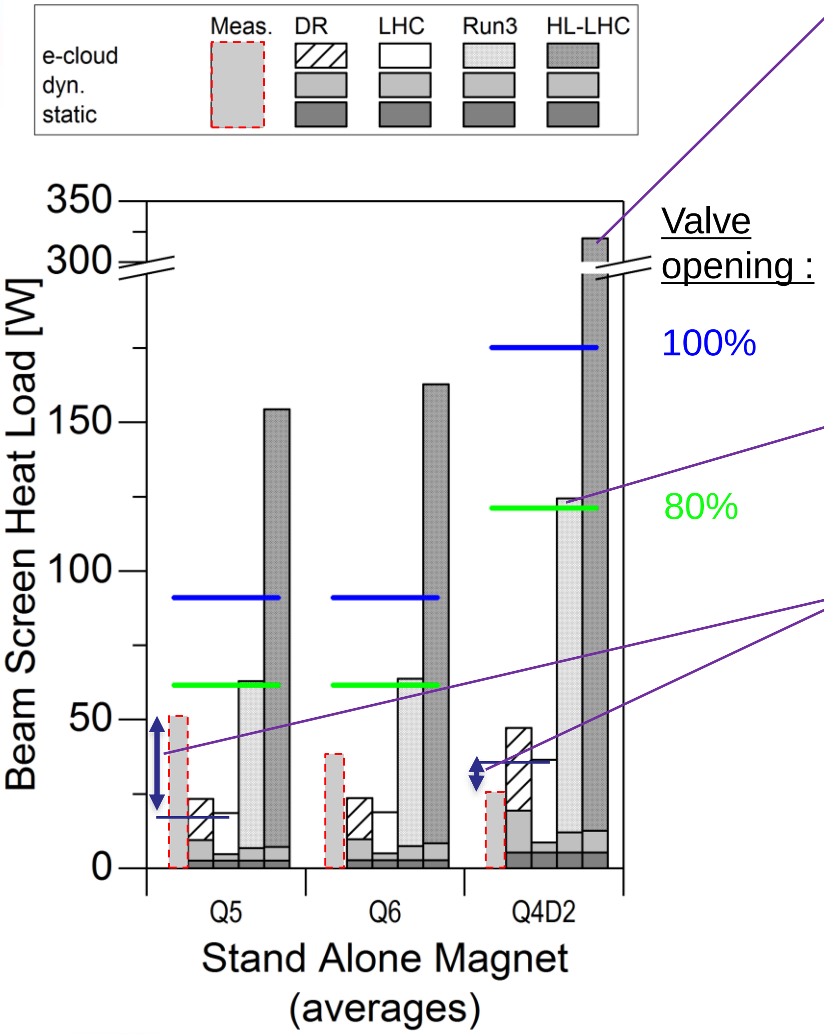
- Software modification should be enough to cool the matching sections ➔ further action to be evaluated on a case by case.

Device	Heat load 2015 [W]	Heat load 2016 [W]	Heat load LIU (SEY ~ 1.2) [W]	Limit 2015 (80%) [W]	Limit 2016 (100%) [W]	Limit larger valve seat [W]
IT/IR15	110	165	330	122	185	220
IT-D1/IR28	100	160	320	117	171	194

- IT 1/5 (and 2/8 if not coated) will limit the intensity to:
    - ~1500 b × 2.2×10^{11} ppb or 2748 b × 1.3×10^{11} ppb
    - ~1800 b × 2.2×10^{11} ppb or 2748 b × 1.5×10^{11} ppb
- The possibility of operating the beam screen of the triplet to higher temperature (30 – 35 K) has been investigated but:
    - Expect gas release with temperature variation ➔ background to the experiments
    - Potential stability issues due to electron cloud in the triplets due to the large β functions. Development of tools and studies ongoing ➔ very computing intensive

Estimated heat loads on the beam screen circuit of SAMs

Example with **average** values:



e-clouds are significant on SAMs for HL-LHC!

e-clouds on Q5+Q6+Q4D2 will require **~600W** at 4.5-20 K.

- This is ~20% of the 3 kW available for e-clouds.
- *Surface treatment* on the BS pipes could restore valuable capacity.

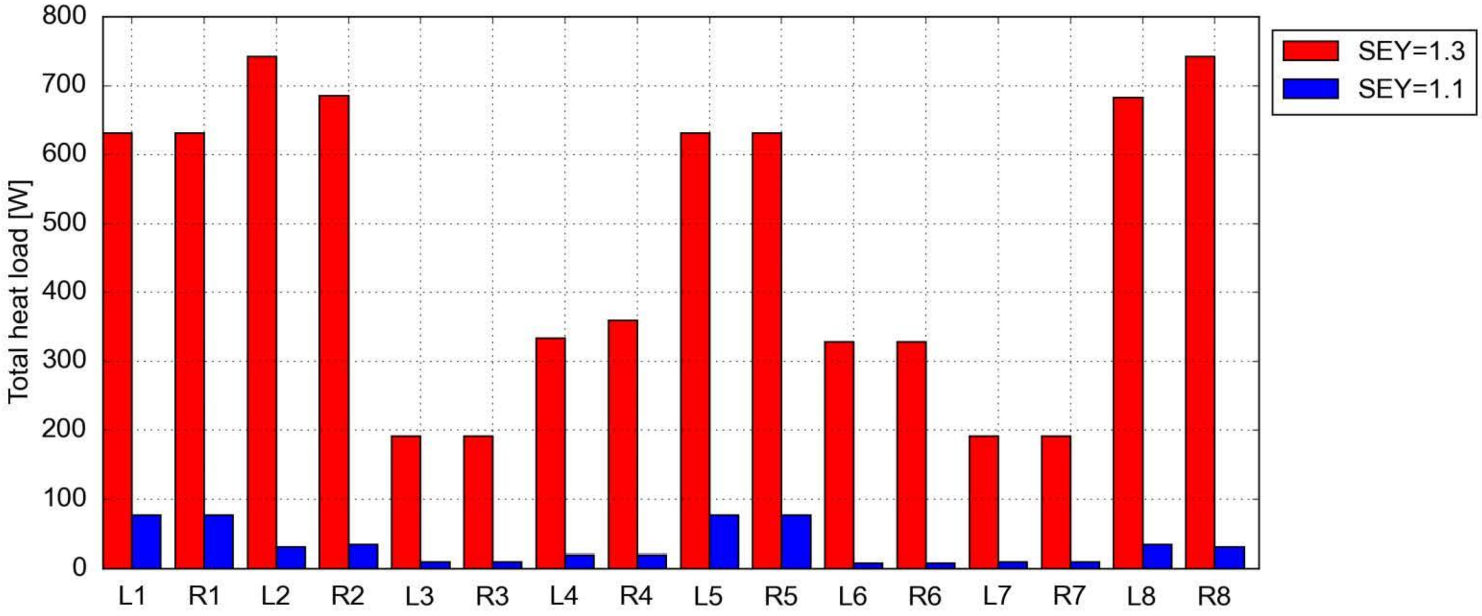
Valve opening to become limiting factor in Run3.

- Change of valve seat is recommended at LS2.
- Measurements indicate that this is already the case in Run2 for some magnets.

Clear discrepancies between measurements and theory.

- Detailed analysis of measured data for static+dynamic is mandatory to perform correct extrapolation (and improve understanding).

Twin-bore magnets in the LSS



- The **experimental IRs** are by far the most critical (due to larger number of cold devices)
  - Load **IR2 and IR8** will affect the neighboring arcs

    → Low SEY coating of the matching sections is desirable, especially at R2 and L8 which are cooled by less powerful cryoplants (see presentation by WP9)
  - **IR1 and IR5** will be equipped with **dedicated cryoplants** → if not coated, load of matching sections needs to be taken into account in the design (info provided to WP9)
  - Presently **baffle plates** are installed behind pumping slots of all SAM magnets (to support hydrogen cryosorber) → if no drawback, this should be kept also for magnets operated at 1.9 K

Inner triplets

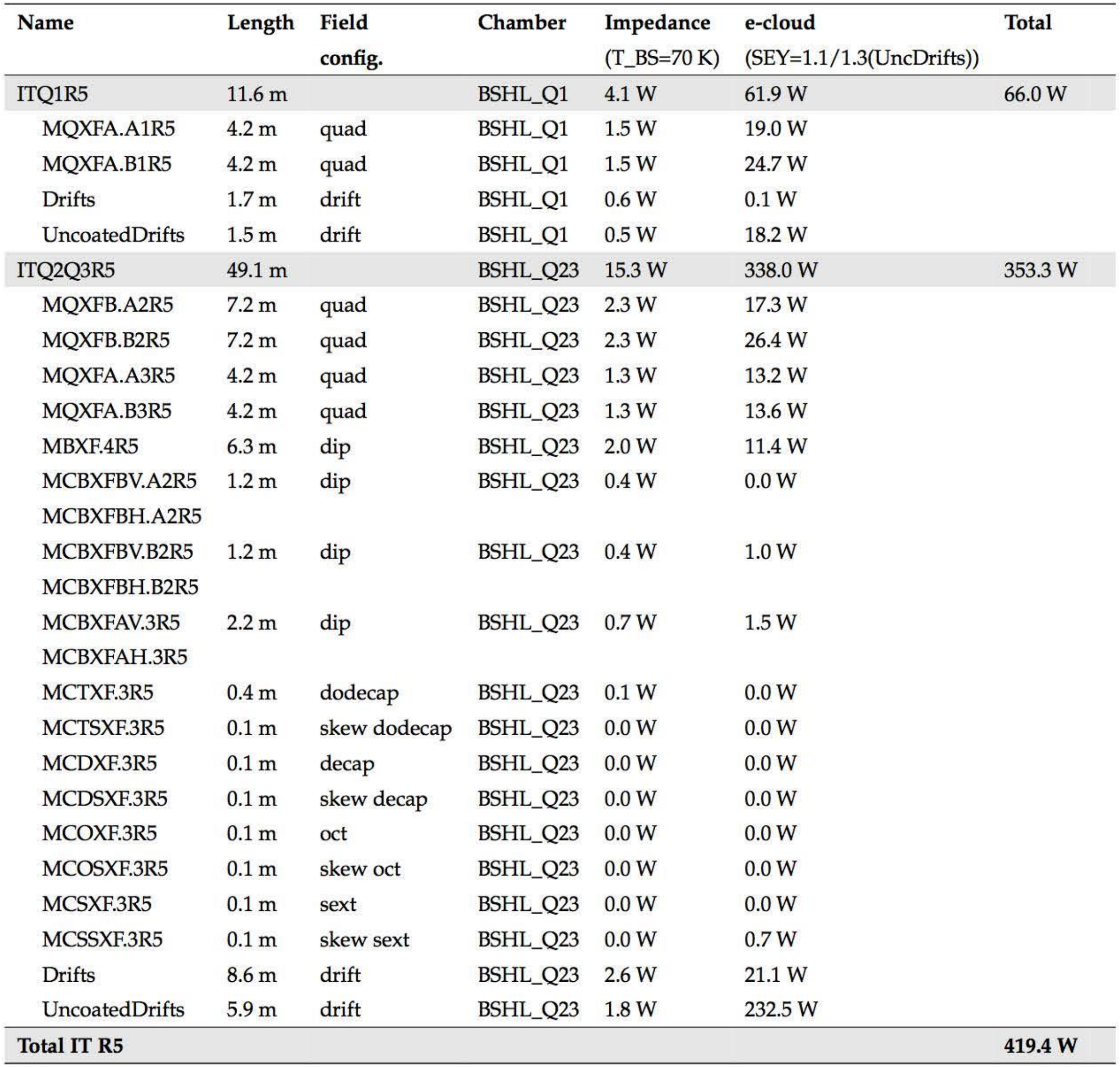
	SEY = 1.3	SEY = 1.1	SEY=1.1 (cold masses) SEY=1.3 (elsewhere)
Inner Triplet IR1&5	1.5 kW	170 W	420 W
Inner Triplet IR2&8	1 kW	50 W	82 W

- Large heat load **reduction (10-fold) expected from low SEY coating**
- Significant load added by e-cloud in **un-coated drifts** between the cold masses, especially in **IR1&5**. Proposed strategy:
  - Length of uncoated parts should be minimized
  - Remaining load should be taken into account in the design of new cryo for IR1&5 (info provided to WP9)
  - Impact on beam stability needs to be crosschecked
- Ongoing work: quantify effect of possible **electron accumulation** over many turns in the low SEY range (1.0<SEY<1.1)

Inner triplets

Triplets in IR1&5

Detailed tables have been compiled



Name	Length	Field config.	Chamber	Impedance (T_BS=70 K)	e-cloud (SEY=1.1/1.3(UncDrifts))	Total
ITQ1R5	11.6 m		BSHL_Q1	4.1 W	61.9 W	66.0 W
MQXFA.A1R5	4.2 m	quad	BSHL_Q1	1.5 W	19.0 W	
MQXFA.B1R5	4.2 m	quad	BSHL_Q1	1.5 W	24.7 W	
Drifts	1.7 m	drift	BSHL_Q1	0.6 W	0.1 W	
UncoatedDrifts	1.5 m	drift	BSHL_Q1	0.5 W	18.2 W	
ITQ2Q3R5	49.1 m		BSHL_Q23	15.3 W	338.0 W	353.3 W
MQXFB.A2R5	7.2 m	quad	BSHL_Q23	2.3 W	17.3 W	
MQXFB.B2R5	7.2 m	quad	BSHL_Q23	2.3 W	26.4 W	
MQXFA.A3R5	4.2 m	quad	BSHL_Q23	1.3 W	13.2 W	
MQXFA.B3R5	4.2 m	quad	BSHL_Q23	1.3 W	13.6 W	
MBXF.4R5	6.3 m	dip	BSHL_Q23	2.0 W	11.4 W	
MCBXFBV.A2R5 MCBXFBH.A2R5	1.2 m	dip	BSHL_Q23	0.4 W	0.0 W	
MCBXFBV.B2R5 MCBXFBH.B2R5	1.2 m	dip	BSHL_Q23	0.4 W	1.0 W	
MCBXFAV.3R5 MCBXFAH.3R5	2.2 m	dip	BSHL_Q23	0.7 W	1.5 W	
MCTXF.3R5	0.4 m	dodecap	BSHL_Q23	0.1 W	0.0 W	
MCTSXF.3R5	0.1 m	skew dodecap	BSHL_Q23	0.0 W	0.0 W	
MCDXF.3R5	0.1 m	decap	BSHL_Q23	0.0 W	0.0 W	
MCDSXF.3R5	0.1 m	skew decap	BSHL_Q23	0.0 W	0.0 W	
MCOXF.3R5	0.1 m	oct	BSHL_Q23	0.0 W	0.0 W	
MCOSXF.3R5	0.1 m	skew oct	BSHL_Q23	0.0 W	0.0 W	
MCSXF.3R5	0.1 m	sext	BSHL_Q23	0.0 W	0.0 W	
MCSSXF.3R5	0.1 m	skew sext	BSHL_Q23	0.0 W	0.7 W	
Drifts	8.6 m	drift	BSHL_Q23	2.6 W	21.1 W	
UncoatedDrifts	5.9 m	drift	BSHL_Q23	1.8 W	232.5 W	
Total IT R5						**419.4 W**

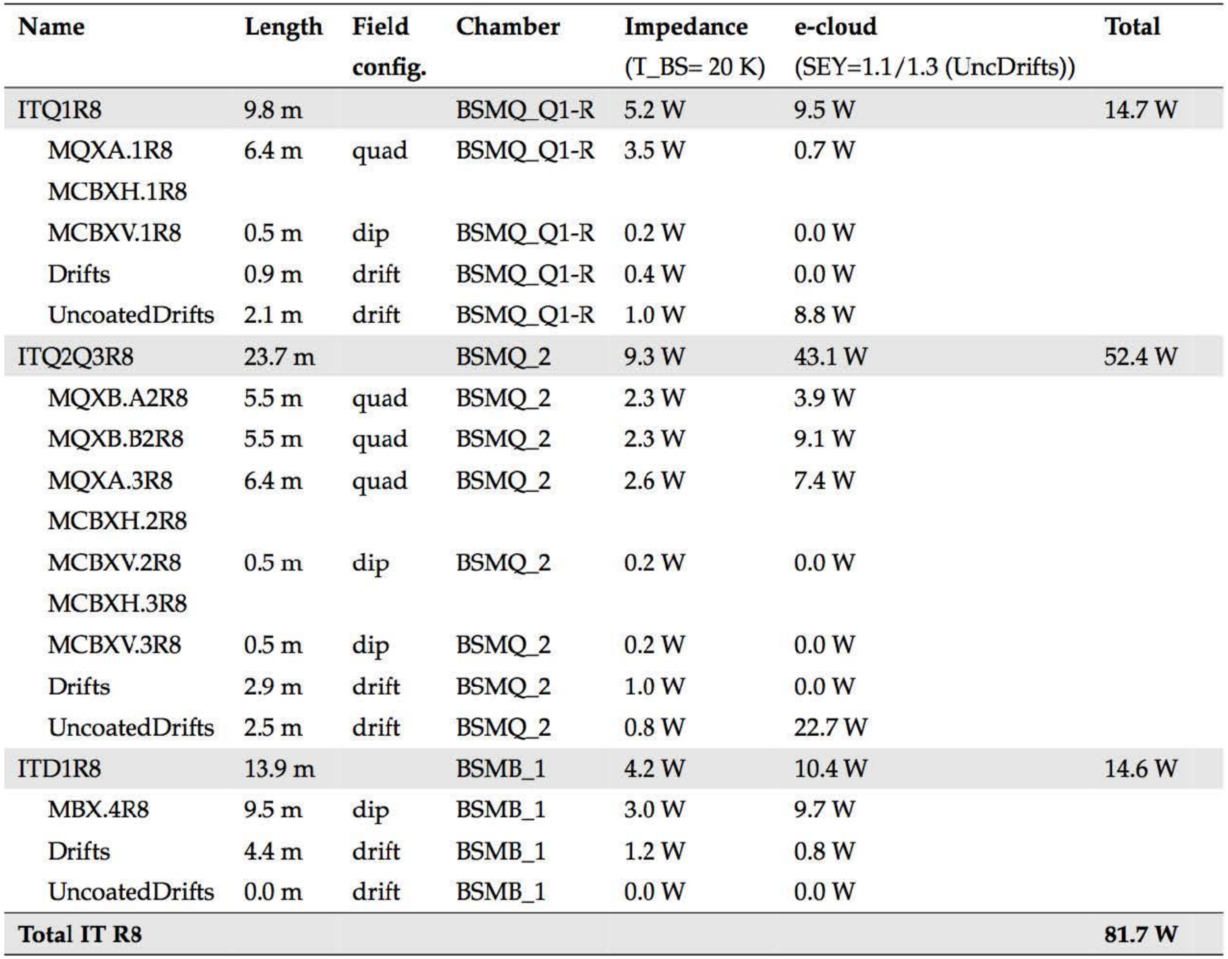
See also G. Skripka and G. Iadarola, "Beam-induced heat loads on the beam screens of the inner triplets for the HL-LHC", to be published, draft available here

Inner triplets

Triplets in IR2&8

Detailed tables have been compiled

Studies performed also for Inner Triplets in IR2 and IR8



Name	Length	Field config.	Chamber	Impedance (T_BS= 20 K)	e-cloud (SEY=1.1/1.3 (UncDrifts))	Total
ITQ1R8	9.8 m		BSMQ_Q1-R	5.2 W	9.5 W	14.7 W
MQXA.1R8	6.4 m	quad	BSMQ_Q1-R	3.5 W	0.7 W	
MCBXH.1R8						
MCBXV.1R8	0.5 m	dip	BSMQ_Q1-R	0.2 W	0.0 W	
Drifts	0.9 m	drift	BSMQ_Q1-R	0.4 W	0.0 W	
UncoatedDrifts	2.1 m	drift	BSMQ_Q1-R	1.0 W	8.8 W	
ITQ2Q3R8	23.7 m		BSMQ_2	9.3 W	43.1 W	52.4 W
MQXB.A2R8	5.5 m	quad	BSMQ_2	2.3 W	3.9 W	
MQXB.B2R8	5.5 m	quad	BSMQ_2	2.3 W	9.1 W	
MQXA.3R8	6.4 m	quad	BSMQ_2	2.6 W	7.4 W	
MCBXH.2R8						
MCBXV.2R8	0.5 m	dip	BSMQ_2	0.2 W	0.0 W	
MCBXH.3R8						
MCBXV.3R8	0.5 m	dip	BSMQ_2	0.2 W	0.0 W	
Drifts	2.9 m	drift	BSMQ_2	1.0 W	0.0 W	
UncoatedDrifts	2.5 m	drift	BSMQ_2	0.8 W	22.7 W	
ITD1R8	13.9 m		BSMB_1	4.2 W	10.4 W	14.6 W
MBX.4R8	9.5 m	dip	BSMB_1	3.0 W	9.7 W	
Drifts	4.4 m	drift	BSMB_1	1.2 W	0.8 W	
UncoatedDrifts	0.0 m	drift	BSMB_1	0.0 W	0.0 W	
Total IT R8						**81.7 W**

See also G. Skripka and G. Iadarola, "Beam-induced heat loads on the beam screens of the inner triplets for the HL-LHC", to be published, draft available here

Twin-bore magnets in the LSS

- Generated a **table** for each IR, combining the estimates from **impedance and e-cloud effects**

Name	**Length**	**Field config.**	**Chamber**	**Impedance** (T_BS=20 K)	**e-cloud** (SEY=1.3/1.1)	**Total** (SEY=1.3/1.1)
D2L1	13.2 m		BSHL_D2	3.6 W	227.0/46.3 W	230.6/49.9 W
MBRD.4L1.B1	7.8 m	dip	BSHL_D2	2.2 W	110.6 W/31.5 W	
MCBRDH.4L1.B1	1.8 m	dip	BSHL_D2	0.5 W	25.6 W/7.3 W	
MCBRDV.4L1.B1	1.8 m	dip	BSHL_D2	0.5 W	25.5 W/7.3 W	
Drifts	1.8 m	drift	BSHL_D2	0.4 W	65.3 W/0.2 W	
Q4L1	9.0 m		BSHL_Q4	3.1 W	155.1/12.8 W	158.2/15.9 W
MQYY.4L1.B1	3.8 m	quad	BSHL_Q4	1.4 W	107.5 W/0.1 W	
MCBYYH.4L1.B1	1.8 m	dip	BSHL_Q4	0.6 W	24.1 W/6.3 W	
MCBYYV.4L1.B1	1.8 m	dip	BSHL_Q4	0.6 W	23.3 W/6.2 W	
Drifts	1.6 m	drift	BSHL_Q4	0.5 W	0.2 W/0.2 W	
Q5L1	8.7 m		BSMQ_2	4.2 W	120.8/0.6 W	125.0/4.8 W
MQY.5L1.B1	3.4 m	quad	BSMQ_2	1.8 W	104.5 W/0.1 W	
MCBYV.A5L1.B1	0.9 m	dip	BSMQ_2	0.4 W	6.2 W/0.0 W	
MCBYH.5L1.B1	0.9 m	dip	BSMQ_2	0.4 W	3.6 W/0.0 W	
MCBYV.B5L1.B1	0.9 m	dip	BSMQ_2	0.4 W	6.2 W/0.0 W	
Drifts	2.6 m	drift	BSMQ_2	1.2 W	0.3 W/0.3 W	
Q6L1	6.9 m		BSMQ_1	5.3 W	112.2/0.4 W	117.4/5.7 W
MQML.6L1.B1	4.8 m	quad	BSMQ_1	3.7 W	111.9 W/0.2 W	
MCBCH.6L1.B1	0.9 m	dip	BSMQ_1	0.7 W	0.1 W/0.1 W	
Drifts	1.2 m	drift	BSMQ_1	0.8 W	0.2 W/0.2 W	
Total LSS						**631.3/76.3 W**

Dipole correctors and "drifts" can be non-negligible w.r.t. total!

For SEY =1.3 **e-cloud contribution is dominant**

Surface treatment providing **SEY=1.1 very effective in reducing the heat load**