Electron cloud impact on LHC cryogenics

Joint Accelerator Performance Workshop 2023, Montreux

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TE-CRG

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https://indico.cern.ch/event/1337597/overview

INTRODUCTION

- Beam screen heat load evolution in LHC from Run 2 to Run 3
  - 6 years of operation @ 25ns
  - First real experience of hybrid scheme induced heat loads in 2023
  - Screening the heat loads: results of measurements performed in LHC instrumented half-cells

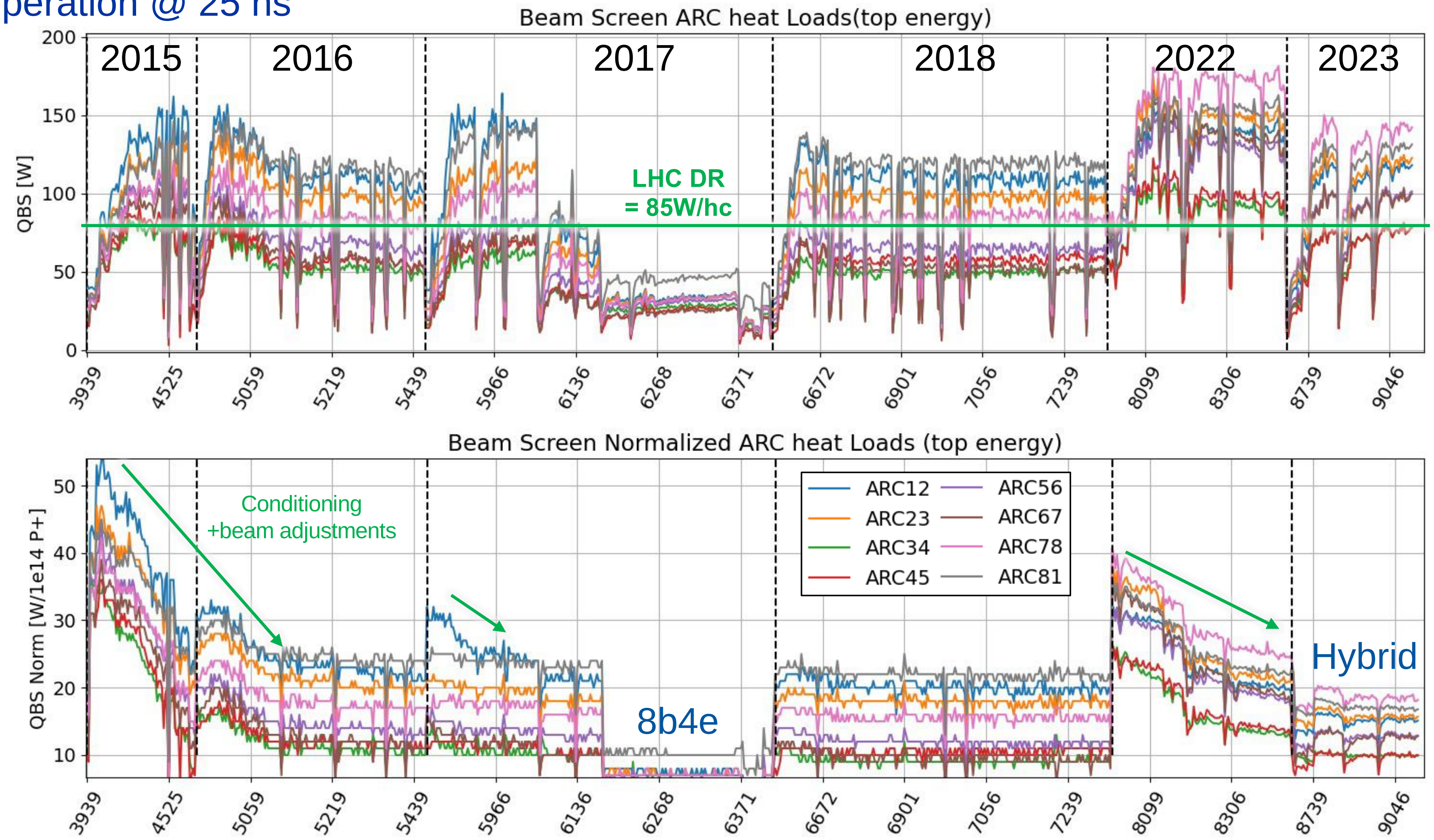
- Carbon coating effect in the machine: observation in Q5L8

- Heat load estimation in drift with PIMS sensors (instrumented cells)

- Cryogenic capacity limitations and possible optimisations (until LS3)

Beam Screen Heat Load Energy @ top energy

- 6 years of operation @ 25 ns



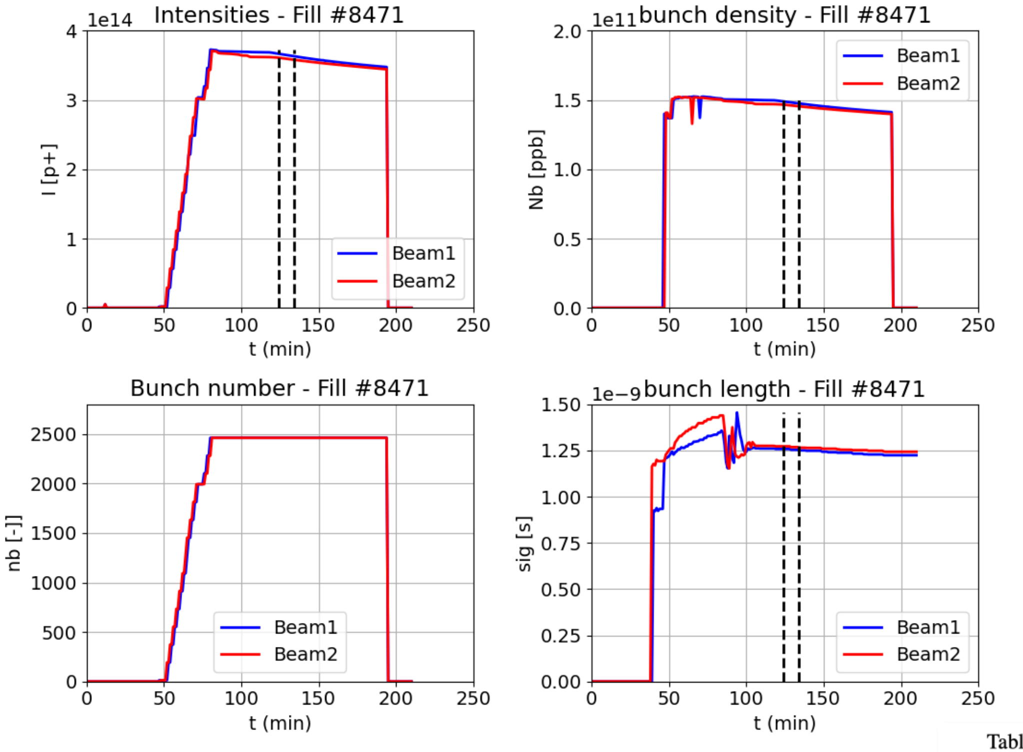
NB: All beam screen heat loads for each fill are available in the Beam Performance Tracking website + NXCALS

Typical Physics fills: 2022 vs 2023

Fill #8471 (23rd November 2022)

25ns_2462b_2450_1737_1735_180bpi_17inj_2INDIV

BCMS scheme : 5x36b trains



σ = 1.25 ns

N = 2462 bunches

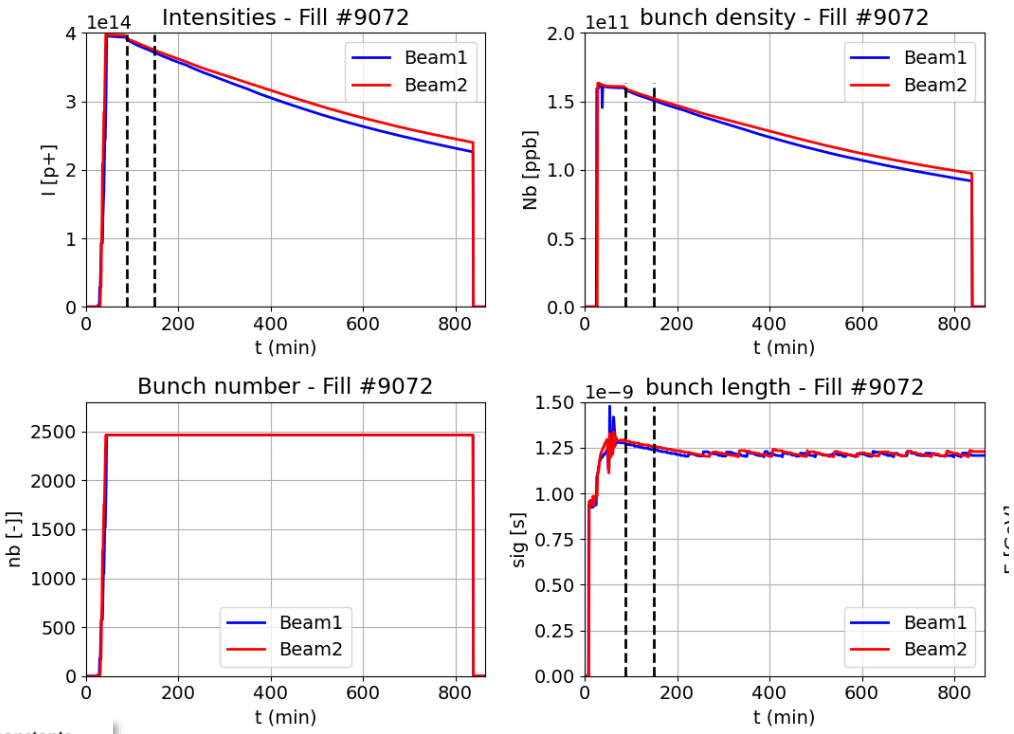
N = 1.5e11 ppb

I_{tot} = 3.6e14

Fill #9072 (16th July 2023) – before ITL8 event

25ns_2464b_2452_1842_1821_236bpi_12inj_hybrid

Hybrid scheme : 56b (8b4e) + 5x36b trains



σ = 1.27 ns

n = 2464 bunches

N = 1.6e11 ppb

I_{tot} = 3.9e14

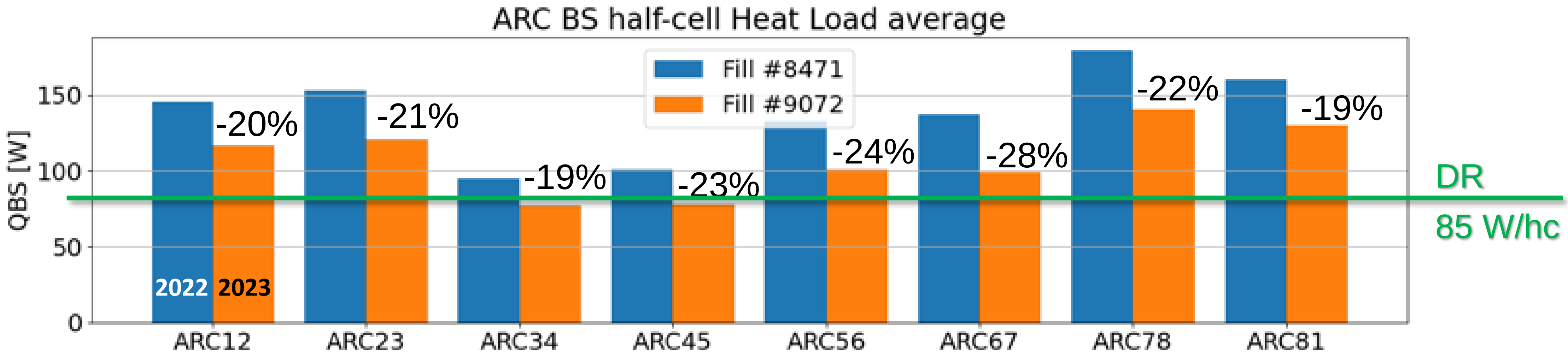
Table 2: LHC Beam screen heat load constants

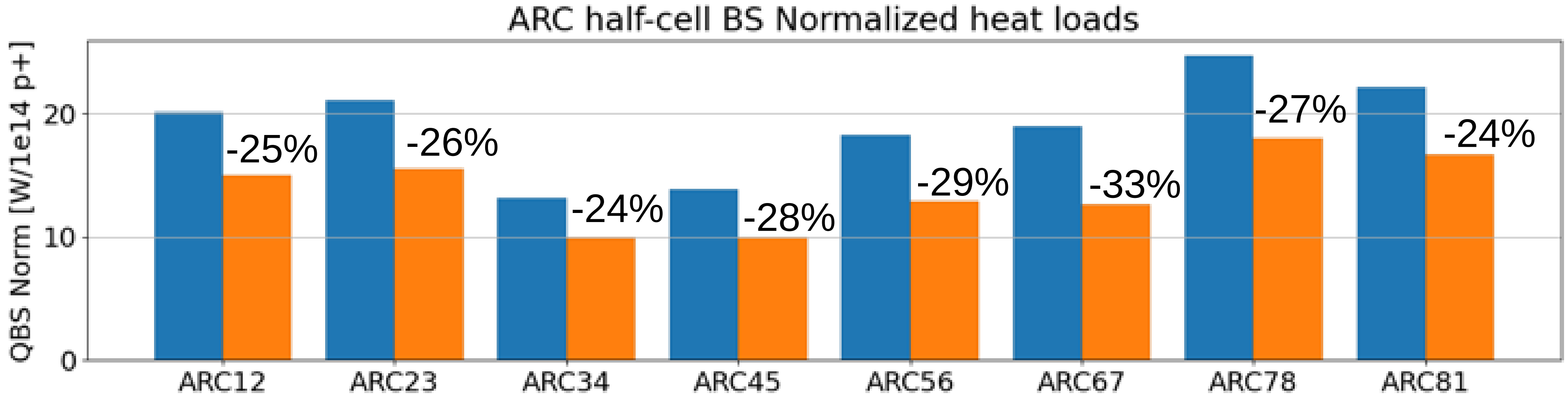
Name	Description	Value
L	Beam screen length	$53\ m$
E_0	Nominal energy	$7\ TeV$
E_{inj}	Injection energy	$0.45\ TeV$
E_{ramp}	Final energy after ramp	$6.5\ TeV$
Nb_0	Nominal protons per bunch	$1.15 \cdot 10^{11}$
nb_0	Nominal bunch number	2808
σ_0	Nominal bunch length mean	$1.06\ ns$
Q_{sr0}	Nominal synch. rad. load	$0.165\ W/m$
Q_{ic0}	Nominal image current load	$0.135\ W/m$
p	Bunch dependence factor	-1.5

Heat load comparison 2022 vs 2023

2022 Fill #8471: 25ns_2462b_2450_1737_1735_180bpi_17inj_2INDIV (5x36b)

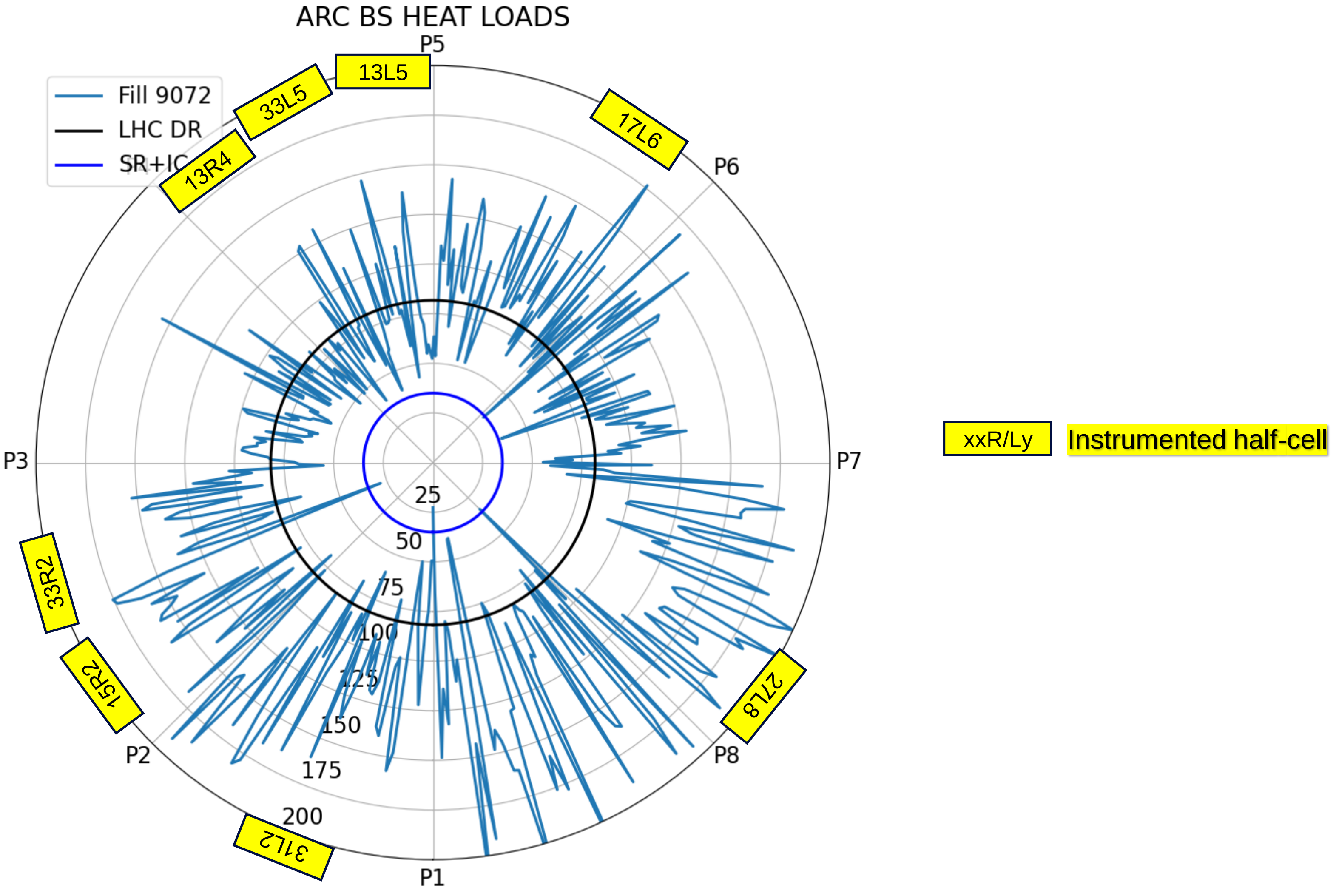
2023 Fill #9072: 25ns_2464b_2452_1842_1821_236bpi_12inj_hybrid (56b (8b4e) + 5x36b trains)





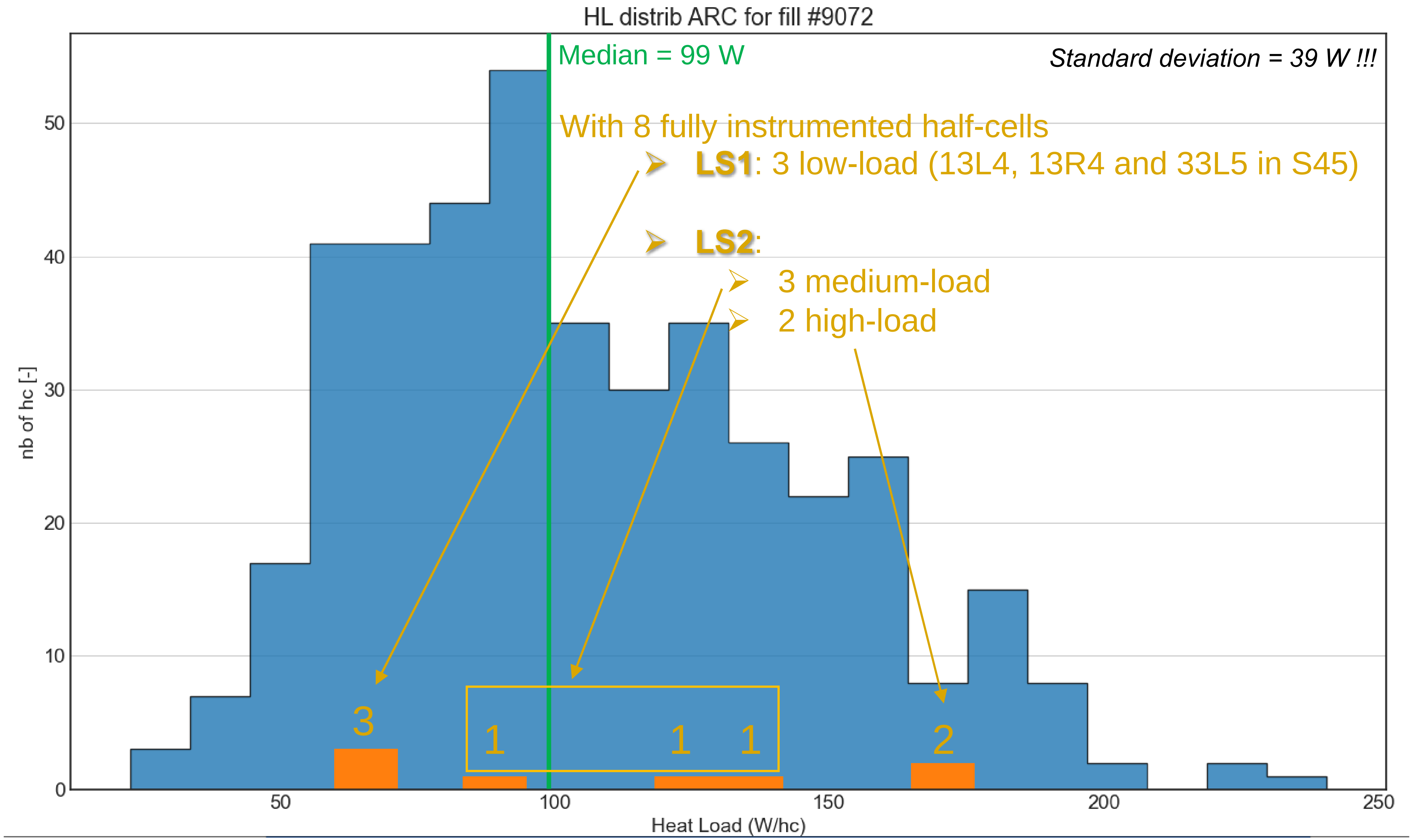
Heat load repartition in 2023

Fill #9072 (16th July 2023): 25ns_2464b_2452_1842_1821_236bpi_12inj_hybrid



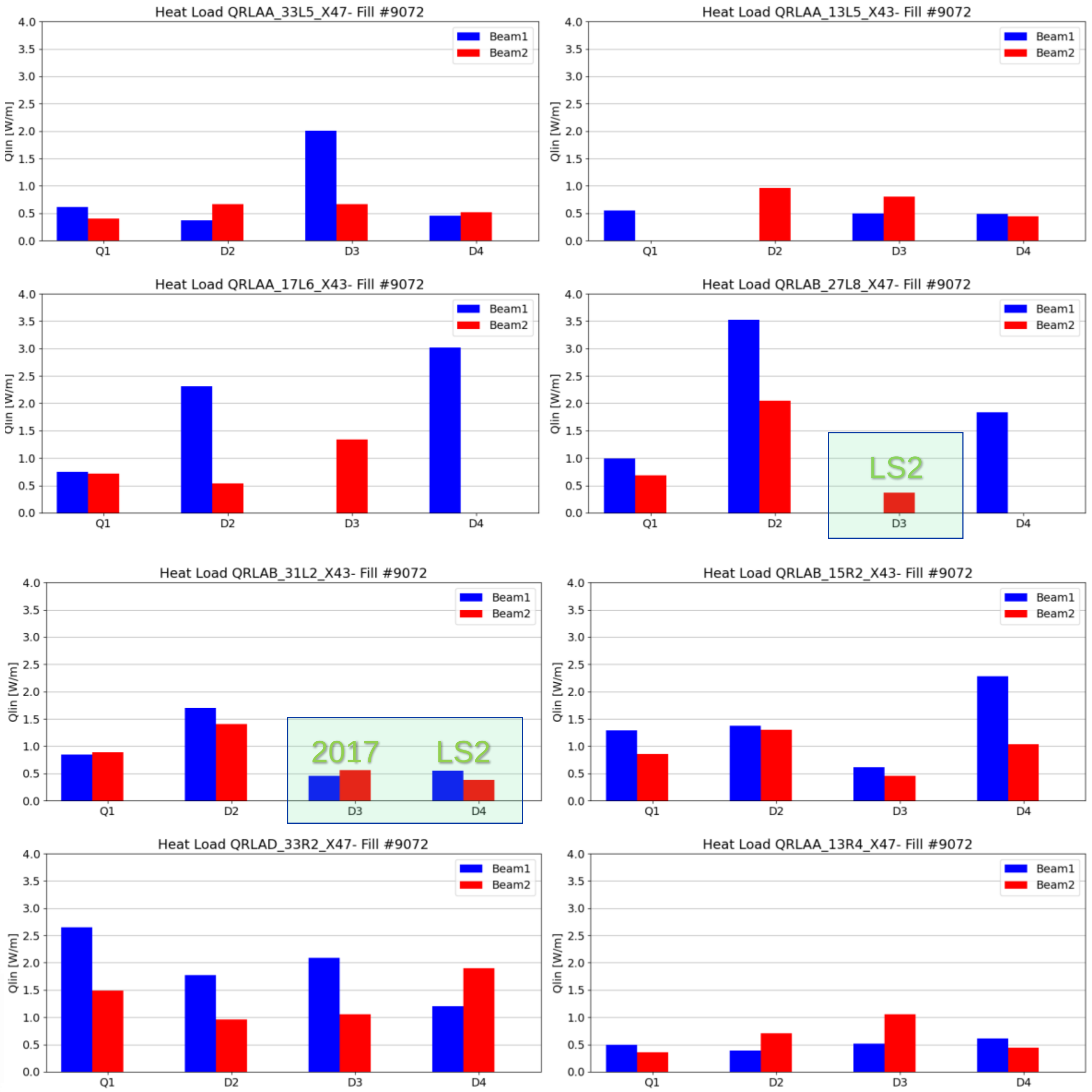
- The 416 ARC half-cells are represented on the ring (53m each)

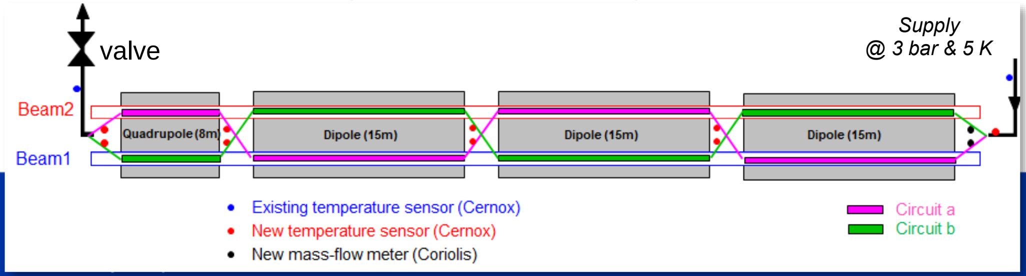
Heat load distribution over LHC



Results of the new cryo instrumentation

- Full instrumentation of 8 half-cells validated in 2022, please refer to Chamonix Workshop 2023
- 64 individual apertures instrumented (48 in dipoles + 16 in quadrupoles)
- 6 apertures missing due to instrumentation issues
  - 1 sensor lost in 13L5 (need to open the IC)
  - 2 sensors badly calibrated in 17L6 and 27L8, to be corrected during EYETS’23
- Over the instrumented half-cells:
  - 1 magnet exchanged in 2017
  - 2 magnets exchanged in LS2



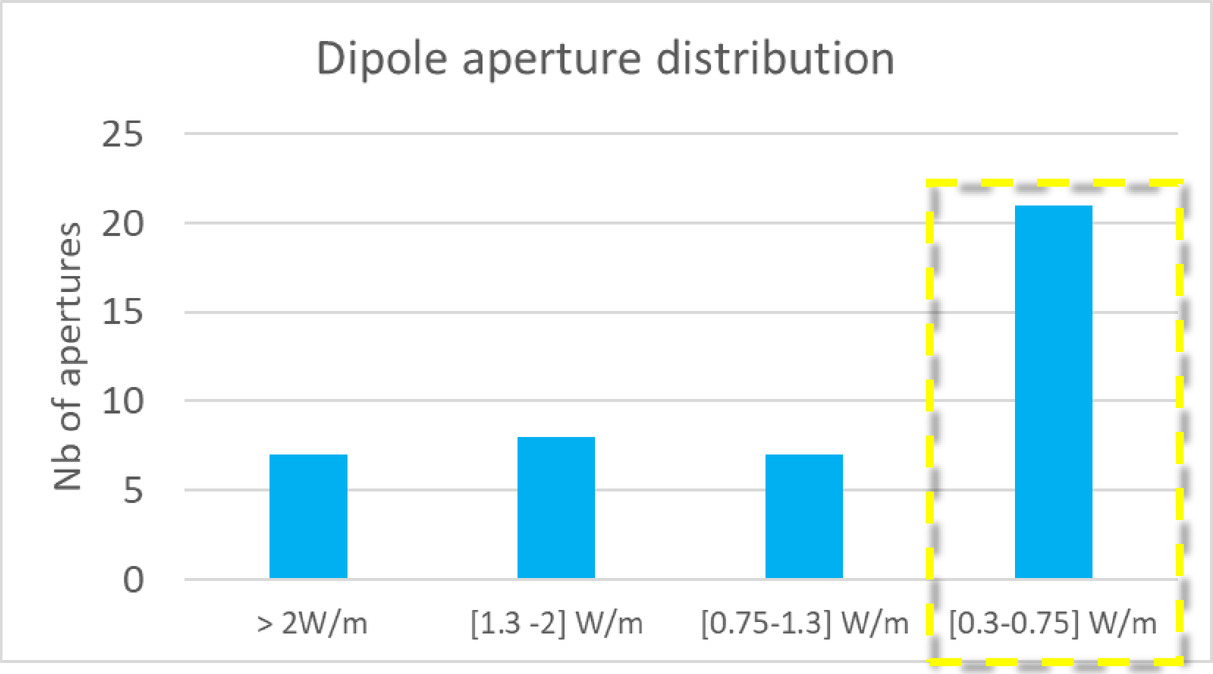


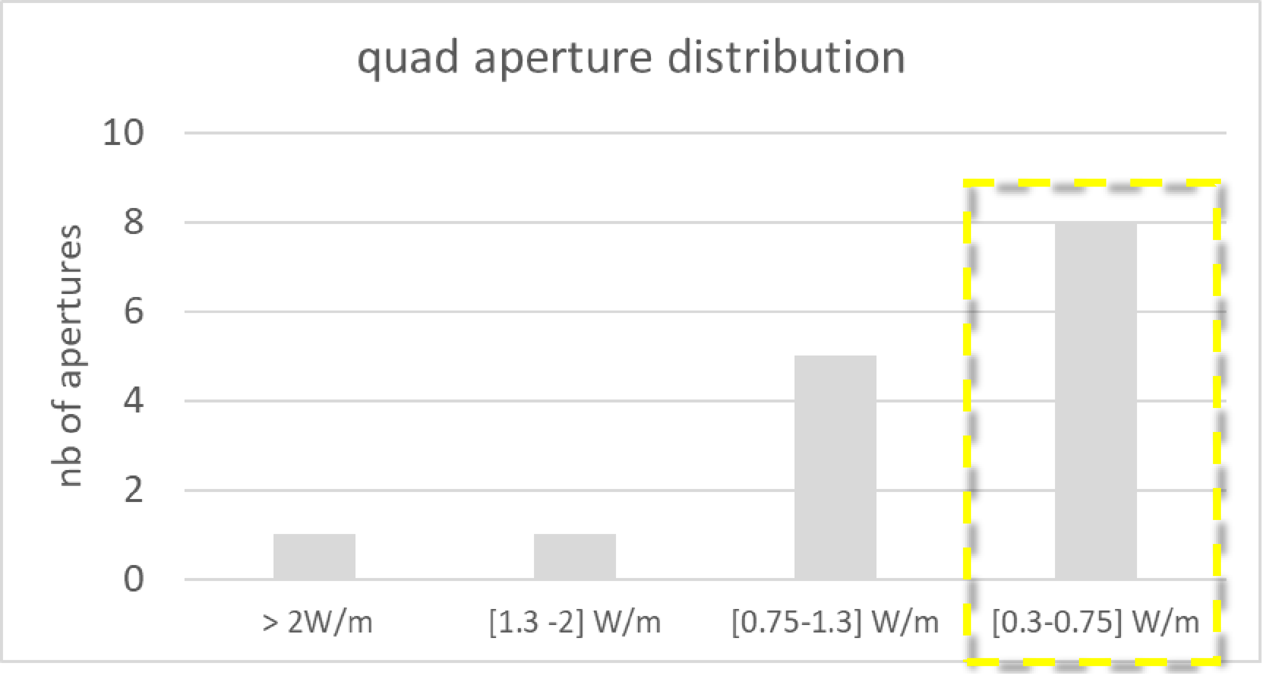
Magnet exchanged since 2017

Statistics on instrumented apertures

- *Expected heat loads for such a fill (#9072, 2023 reference for this talk):*

  - ≈ 0.3 W/m for [SR + IC]

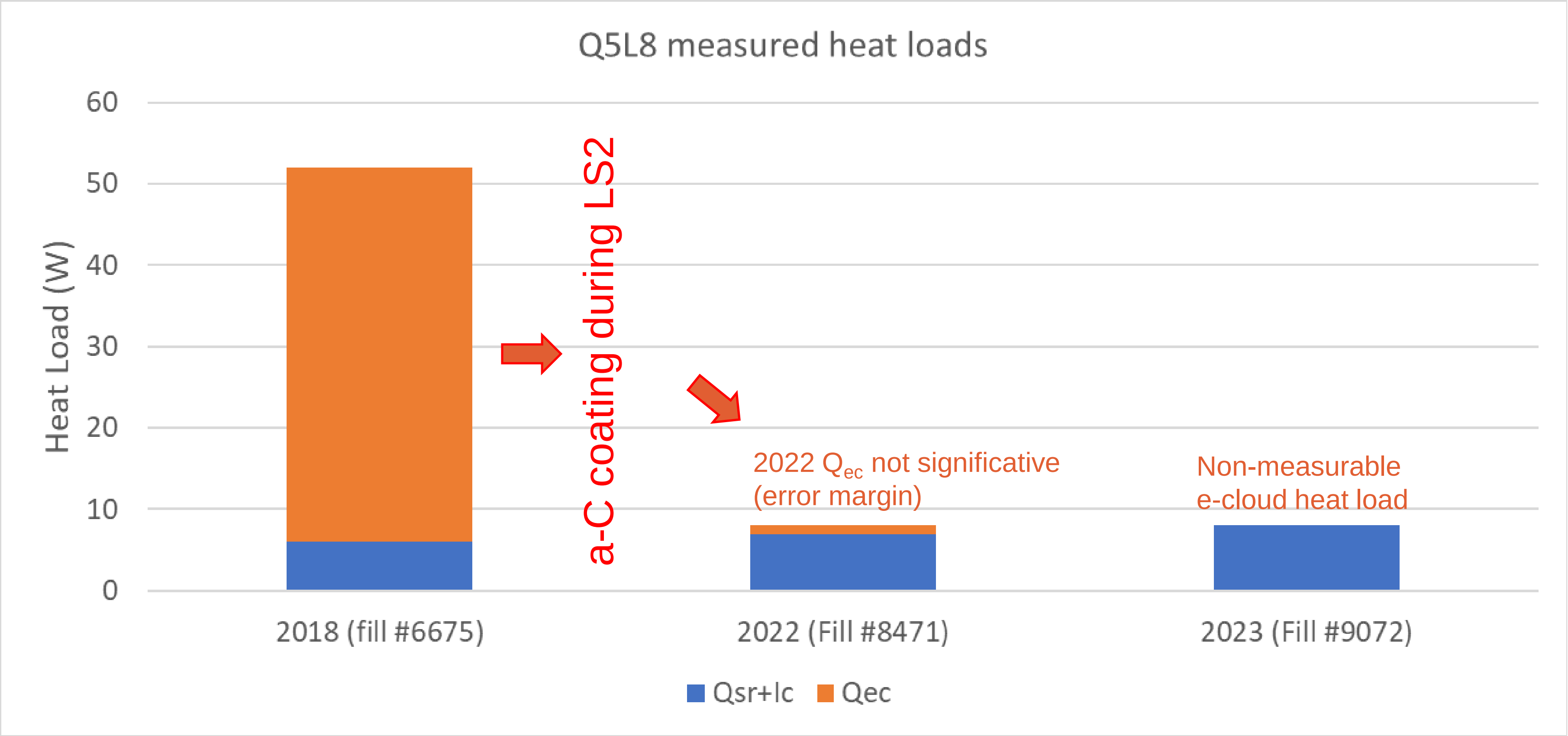




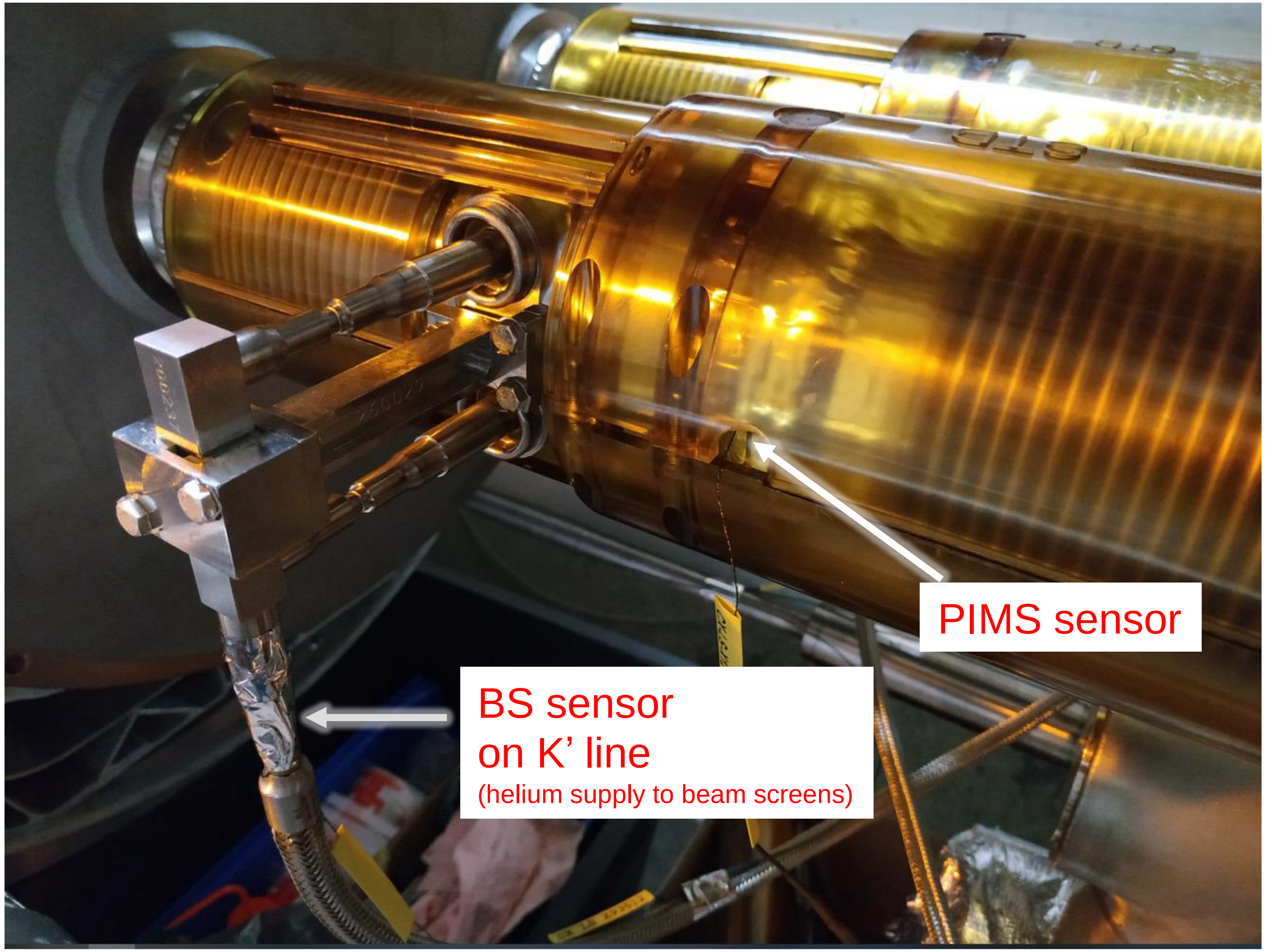
- *Quite important dispersion of the heat loads within the apertures*

Q5L8: carbon coating effect in the machine

- Amorphous carbon coating performed by TE-VSC during LS2 on Q5L8 beam screens
  - No e-cloud heat load observed anymore after the a-C coating
  - Note that a-C coating is different from the forecast coating in the BST project (too long treatment)



PIMS and BS temperature sensors



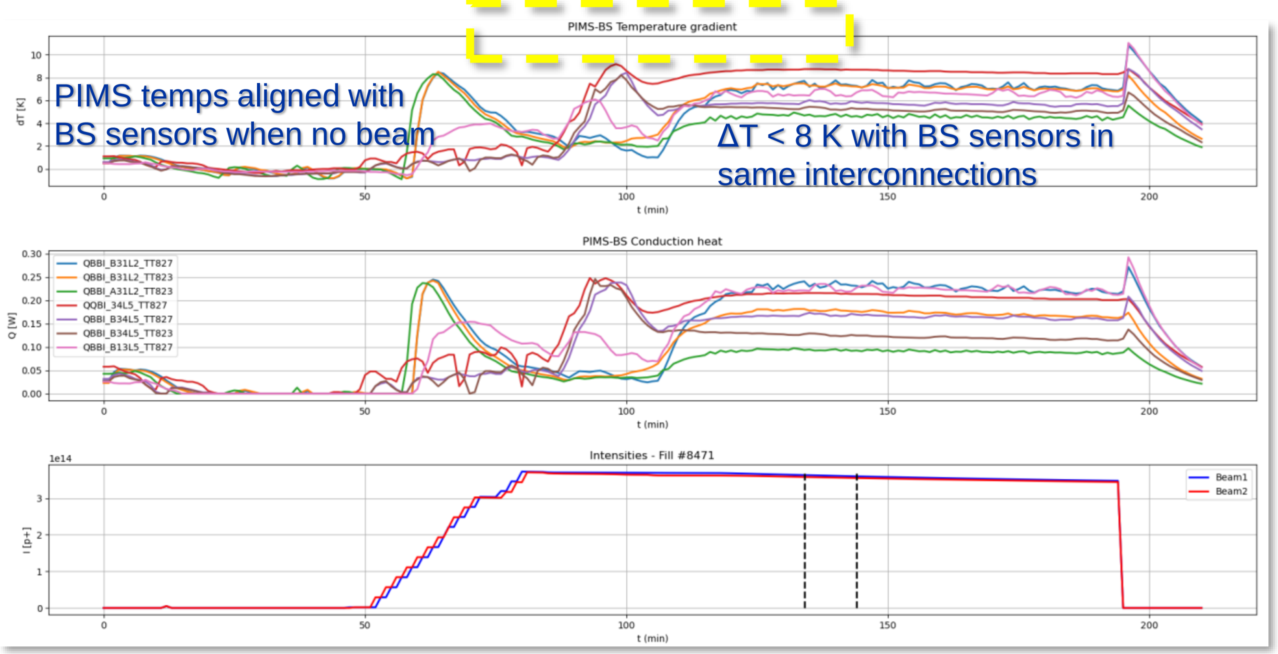
- 7 PIMS are instrumented over the LHC:
  - 3 in 31L2
  - 1 in 13L5
  - 3 in 33L5
- They allow to verify the deposition (or not) of unexpected heat load on the PIMS, and in general in the interconnections

Heat conduction BS-PIMS

Is it normal to observe a ΔT ~ 8 K between BS and PIMS ?

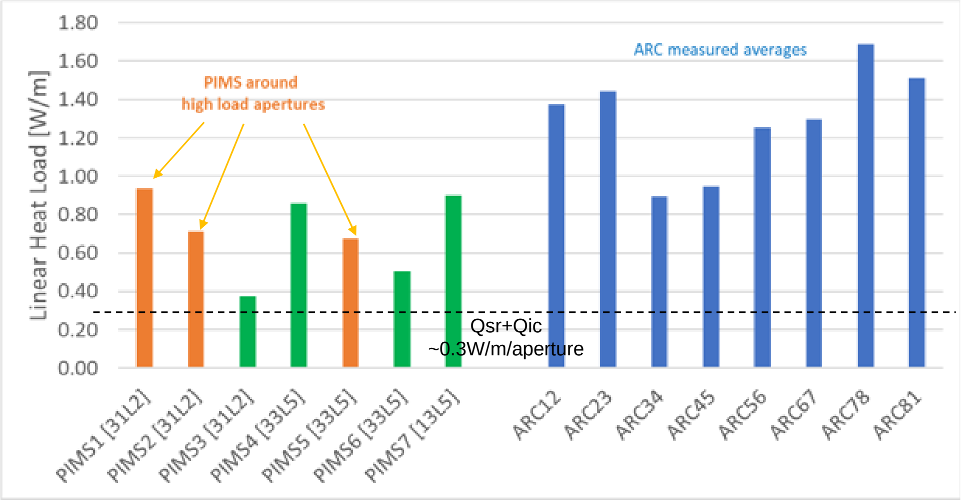
- *PIMS heat load estimation by conduction:* $\dot{Q} = \int_{T_{BS}}^{T_{PIMS}} k(T) \cdot dT \cdot \frac{A}{\Delta x}$
- *k_{SS} (10 K) ~ 0.9 W/m-K*
- *A ~ 12 cm^2 (~ total cross section between PIMS and BS)*
- *dx ~ 5 cm (length between BS active cooling and PIMS sensors)*
- *ΔT ~ 8 K ➔ Q ~ 0.2 W in the PIMS over 25 cm*

➔ Q ~ 0.8 W/m in one PIMS



In Fill #8471 (23.11.2022), 1 hour after stable beams :

- Qsr + Qic = 0.3 W/m/aperture
- Qec in ARC34 =0.6 W/m/aperture in average (lowest sector)
- Observed ΔT is compatible with expectations
- All PIMS temperatures show similar behaviour
- No difference between high & low heat load magnets around



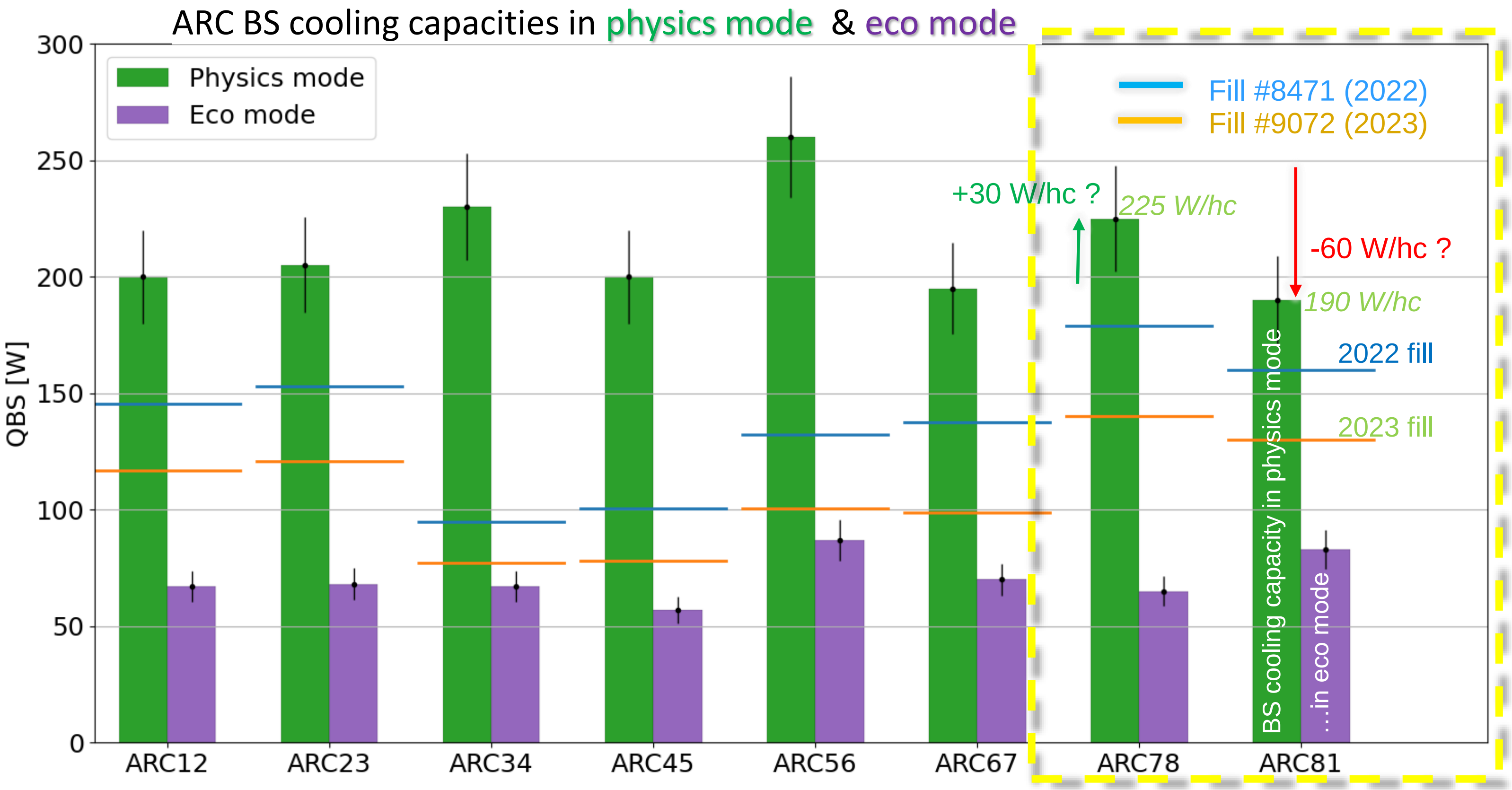
PIMS conduction heat loads obtained in fill #8471 (23.11.2022), compared with the ARC linear heat loads

➢ To explain the additional extra heat loads observed in some apertures around these PIMS (like 1,2 & 5), we should measure a PIMS heat load of ~40 W/m !

➢ The extra heat loads measured in some apertures cannot come exclusively from the PIMS

Cryogenic capacity limitations

- New balancing of refrigerators cooling capacities between S78 and S81 allows to recover margin in S78 (all thermal shields are set on S81 refrigerator to alleviate S78 refrigerator)
  - ➢ Configuration tested at the end of 2022, reconducted in 2023, but new estimated capacities to be tested
  - ➢ *Would require a test of ≈ 1 week to precisely assess the capacities in this cryoplants arrangement*



- More cooling margin in 2023…
- …but not possible to operate in eco mode during proton physics

CONCLUSIONS

- From 2022 to 2023, it was possible to increase the intensity per bunch thanks to the implementation of the hybrid injection scheme, which allowed to significantly reduce the beam screen heat loads by reducing the e-cloud effect.

- Additional instrumentation in 8 selected half-cells allowed to investigate the behaviour of the BS heat loads at the magnet/aperture level. They are well representative of the entire machine, and they reveal large differences across the half-cells and the apertures. Moreover, all recently replaced magnets demonstrate low heat loads.

- a-C coating performed by TE-VSC on Q5L8 during LS2 allowed to reduce on this magnet the e-cloud heat load to a non-measurable level

- Instrumentation of 7 PIMS allowed to verify that extra heat loads measured in some apertures were not induced by these equipment – however, remains marginal.

- Cryoplants re-arrangement in S78&S81 allowed to recover cooling capacity in S78, detrimentally to S81
  - To accurately re-assess the available cooling capacities in those 2 sectors, 1-week test is needed

➢ Ready for next year run towards higher beam intensity and matching the cryogenic capacities!

THANK YOU
FOR YOUR ATTENTION

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