Available cooling power -

Refrigeration assessment of the existing cryogenic plants for the HL-LHC

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with input from S. Claudet, A. Perin, G. Iadarola (& WP2)

7th HL-LHC Collaboration Meeting (Indico 647714)

CIEMAT, Madrid

16 November 2017

Outline

1. Introduction
   - Cryo-Configuration for HL-LHC
   - Type of data for heat load estimations
2. Heat loads and capacity margins…
   - … as seen by the equipment in the tunnel
   - … as seen by the refrigerators (not all at the surface)
3. Specific case for SAMs
4. Conclusions

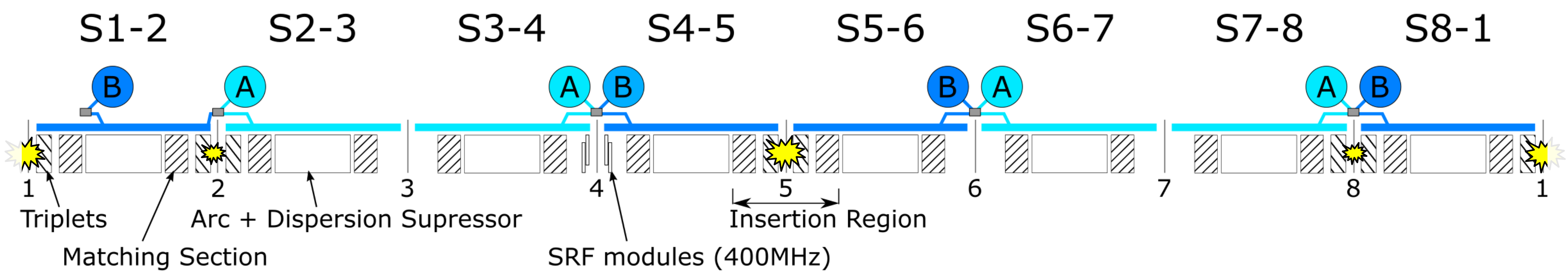
Cryogenic Configuration
(LHC vs HL-LHC)

Modification towards HL-LHC

Cryogenic Plants:

ex-LEP LHC HL-LHC

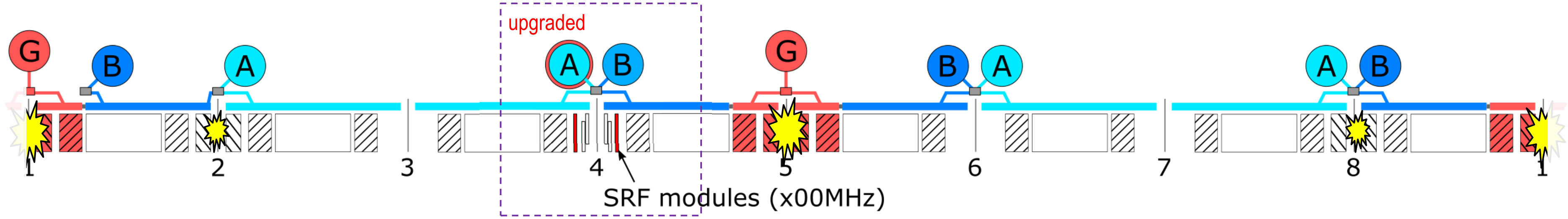
LHC (from 2010)



Cryo-configuration is **similar for all Sectos but has 3 "singularities":** HighL / LowL triplets and RF cavities

HL-LHC (from 2026)

Proven feasibility for P4 upgrade.
To become baseline after ECR.

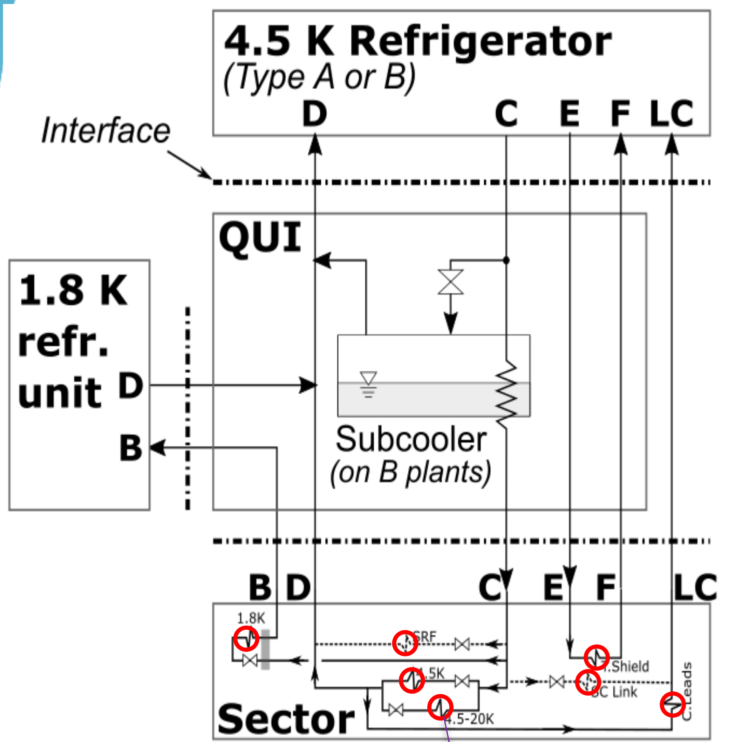


New cryo-configuration:
- New cryoplants for **HighL triplets**.
- Upgraded* Point4 for **RF cavities.**
- Existing plants still cooling **LowL triplets**.

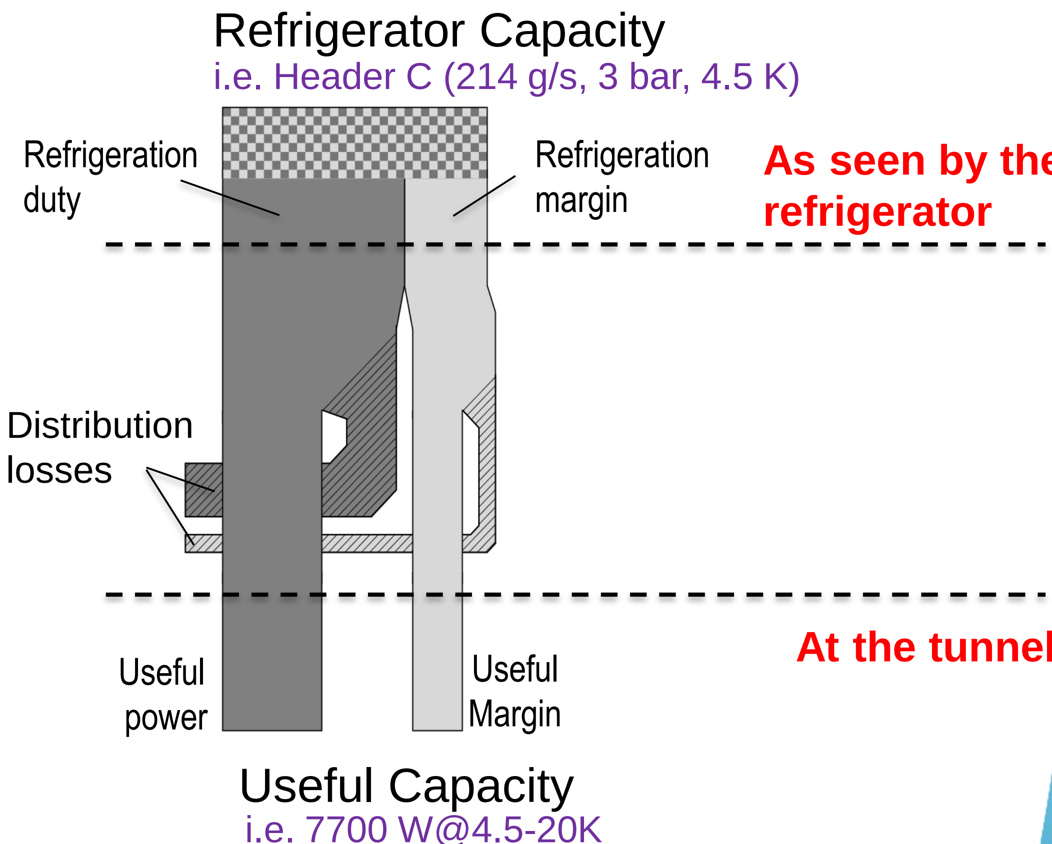
S2-3 & **S7-8** will be weakest sectors:
- ➢ Unchanged cryo-configuration
- ➢ Have LowL Triplets
- ➢ Cooled by *weaker* A-plants (exLEP)

***) Cooling of RF cavities** is: "transparent" for **S3-4** thanks to upgraded plant, and covered by higher overall capacity at **S4-5** (with remaining local capacities at least higher than S6-7).

Distribution of refrigeration power at the existing cryoplants



Beam Screen @4.5-20K



- Distribution losses are taken into account.
  - **Refrigerator capacity > Useful cooling capacity at the tunnel**

Type of data used for heat load estimations

	TE-CRG-OP: Measured	Design Report	WP9 / WP2: LHC	Run3	HL-LHC
Heat-In leaks	Timber	Design Report (DR)	DR	scaling	scaling
Resistive heating			DR	scaling	scaling
Synchrotron radiation			WP2	*WP2*	WP2
Image current			WP2	*WP2*	WP2
Electron clouds			*WP2*	*WP2*	WP2
Beam gas scattering			DR	scaling	scaling
Secondary particle losses			DR	scaling	scaling

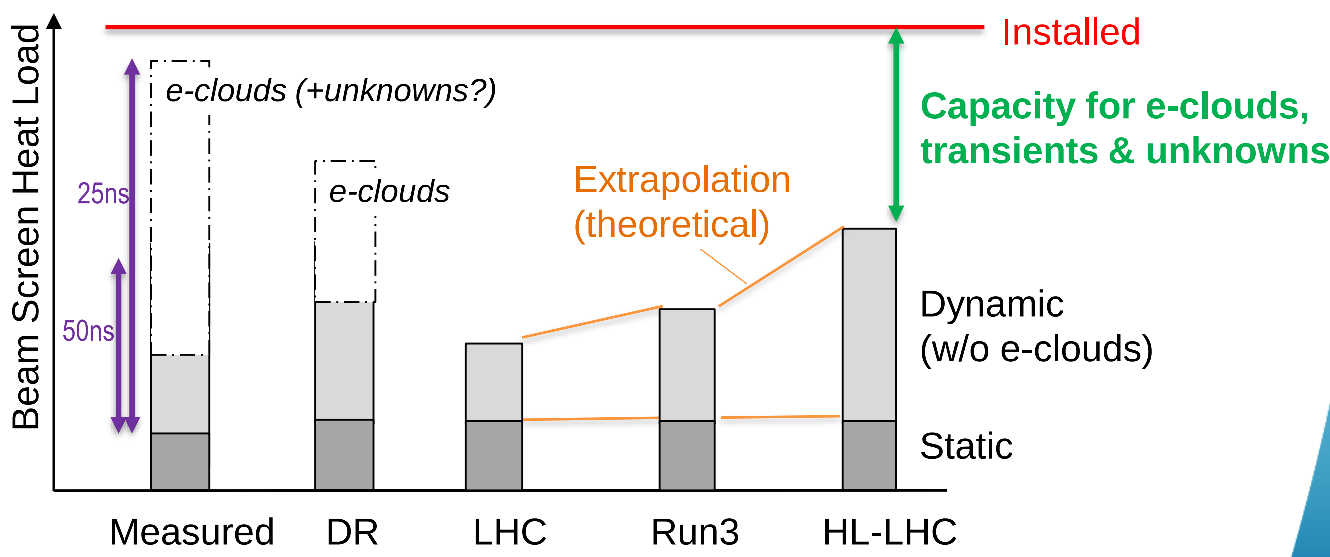
DR = if possible from Design Report, otherwise reconstructed from HLWG2000.

WP2-calculations confirm scaling laws for SR & IC

For now, values are from DR/scaling. WP2-values will be provided soon.

Still many uncertainties to commit on hard figures for ***e-clouds*** (!)

- Instead, we quantify the **"remaining capacity available for e-clouds".**



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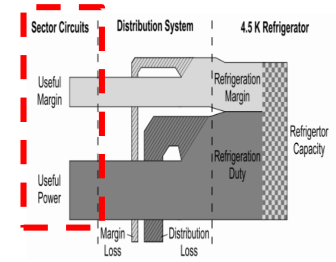
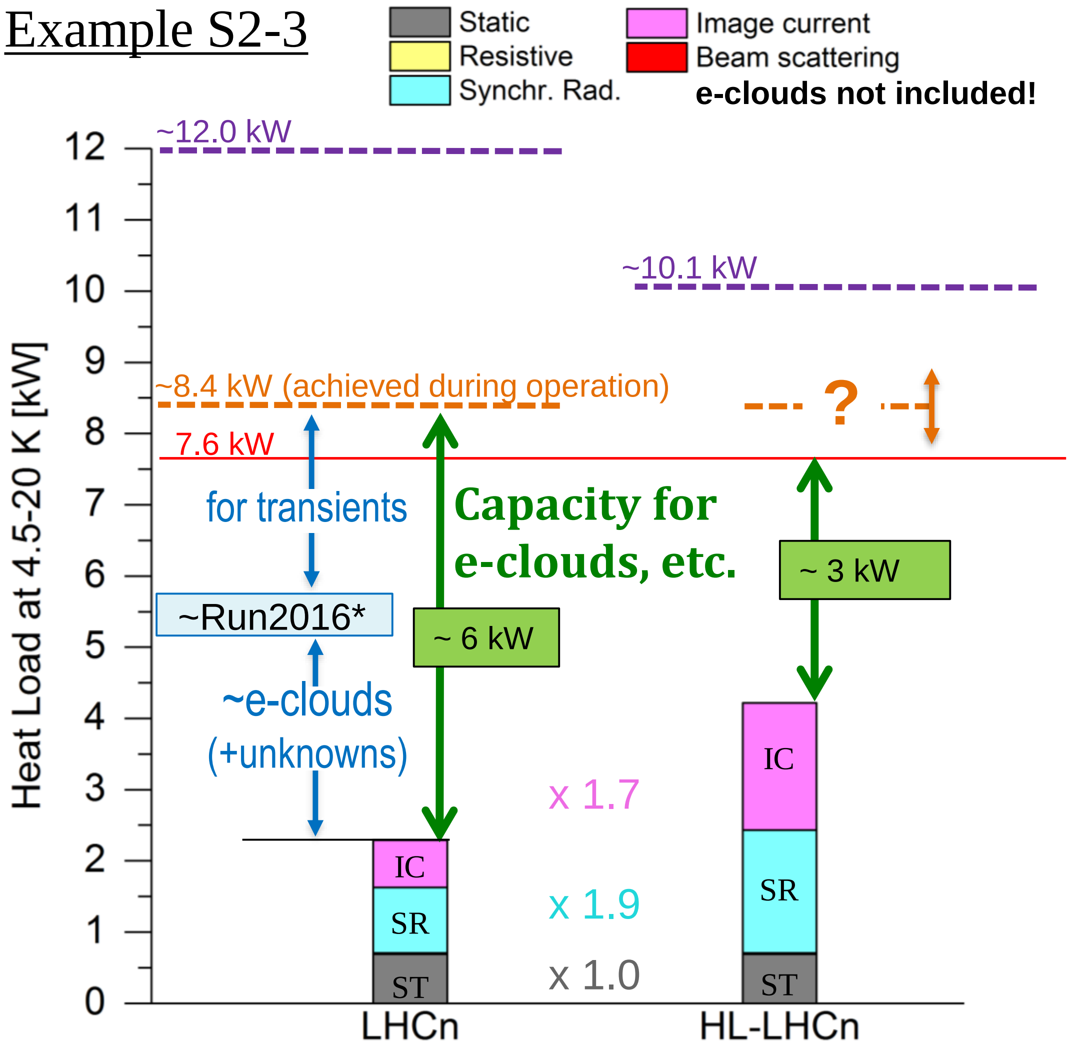
w/o e-clouds!

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



Example S2-3



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".

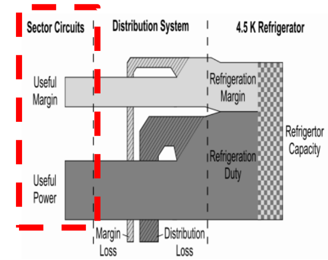
* i.e. Fill 5448 (2220b)

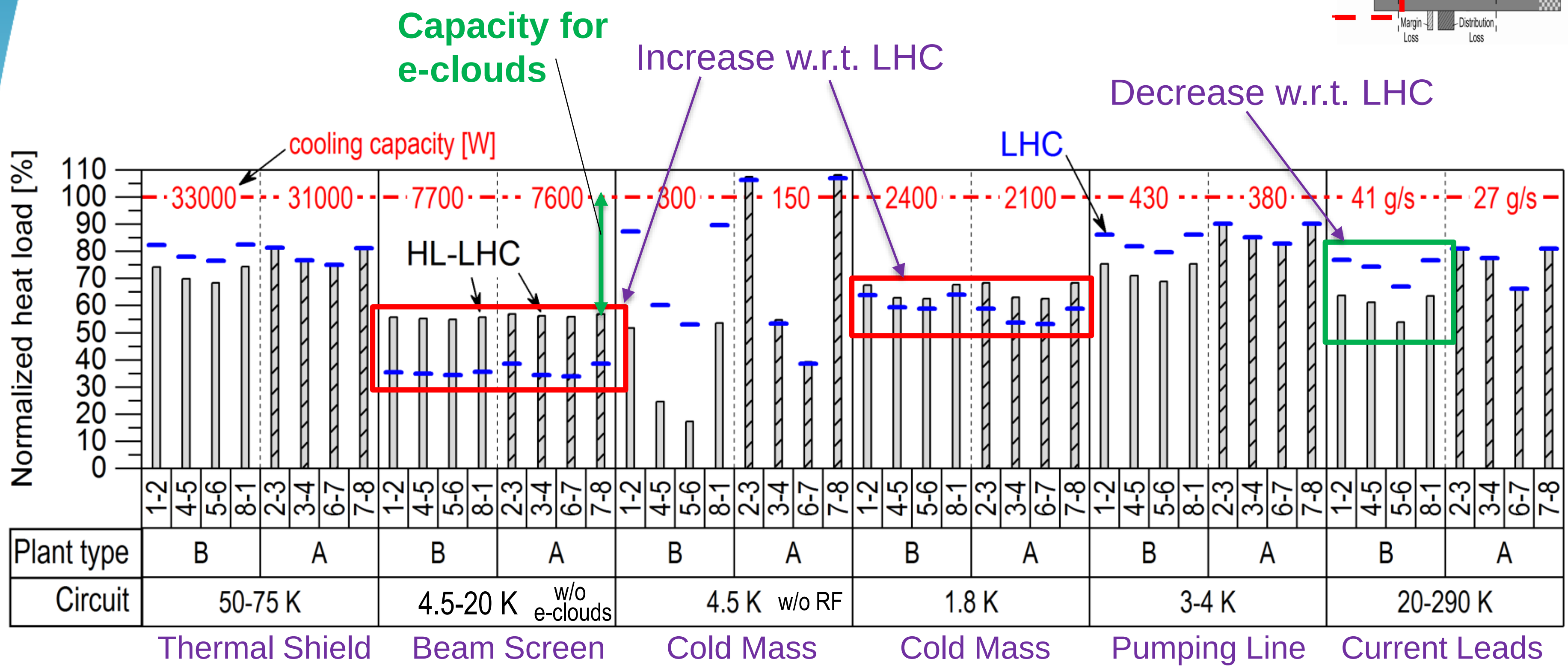
From LHC Assessment

From extrapolations and new calculations

w/o e-clouds!

Estimated HL-LHC heat loads at the tunnel (w/o LSS1/5, RF)

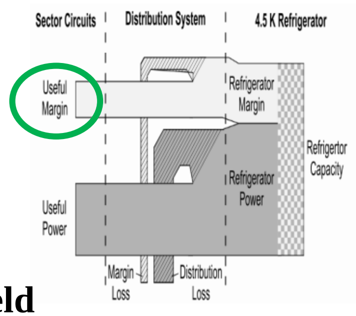




- **The bulk of the increase in heat-load is in the beam screens.**
  - **Remaining beam-screen capacity (~ 3 kW) is for e-clouds, transients & unknowns.**
- Similar levels of heat load at a given circuit across the 8 plants.
- There is some margin available, but a "capacity transfer" between circuits is only possible to a limited extend.

w/o e-clouds!

Available cooling capacity at the tunnel



HL-LHC (alternative 2)

3.2-3.4 kW available for e-clouds, transients & unknowns

Strongest: (S4-5) / S5-6
Weakest: S2-3 / S7-8

- S3-4: RF cooling is „transparent“ (plant upgrade matches RF and DSL needs)
- S4-5: Capacity is “transferred” to cover the RF needs (→ avail. cap. S4-5 ≥ S6-7)

Performance test done March’17
(methodology)

Approach: Use elec. heaters to simulate heat loads on cold masses (1.8 K) and BScreens.

Current performance tests not as “ideal” as initial acceptance tests.

- Initial acceptance tests for newer LHCB cryoplants were performed with a dedicated test cryostat. This was not possible for older LHBA plants because their interface to the tunnel is underground.
- Current tests are performed in the „shadow“ of other LHC activities
  → refrigeration stability and cryo-maintain signal to be ensured at all times.

Manual Settings

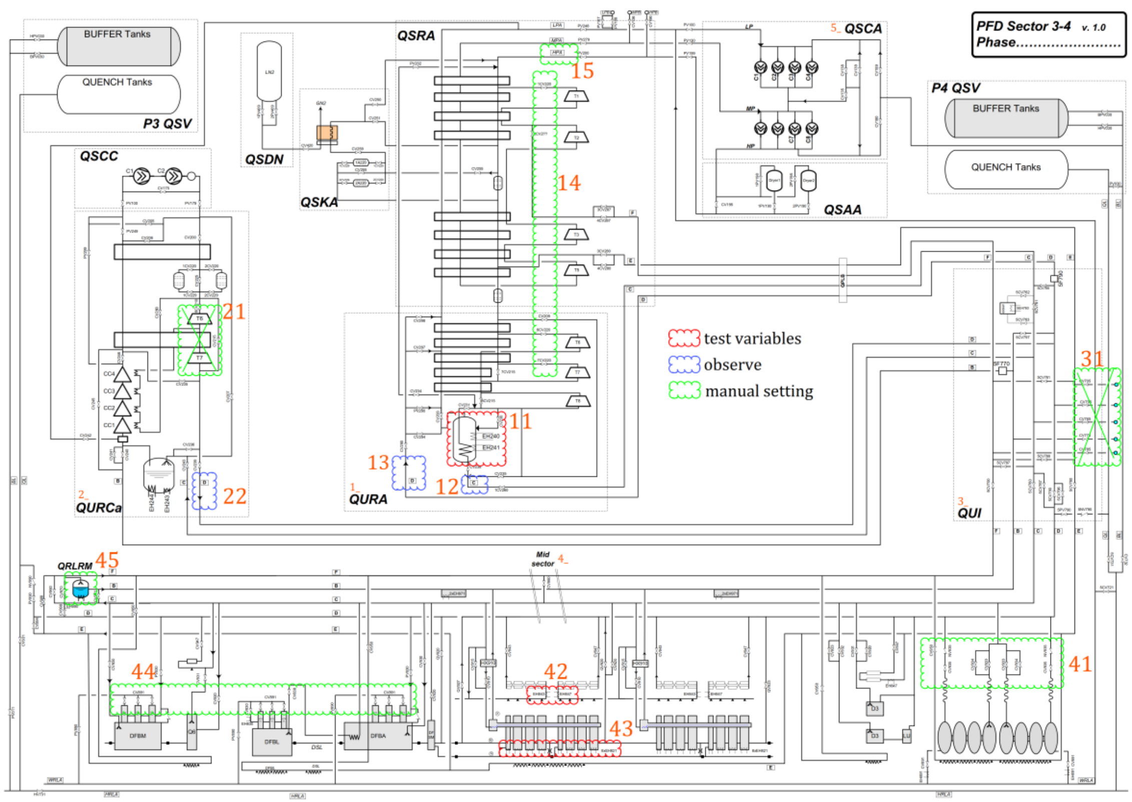
14: Turbines at cold box at max. capacity
15: HP line at max. pressure
21: turbines at cold compressor are turned off
31: One cryoplant serves only one sector
41: With or w/o RF cavities
44: Elec. heaters to simulate current lead cooling
45: Return modules at QRL

Test variables

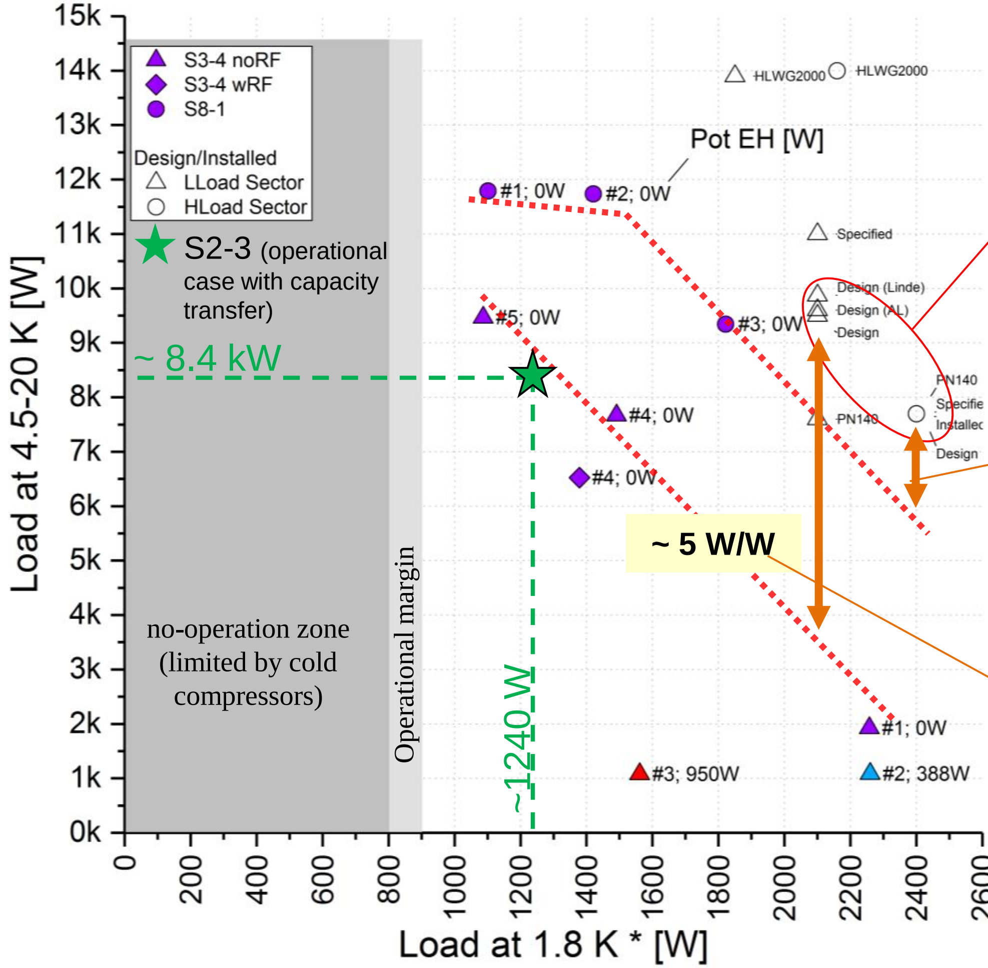
11: Heater at the phase separator
42: Elec. heater on BS
43: Elec. heater on 1.8 K mass

Monitored parameters

11: Liquid level of phase separator
12: Header C stream from the cold box (m, T, p)
13: Header D stream to the cold box (m, T, p)
43: Cold mass temperature
-- : Cryo-mantain signal for the sector



Performance test done March'17
(first result analysis)



* considers static loads (~800W), dynamic loads (by EH at magnets) and massflow at return modules

Design/Installed capacity

Variation from measurements w.r.t. to design/installed capacity.

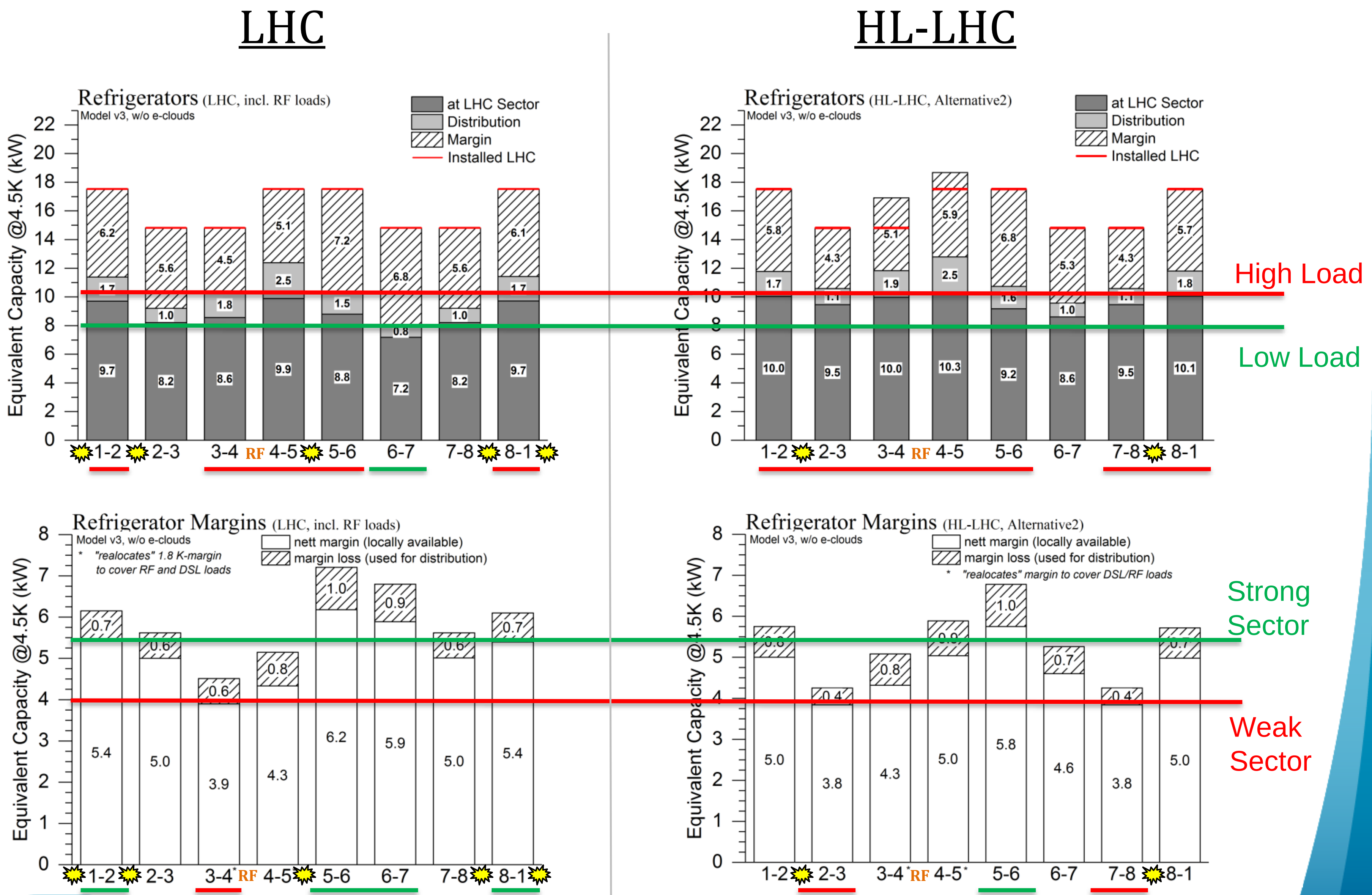
Capacity transfer from 1.8K to 4.5-20 K is close to the theoretical value of 5.23 W/W.

The effects of the various settings are well understood, but their relative impact needs to be quantified.

w/o e-clouds!

Refrigerator Assessment

Results based on *model v.3*, for existing LHC refrigerators only



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Specific case for Stand Alone Magnets (SAMs)

Already identified as possible show stopper for which turn around strategies are proposed.

In general, 2 ways to solve the problem:

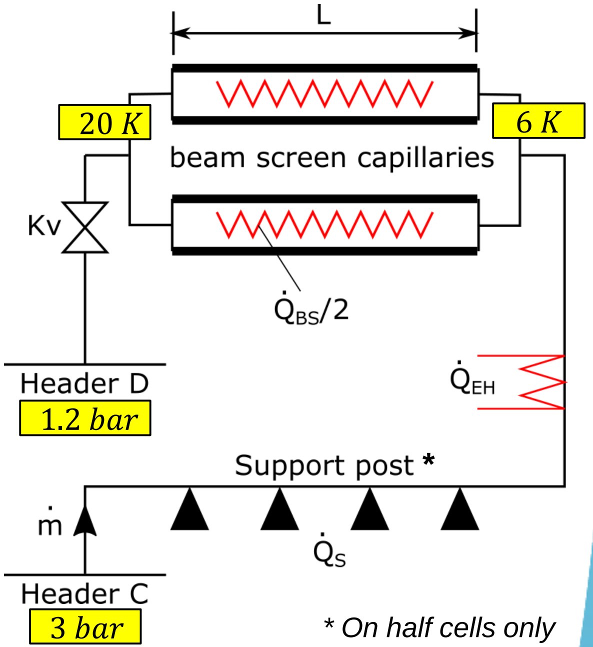
1) Increase of cooling capacity…

a) by increasing the mass flow (unfortunately limited). Investigated to allow a short-term solution and win extra time (LS3?) letting option 2) to mature.

b) by increasing the outlet temperature T_{out} at BS from 20 K to 30 K. (for LSS only)

2) Surface treatment of the BS (i.e. coating with aC) to reduce the generated heat loads.

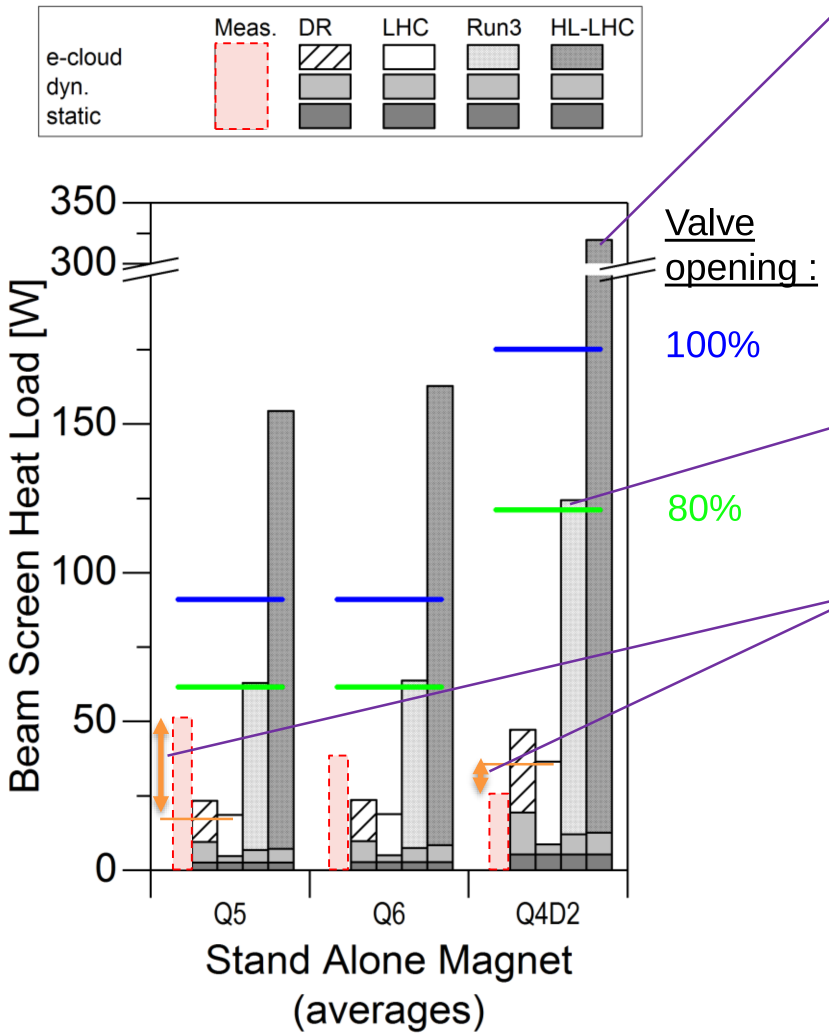
- Currently baseline for all triplets and under discussion for some stand alone magnets.
- Assessment to define if suitable for medium/long term future (risk vs. reduction in heat loads).



* On half cells only

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.

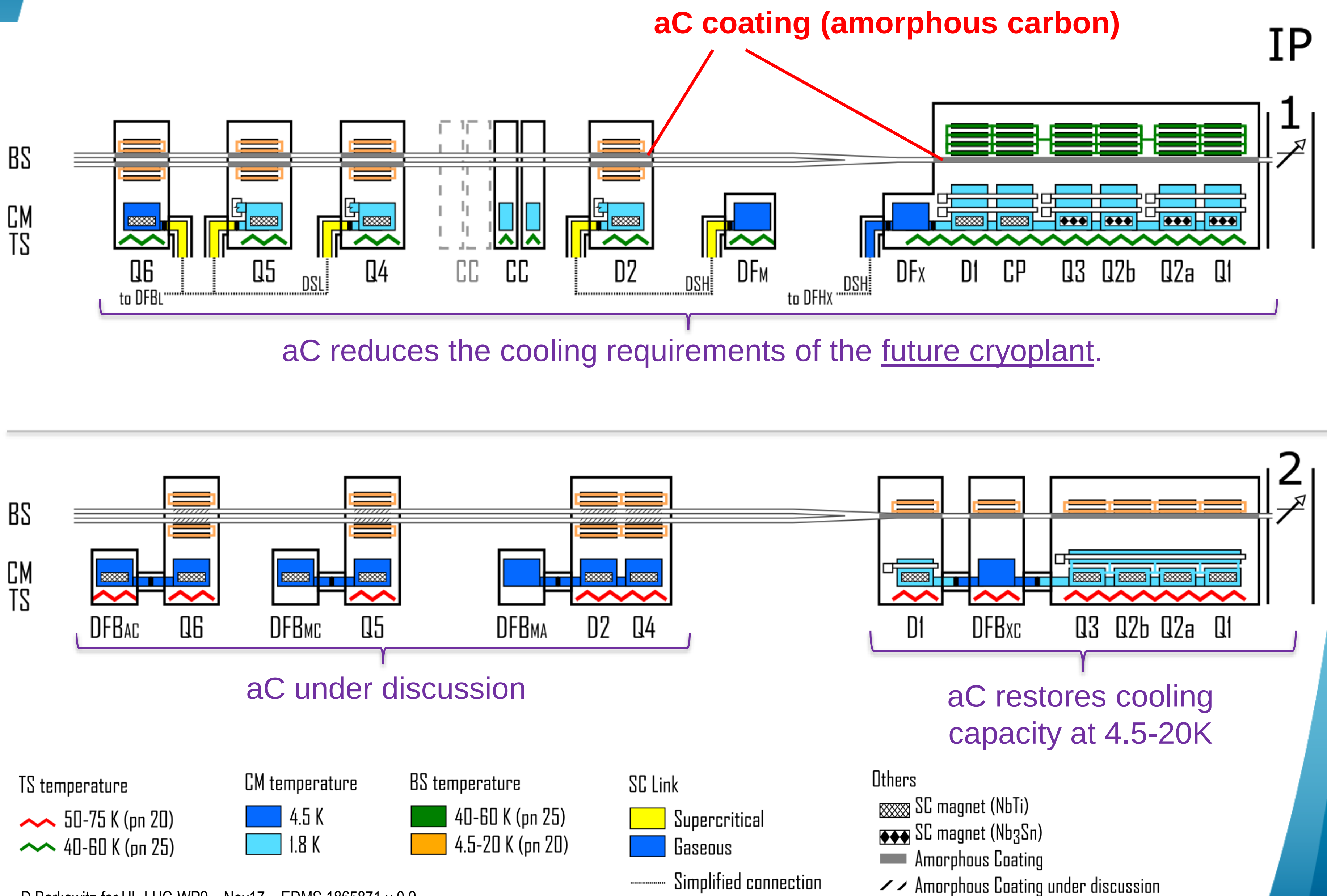
Valve opening to become limiting factor in Run3.

- 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).

Surface treatment of the BS pipes



D.Berkowitz for HL-LHC WP9 – Nov17 – EDMS 1865871 v.0.9.

Conclusions

1. We need to take a closer look at LHC loads to understand discrepancies with theoretical values. (new dedicated task force at A&T sector)
- Or maybe are there unknown heat load sources?
- Extra diagnostics to be studied for LS2?

2. Heat loads on HL-LHC (excl. e-clouds!)
- Less capacity available for e-clouds + transients + unknowns at 4.5-20 K .
- ➢ ~3.2 kW instead of ~5 kW for LHC (or even ~6 kW with capacity transfer).
- Although there is some capacity available at the other temperature levels, note that a "capacity transfer" is only possible to a limited extend.
- "Transfer efficiency" is under investigation to quantify its impact.

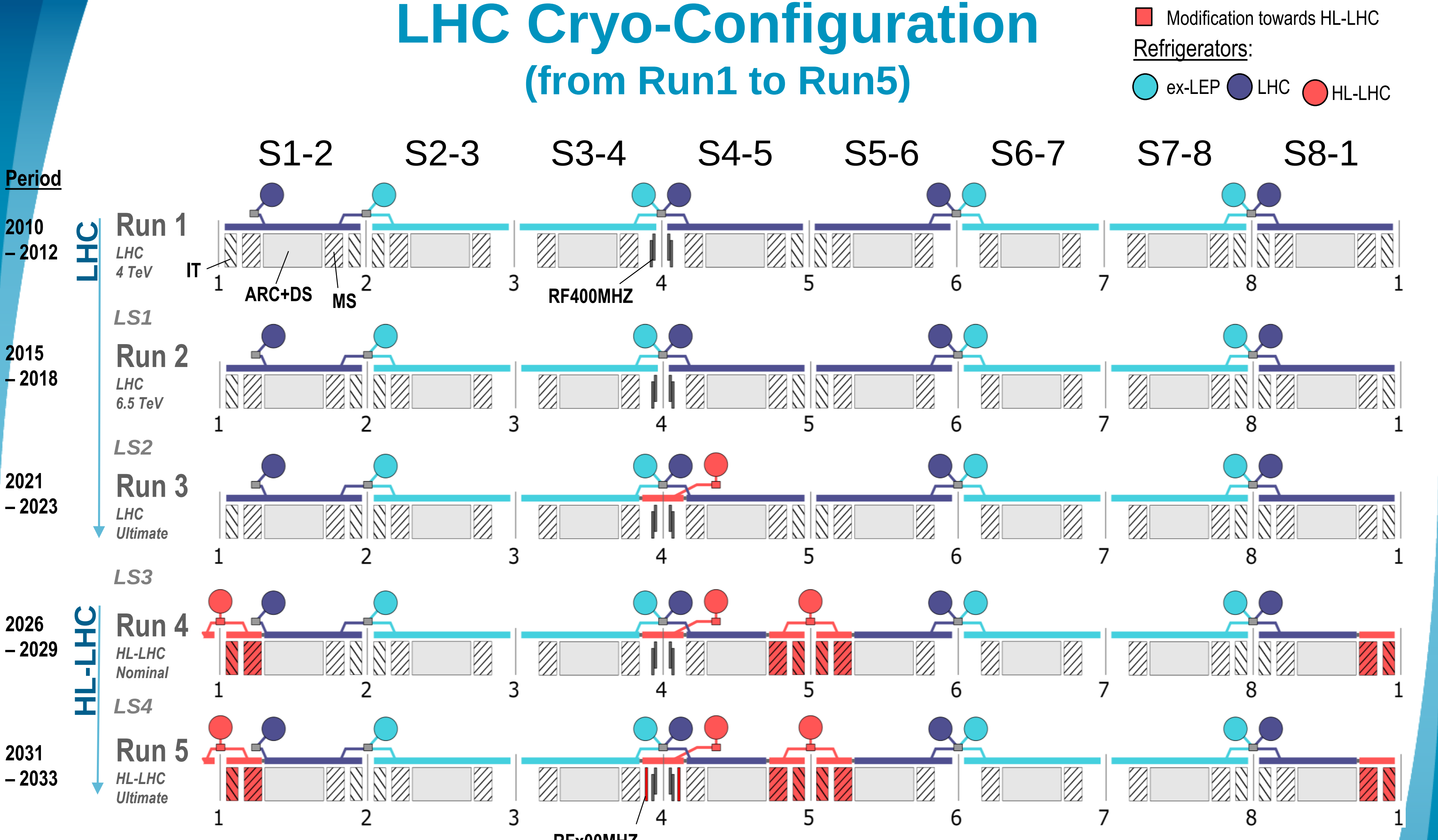
3. Surface treatment on BS restores cooling capacity at 4.5-20K.
- This is baseline for all triplets (new triplets at P1/5 and existing at P2/8)
- Priority 1: R2 / L8 to help *weaker* Sectors (LHCA plants with triplets).
- Priority 2: L2 / R8 to recover spare capacity from LHCB plants.

4. To be decided the strategy to deal with SAMs at P1/5:
- Option A: Reduce the cooling requirements with surface treatment on BS
- Option B: Specify a higher cooling capacity for the new LHCG plants

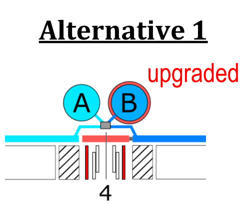
Thank you

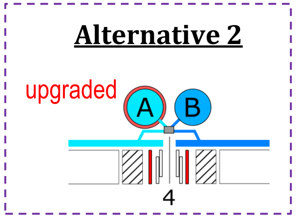
See backup slides for complementary information…

LHC Cryo-Configuration
(from Run1 to Run5)



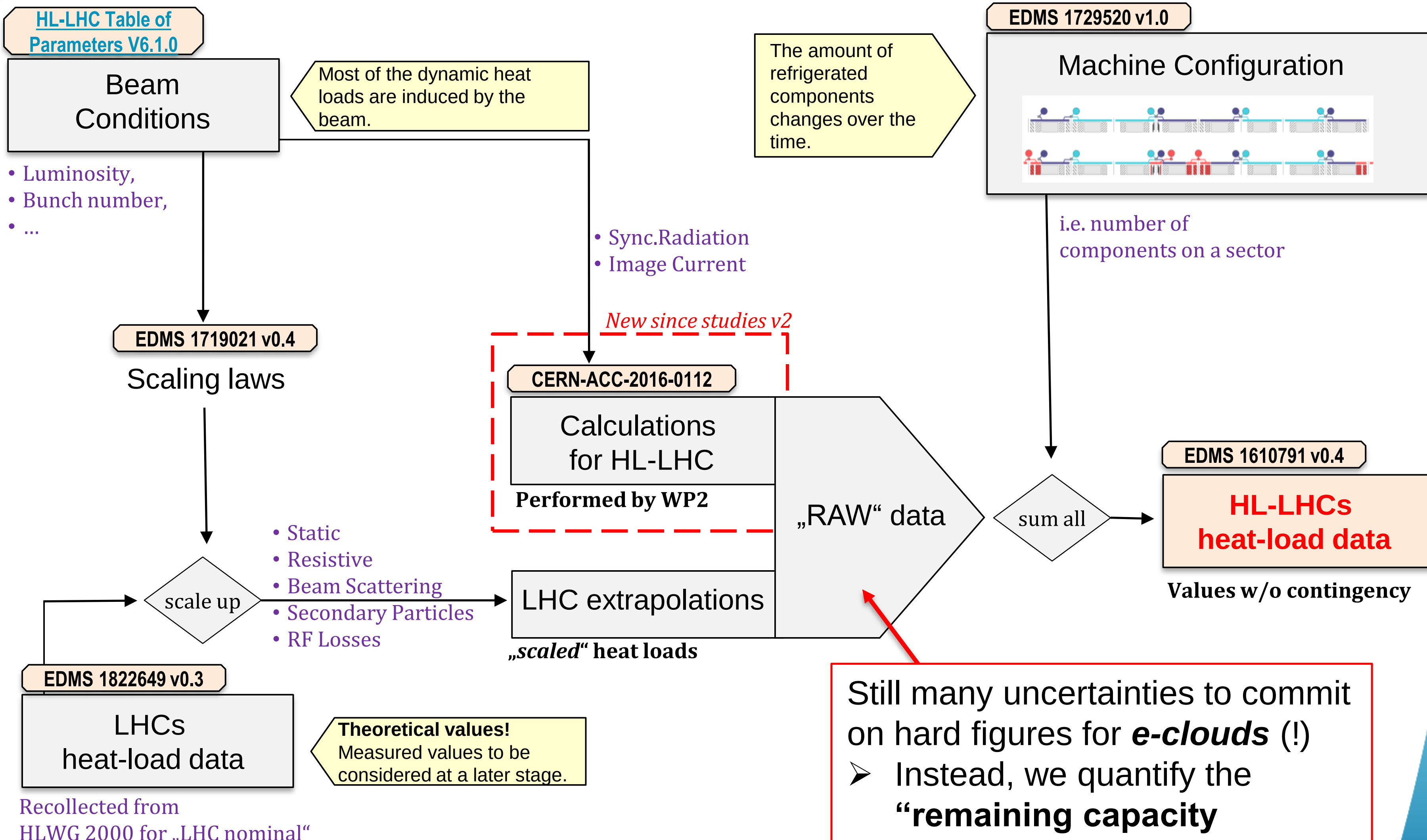
D.Berkowitz for HL-LHC WP9 – Oct16 – EDMS 1729520 v.1.0.





To become baseline after ECR.

Methodology for heat load estimations on <u>existing</u> cryoplants (As for *heat load studies v3*)



Type of data used for heat load estimations

Machine parameters impacting the cryogenic system

Machine	Energy E [TeV]	Bunch population Nb [p^+/bunch]	Bunch number nb [-]	Bunch length $4\sigma_\tau$ [ns]	Luminosity * L [10^{34} Hz / cm^2]
LHC	7	1.15E+11	2808	1.0	1
Run 3	7	1.70E+11	2748	1.0	1.75
HL-LHC	7	2.20E+11	2748	1.2	5

* At the high-luminosity detectors ATLAS and CMS.

EDMS 1719021 v0.4

Heat load mechanism	Heat load data for the HL-LHC machine	
	Extrapolated (scaling laws)	Calculated
Heat-In leaks	x1	-
Resistive heating	x1 $(\sim E^2)$	-
Synchrotron rad.	-	x1.9
Image current	-	x1.7
Electron clouds	-	-
Beam scattering	x1.9 $(\sim Nb \cdot nb)$	-
Secondary particles	x5 $(\sim E \cdot L)$	-
RF losses	x1	-

Still many uncertainties to commit on hard figures for ***e-clouds*** (!)

- Instead, we quantify the **"remaining capacity available for e-clouds".**

Refrigeration margin to cover e-clouds, transients and unknowns

„RAW" data

sum all

HL-LHCs heat-load data

Values w/o contingency

Comparison of heat load data

(extrapolations vs. calculations)

Synchrotron Radiation

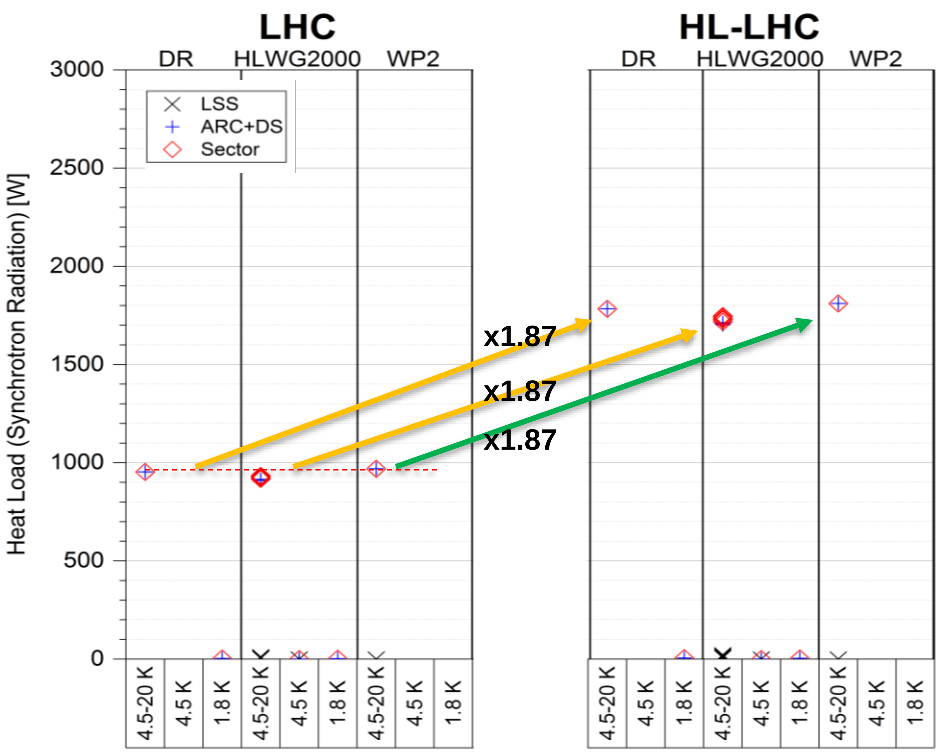
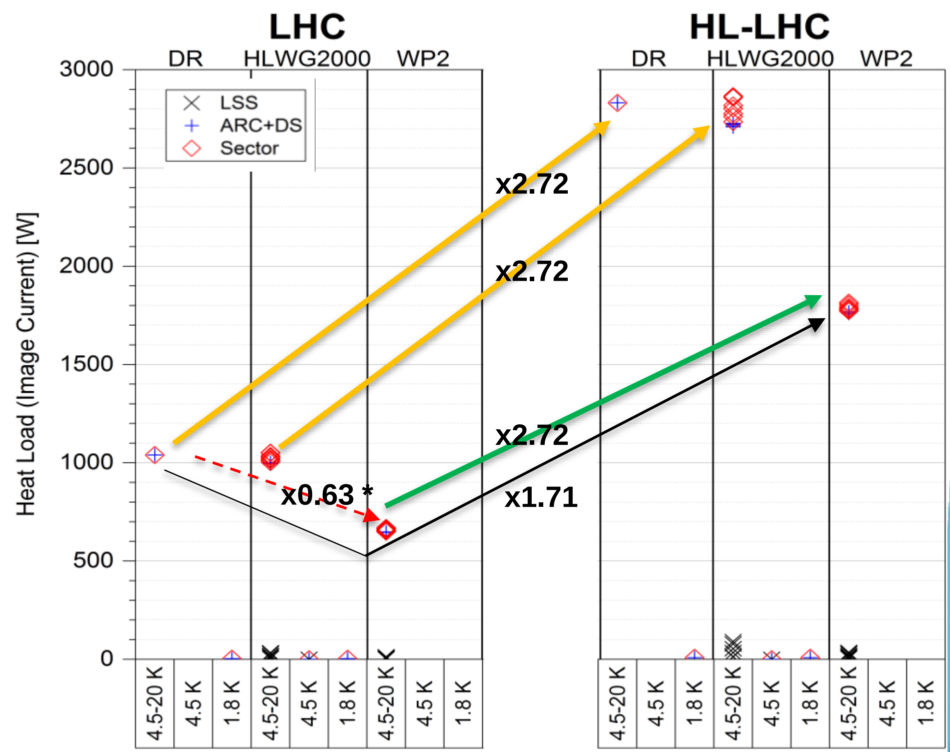


Image Current



*** no BPM bellows.** (see WP2/9 Meeting 9Nov16, Indico 570272)

Comparing extrapolations (LHC-DR, HLWG200) vs calculations (by WP2)

- Synchrotron Radiation: values are similar.
- Image current: WP2 are lower due to different assumptions (i.e. no BPM)

WP2-calculations confirm scaling laws for SR & IC

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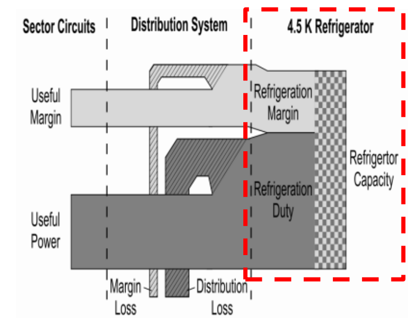
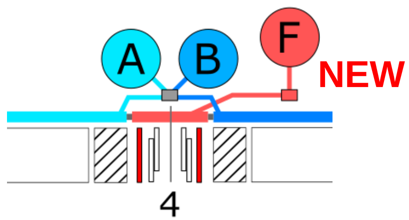
Alternative scenarios to cool the SRF modules at point 4

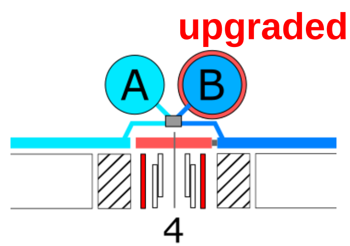


For an useful cooling capacity of 2 kW at 4.5 K

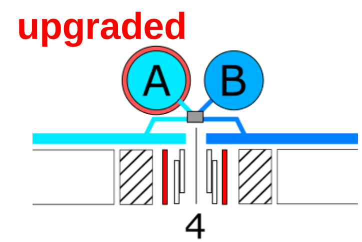
Baseline

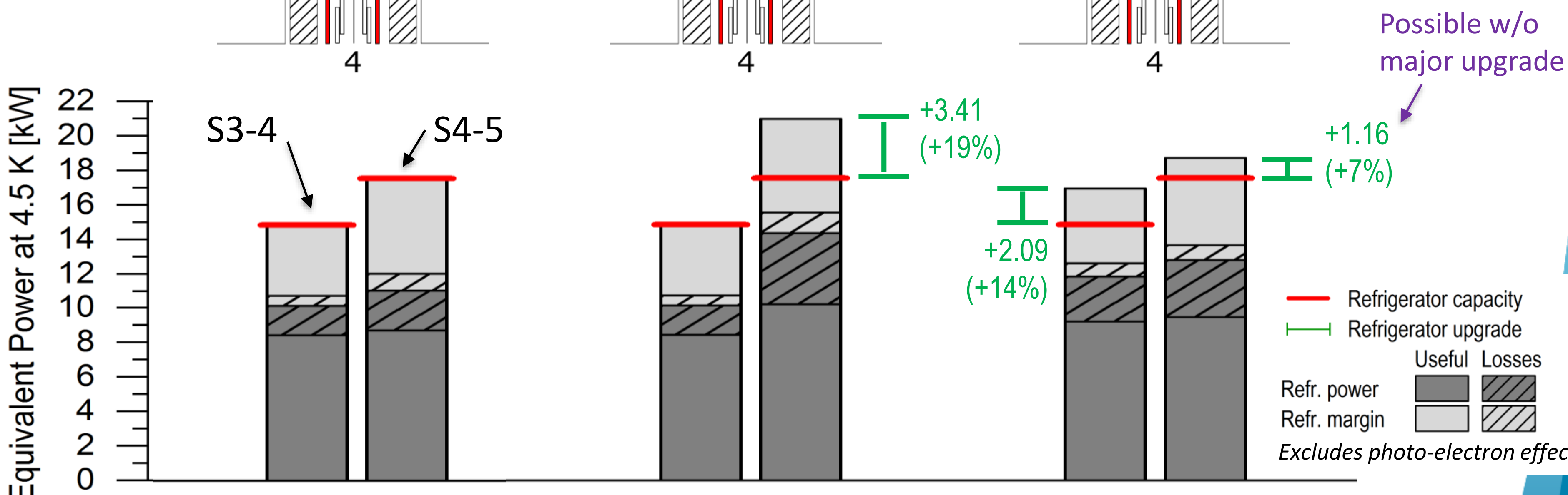


Alternative 1



Alternative 2





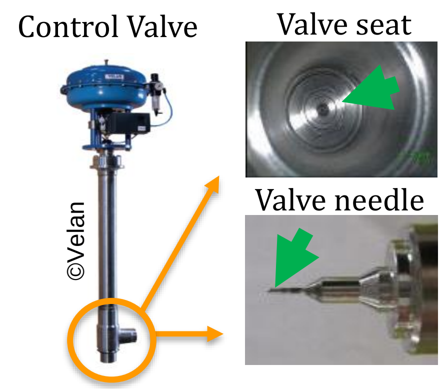
- After upgrade, the refrigerator margin aligned to the other plants

Possible actions to increase the BS cooling capacity

3 different actions are possible:

Complexity →

#	0	1	2	3
Action	None (as it is now)	Open valves (fully)	Change valve seat	Change valve body
Remarks	Valve opening **$O_{\%}$=80%** SAM: **KV = 0.05** Semi-SAM: **KV = 0.1** IT: **KV = 0.26** ARC cell: **KV = 0.39**	Valve opening **$O_{\%}$=100%** *could be done right away*	For SAM / Semi-SAM can be increased to **KV=0.3** *(confirmed by supplier)* IT and ARC cell **KV=t.b.c.**	Requires cutting the pipes!
Cooling Capacity [W] *	SAM ≈ *62* Semi-SAM ≈ *122* ARC cell ≈ *300*	SAM ≈ *90* Semi-SAM ≈ *175* ARC cell ≈ *338*	SAM ≈ *450* Semi-SAM ≈ *400* ARC cell ≈ *365*	SAM ≈ *790-1100* Semi-SAM ≈ *590-700* ARC cell ≈ *375*



** see appendix3 for table with cooling capacities*

demands more cooling capacity from the cryoplant !

Details in study: "Increase of BS capacity at the LSS of the HL-LHC" – D.Berkowitz

Chamonix 2017

IT LowL (45 m) - Influence of BS temperature

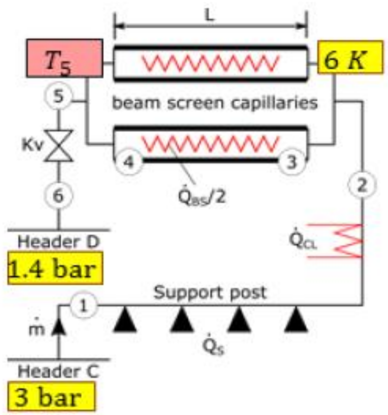
Example: **IT LowL**

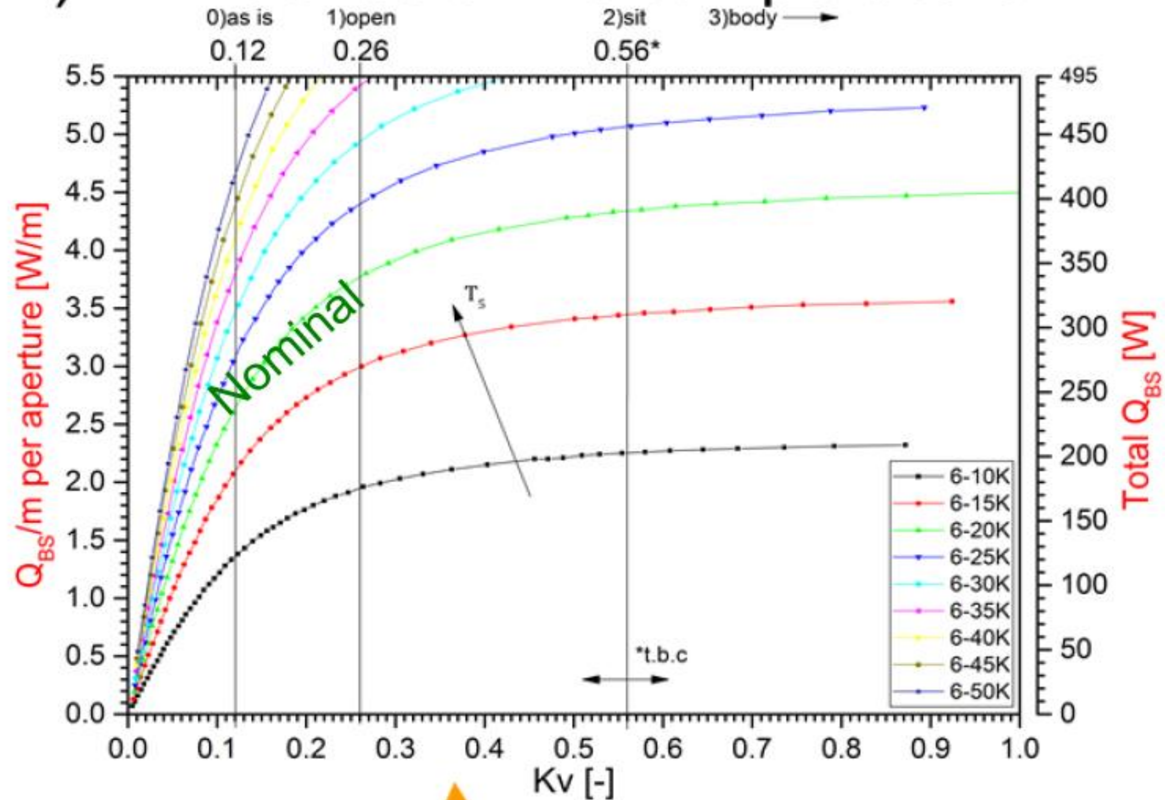
$T_2 = 6\ K$ (BS inlet)

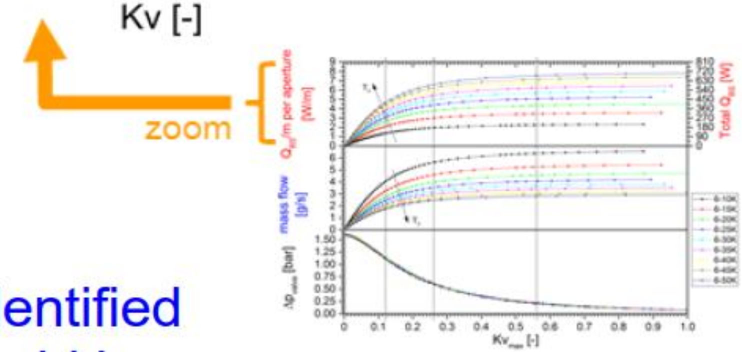
$T_5 =$ BS outlet

$L = 45\ m$

$Kv_{max} = 0.26$ (installed)







$T_5 = 20\ K \rightarrow 30\ K$

Increase of cooling capacity to up to +25%

Only a local and temporary solution identified to help until a more drastic solution could be applied (Coating or equivalent)