Electron cloud in 2016: cloudy or clear?

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Acknowledgements:

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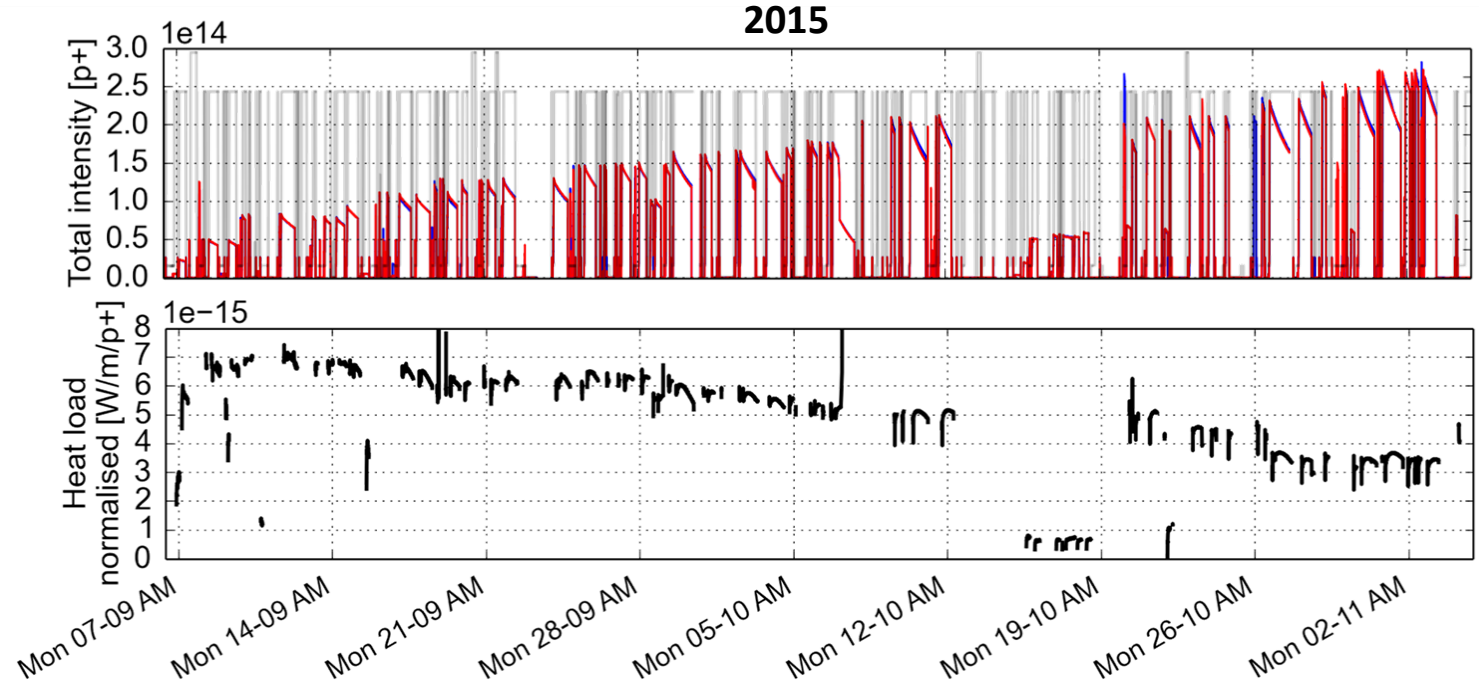
Outline

- Introduction
- Intensity ramp-up
  - Scrubbing
  - Recovering 2015 conditions
- Conditioning during physics 2016
  - Heat load evolution
  - Reference fills
  - Electron dose
  - SEY estimate
- E-cloud studies in 2016
  - Higher beam screen temperature
  - Hybrid filling scheme
- Summary
- Outlook

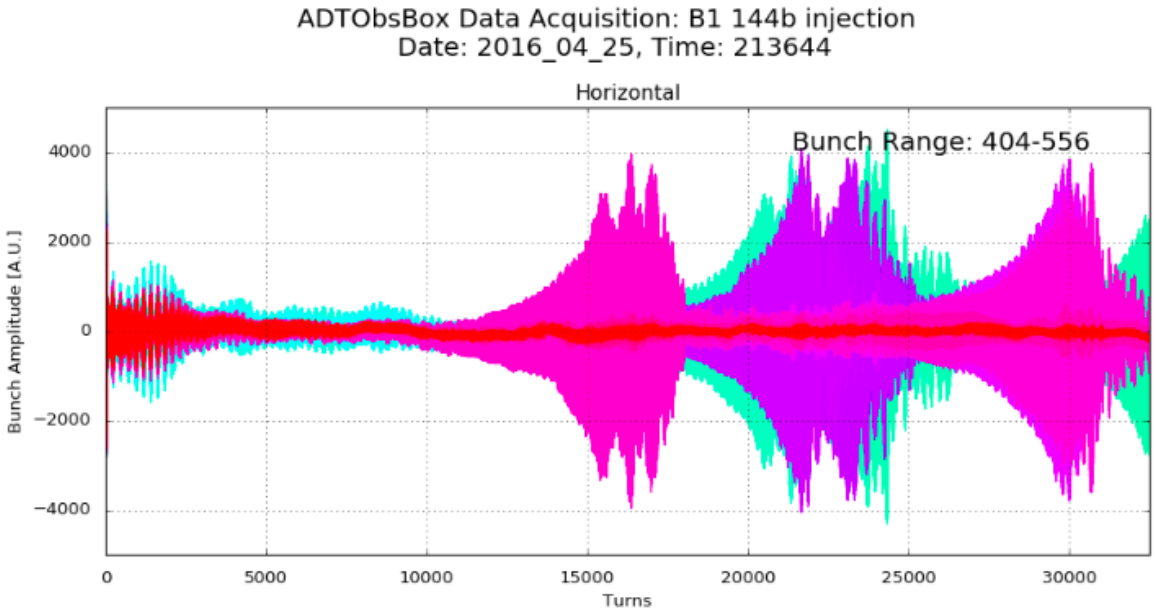
Introduction

- In 2015, first operation at 6.5 TeV with 25 ns beam, and e-cloud
  - Heat load induced by electron cloud limited the intensity that could be stored
  - Conditioning was observed throughout the year, but full e-cloud suppression did not occur
- Prospects for 2016
  - Since the arcs were kept under vacuum over the YETS 2015, the situation at the end of 2015 was expected to quickly be recovered after start-up in 2016
  - Continued conditioning during operation 2016



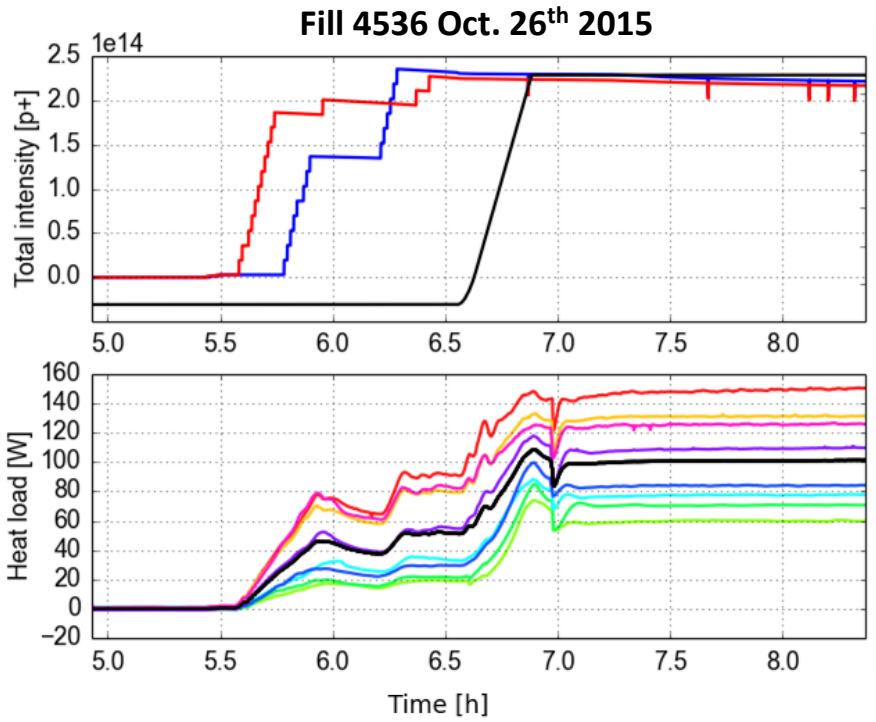
Scrubbing

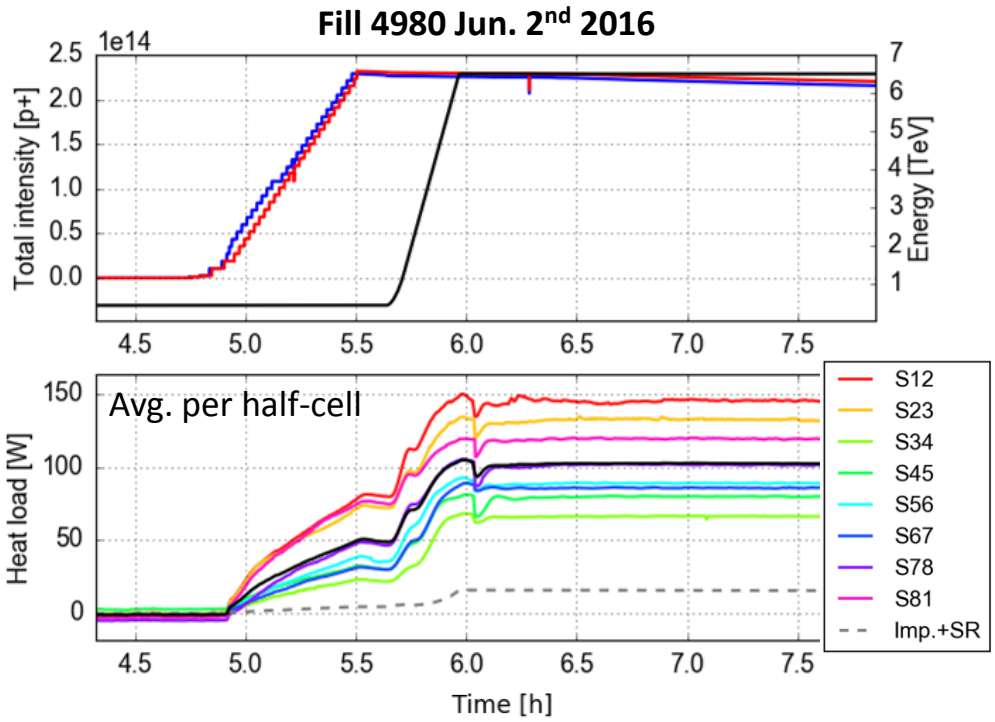
- Initially clear signs of deconditioning wrt end 2015
  - Instabilities at injection, larger heat load and stable phase shift
- 4 days of scrubbing allocated → only 1 day realised, due to SPS TIDVG vacuum issue
  - Sufficient to recondition machine: up to ~1800 bunches/beam with 216 bpi
  - Injections with 288 bunches were not used
- Generally less problems than during 2015 operation
  - New feed-forward effectively limited cryogenics problems at injection
  - E-cloud tunes and settings were used from the beginning → good lifetimes
  - Pressure rise in MKI's still occasionally a limitation



2015 condition recovered

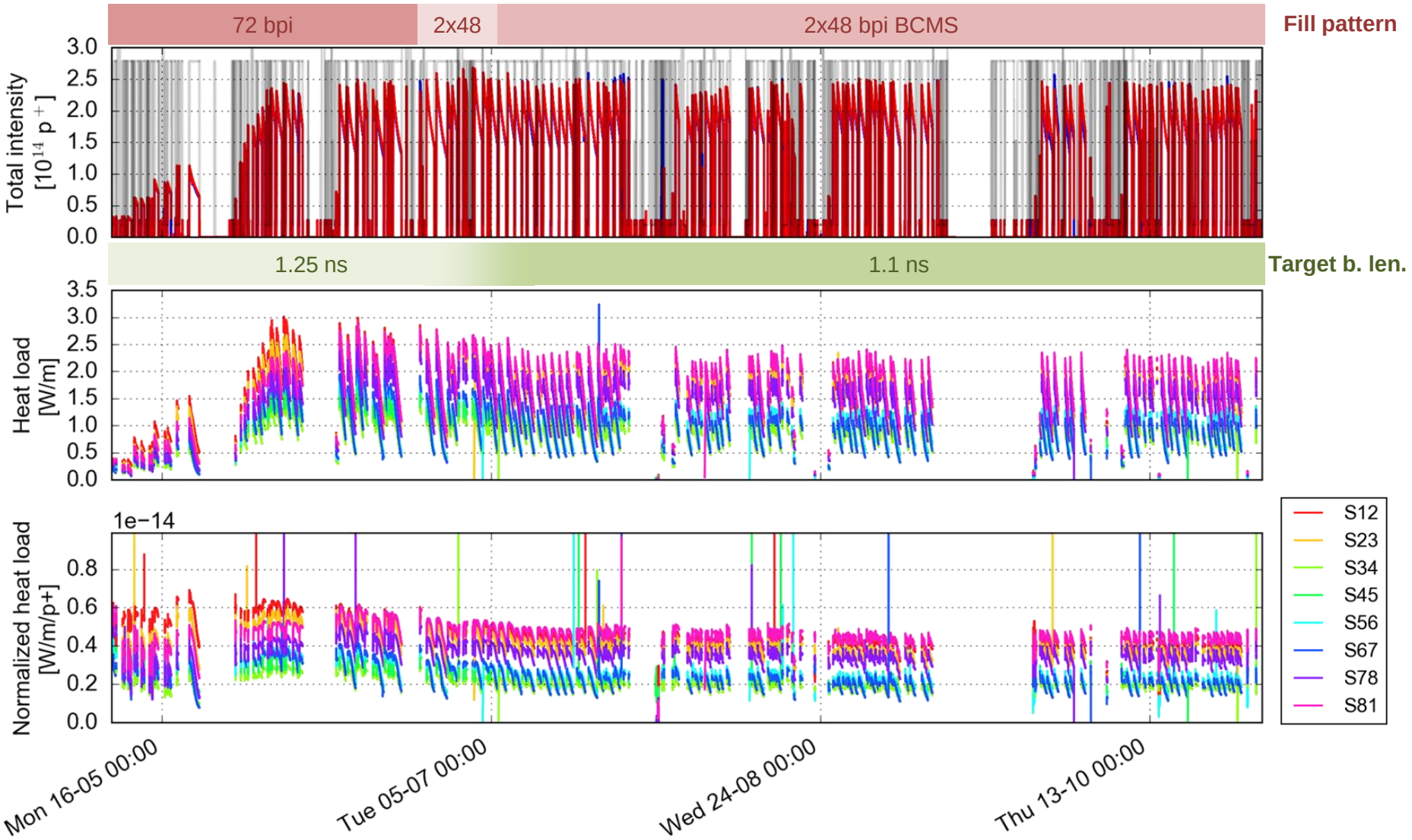
- After the intensity ramp-up, the conditions at the end of 2015 were fully recovered
  - Very similar arc heat loads
  - Difference between sectors remains basically the same as in 2015
- Heat loads much larger than expected from impedance and synchrotron radiation
  → dominant contribution from e-cloud





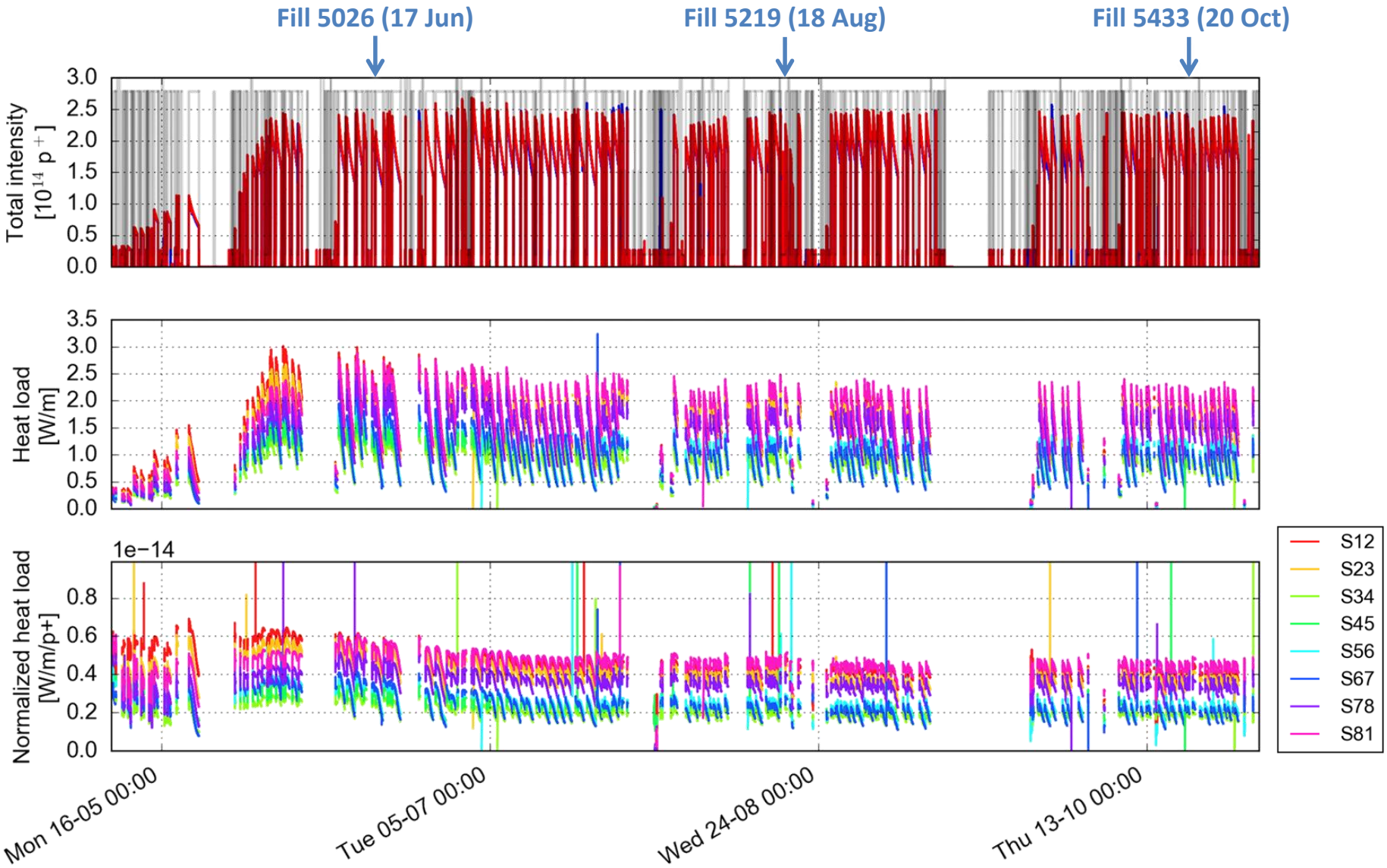
Arc heat load evolution in 2016

- Slightly decreasing trend observable, but difficult to disentangle from changed settings: bunch intensity, filling pattern, bunch length



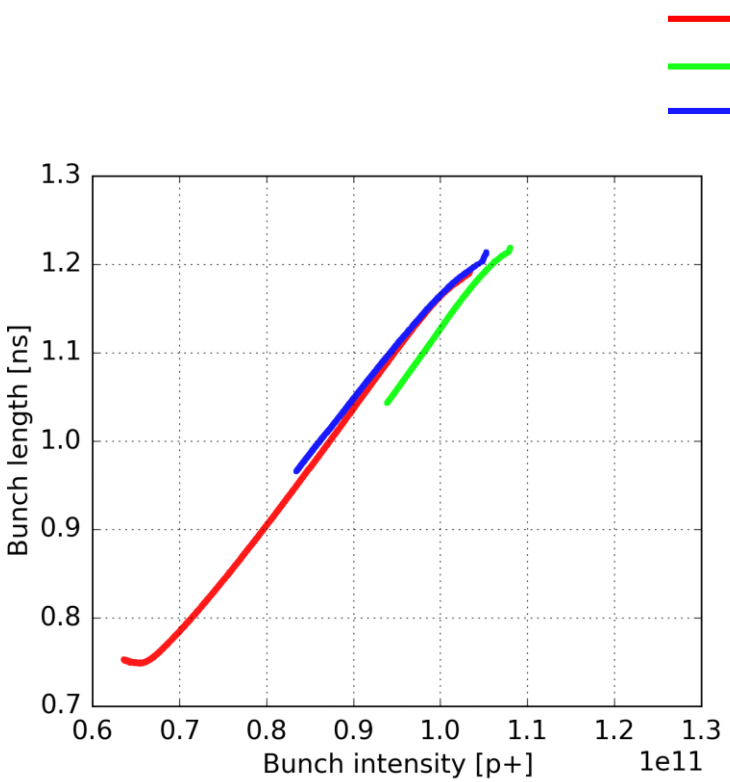
Arc heat load evolution in 2016

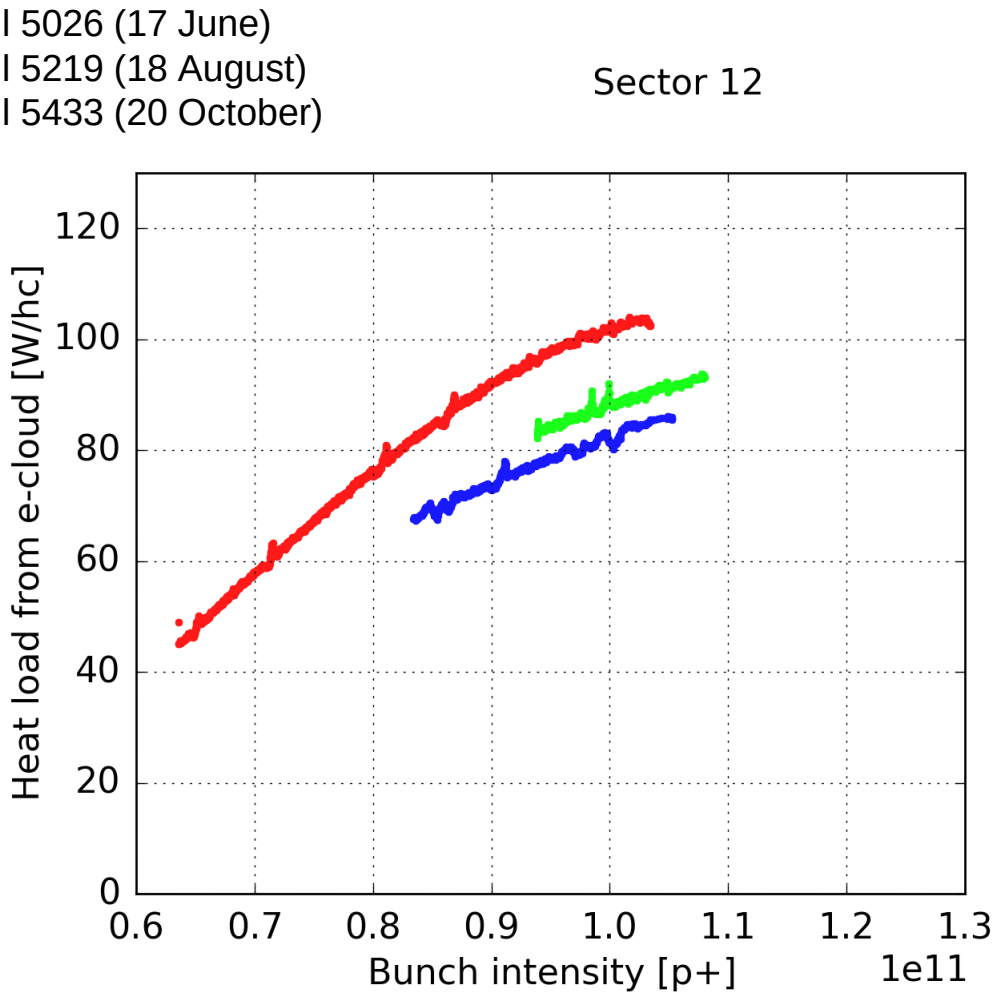
- To evaluate conditioning, performed reference fills with very similar beam parameters



Reference fills

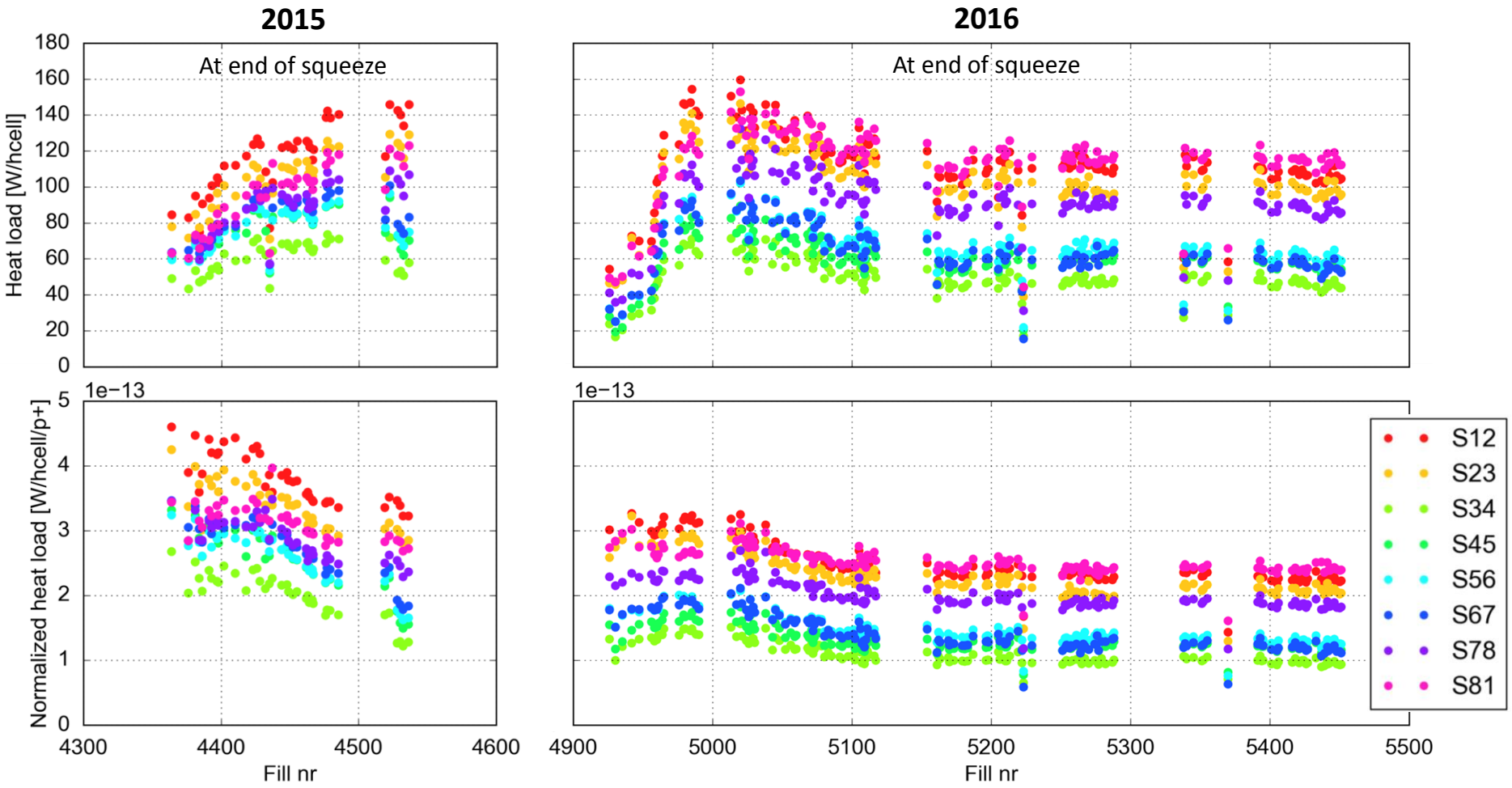
- A reduction of the heat load from e-cloud at 6.5 TeV is observed in all sectors





Arc heat load evolution 2015-2016

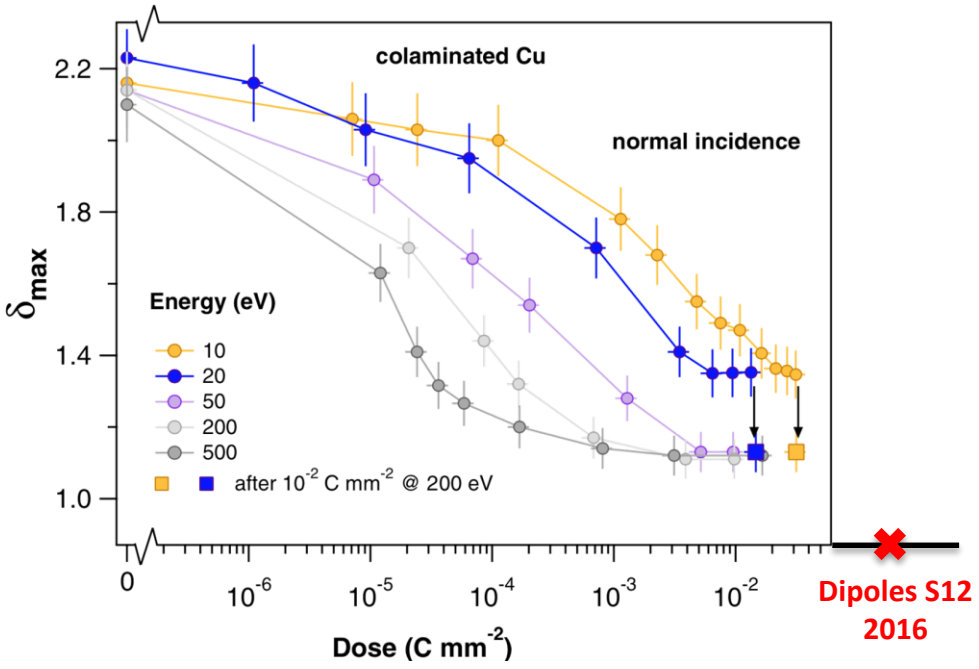
- Normalized heat load reduced by ~30% over 2 months in 2015
  ~20% over 6 months in 2016
- In 2016, a larger reduction in all sectors during the first 2 months, than the last 4 months
  - No apparent correlation between change of slope and settings



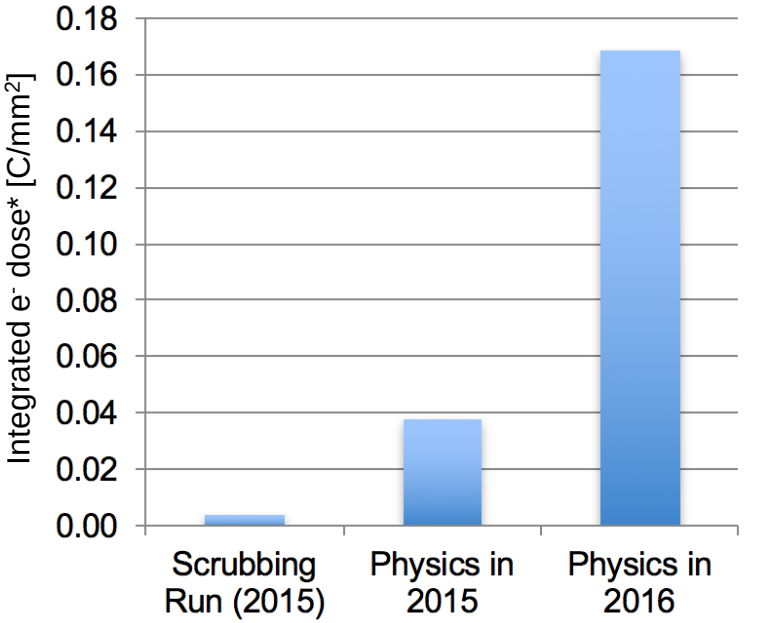
Electron dose

- In lab experiments, scrubbing becomes exponentially slower while reducing the SEY
- The accumulated electron dose in the LHC arcs can be estimated from the integrated heat load, using the electron energy spectrum from PyECLOUD simulations
- Counting only electrons with $E_{impact} > 50$ eV, the estimated electron dose in the arc dipoles during 2016 is at least 20 times larger than the dose needed in the lab for full e-cloud suppression

  → Conditioning appears slower in the machine



R. Cimino, V. Baglin et al., " Phys. Rev. Lett., Aug 2012

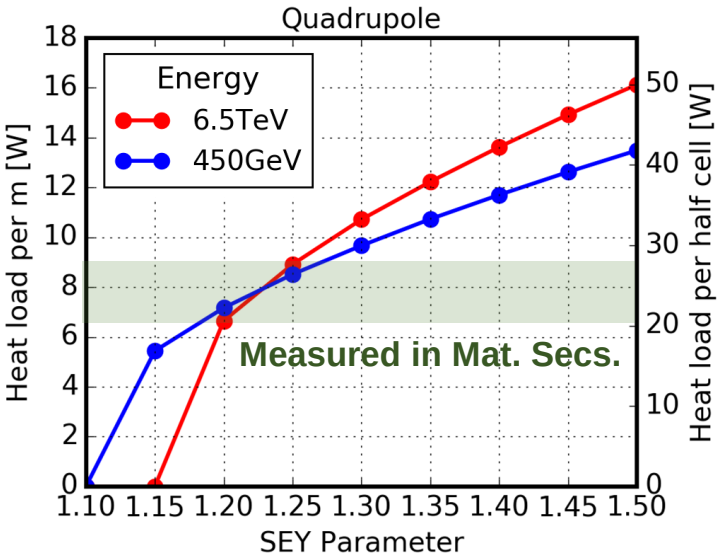


*Electrons with energy lower than 50 eV are not considered

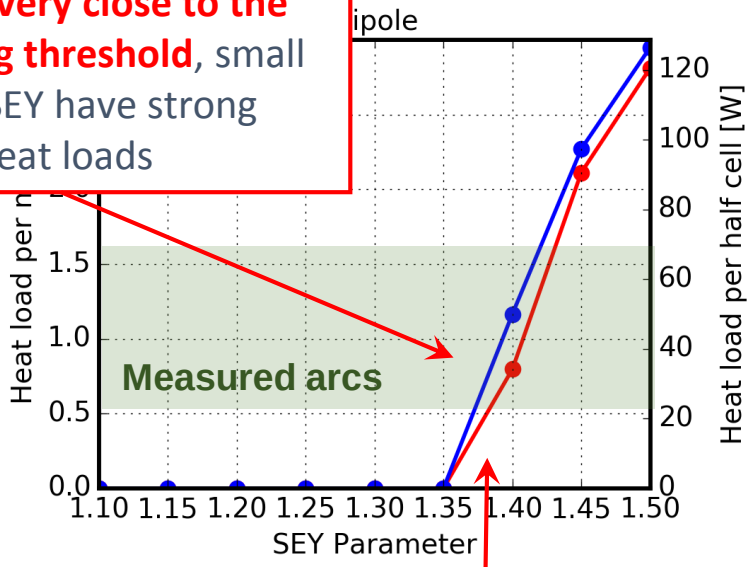
SEY reconstruction

- PyECLOUD simulations performed with measured bunch-by-bunch parameters to reconstruct the SEY of the chambers

  → Less straightforward than in the past since the assumption that dipole heat loads are largely dominant cannot be made anymore



Dipoles are **very close to the multipacting threshold**, small changes in SEY have strong impact on heat loads

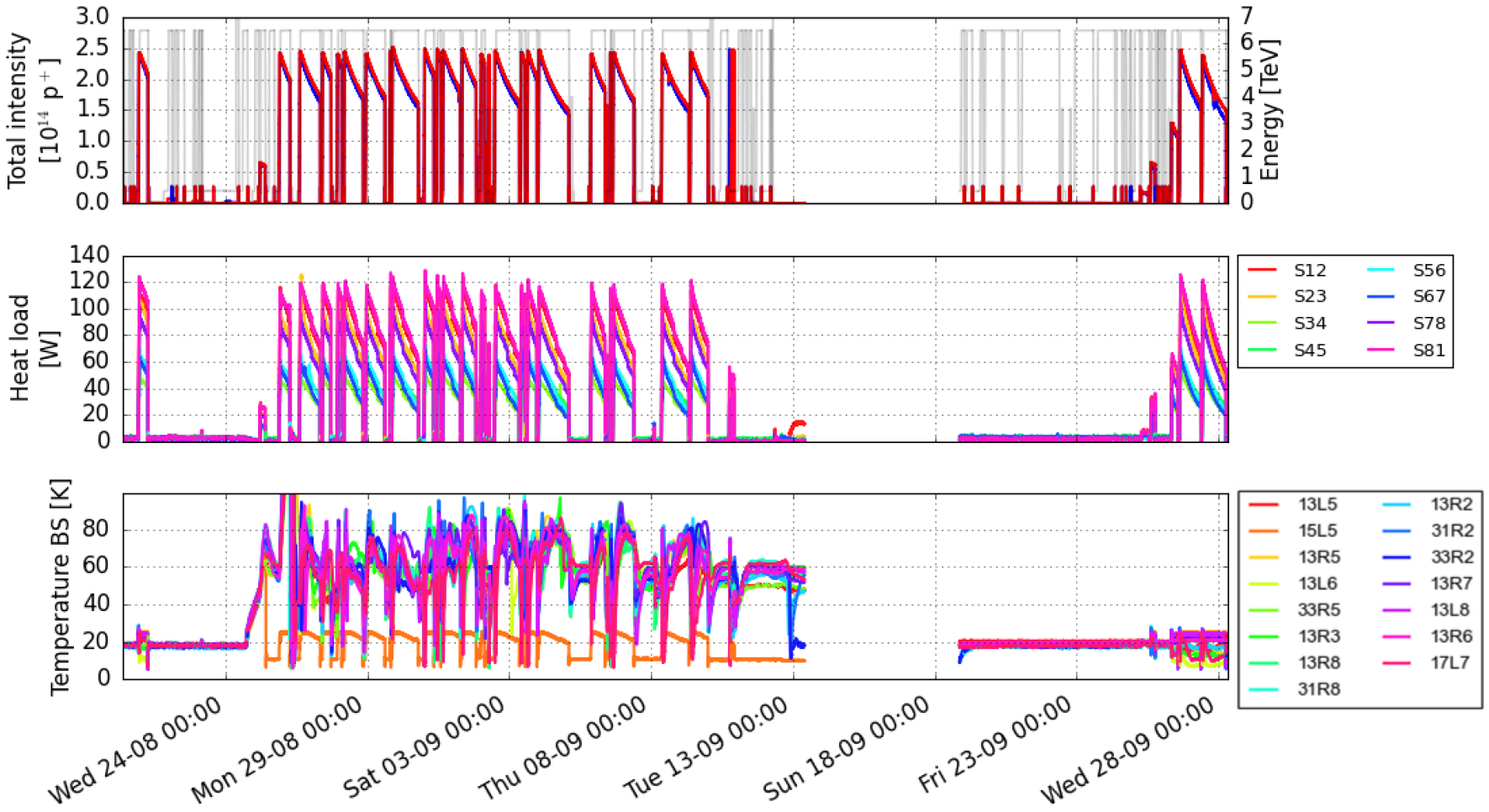


Work in progress!

Large heat-load differences among sectors actually translate in **rather small differences in SEY**

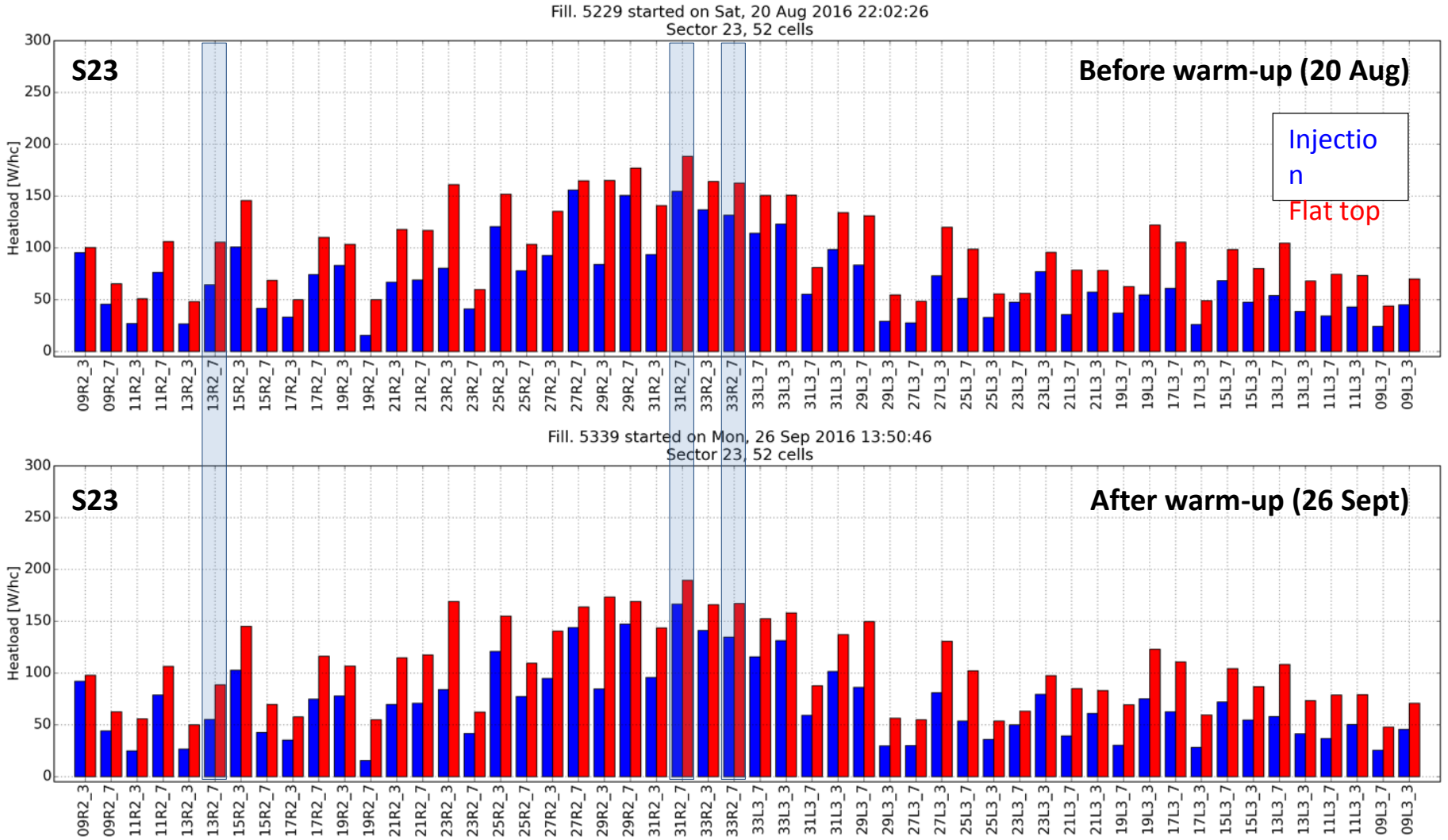
Beam screen temperature

- Selected cells were kept at T ≈ 70 K for 2 weeks of physics (26 Aug – 9 Sept) to observe possible impact on the scrubbing process



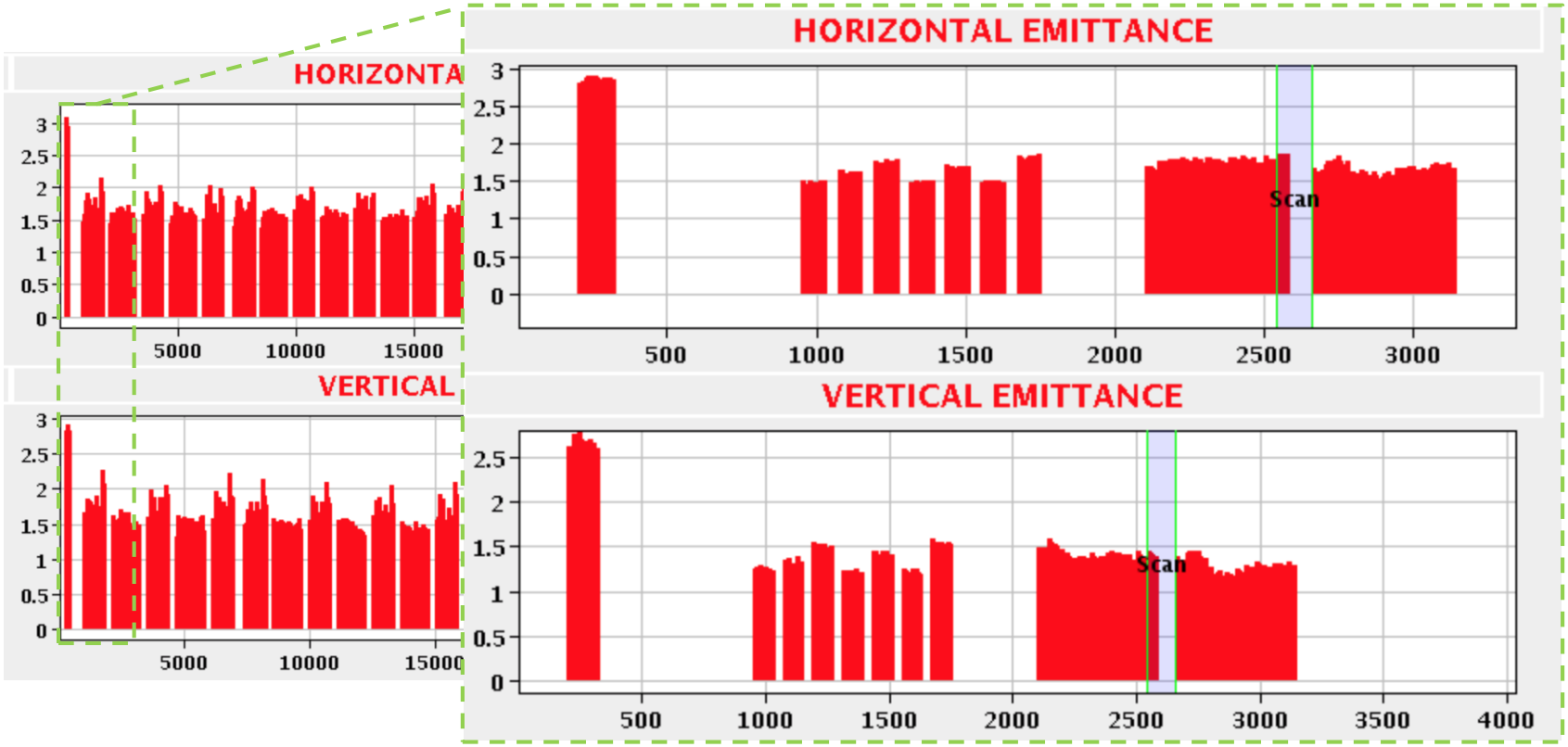
Beam screen temperature

- Cell-by-cell heat load pattern along the machine is extremely reproducible
- No particular difference can be identified on the warmed up cells in any sector



Hybrid filling scheme

- 8b+4e filling scheme designed to suppress e-cloud, confirmed experimentally in 2015
- Hybrid filling pattern combining standard 25 ns trains and 8b+4e trains can be used to adapt the heat load to the available cooling capacity
- Tested in MD with 1908 bunches: 55% 25ns BCMS + 45% 8b+4e
  - 15% less bunches than equivalent standard filling scheme



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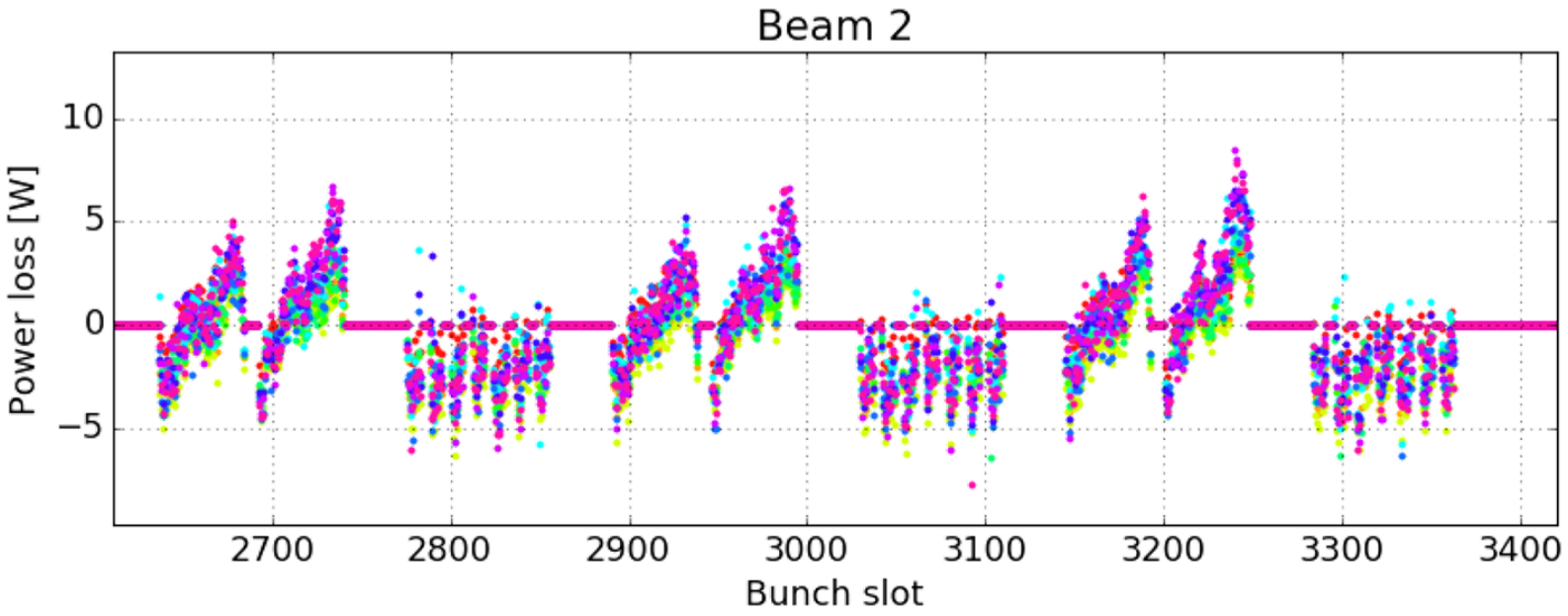

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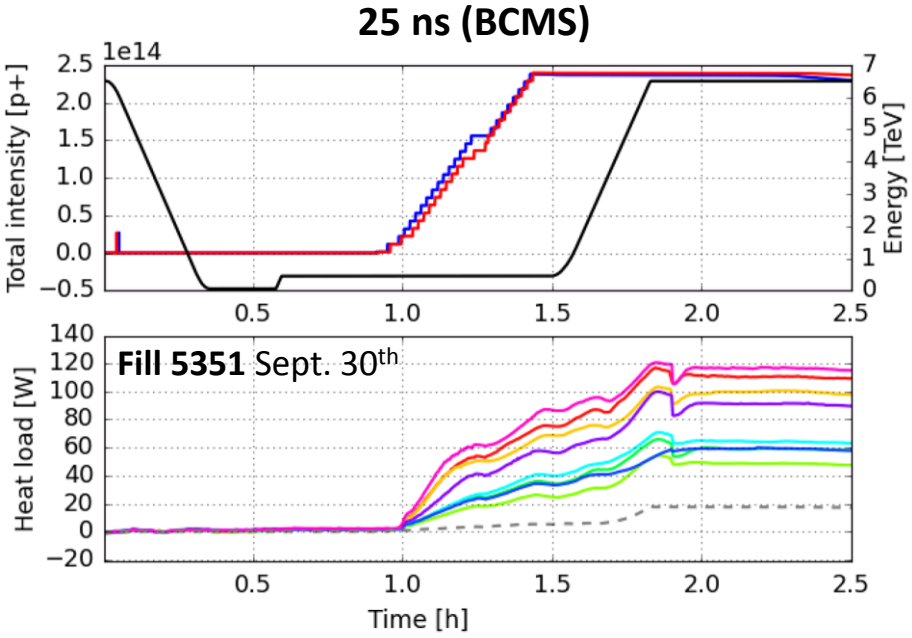
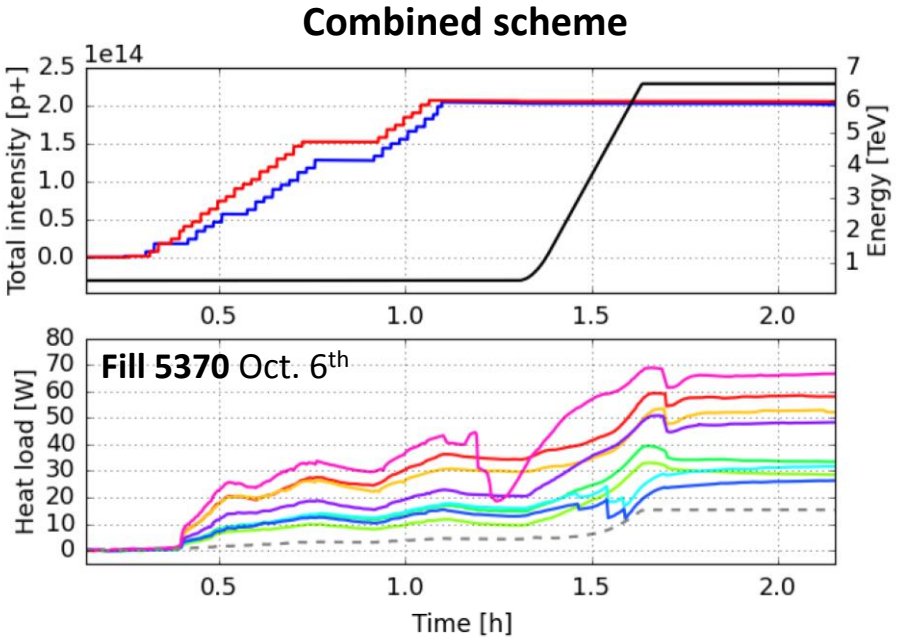
  - 15% less bunches than equivalent standard filling scheme
  - Stable phase data shows that 8b+4e trains stay e-cloud free
  - A 40% reduction of heat load observed in the most critical sector





Summary of 2016

- Electron cloud was the main contributor to arc heat loads throughout the year
  - Not a limiting factor for performance, due to restrictions from SPS TIDVG
  - Improved cryo feed-forward effectively limited problems at injection

- A decrease (roughly 20%) of normalized heat load observed during the year
  - Larger decrease during first 1/3 of run than last 2/3
  - Operating cells (2 weeks) at higher temperature has no evident effect on evolution

- Accumulated electron dose on beam screen four times larger than in 2015
  - Based on lab experiments should be largely sufficient for full scrubbing

- Difference in heat load between sectors stayed similar throughout 2016
  - Based on PyECLOUD simulations, corresponds to only small SEY difference

- Hybrid BCMS - 8b+4e filling scheme confirmed to provide a significant decrease of heat load per bunch
  - Most likely not necessary for 2017, but could be needed for Run 3 and HL-LHC

Outlook

- Especially with BCMS beams, the heat load from e-cloud will not be a strong limitation for the LHC performance reach (see talk of G. Iadarola tomorrow)
- But in the future, for HL-LHC, we need to do better (due to higher bunch intensity)

→ Several topics need to be further investigated:

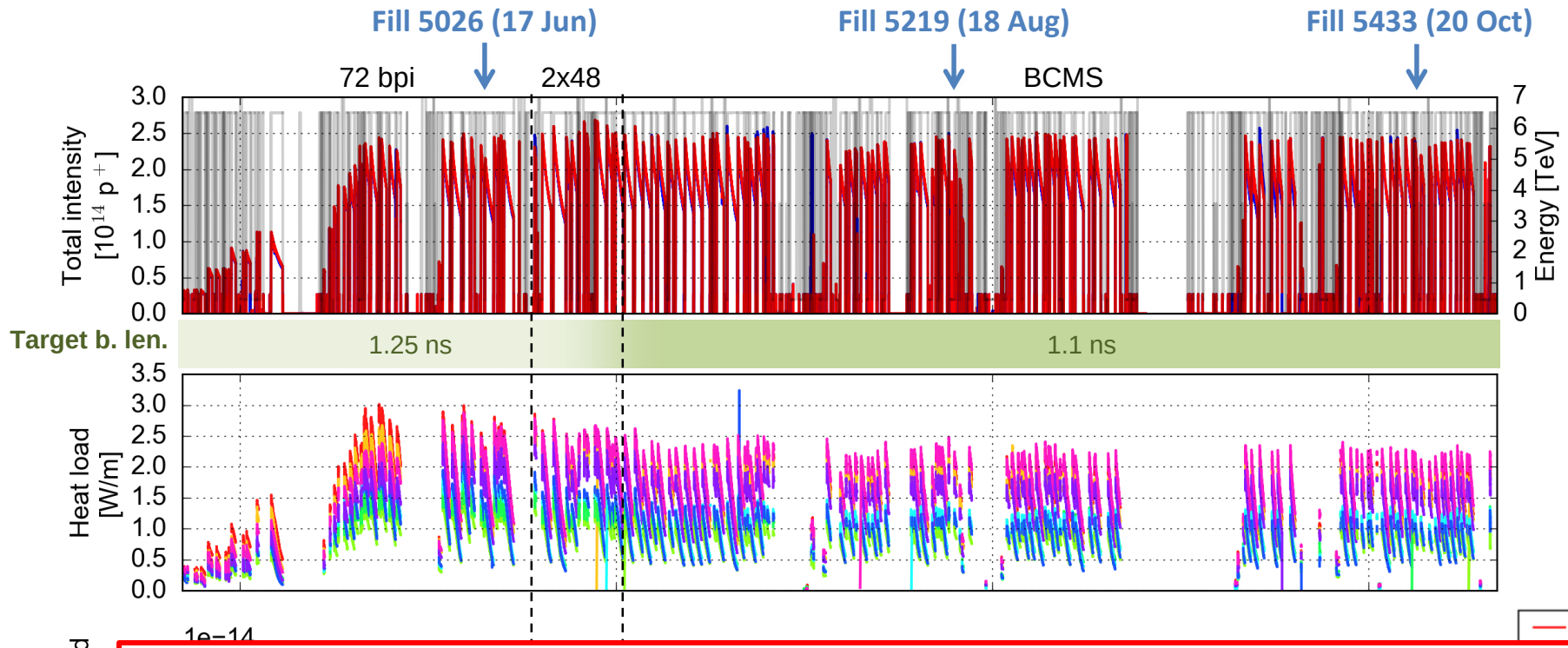
- Difference between sectors
- Scrubbing evolution
  - Beam configurations to improve scrubbing (longer trains, higher bunch intensities, doublets…)
  - Difference in machine vs lab
  - Effect of beam screen temperature (higher T, longer period)?
- Arc cell heat load breakdown (dipoles, quadrupoles, drifts)
  - Data from new instrumented cells in S12
  - Ongoing effort to improve accuracy of heat load measurements
- More detailed input for simulations
  - Synchrotron radiation tracking and photoelectron generation
  - Surface characterization from lab studies (SEY measurements)

Extra slides

Arc heat load evolution in 2016

Slightly **decreasing trend** but **difficult to disentangle** from changes in beam conditions:

→ We performed **reference fills** with very similar beam parameters



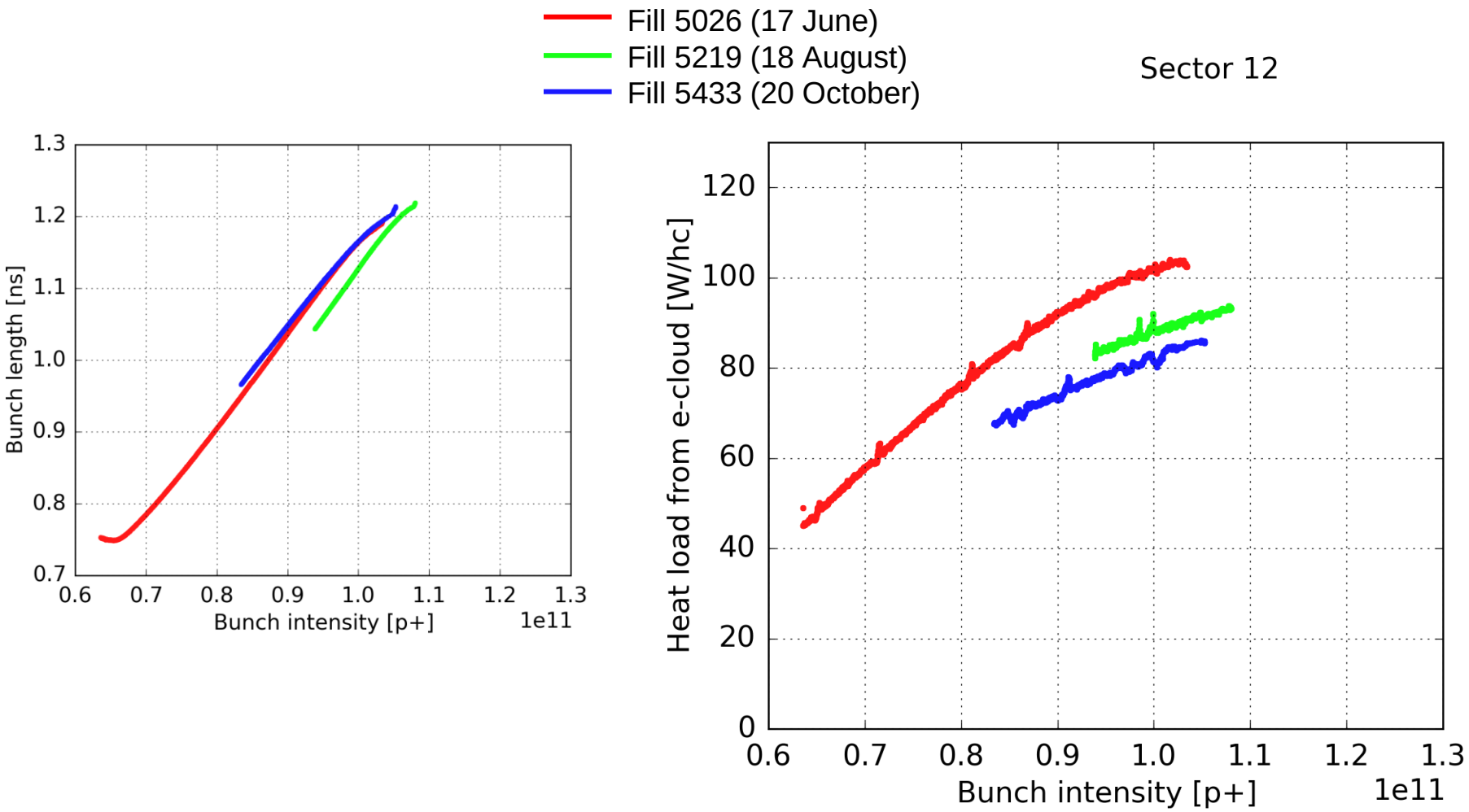
Reverted to settings of fill 5026:

- **Filling scheme**: 2040 bunches in trains of **72b** (standard production scheme in the PS)
- **Target bunch length** for controlled blow-up in the ramp: flat at 1.25 ns
- **Octupole knob at injection:** -1.5 (higher values used for BCMS beam)

Reference fills went to Stable Beams and were used for physics production

Reference fills

- A **reduction on the heat load at 6.5 TeV** is observable in all sectors



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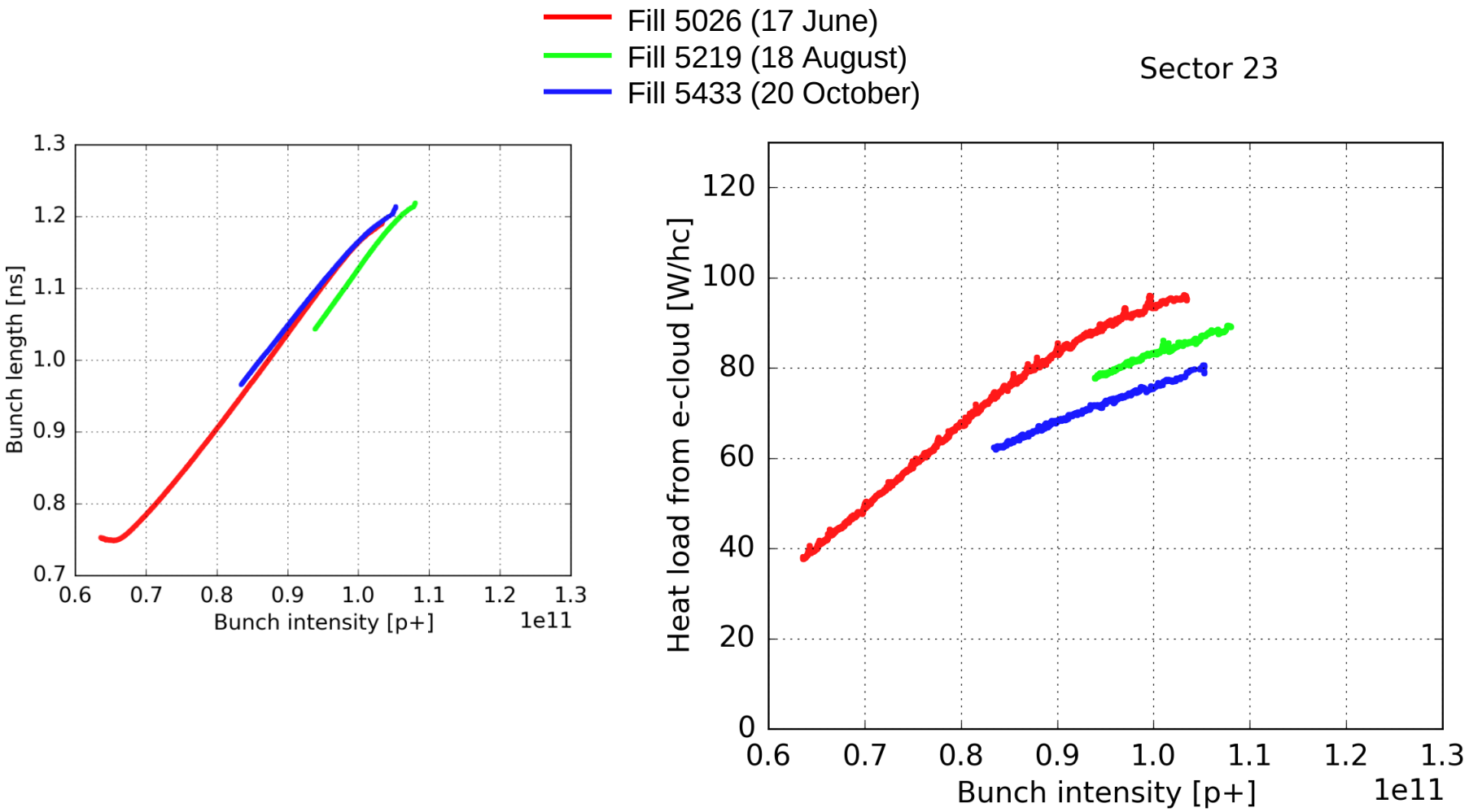

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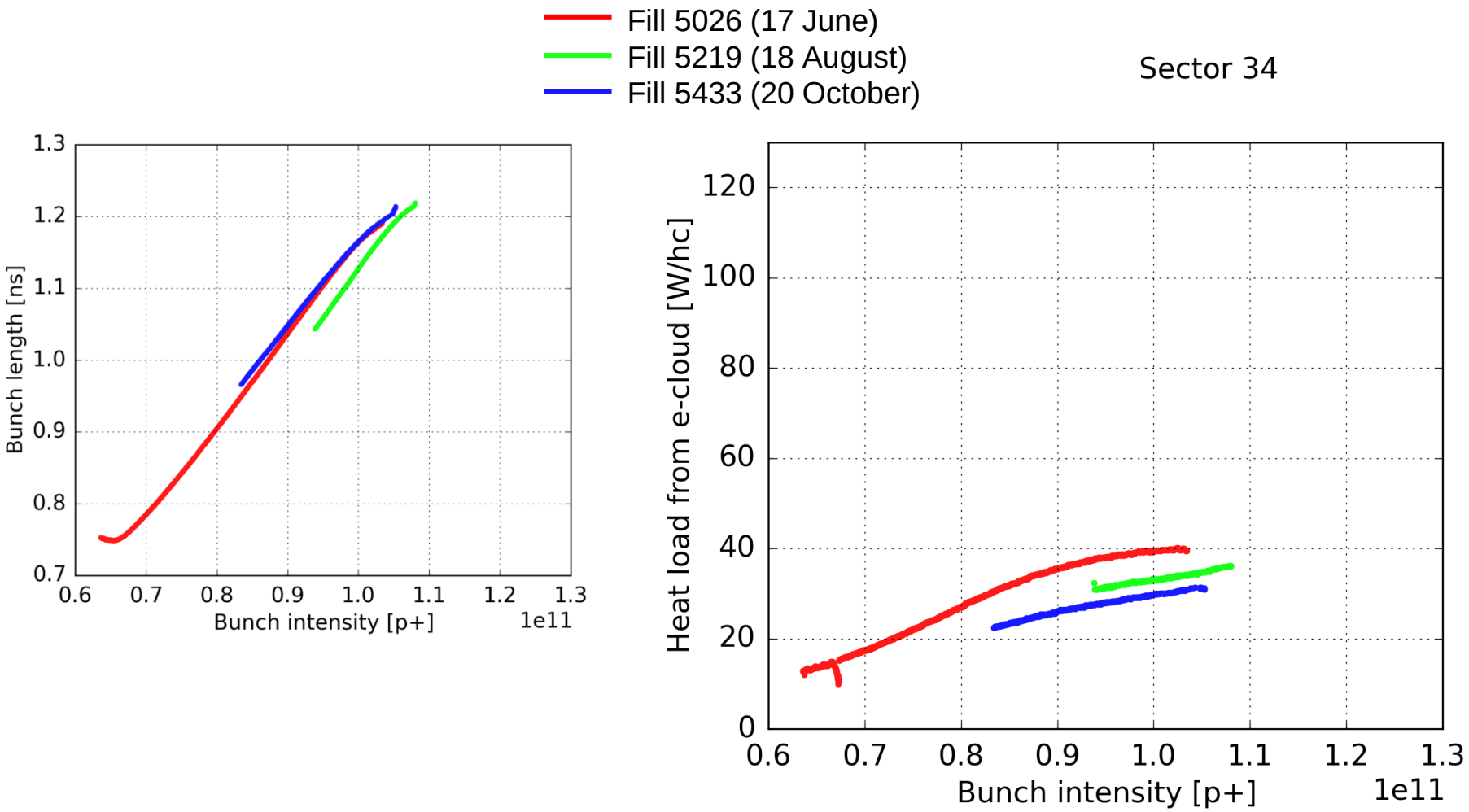

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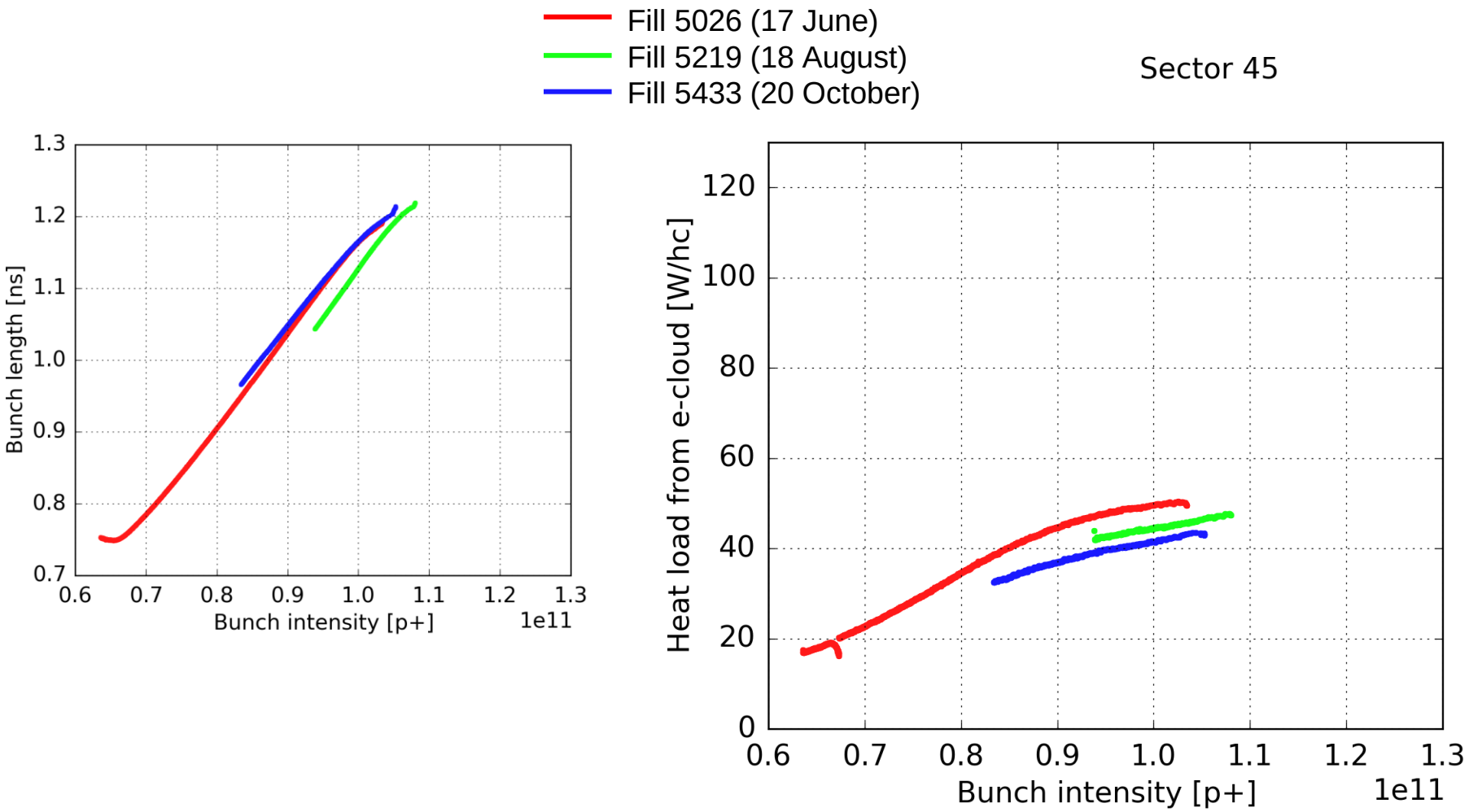

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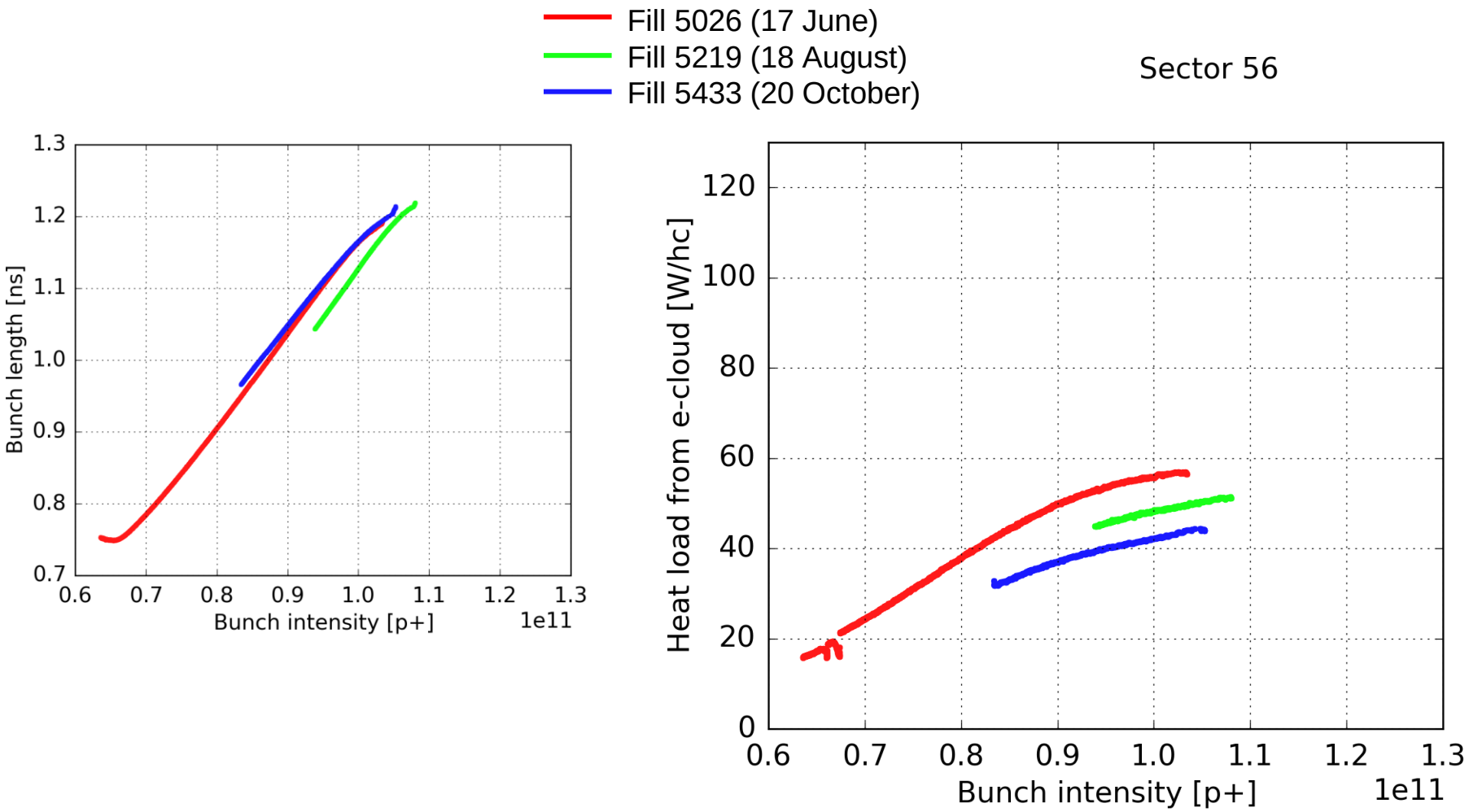

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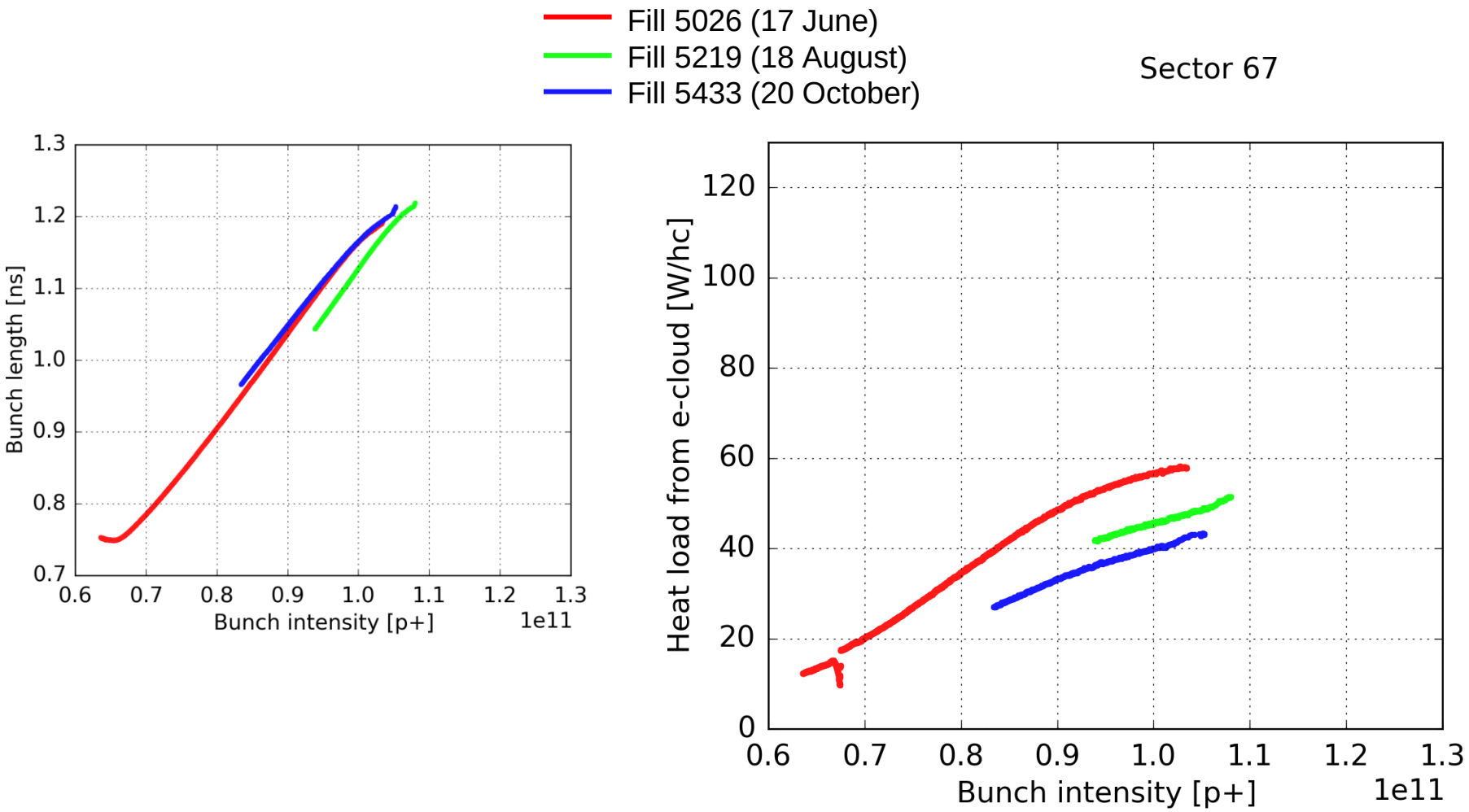

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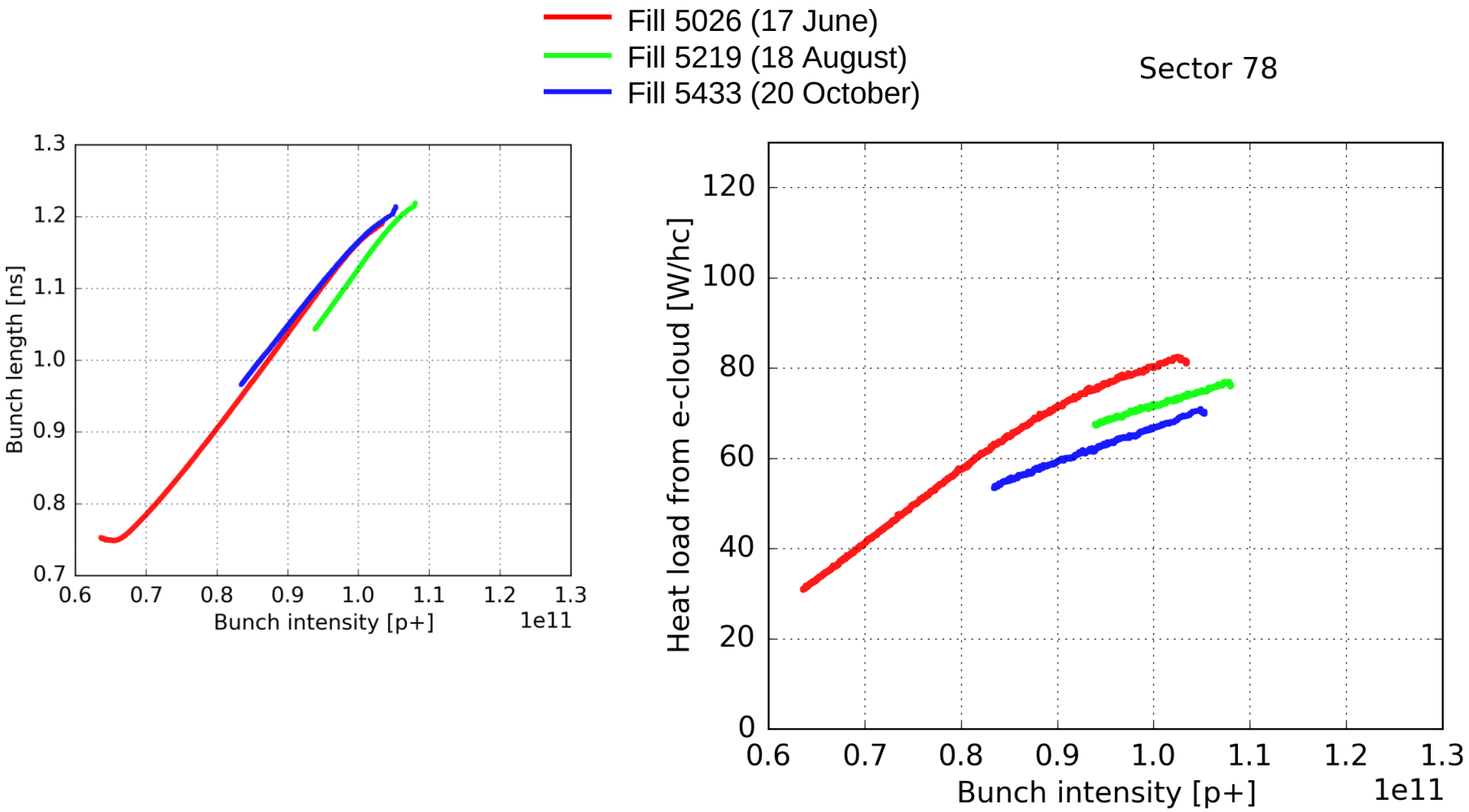

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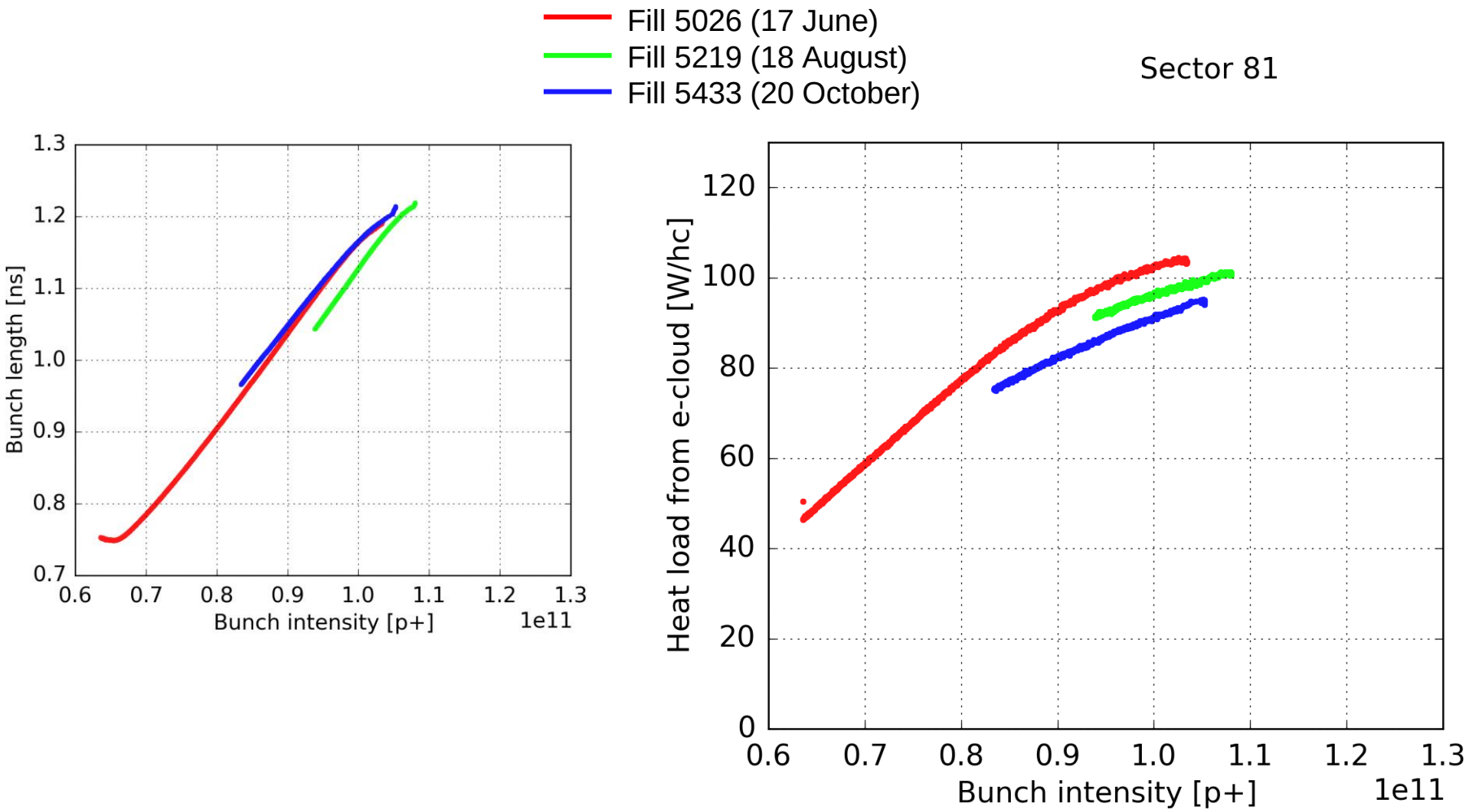
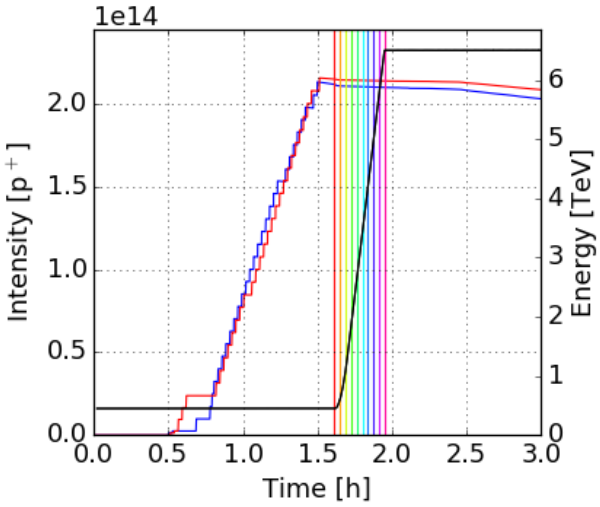
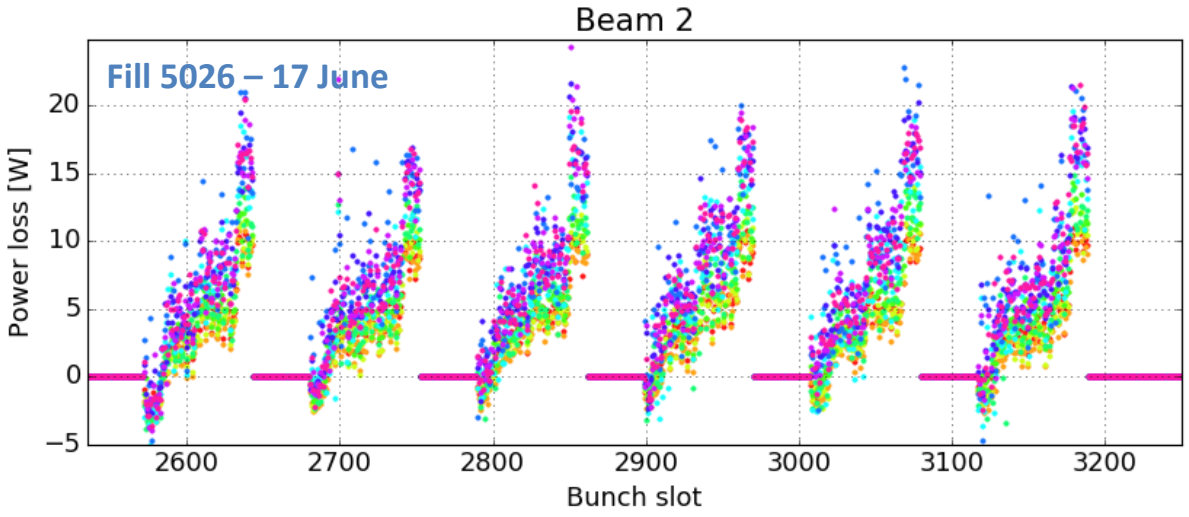
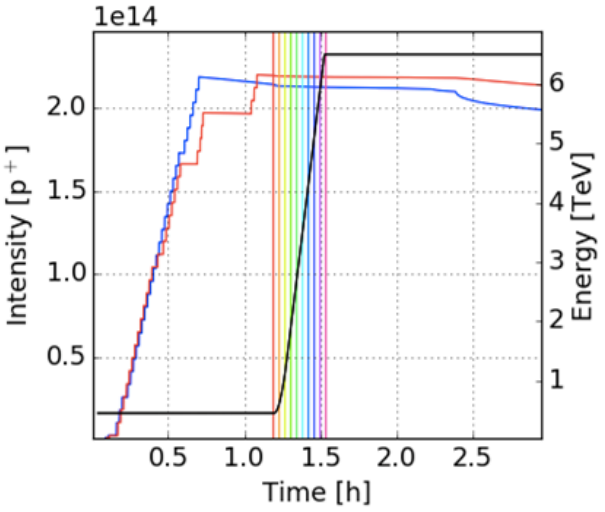


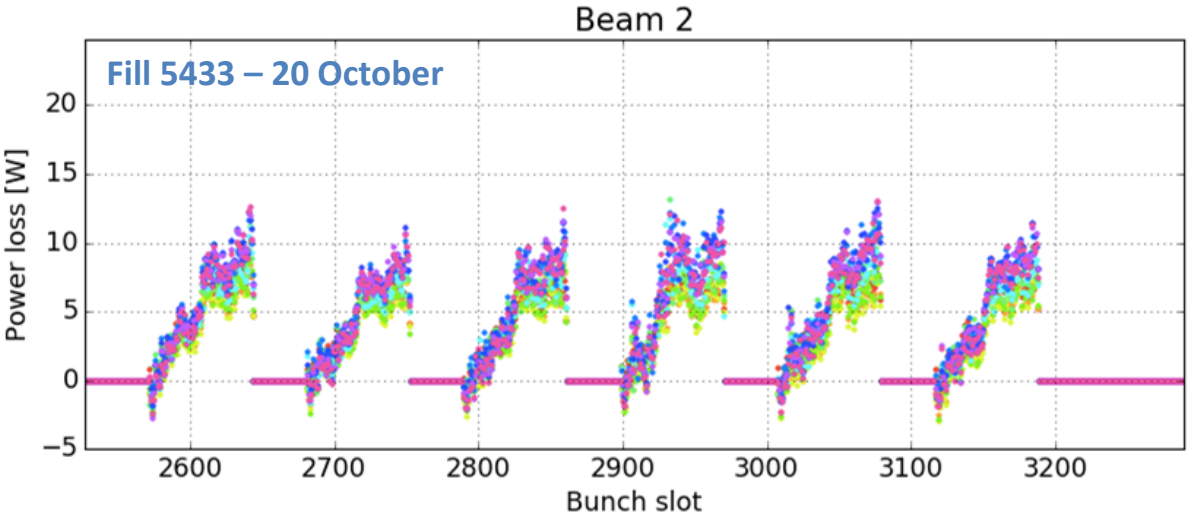
Stable phase comparison

- **Bunch-by-bunch power loss** confirms the improvement

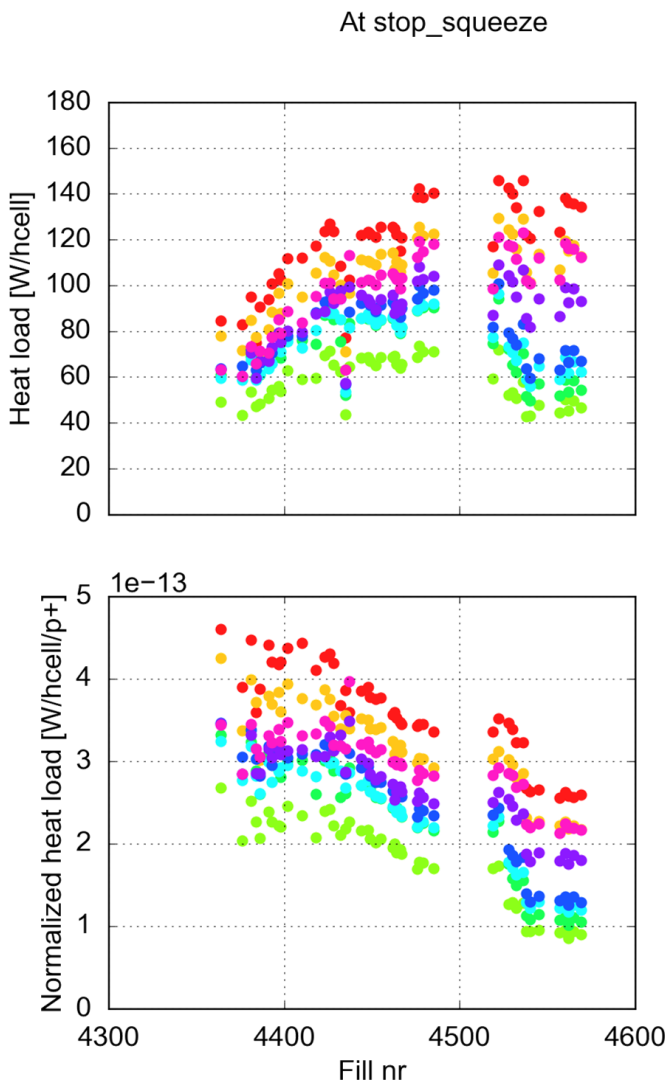


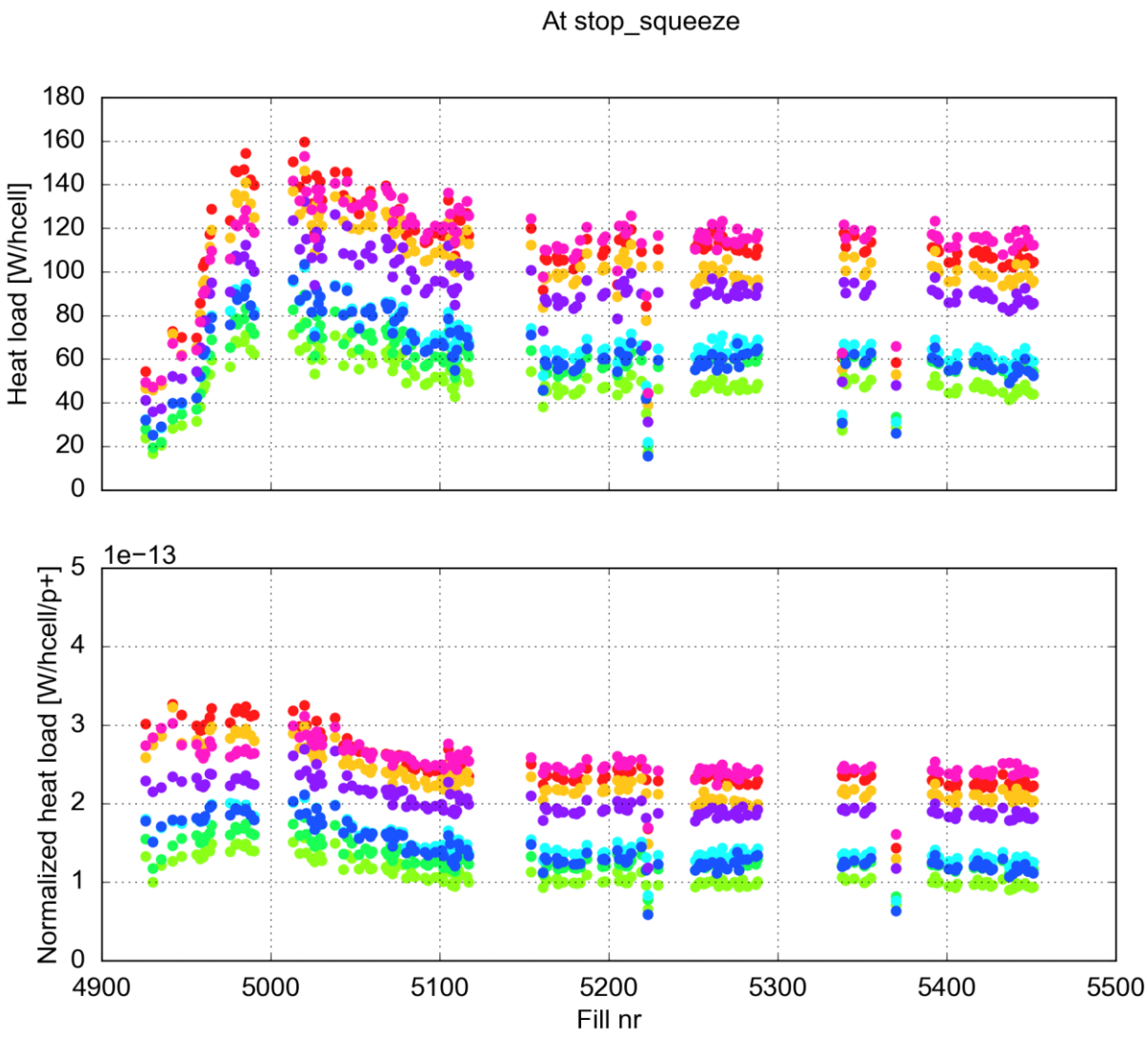




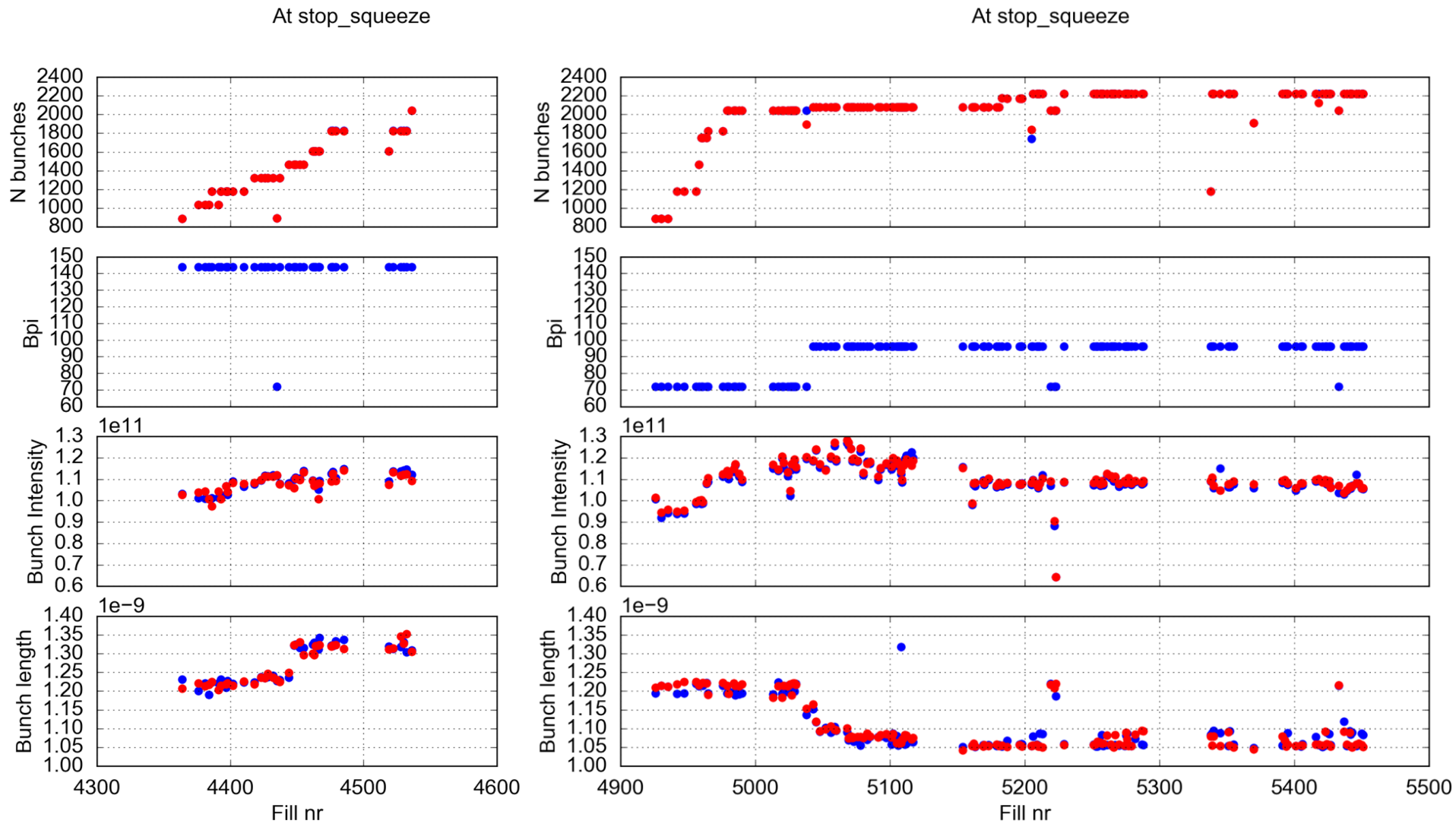


Heat loads 2015-2016



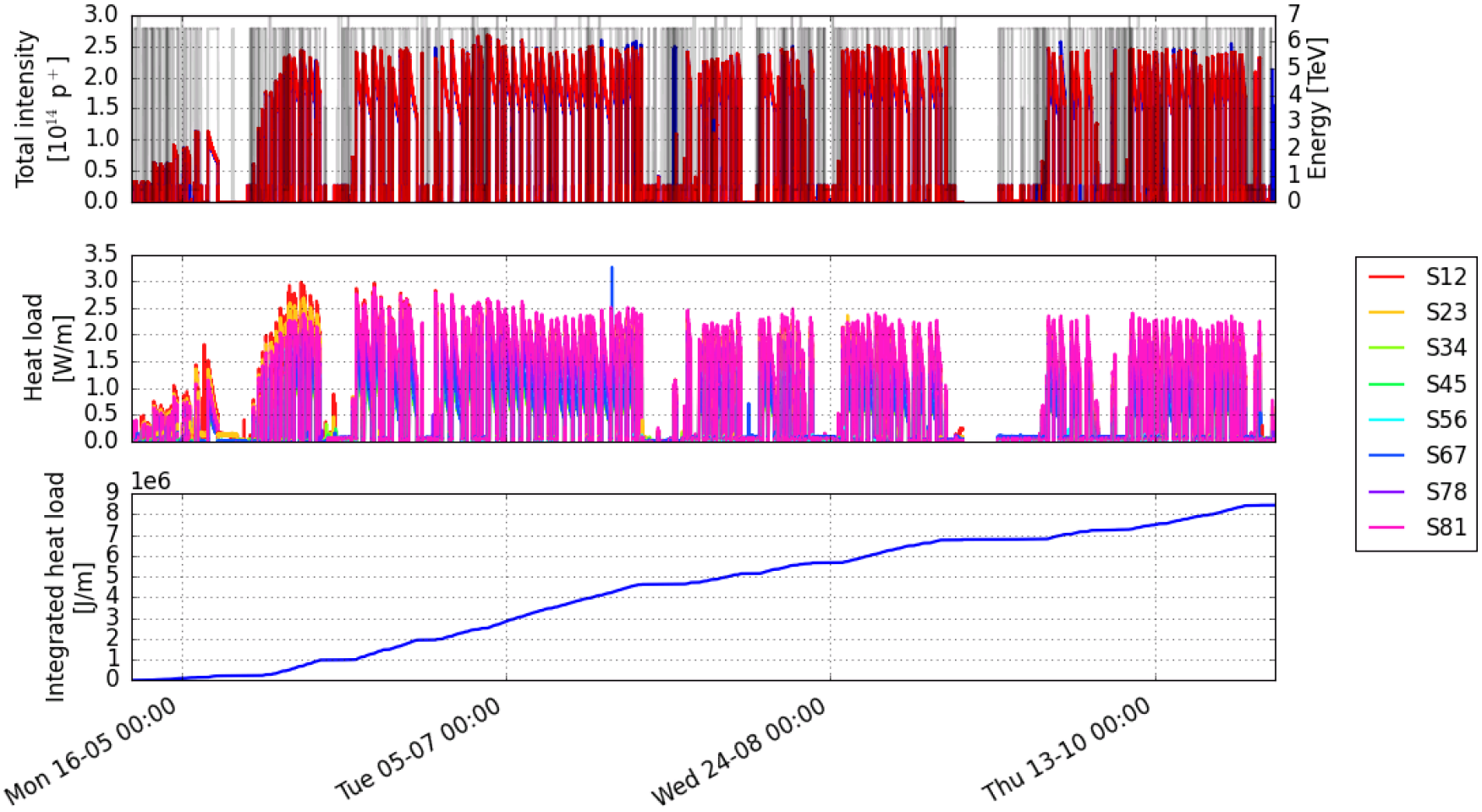


Beam parameters 2015-2016



Computation of the integrated electron dose

The **integrated heat load** can be directly from the cryogenics measurements



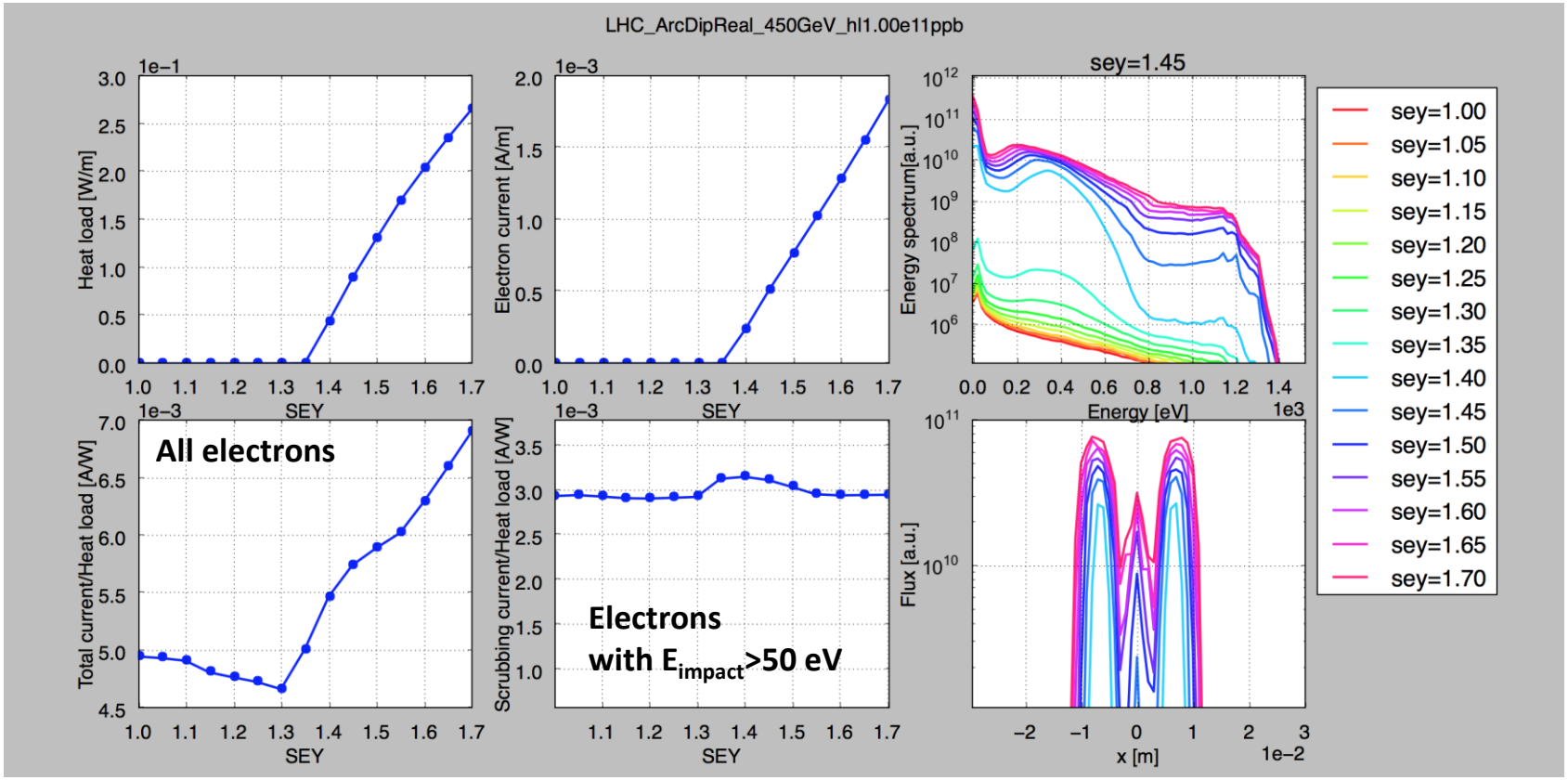
Computation of the integrated electron dose

From **PyECLOUD simulations** we obtain a **conversion factor** of **3 mA/W**

→ Equivalent to an **average energy** of the impacting electron of **333 eV**

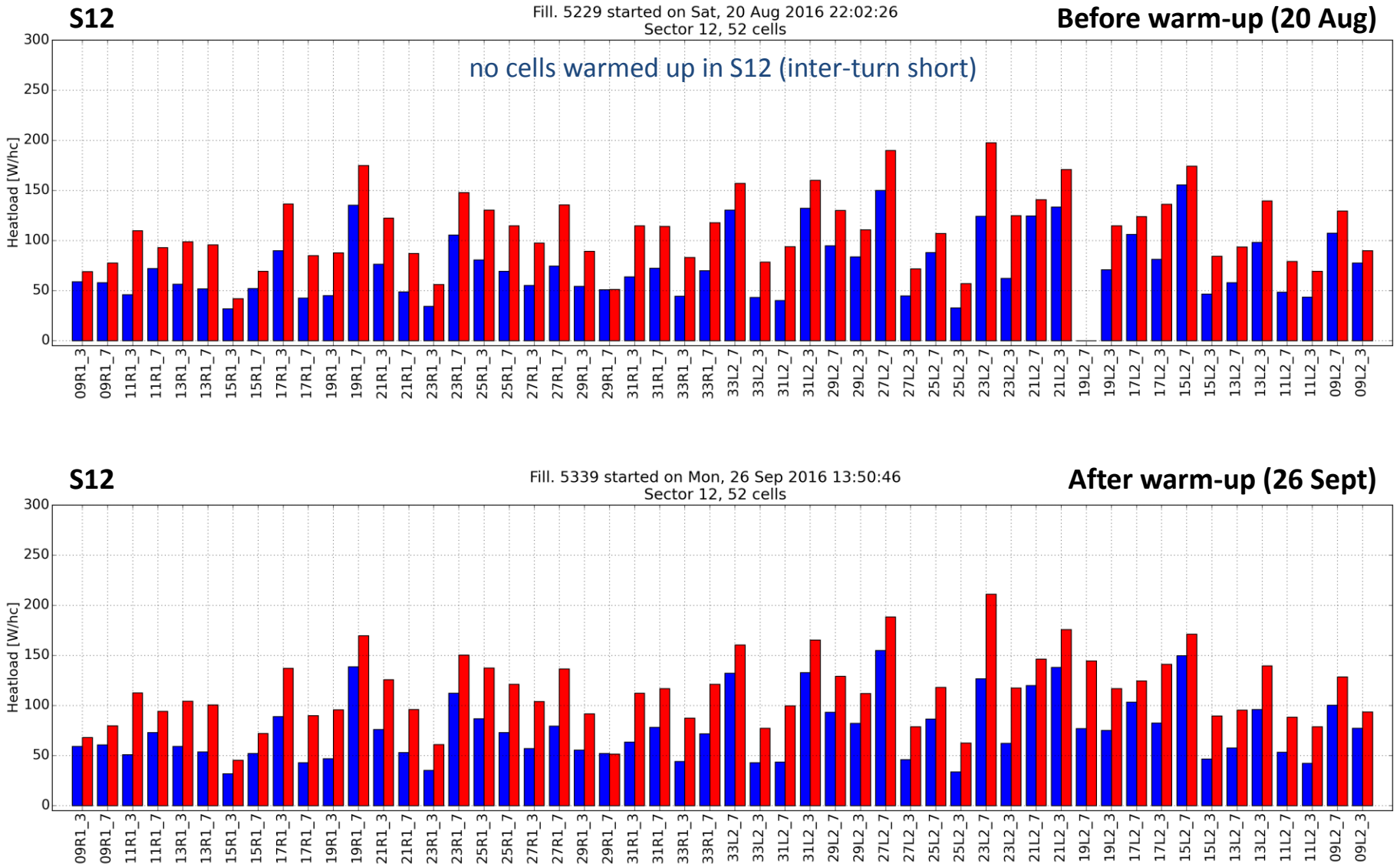
→ Consistent with simplified back-of-the-envelope calculation

We count only "good" scrubbing electrons **E_{impact}>50 eV**



Heat load in individual half-cells

Heat load pattern along the machine is **extremely reproducible**



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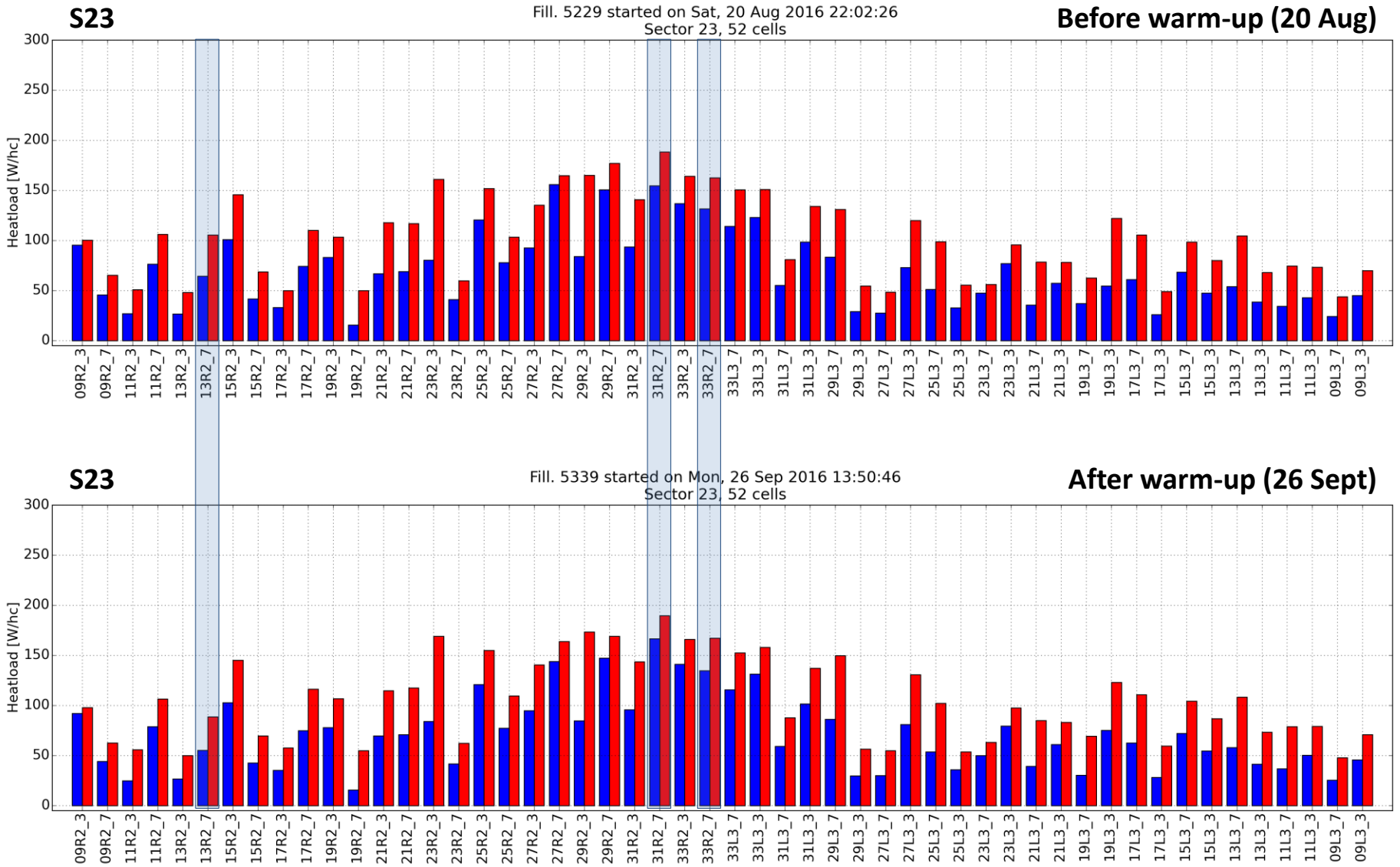

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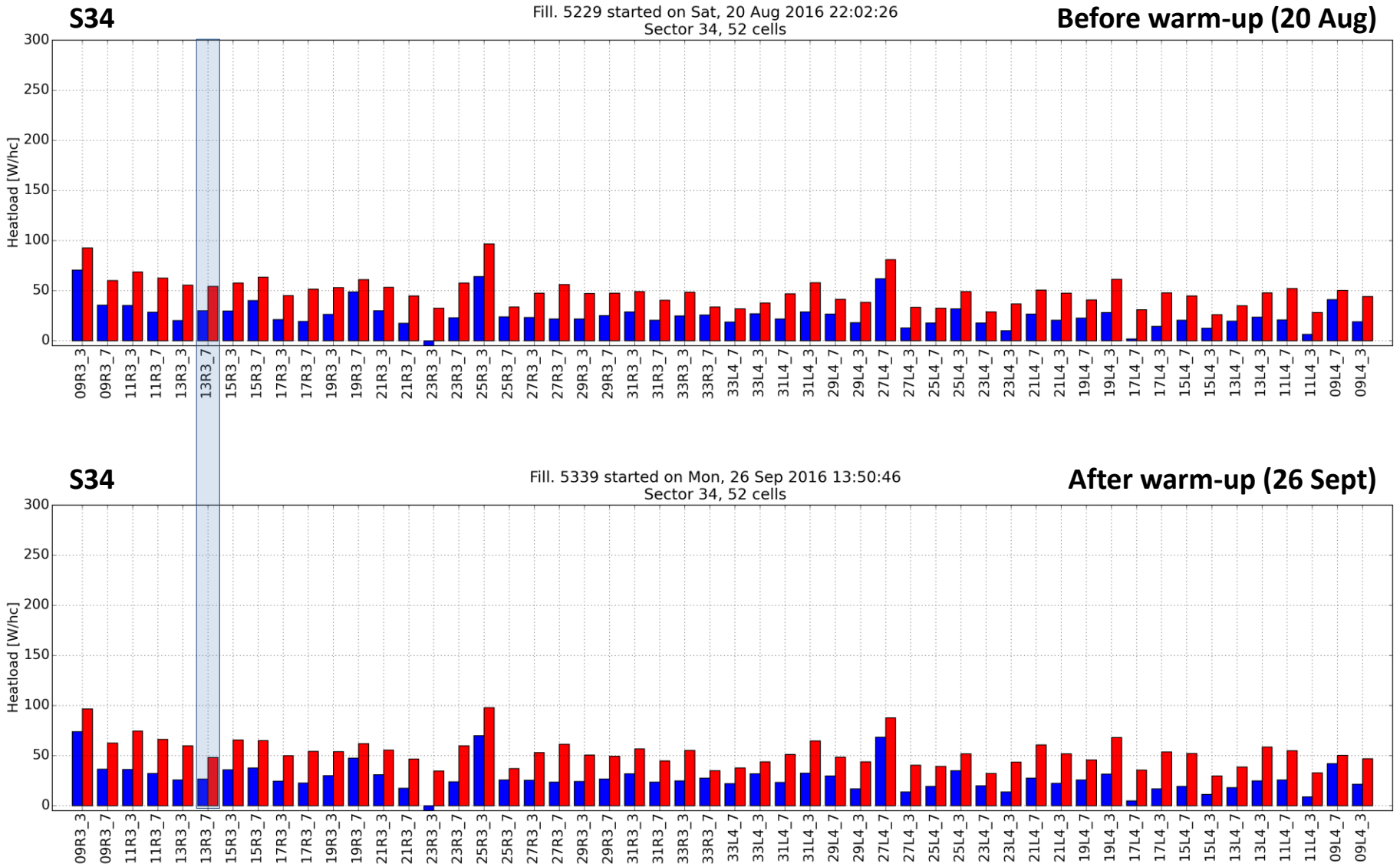

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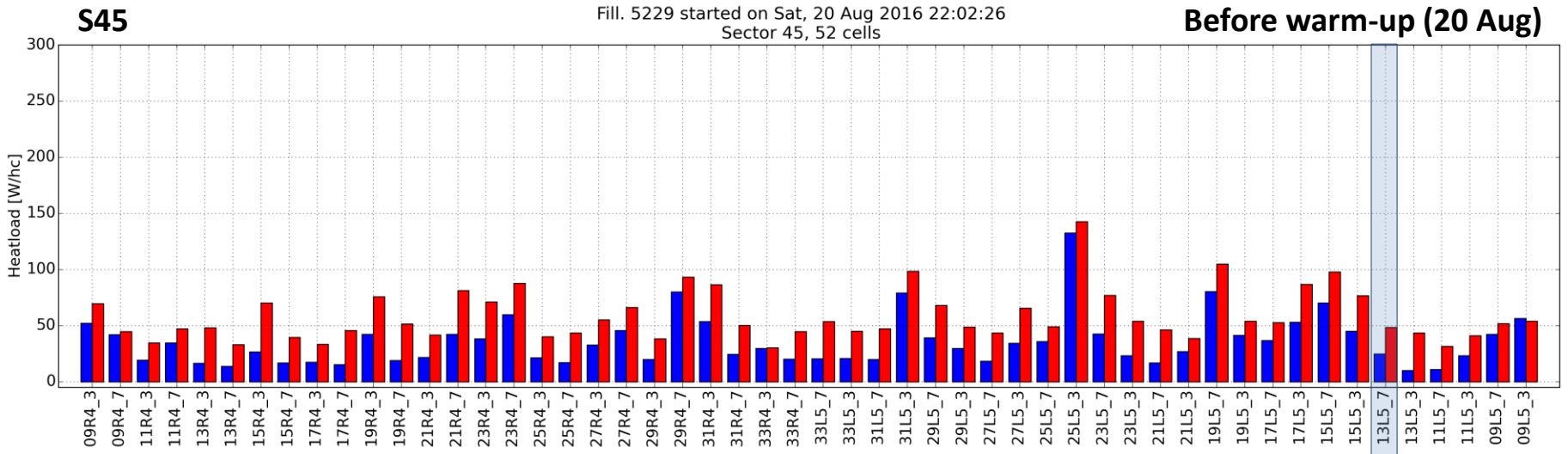

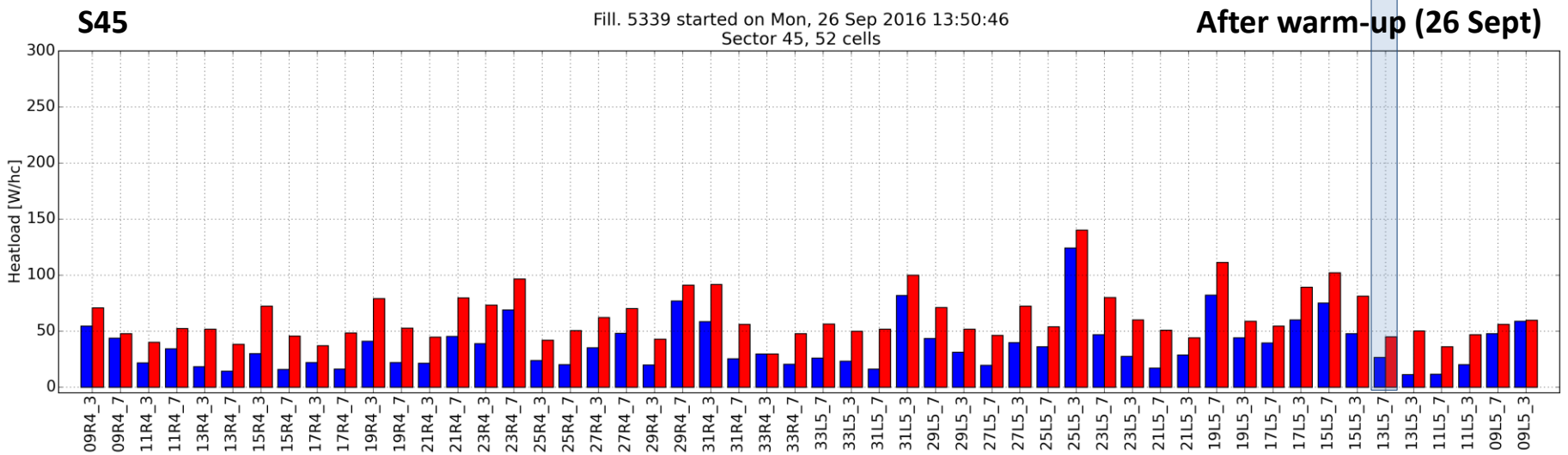

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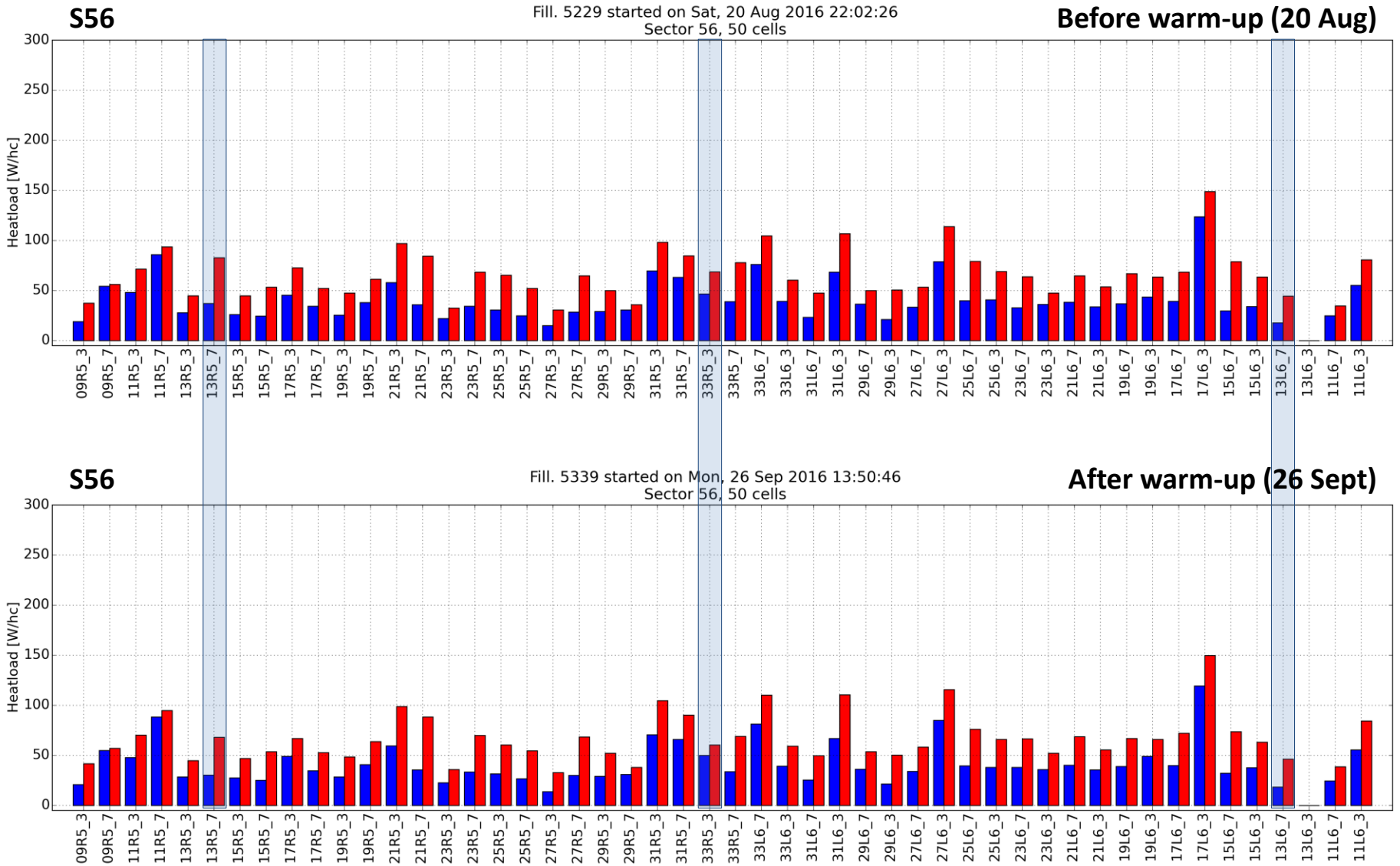

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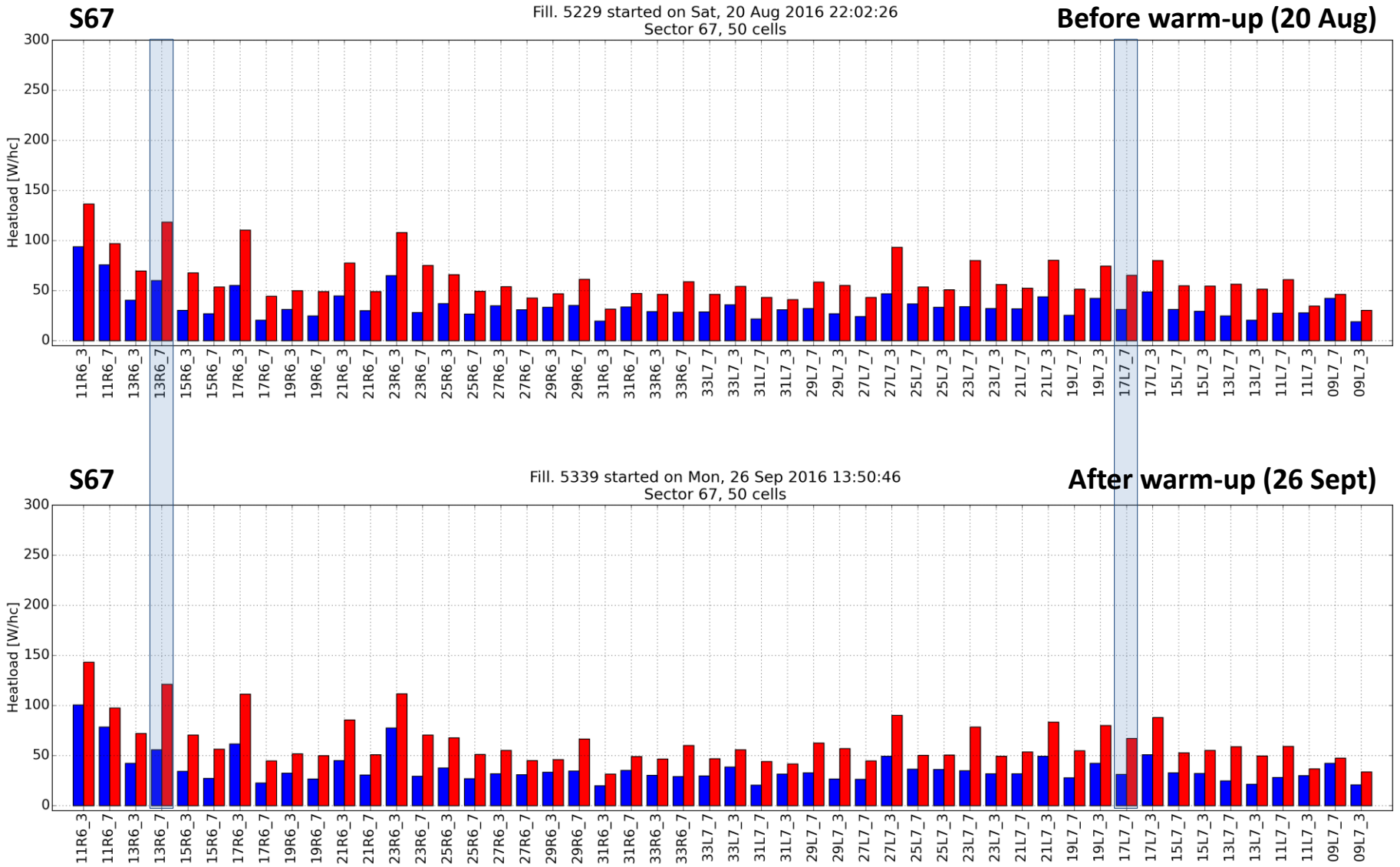
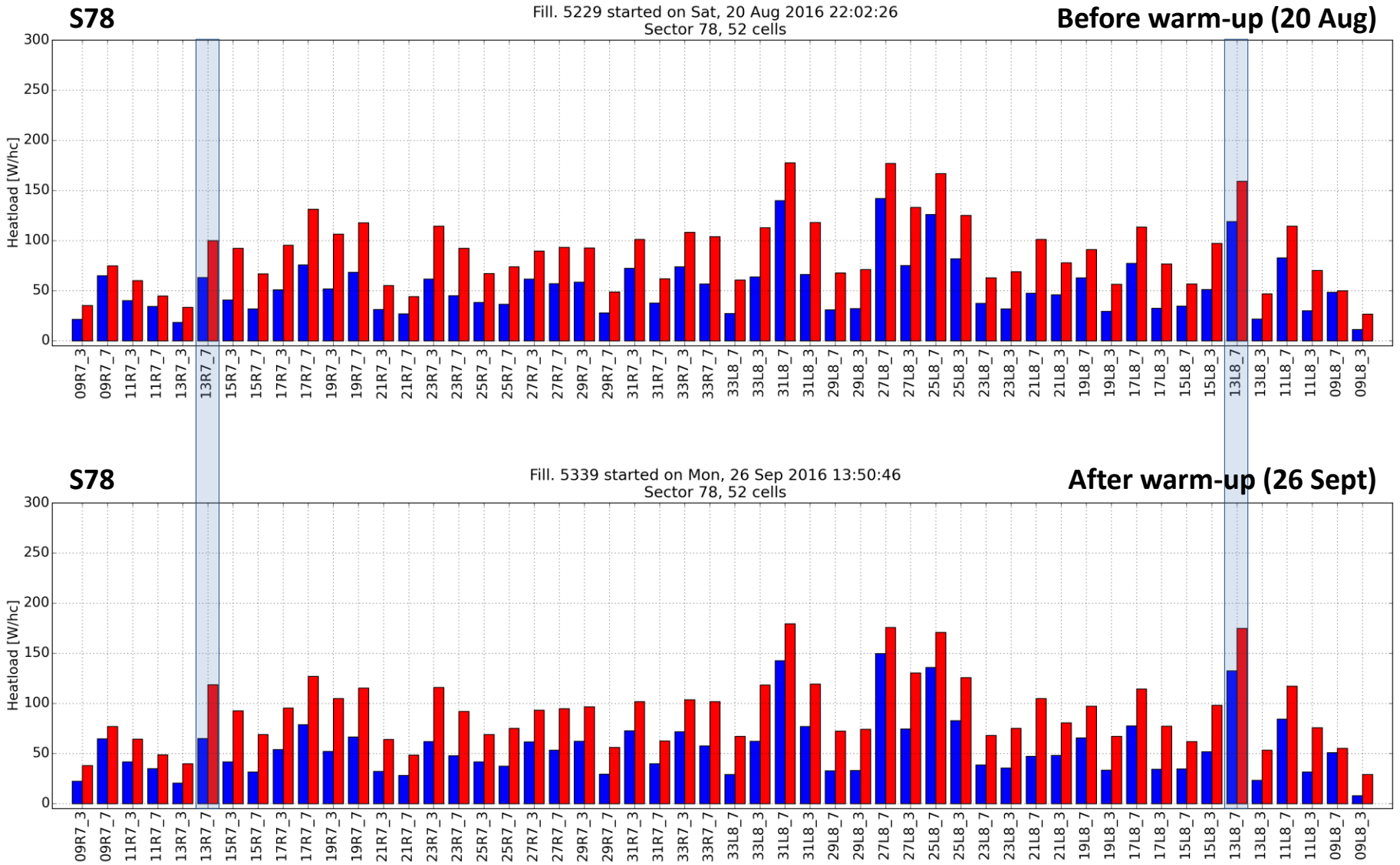


Heat load in individual half-cells

Heat load pattern along the machine is **extremely reproducible**

- **No particular change** can be identified **on the warmed-up cells**



Heat load in individual half-cells

Heat load pattern along the machine is **extremely reproducible**

- **No particular change** can be identified **on the warmed-up cells**