Review of filling schemes for the HL-LHC

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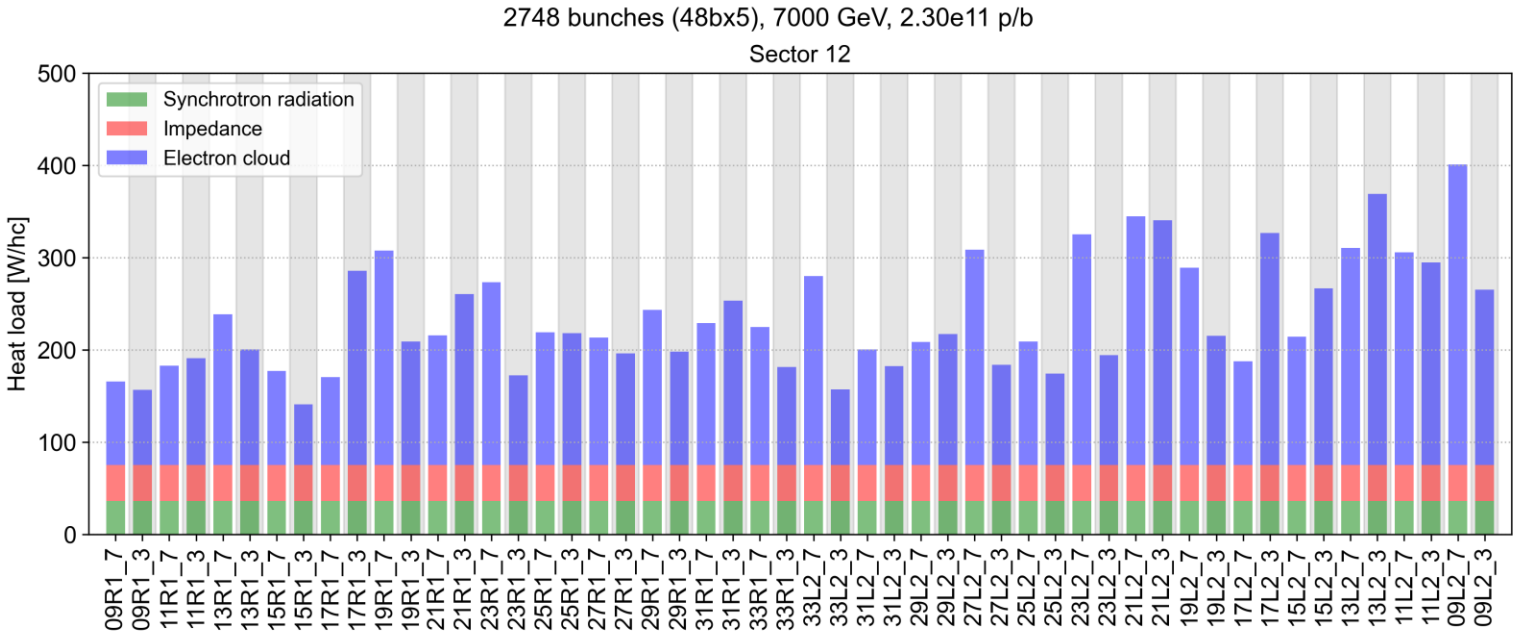
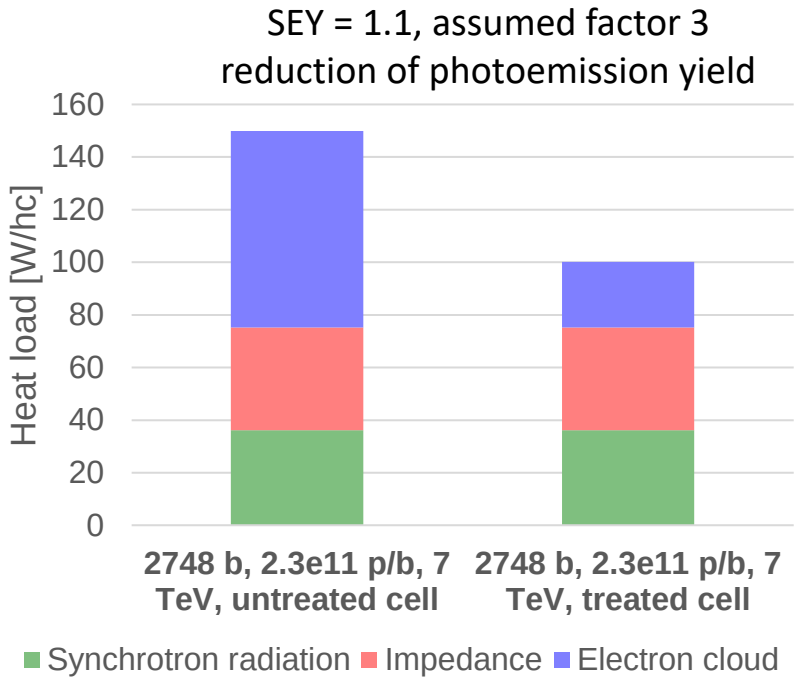
HiLumi WP2 Meeting
2 July 2024

Recap: heat load estimates for Run 4

- The heat load predictions for Run 4 are based on:
  - Estimate of cell-by-cell heat loads with 2.3e11 p/b for 2748 bunches without BST
  - Estimate of half-cell heat load after BST

→ Used as input for half-cell selection and cryo margin estimates
  - Margin needed for uncertainty in estimates and room for possible degradation (in untreated cells only)

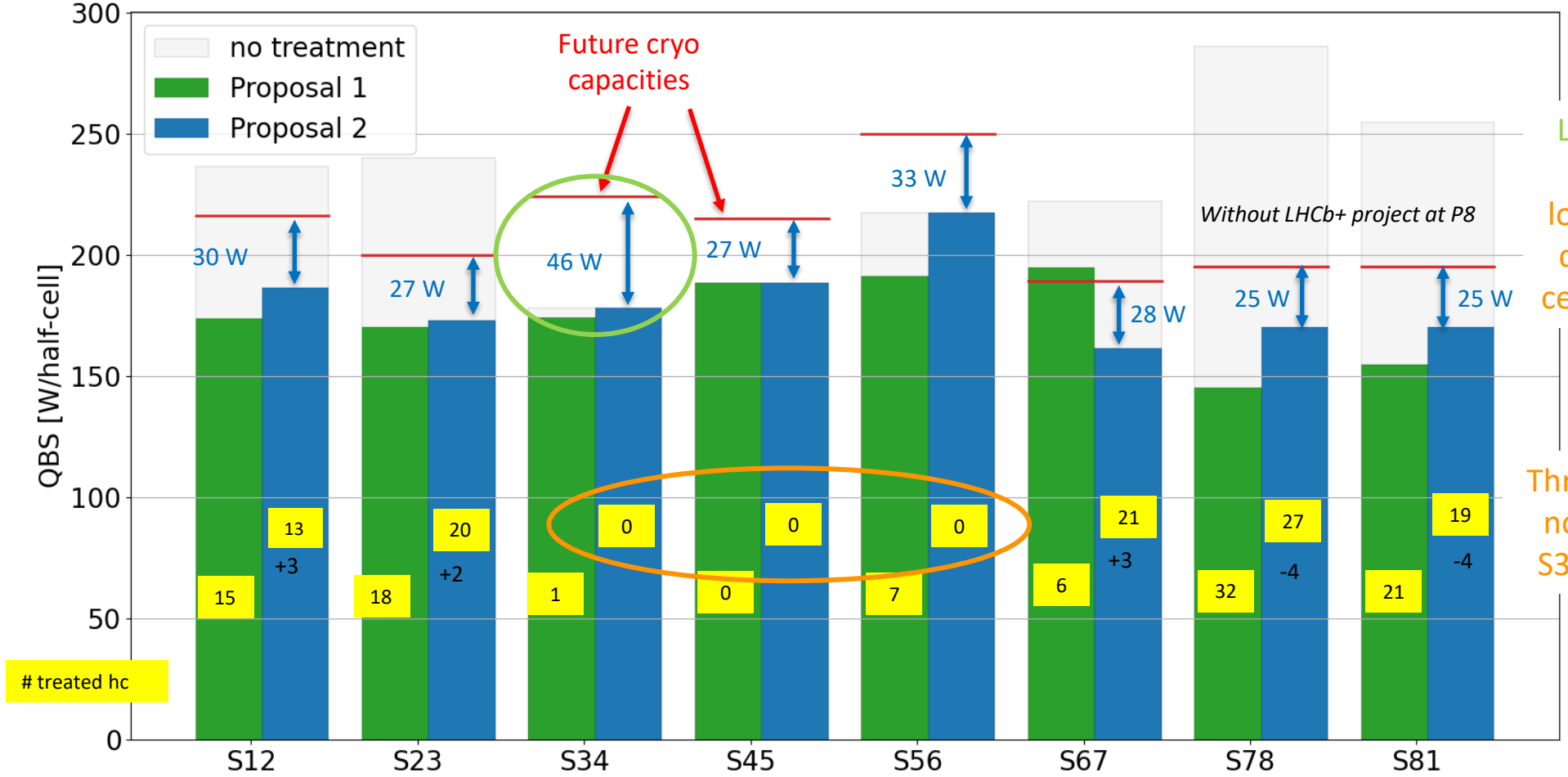




Recap: first half-cell selection & heat load margin

First proposed half-cell selection, optimised to gain similar heat load margin in all sectors

- **Proposal 1** (top 100 cells): S67 heat loads above the cryo capacity limits
- **Proposal 2** (optimised): > 25 W/half-cell of margin in each sector (~10-15%)



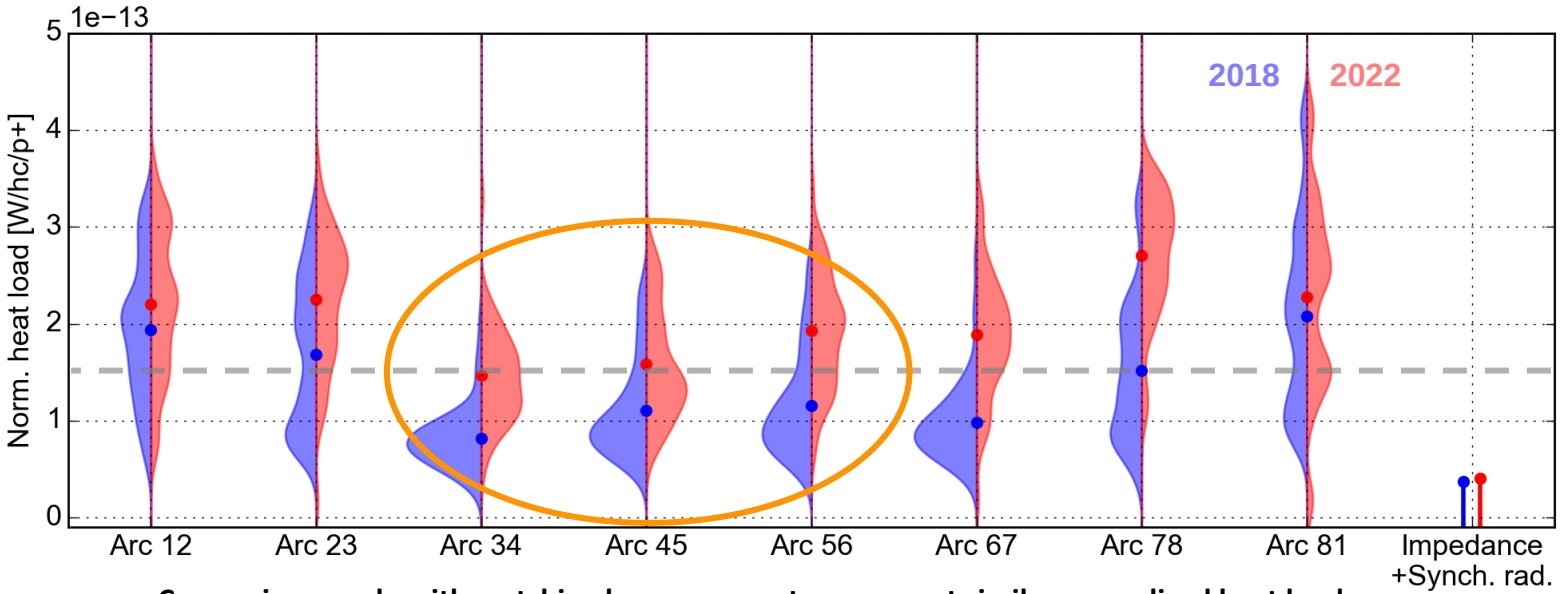
Larger heat load margin in S34: lowest margin for degradation per cell in S45 and S56

Three sectors with no treated cells: S34, S45 and S56

B. Bradu, First proposal of half-cells to be treated, Beam-induced heat load task force meeting, Sep 2023

Heat load distribution in untreated sectors

- The average heat load in these sectors in Run 3 is similar to that of S78 in Run 2

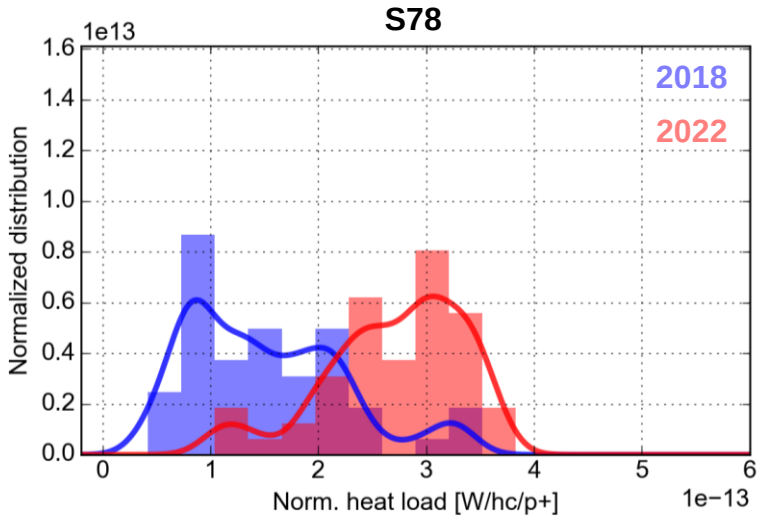


Comparison made with matching beam parameters – expect similar normalised heat load

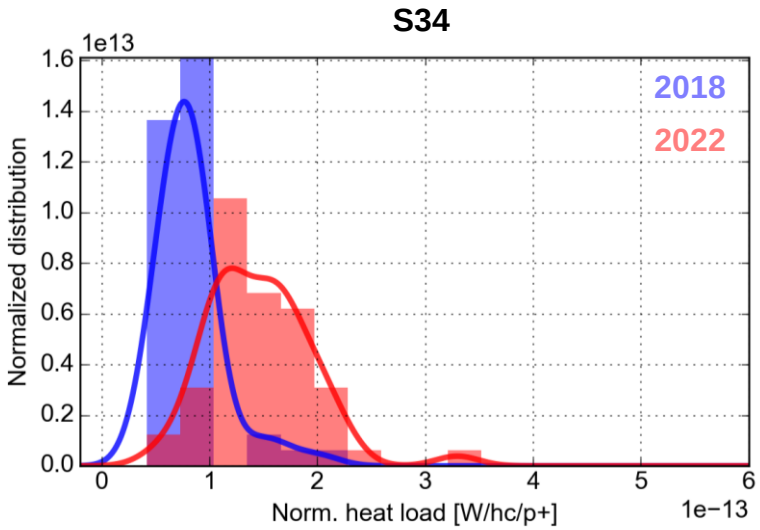
Fill	7252	8484
Started on	03 Oct 2018 01:41	25 Nov 2022 06:56
T_sample [h]	1.40	7.70
Energy [GeV]	6499	6799
N_bunches (B1/B2)	2556/2556	2462/2462
Intensity (B1/B2) [p]	2.82e14/2.85e14	2.65e14/2.75e14
Bun.len. (B1/B2) [ns]	1.09/1.12	1.13/1.13
H.L. exp. imped. [W]	8.89	8.14
H.L. exp. synrad [W]	12.07	13.76
H.L. exp. imp.+SR [W/p+]	3.70e-14	4.06e-14
T_nobeam [h]	0.20	0.20

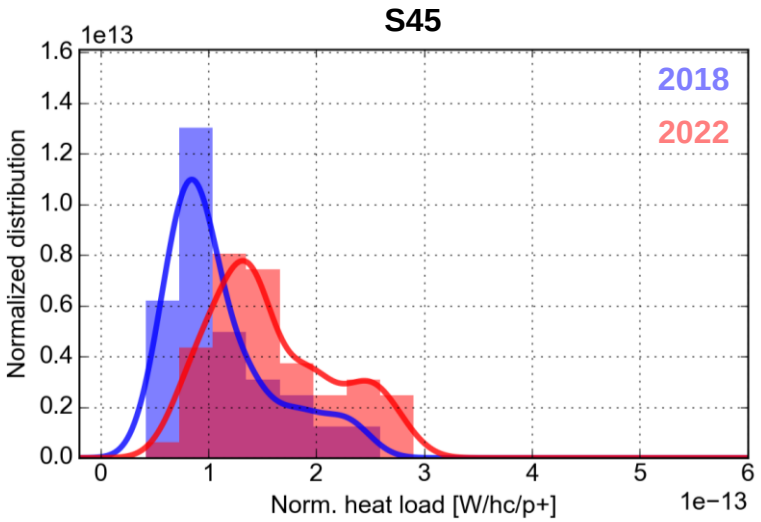
Heat load distribution in untreated sectors

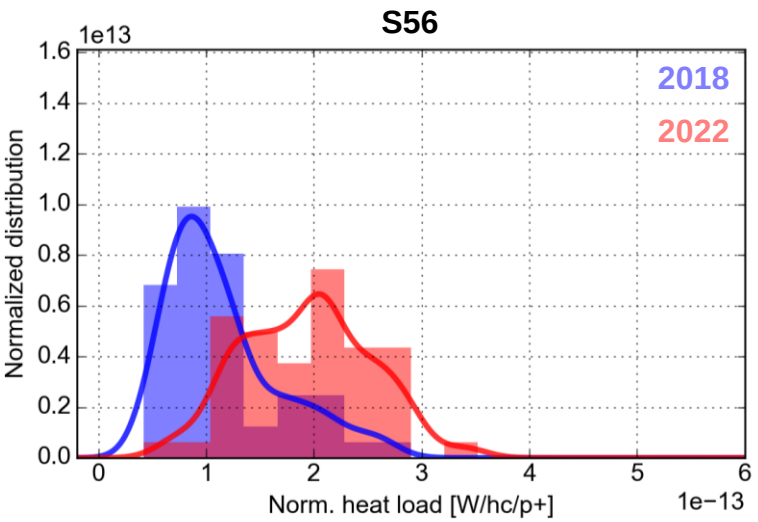
- Their cell-by-cell heat load distribution is also not that different from the one of S78 in Run 2



It is plausible that these sectors could degrade to a similar extent as S78 after LS2







Recap: achievable performance for HL-LHC

- We can consider possible scenarios where S56 or S45 degrade to the current level of S78
  - Both cases would imply a similar or smaller degradation than S78 underwent in LS2
  - Due to the higher cryo capacity, the performance limitation is less severe than from S78 without treatment
- The 8b+4e beam is always a fall-back solution in case of severe further degradation
  - Compatible with degradation of full sector to level of worst half-cells today

Scenario	Beam	N bunches	8b+4e	BST	LS3 degradation	Int. lumi/day [fb^{-1}]	
Baseline	5x48b	2748	-	Yes	No	3.4	ref
Degraded S56	Hybrid	2590	17%	Yes	Yes	3.2	-6%
Degraded S45	Hybrid	2460	32%	Yes	Yes	3	-12%
No BST	Hybrid	2320	47%	No	No	2.8	-18%
Worst case	8b+4e	1972	100%	No/Yes	Yes	2.4	-30%

Rough luminosity estimates with LPC calculator, assuming μ=130, n_b=2.3 x 10^{11} p, L_{lev}= < 5e-34 cm^{-2} s^{-1}

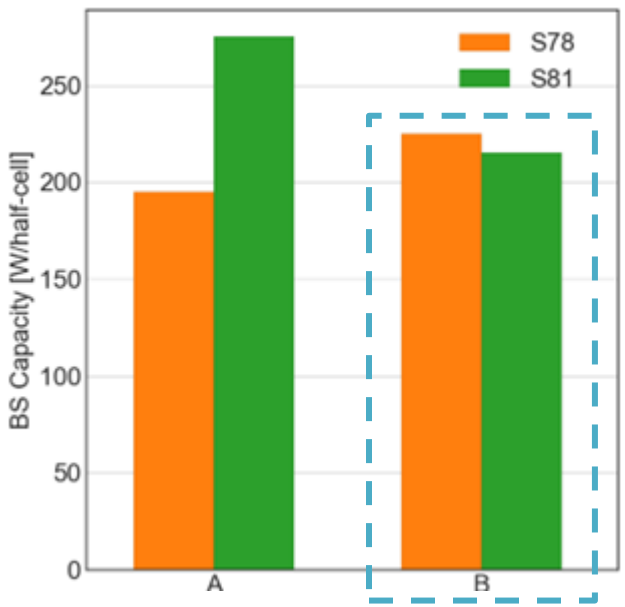
Half-cell selection for beam screen treatment

- Many iterations on half-cell selection between the HL-LHC annual meeting 2023 and now
  - Subsequent selections had improved margins thanks to assumed increase in cryo capacity in some sectors (including "S78-optimised" mode in P8) and rebalancing the number of treated cells between sectors

P8 "**Physics mode**" vs "**Optimized for S78**"

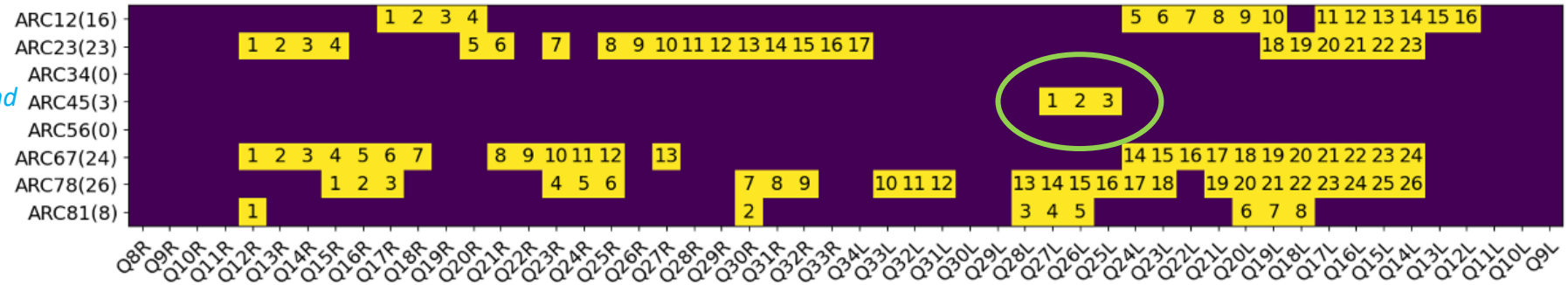
- Degrades the S81 capacity

[Capacities are estimated for this configuration and should be measured/validated in Feb 2024]



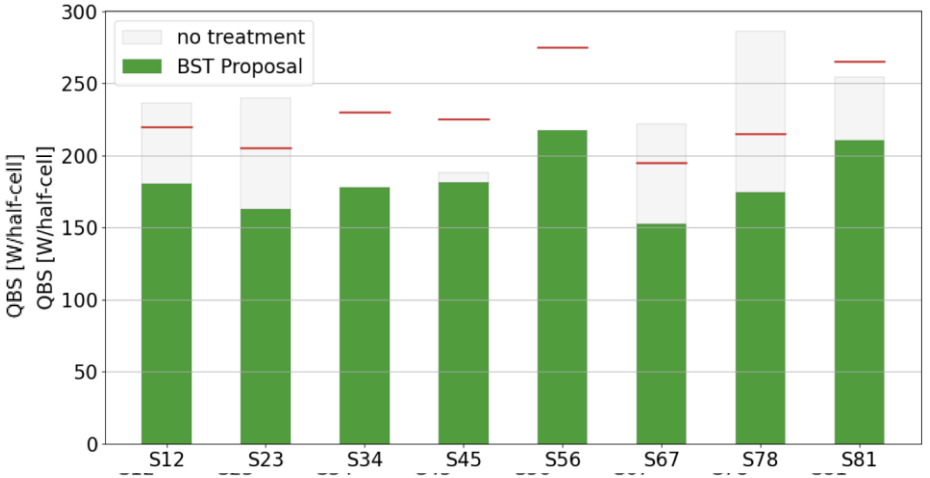
S78 & S81 capacities for the different configurations

Reminder about the #100 hc selected scenario for BST (baseline)



- 120 IC to be opened
- Sector margins
  - [40. 42. 52. 44. 58. 42. 41. 55.]
-

Latest selection before cryo capacity revisions (after cryo tests)



Impact on achievable performance

- Most of these updates were never presented to WP2
  - Only the impact of the S78 optimised mode in P8 (later found unviable) was discussed before Chamonix in January

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Worst case	8b+4e	1972	100%	No/Yes	Yes	2.4	-30%

LS2 degradation of S78 was ~80%

With optimized P8 cryo configuration

Rough luminosity estimates with LPC calculator, assuming μ=130, n_b=2.3 x 10^{11} p, L_{lev}= < 5e-34 cm^{-2} s^{-1}

Half-cell selection for beam screen treatment

- The most recent iteration is due to the revision of cryo capacities after lower-than-expected capacity in S78 in 2024

- S12 : 220
- S23: 205 ➔ 190
- S34: 230
- S45: 225
- S56: 275 ➔ 250
- S67: 195
- S78: 210 ➔ 180
- S81: 265 ➔ 250

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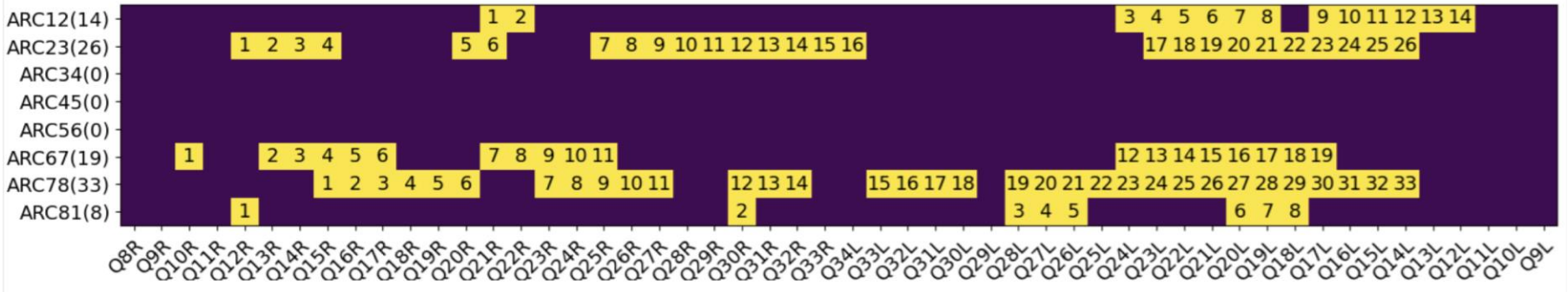
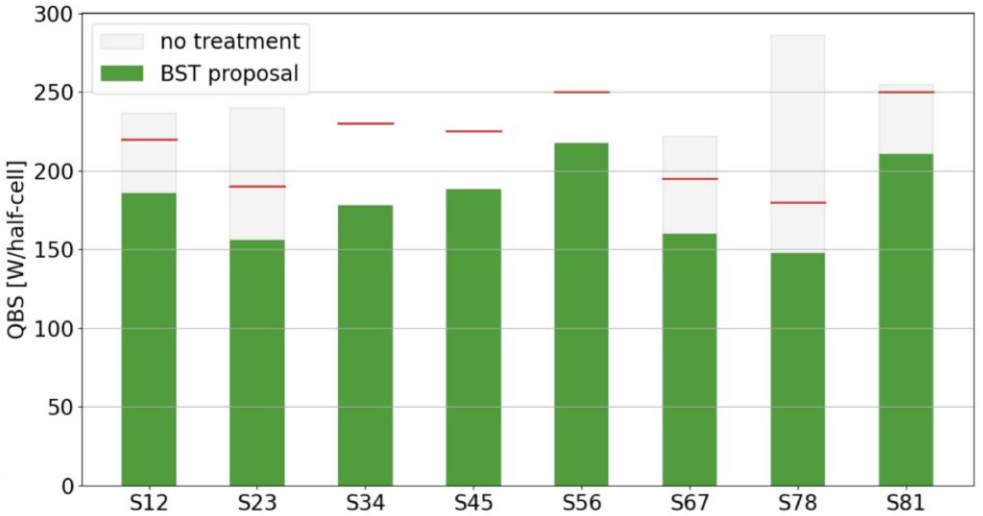
Revised scenario for #100 hc – New Baseline for BST



- Still 120 IC to be opened
- No major changes (only few hc changed)
- No more treated hc in S45
- Sector margins with revised scenario :
  - [34. 34. 52. 37. 33. 35. 32. 40.]



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Impact on achievable performance

- Because most of the improved updates were not presented here, the impact of the capacity reductions compared to previously presented estimates is minimal
  - Only the predicted performance without BST is impacted, emphasising the importance on the project

Scenario	Beam	N bunches	8b+4e	BST	LS3 degradation	Int. lumi/day [fb^{-1}]	
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With reduced cryo capacities

Heat load margins after half-cell treatment

- Although the capacity revision has no impact on the possible degradation scenarios, it implies less margin overall
  - And, in particular, less margin per half-cell in the lower-capacity untreated sectors (S45 and S56)
  - → Increased likelihood of limitations from heat load

Previous baseline scenario

	S12	S23	S34	S45	S56	S67	S78	S81
Number of half-cells	16	23	0	3	0	24	26	8
Margin per half-cell	40	42	52	44	58	42	41	55
Margin per untreated half-cell	58	75	52	**47**	**58**	78	82	65

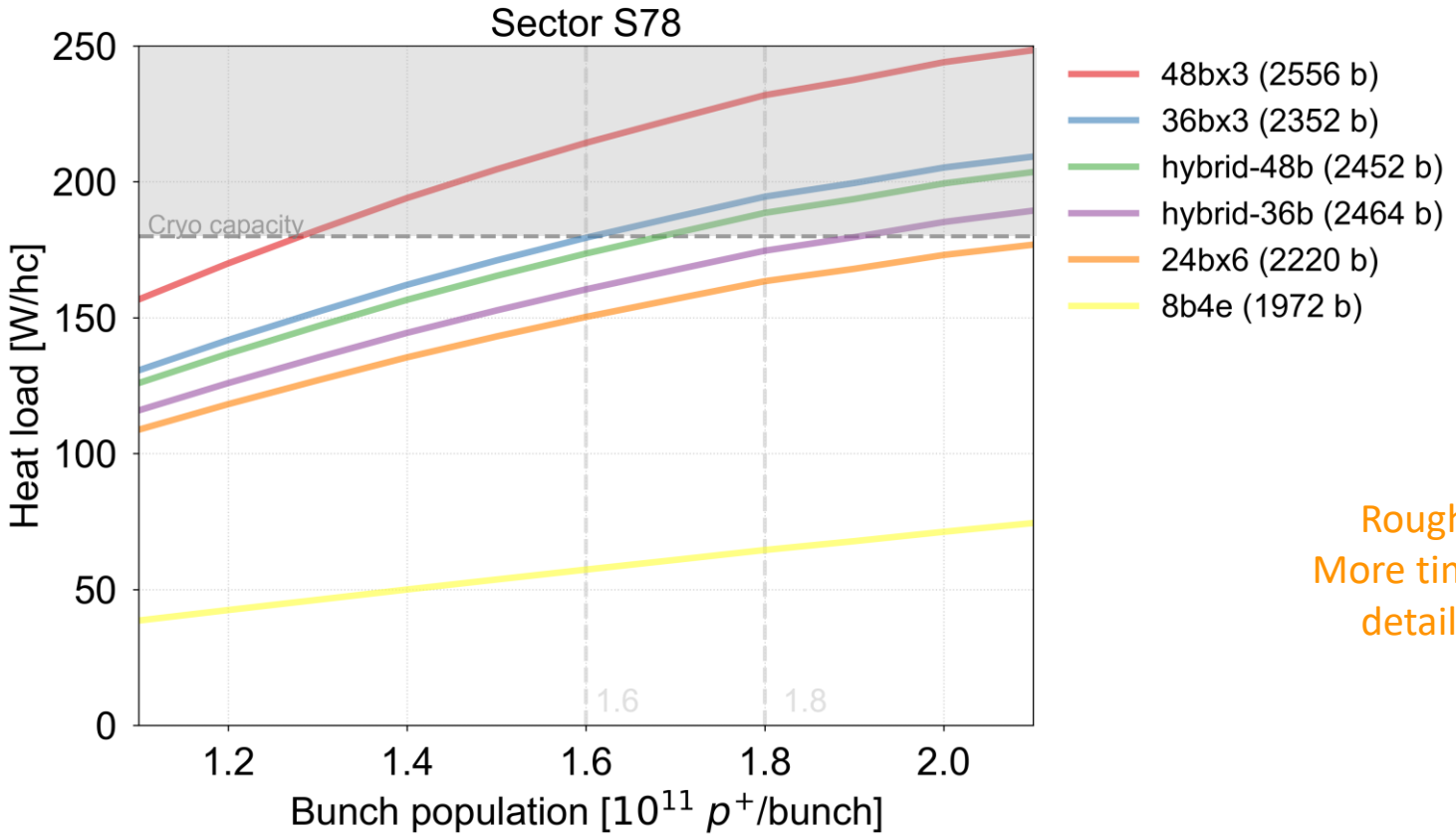
Current baseline scenario

	S12	S23	S34	S45	S56	S67	S78	S81
Number of half-cells	14	26	0	0	0	19	33	8
Margin per half-cell	34	34	52	37	33	35	32	40
Margin per untreated half-cell	47	68	52	**37**	**33**	55	88	47

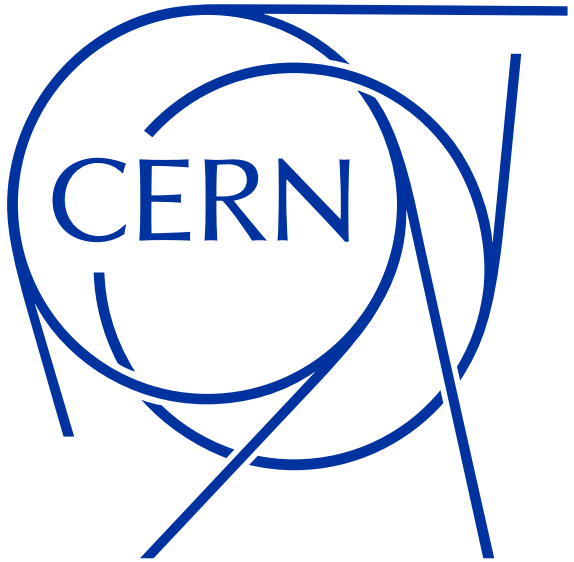
Return to a similar situation as with the first optimised half-cell selection

Run 3 filling schemes

- At 1.6e11 ppb, the number of bunches could be increased by about 5% with the hybrid schemes
  - Not clear if this would translate into a similar increase in integrated luminosity due to: longer SPS flat bottom, emittance imbalance, injection losses? …
- At 1.8e11 ppb, the hybrid brings a larger benefit, around 10%, compared to 6x24b which could be a 25 ns option



Rough estimates
More time needed for detailed analysis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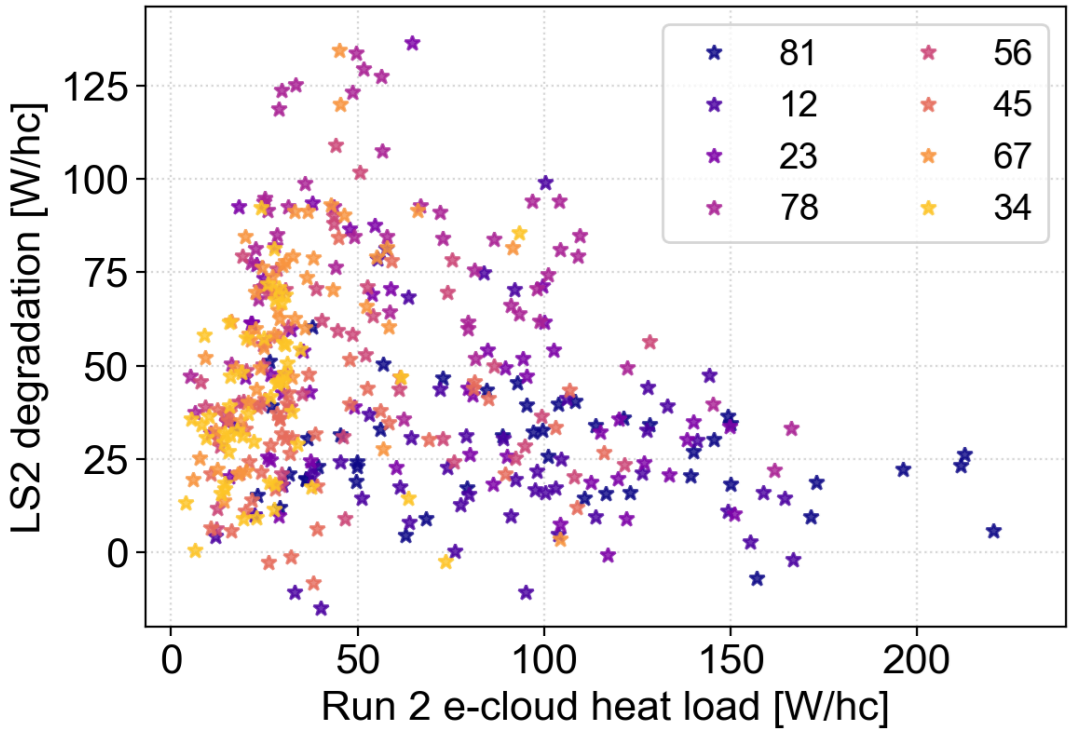
Estimate of degradation in LS2

- While we cannot predict the amount of degradation in LS3, we can estimate the degradation in LS2
  - High heat load cells degraded less than cells with lower initial heat load
    - BST, affecting the highest heat load cells, does not significantly reduce the potential for degradation

LS degradation refers to the difference between 2018 and end 2022,

A better estimate can be achieved in 2024



All heat loads are normalised to the beam parameters of a typical 2018 fill

Estimate of degradation in LS2

- While we cannot predict the amount of degradation in LS3, we can estimate the degradation in LS2
  - High heat load cells degraded less than cells with lower initial heat load
    - BST, affecting the highest heat load cells, does not significantly reduce the potential for degradation
  - If we assume a similar amount of degradation for non-treated cells in LS3 as in LS2, the treated cells roughly balance out the additional degradation in other cells to reach a similar overall level of degradation on average
    - But the resulting cryo limitations depend strongly on which cells/sectors degrade, which we cannot predict

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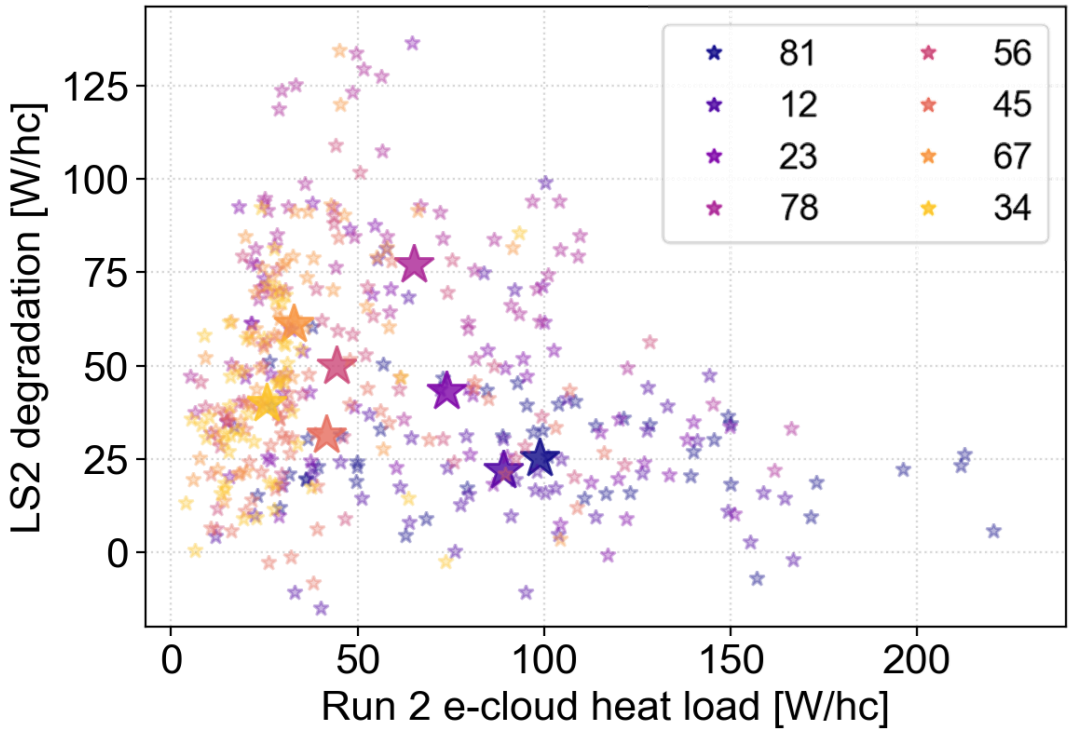
A better estimate can be achieved in 2024



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