Analysis of heat loads on LHC arc beam-screens

Summarizing analysis work done in collaboration by:
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More information available at:
Electron cloud meeting, 14 Jul 2017
Electron cloud meeting, 25 Aug 2017
http://cern.ch/ecloudwg

Outline

- **Introduction**
  - Heat load observations
  - Differences between sectors and between cells
- **Can it be impedance heating?**
  - Observations with different bunch spacing
- **Were the differences always there?**
  - Heat loads with 25 ns in 2012
- **What is the impact of venting, thermal cycle and scrubbing?**
  - Experience with S12 (and others) after 2016-17 EYETS
- **Can we localize the heat deposition magnet by magnet?**
  - Analysis of measurements from instrumented cells and stand-alone magnets
- **Summary and conclusions**

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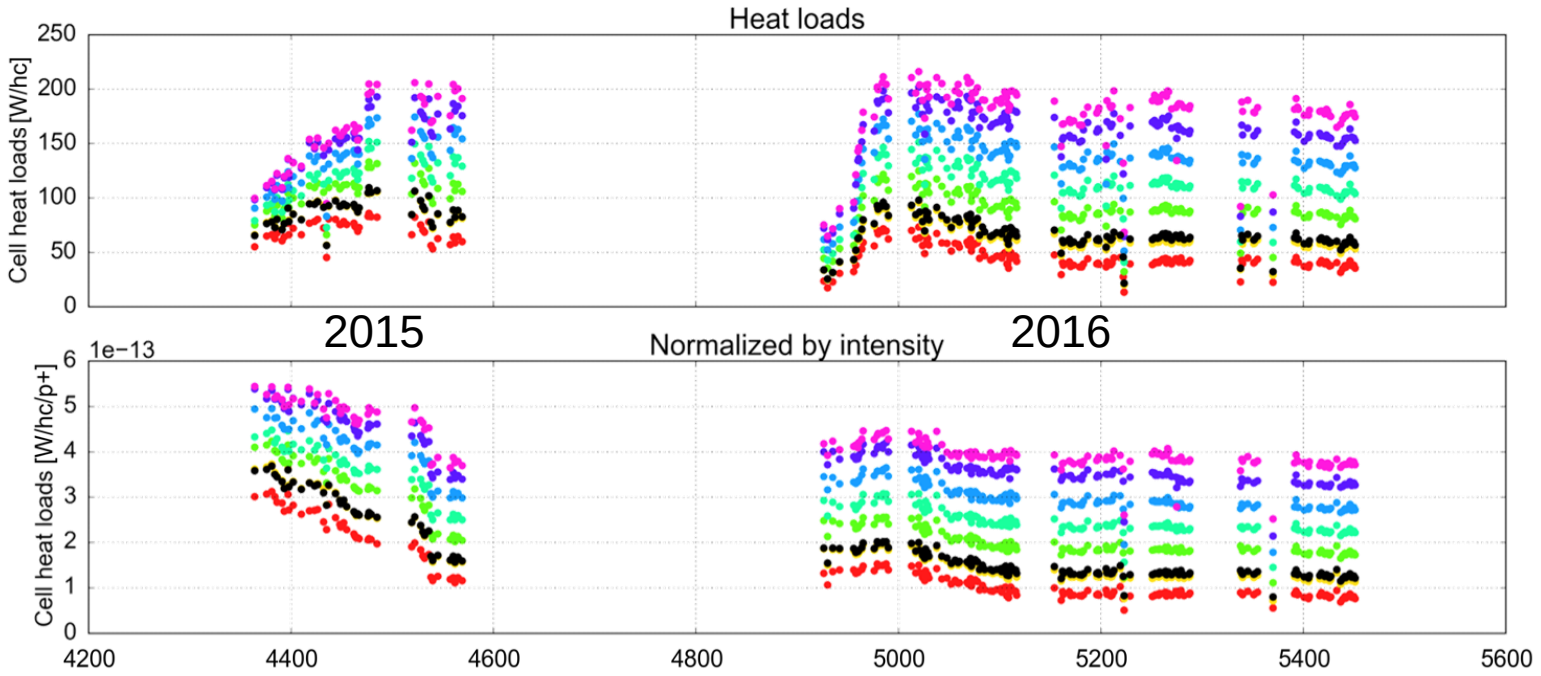
Recap from 2015-16

- During operation with 25 ns beams in Run 2 **large beam-induced heat loads** are measured on the **arc beam screens**
- Even after conditioning accumulated in the 2015-17 runs, the heat loads on the **different arcs are largely uneven** (up to a factor of three)
  - This is unexpected as the eight LHC arcs are on paper identical
- When normalizing heat loads to intensity we find out that the **curves are strongly correlated** and they practically differ only for a constant offset

Data are post processed to use the same calibration for all fills (in collaboration wit TE-CRG)

Recap from 2015-16

- A **similar behavior is observed also at a cell-by-cell level**: normalized heat loads differ only by a constant offset (scrubbing curves never cross!)
- Different **cells are actually conditioning very similarly**, but there seems to be an extra source of heat load, which is different from cell to cell, scales linearly with the number of bunches and does not condition at all



Each color corresponds to **cells with similar heat** loads (within ~15 W)

- 73 cells
- 149 cells
- 70 cells
- 48 cells
- 28 cells
- 21 cells
- 7 cells
- Average

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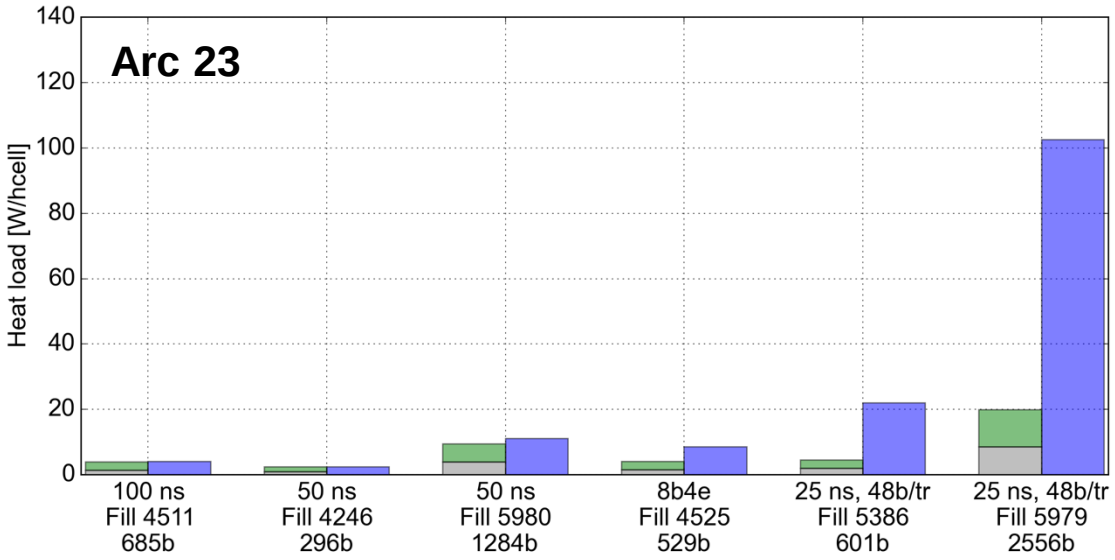
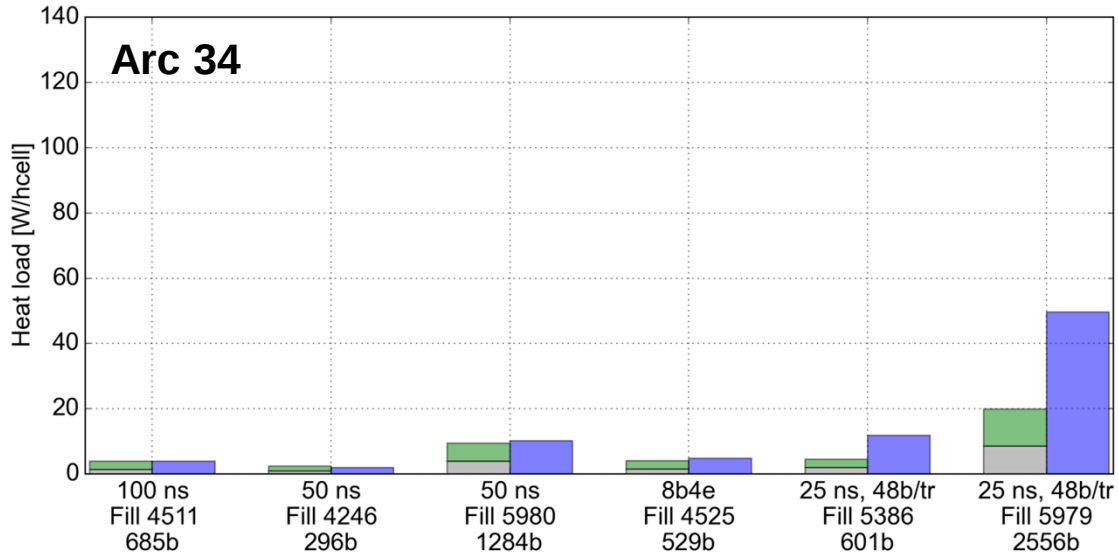
Heat loads with different filling patterns





We analyzed fills performed with **different bunch spacing** in Run 2

Heat loads are compared against expectations from **impedance** and **synchrotron radiation**

Synchrotron Radiation

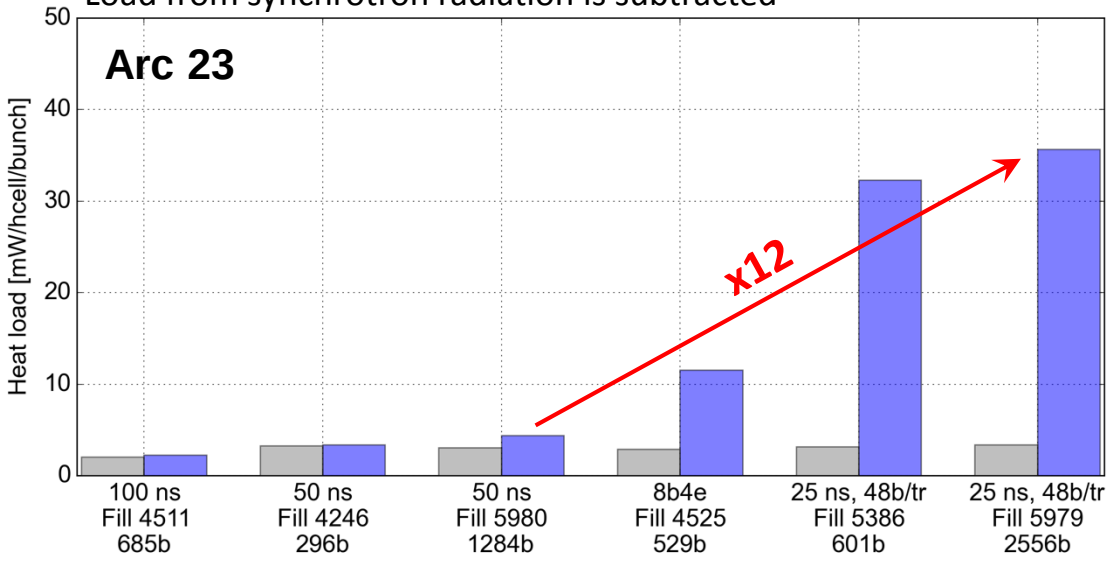
Impedance (R.W.)

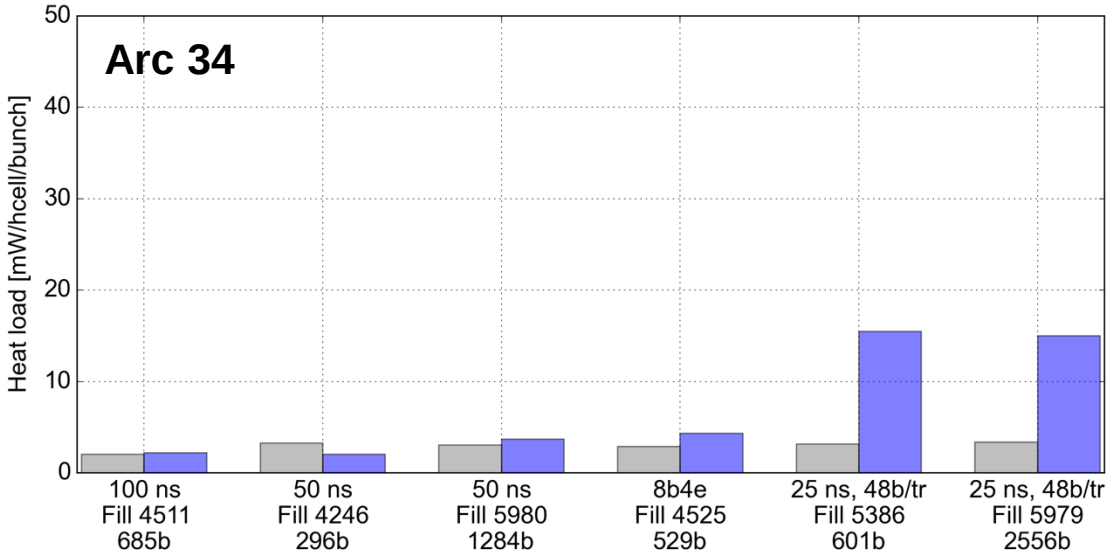
Measured

Comparison for the other sectors can be found here

Heat loads with different filling patterns

Load from synchrotron radiation is subtracted





Normalizing to the number of bunches:
we observe an **increase** in specific heat load **by more than one order of magnitude** between 50 ns and 25 ns bunch spacing

This allows **excluding** that a large fraction of the heat load is due to **impedance**…

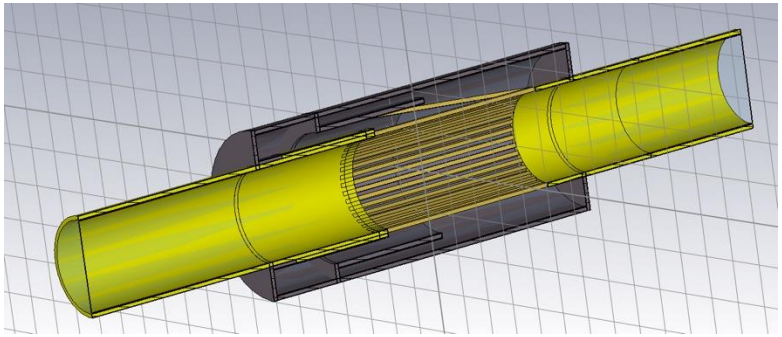
Impedance (R.W.)
Measured

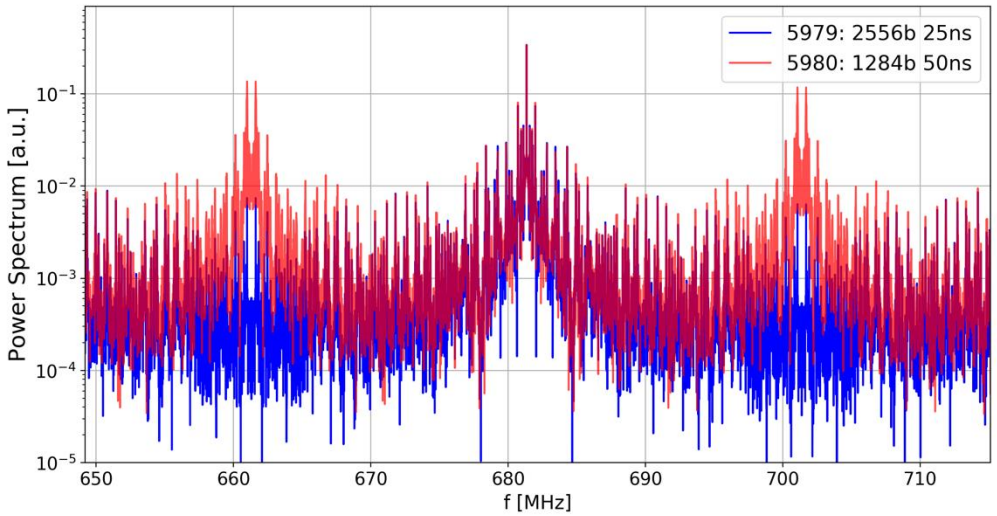
Comparison for the other sectors can be found here

Analysis performed by the impedance team

- Possible **non-conformities in the PIM modules** were studied in simulations in close collaboration with TE-VSC
  - → A significant power deposition can occur only for severe non conformities (e.g. many deformed fingers with lost contact)
  - → Even in those extreme cases large **heat loads should be observed also with 50 ns, which is not the case**
- **A more general exercise** was also conducted considering **generic resonator impedances** in a wide range of frequency, quality factor and shunt impedance:
  - → It was not possible to identify any set of values matching the observations for all analyzed filling patterns

Conclusion: no reasonable impedance can match observations for all bunch spacings





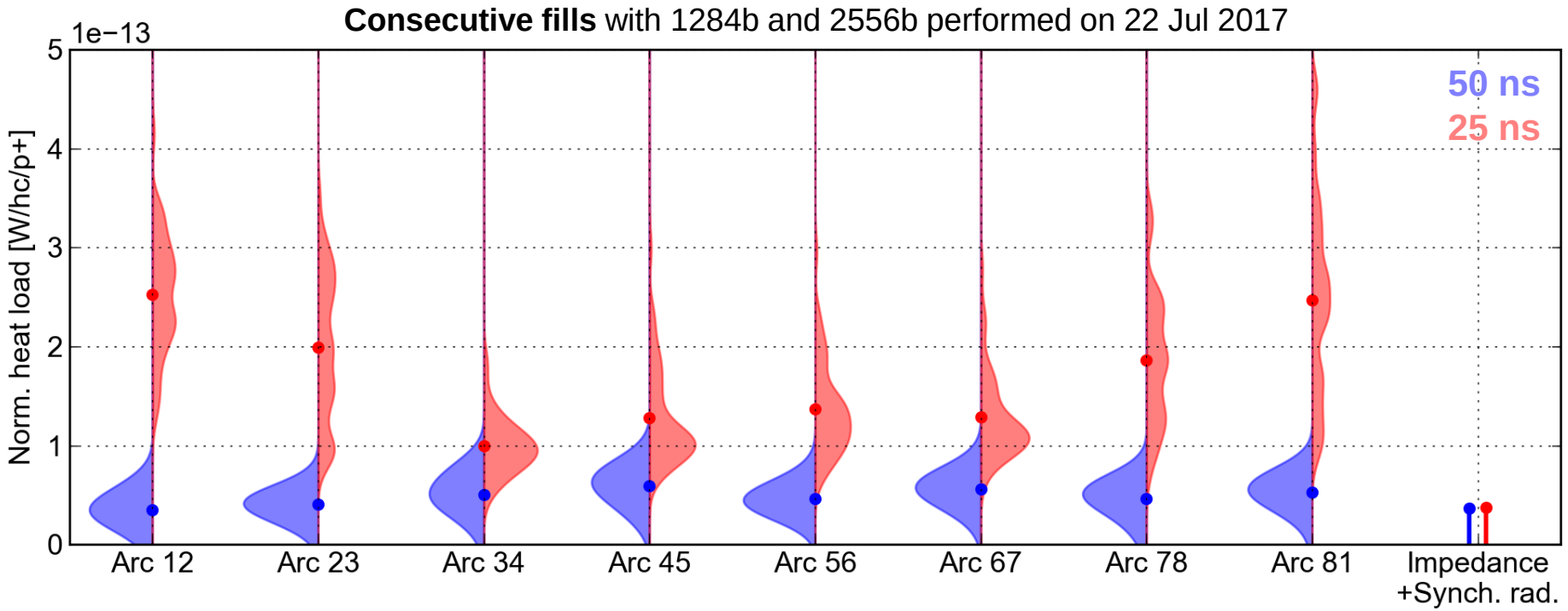
More info on impedance calculations can be found here

Full overview with **arc-by-arc averages** and **spread among cells**

- With 50 ns beams all arcs behave very similarly
- **Differences** in averages and spreads become **very strong with 25 ns beams**

e-cloud is the only mechanism we could think of that is consistent with such a distinctive dependence on the bunch spacing

→ Most likely we are looking for surface modifications in these areas (larger SEY) that are not mitigated by beam conditioning



More data on 50 ns test in 2017 can be found here

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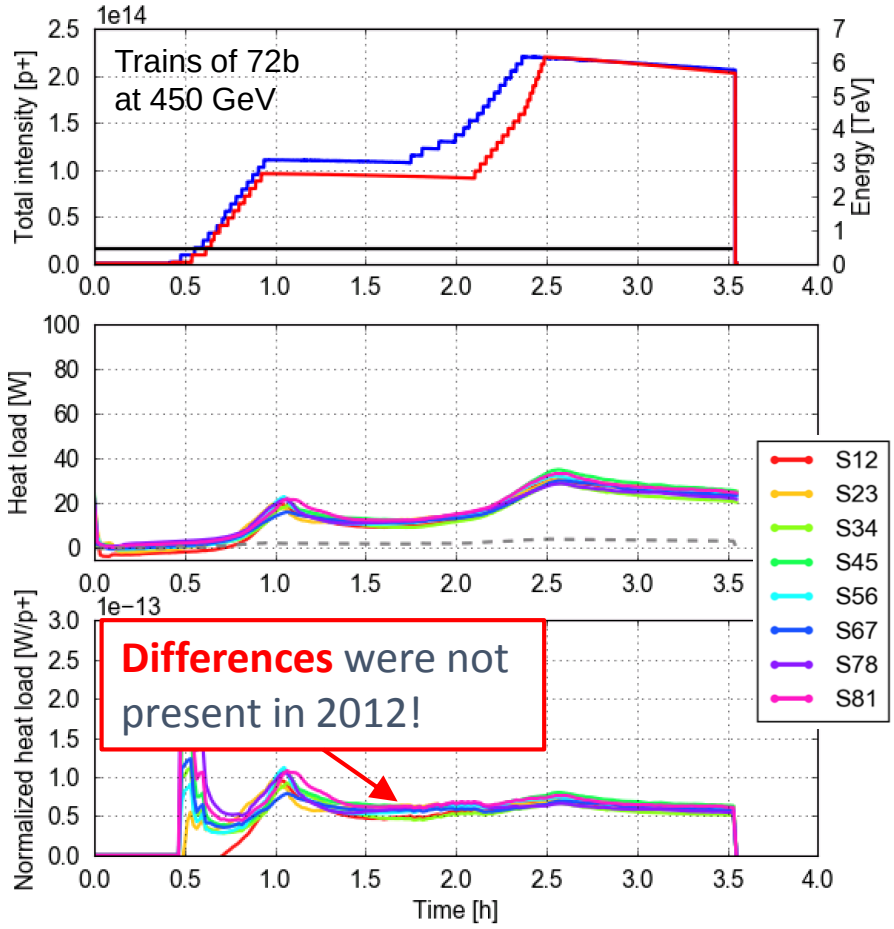
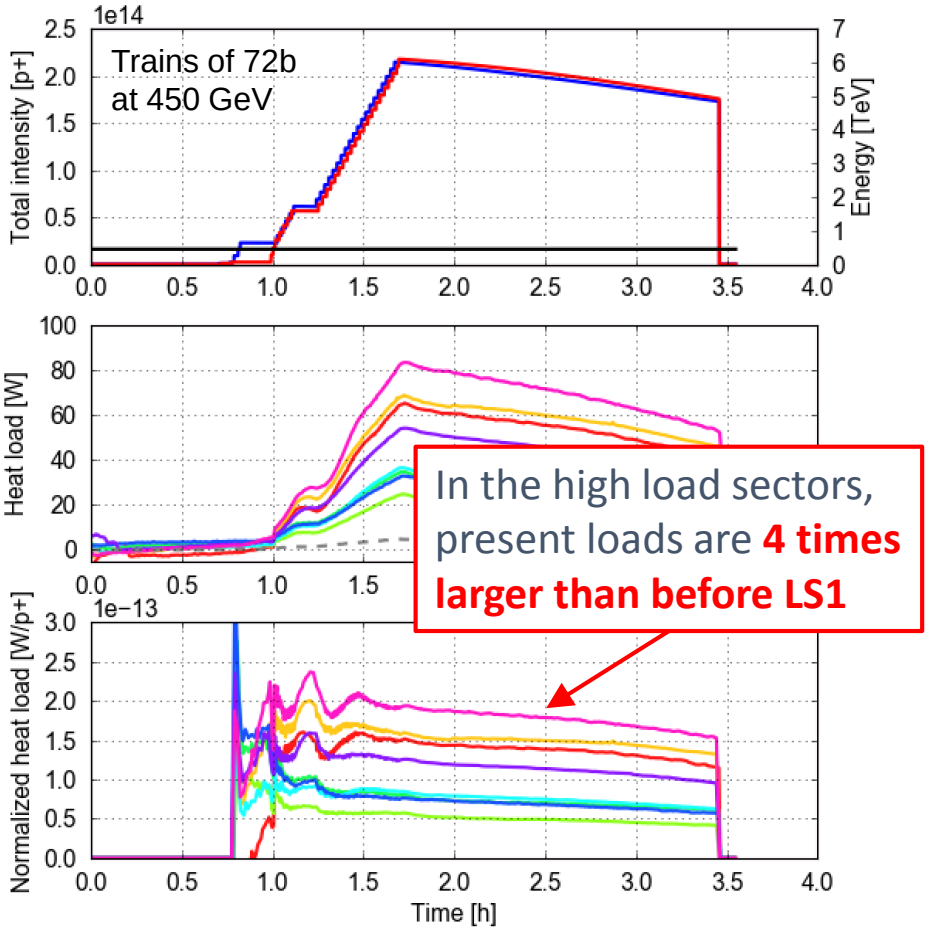
Were the differences always there? – situation before LS1

- A one-week test **period with 25 ns beams took place in 2012**
- We used the raw data recorded at that time **to reconstruct the cell-cy-cell heat load**, that can be directly compared with Run 2 data

2012 (after 3 d of scrubbing at 450 GeV)



2017 (after 7 d of scrubbing at 450 GeV)

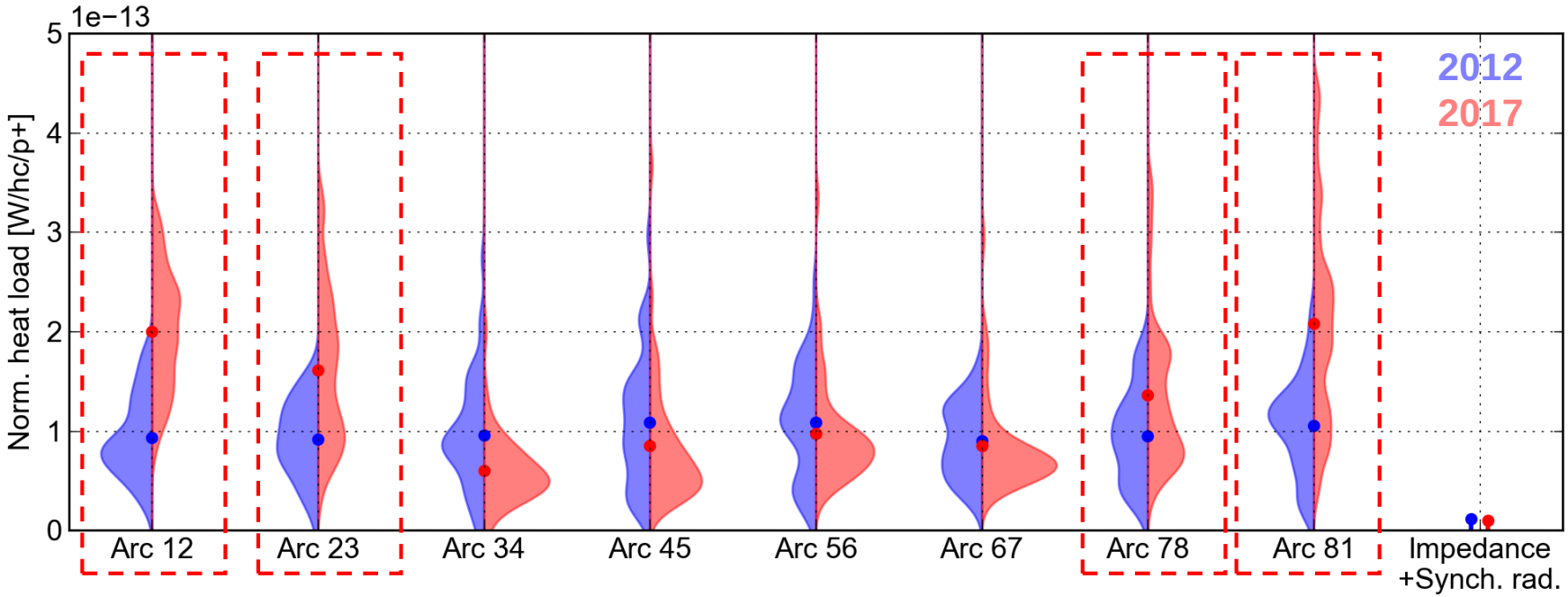


More information on 2012 vs Run 2 comparisons can be found here

Has it always been there?

- A **strong increase between Run 1 and Run 2** can be noticed in arcs 12, 23, 78, and 81

  → Was there any process/change during LS1 that could lead to a surface modification mainly in these sectors?



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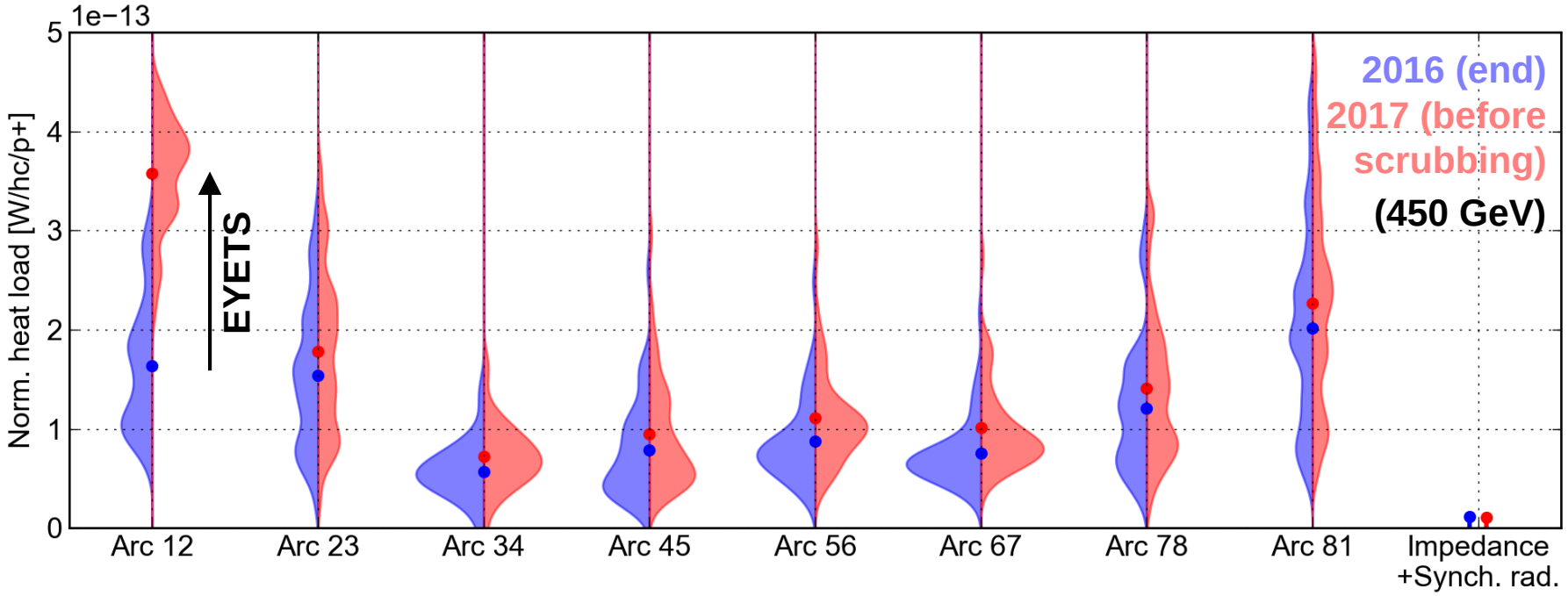
Effect of the 2016-17 EYETS

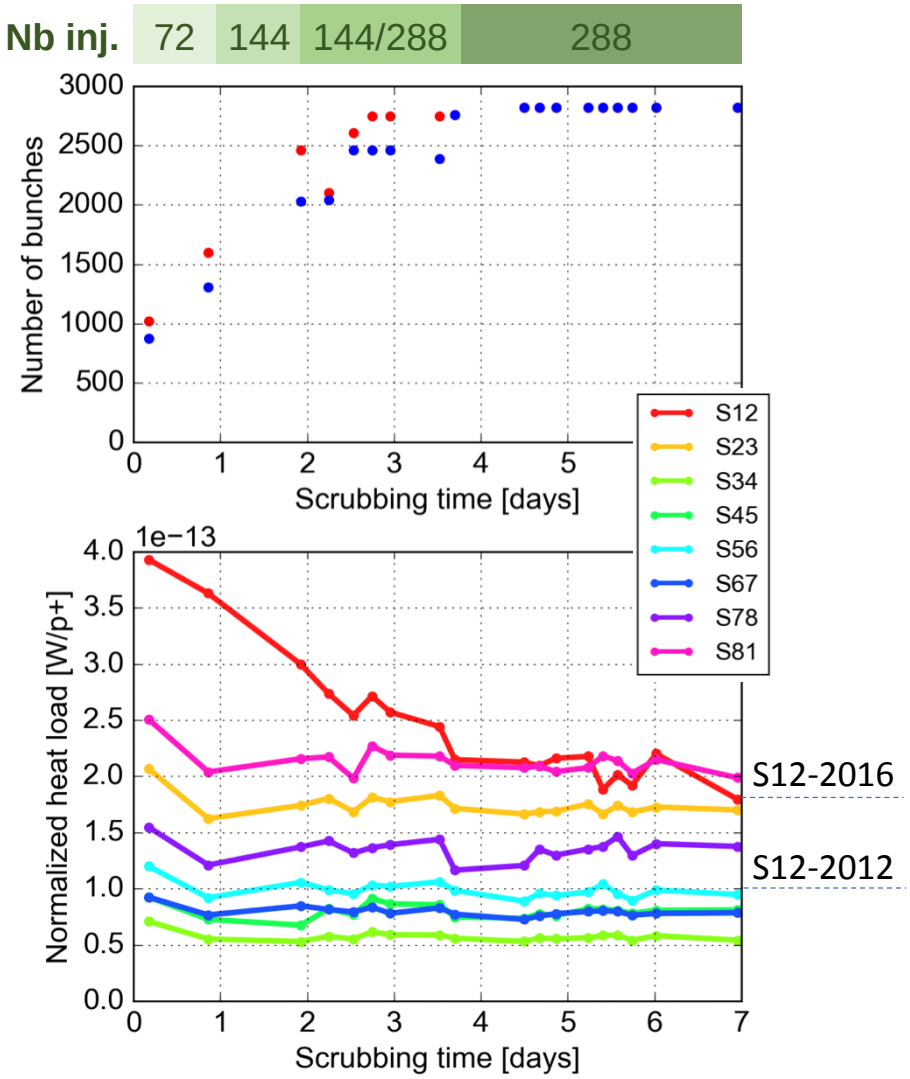
- In the **2016-17 EYETS**, Sector 12 had to be vented to replace a dipole magnet
  - → Useful to study the impact on heat loads of thermal cycle & venting
  - → Particular care taken in the beam screen cooling procedure

- Situation right after the EYETS (before scrubbing):
  - **Large deconditioning observed in S12**
  - Very **limited deconditioning observed in the other arcs**



Arc heat loads during the 2017 scrubbing run

- The data at the selected samples is used to have an **indication of the heat load evolution** during the scrubbing run



Main observations:

Sectors which stayed cold during the EYETS:

- Conditioning observed only **over the first 24h** (recovery of the deconditioning from the EYETS)
- **Difference between sectors** very similar to end-2016 and un-affected by the scrubbing run

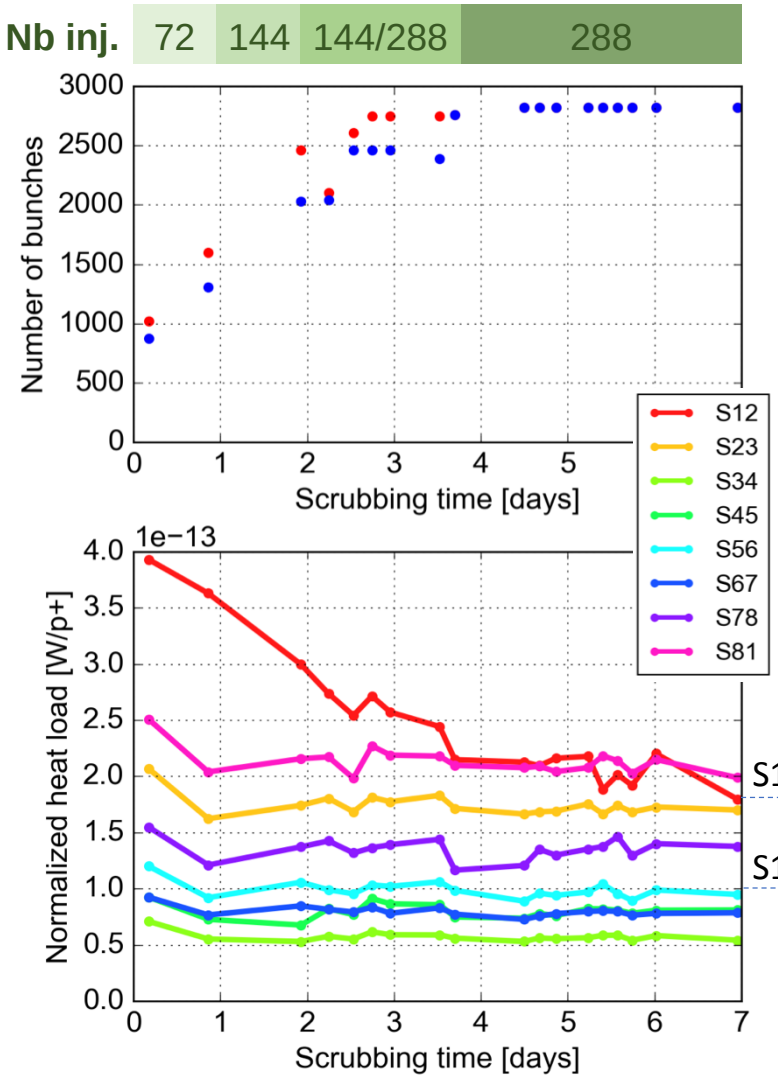
Sector 12 (opened during EYETS):

- Evident conditioning observed over **the first 4 d**
- **On day 4 heat load similar to end-2016** were reached
- **No evolution observed thereafter** (important info for planning future scrubbing runs)

Three days of scrubbing with **trains of 288b had no impact** on heat load levels nor on the difference between sectors (impossible to get back to 2012 levels)

Arc heat loads during the 2017 scrubbing run

- The data at the selected samples is used to have an **indication of the heat load evolution** during the scrubbing run



Proposed recipe
for future scrubbing runs 450 GeV

- **~12-24 h** required **after a Xmas stop** with no arc venting
- **~3-4 days** required to **recondition a single arc after venting**
- **~5-7 days** required in case the **full machine is exposed to air** (more difficult to ramp-up the intensity due to instabilities and poor beam quality)

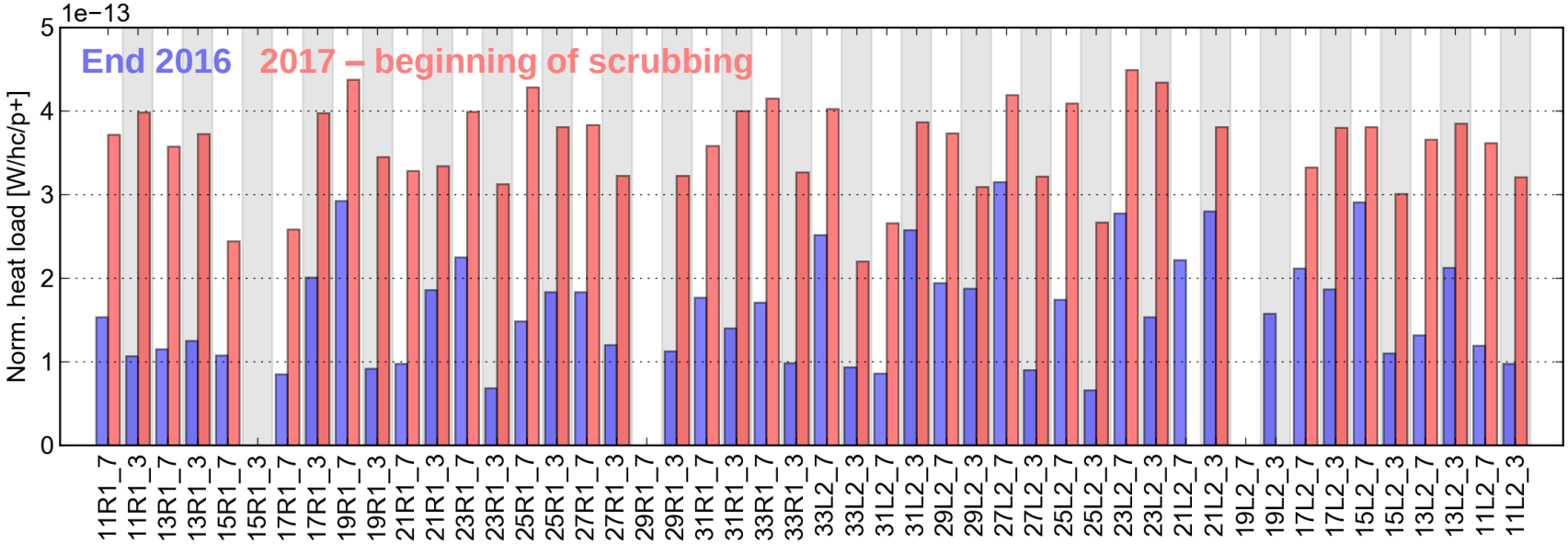
No evolution observed thereafter (important info for planning future scrubbing runs)

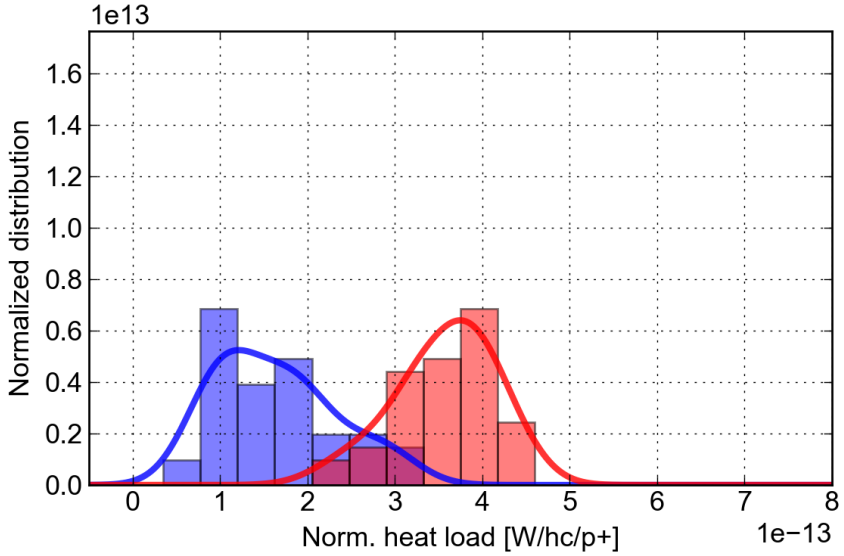
Three days of scrubbing with **trains of 288b had no impact** on heat load levels nor on the difference between sectors (impossible to get back to 2012 levels)

Cell-by-cell analysis at 450 GeV: S12

Particularly interesting to look at cell-by-cell behavior

- Heat load **increase observed on all cells**



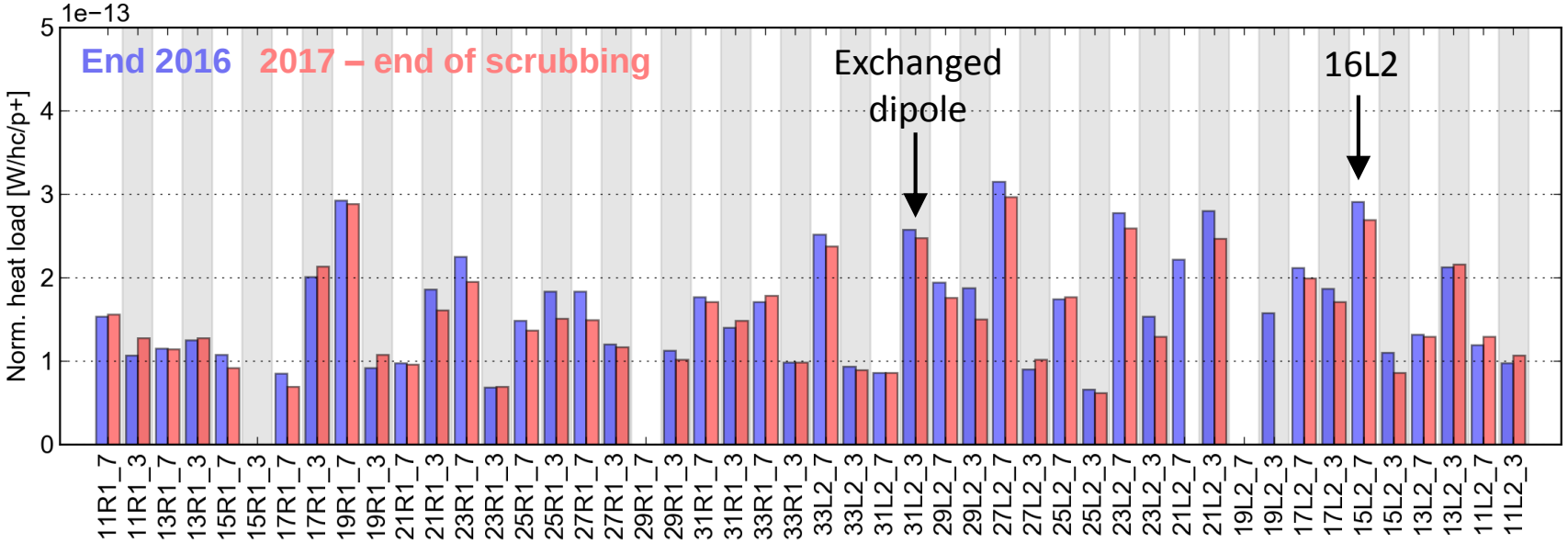


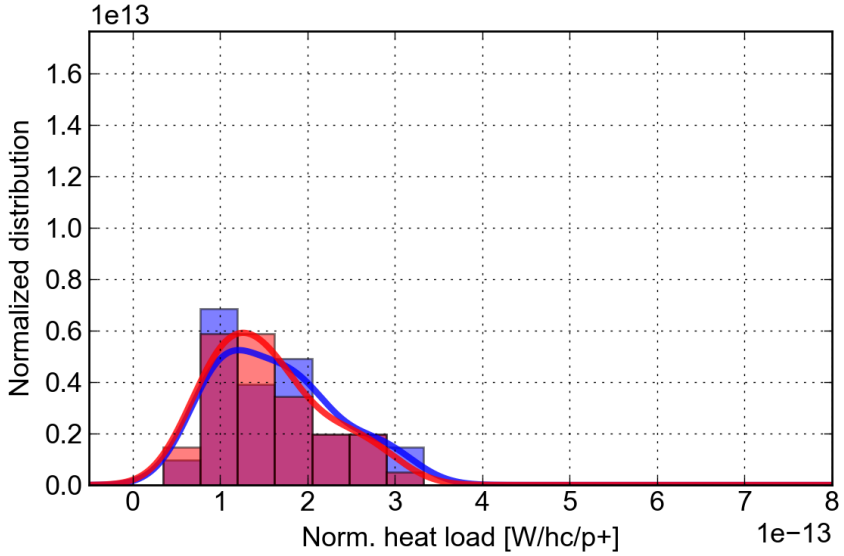
Fill	5433	5728
Started on	19 Oct 2016 22:26	30 May 2017 02:46
T_sample [h]	1.15	1.90
Energy [GeV]	450	450
N_bunches (B1/B2)	2040/2040	1308/1596
Intensity (B1/B2) [p]	2.14e14/2.20e14	1.37e14/1.77e14
Bun.len. (B1/B2) [ns]	1.17/1.18	1.22/1.26
H.L. S12 (avg) [W]	71.03	111.94
H.L. S12 (std) [W]	28.69	16.76
H.L. exp. imped. [W]	4.92	3.30
H.L. exp. synrad [W]	0.00	0.00
T_nobeam [h]	0.01	0.50

Cell-by-cell analysis at 450 GeV: S12

- Situation at the end of scrubbing run was practically **identical to end-2016**

→ Effect of LS1 is somehow more permanent than effect of 2016-17 EYETS

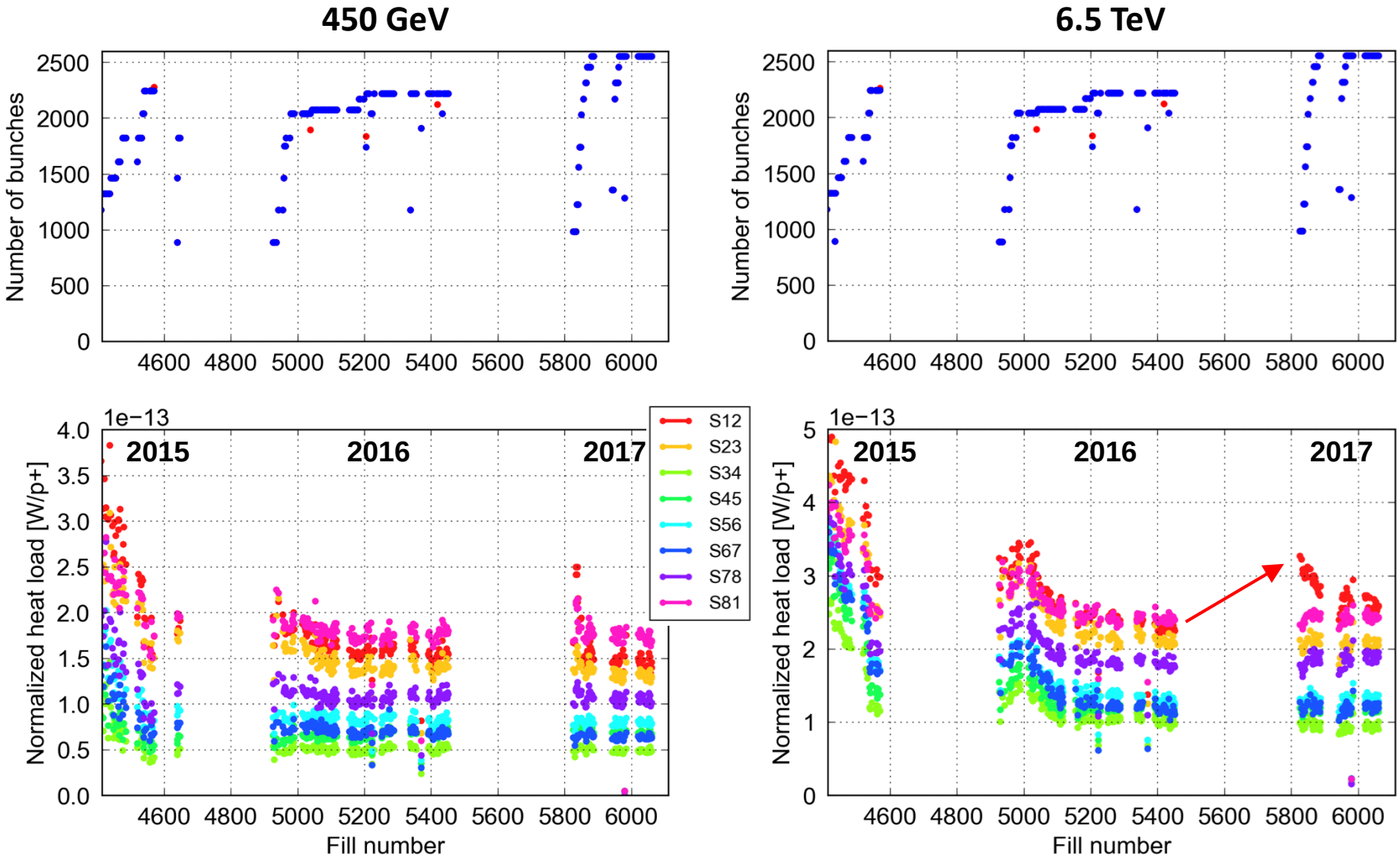




Fill	5433	5814
Started on	19 Oct 2016 22:26	11 Jun 2017 18:55
T_sample [h]	1.15	1.80
Energy [GeV]	450	450
N_bunches (B1/B2)	2040/2040	2040/2040
Intensity (B1/B2) [p]	2.14e14/2.20e14	2.13e14/2.16e14
Bun.len. (B1/B2) [ns]	1.17/1.18	1.15/1.28
H.L. S12 (avg) [W]	71.03	66.24
H.L. S12 (std) [W]	28.69	26.43
H.L. exp. imped. [W]	4.92	4.58
H.L. exp. synrad [W]	0.00	0.00
T_nobeam [h]	0.01	0.70

Heat load data from physics fills

- Apart from S12 slow reconditioning at high energy, **no evolution is observed since mid 2016**



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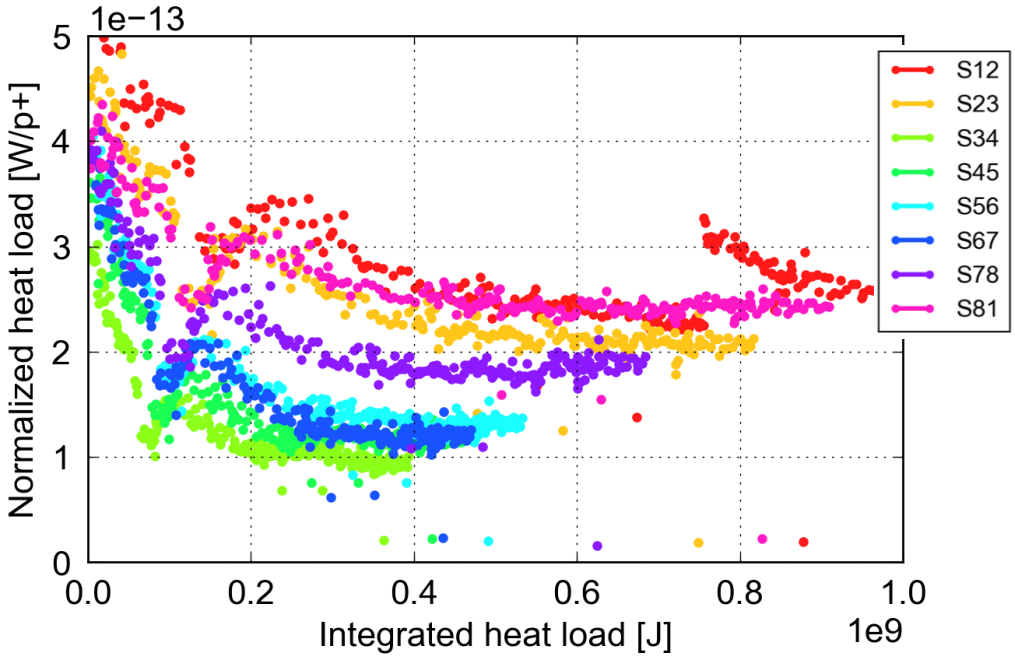
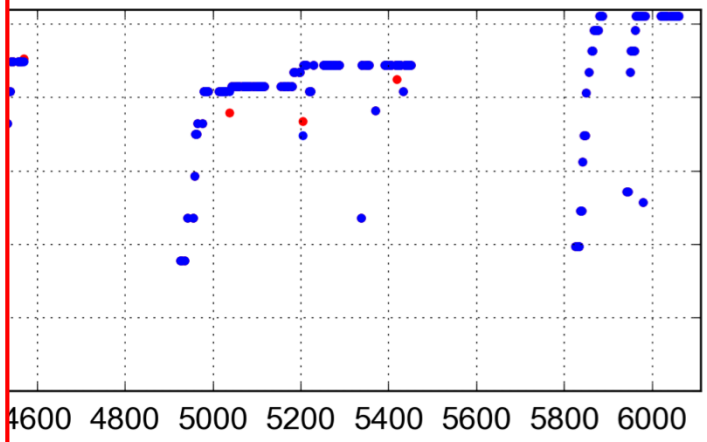
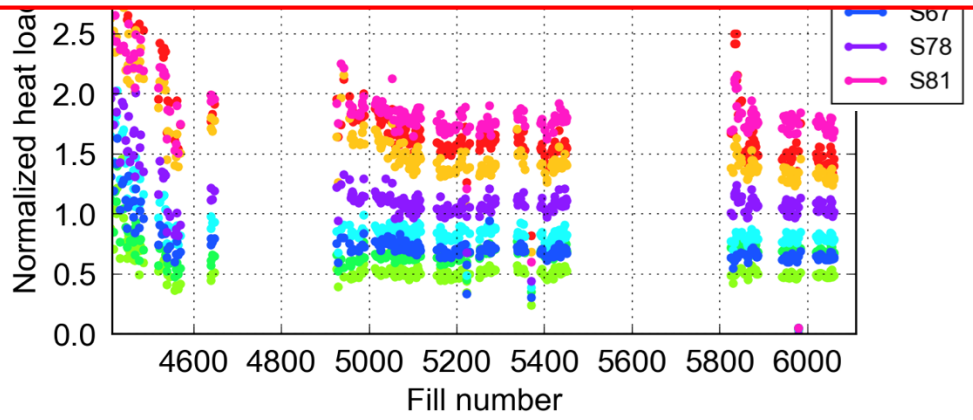
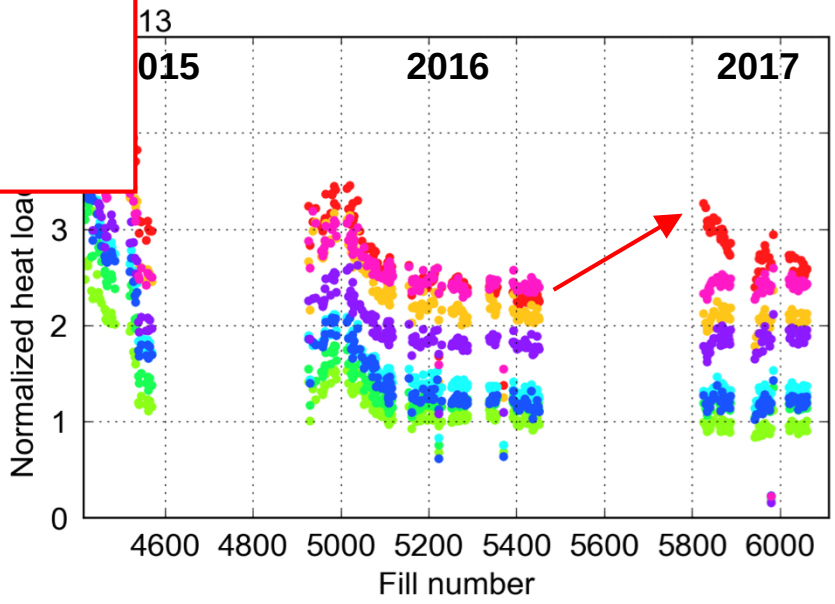
Experimental scrubbing curve at 6.5 TeV



6.5 TeV







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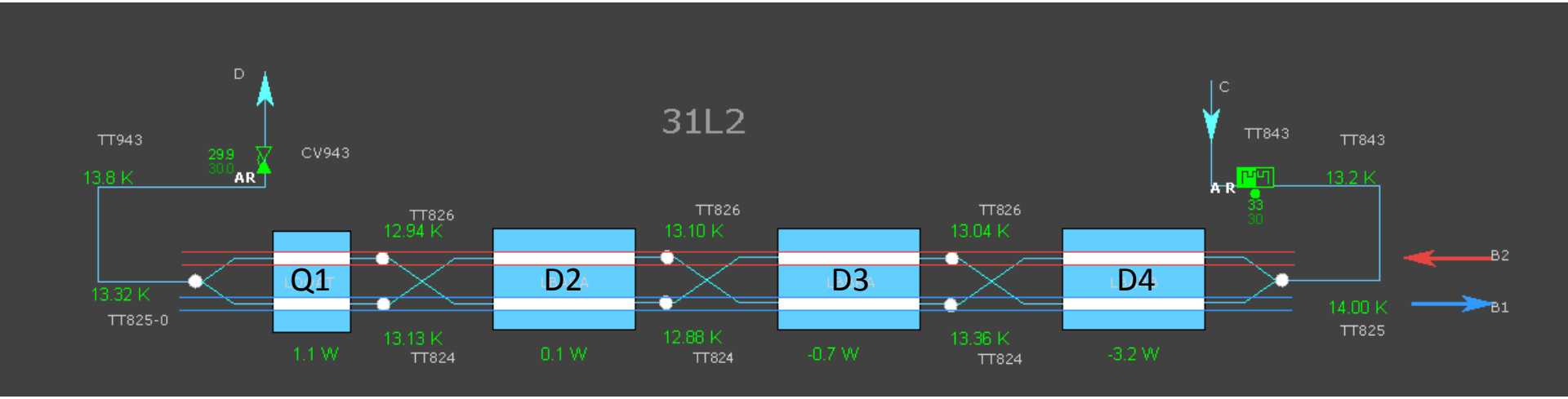
Heat loads in instrumented cells

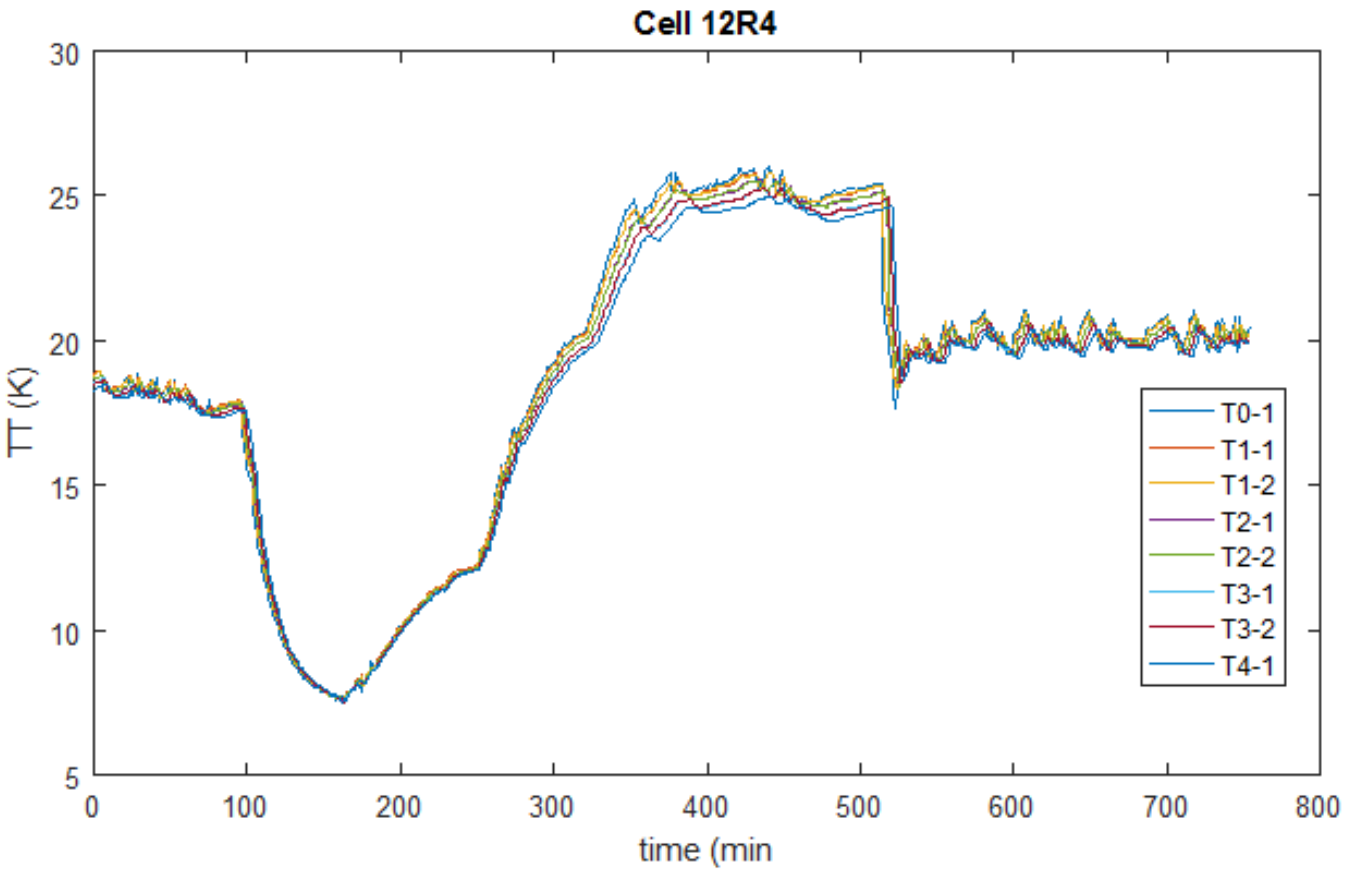
- Cells equipped with **extra thermometers to measure the heat loads magnet by magnet**
  - **3 cells in S45** were instrumented during LS1 (they always showed relatively low heat loads 2016-17)
  - **1 cell in S12** instrumented during the EYETS (it shows a large heat load)



- TE-CRG prepared the procedure to reconstruct the load in each magnet and the list of devices for which the measurement is reliable

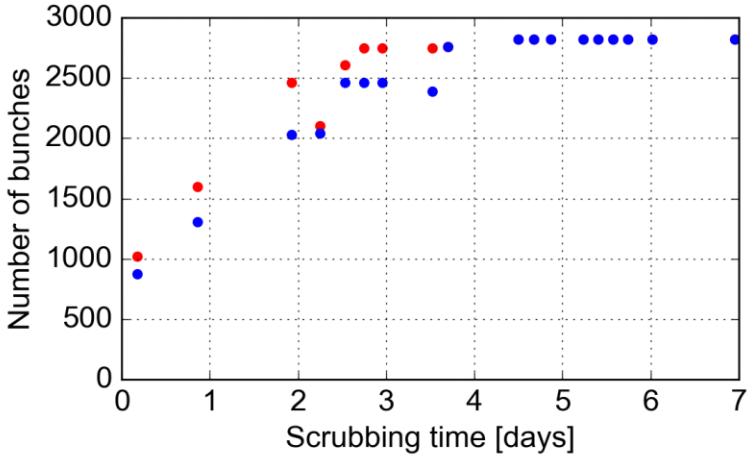
Heat loads in instrumented cells

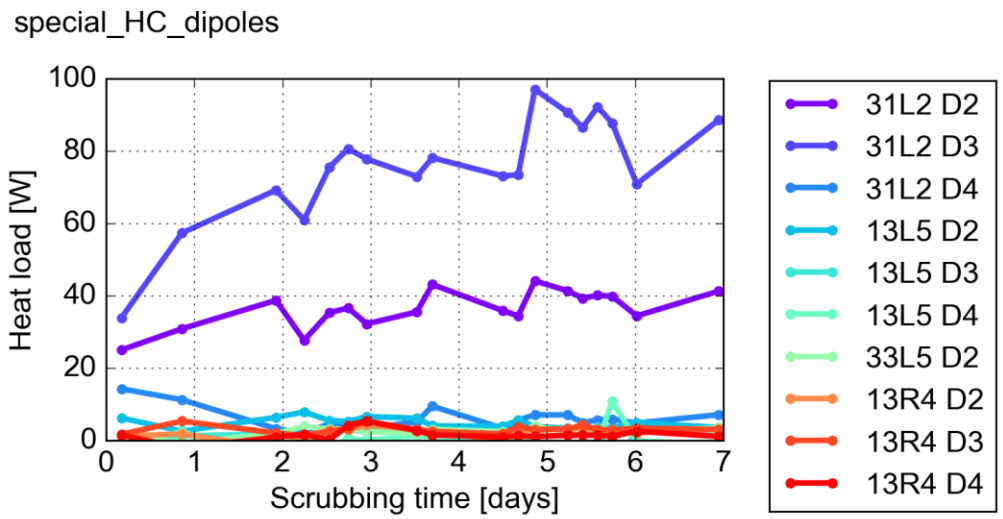
- Tests performed without beam by TE-CRG confirm **that temperature probes are very accurate** → error introduced on the heat load smaller than 0.5 W

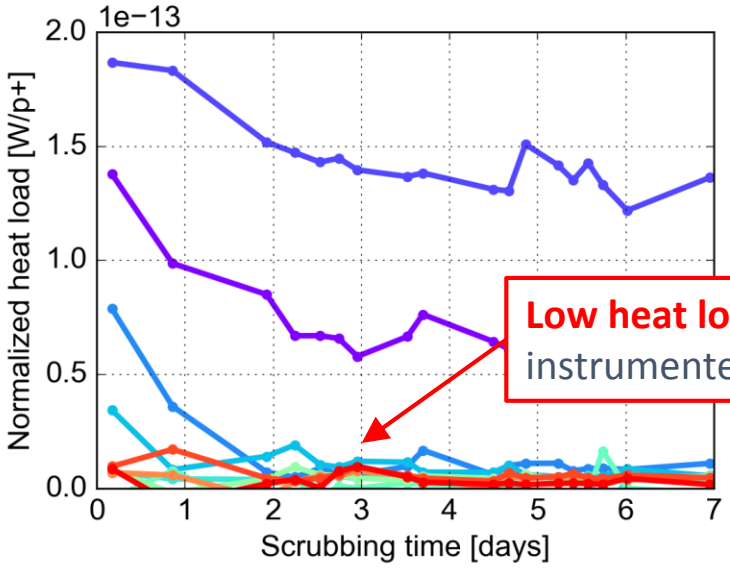


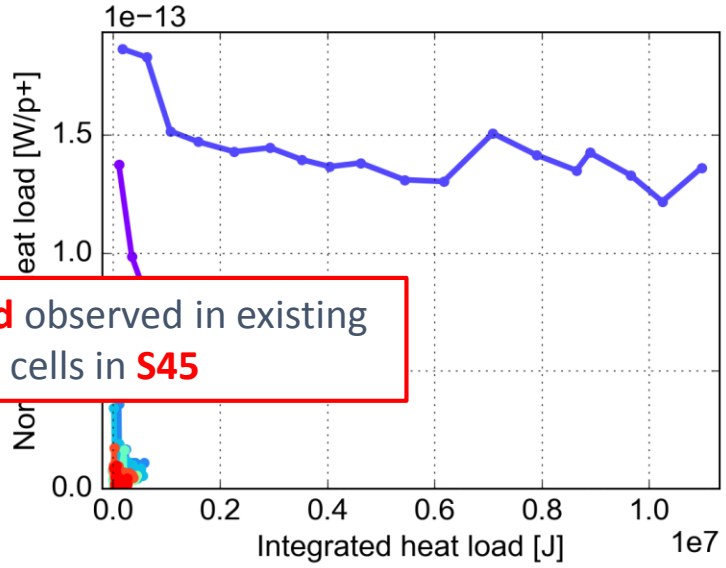
Dipole magnets: scrubbing run data

Nbun inj.	72	144	144/288	288





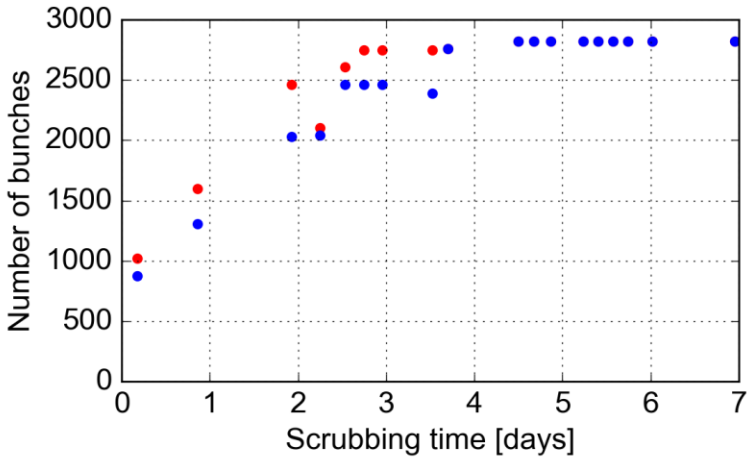


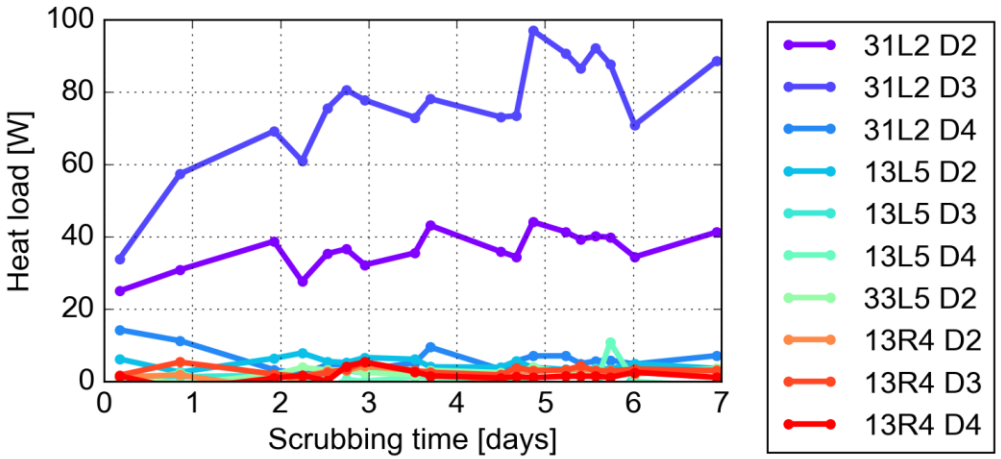


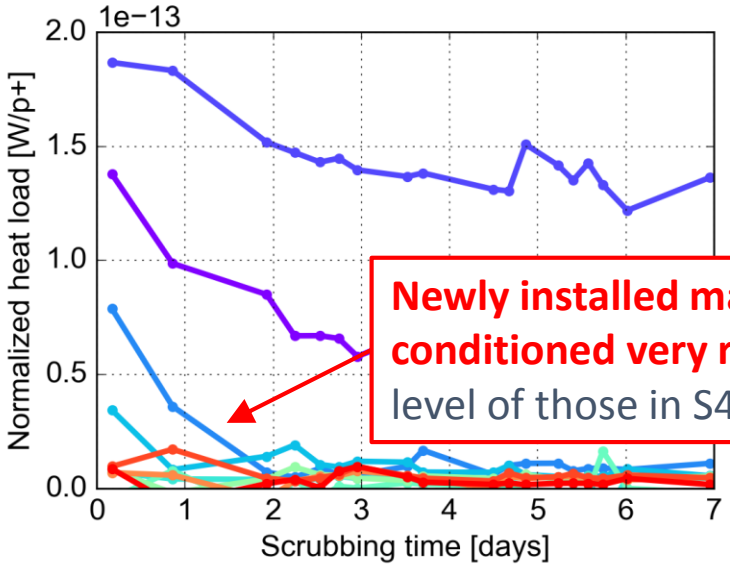
Low heat load observed in existing instrumented cells in **S45**

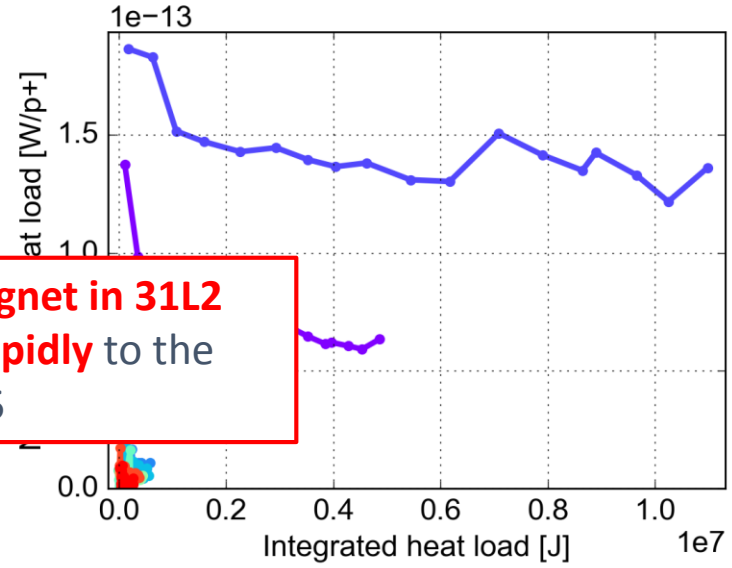
Dipole magnets: scrubbing run data

Nbun inj. 72 | 144 | 144/288 | 288









Newly installed magnet in 31L2 conditioned very rapidly to the level of those in S45

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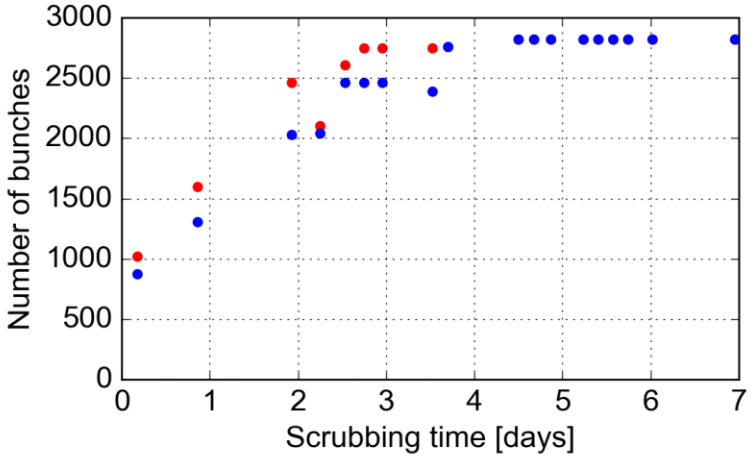
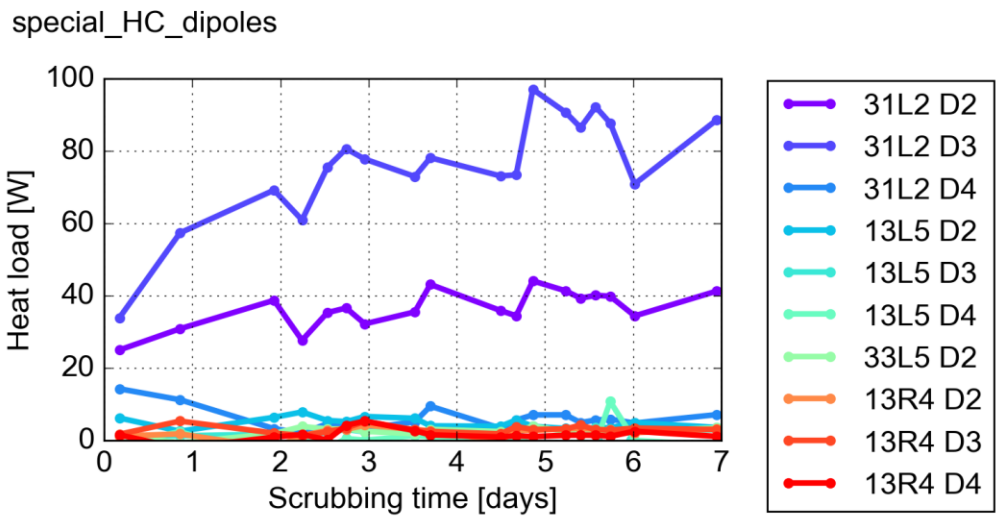
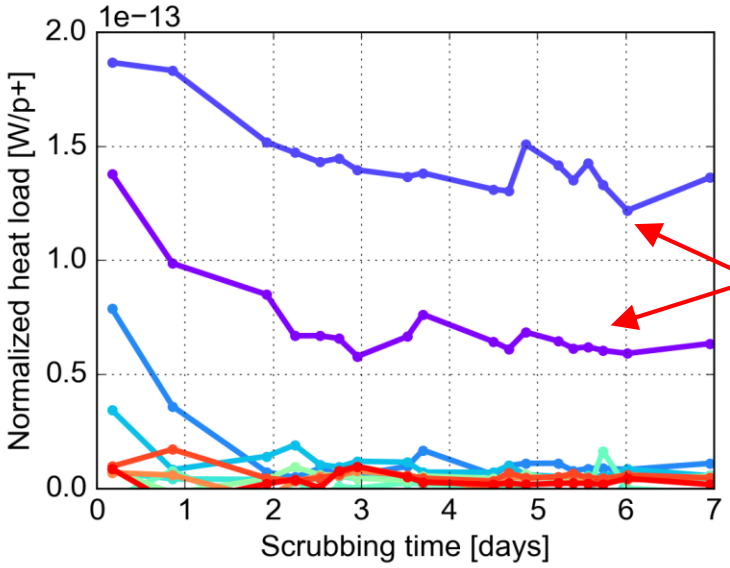
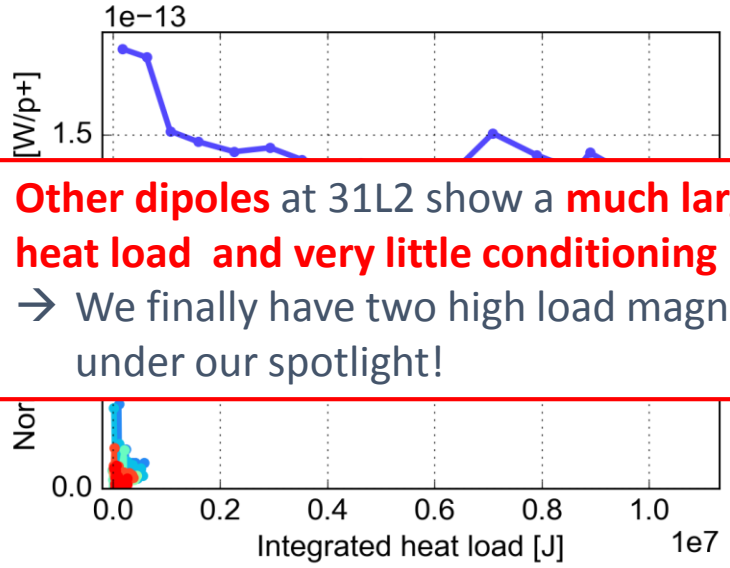






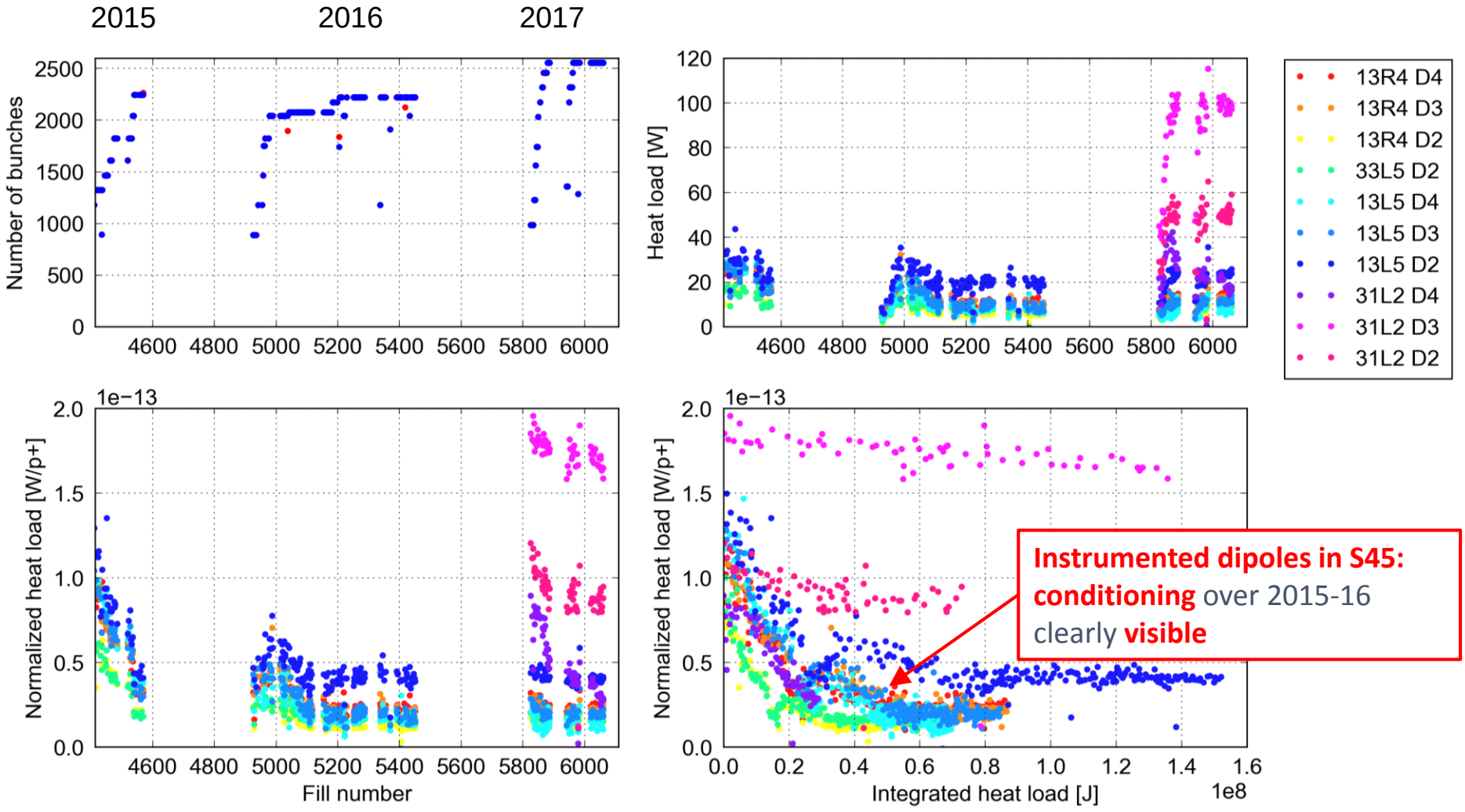


Other dipoles at 31L2 show a **much larger heat load and very little conditioning**

→ We finally have two high load magnets under our spotlight!

Dipole magnets: evolution at 6.5 TeV during run 2

- Complete evolution of the average arc **heat loads at 6.5 TeV over Run 2**
- Only **fills that reached stable beams** are included (→ fills from the scrubbing run are not shown)



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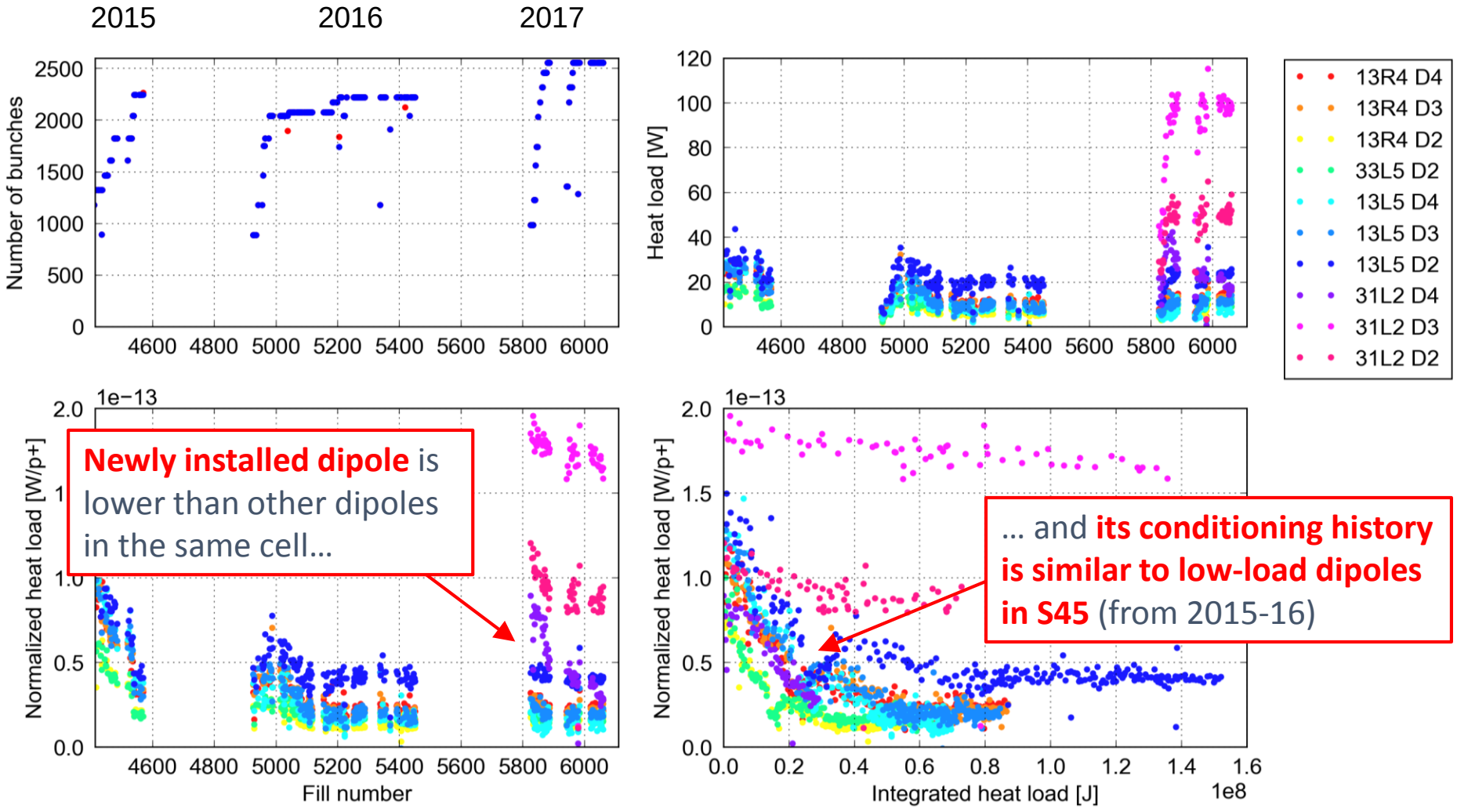

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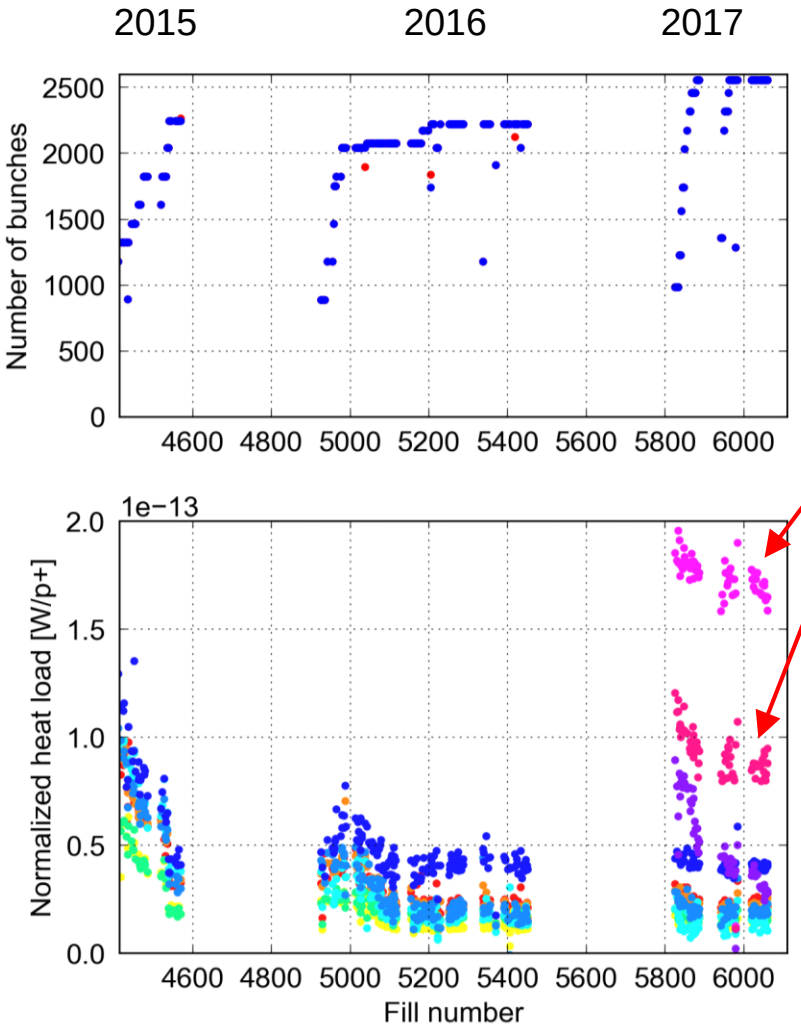
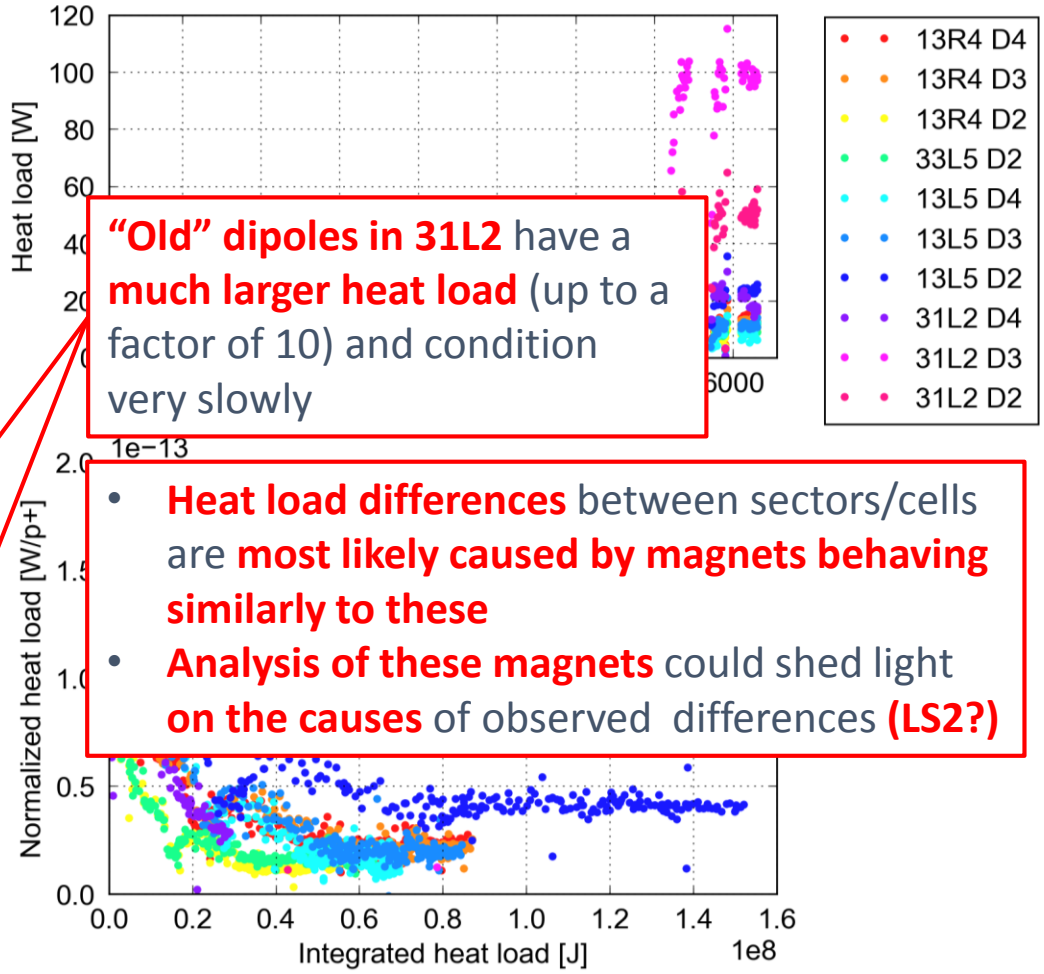
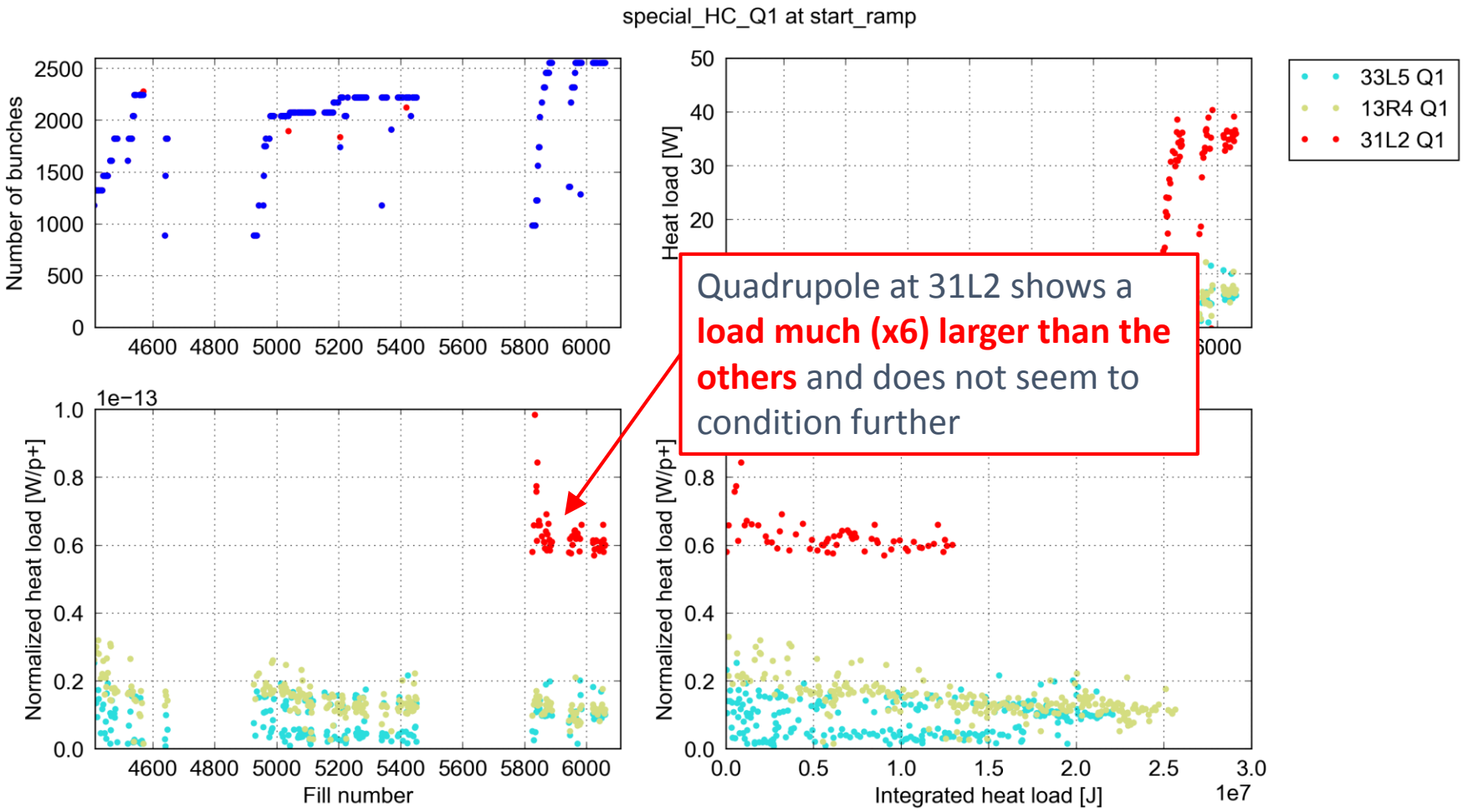




"Old" dipoles in 31L2 have a **much larger heat load** (up to a factor of 10) and condition very slowly

- **Heat load differences** between sectors/cells are **most likely caused by magnets behaving similarly to these**
- **Analysis of these magnets** could shed light **on the causes** of observed differences **(LS2?)**

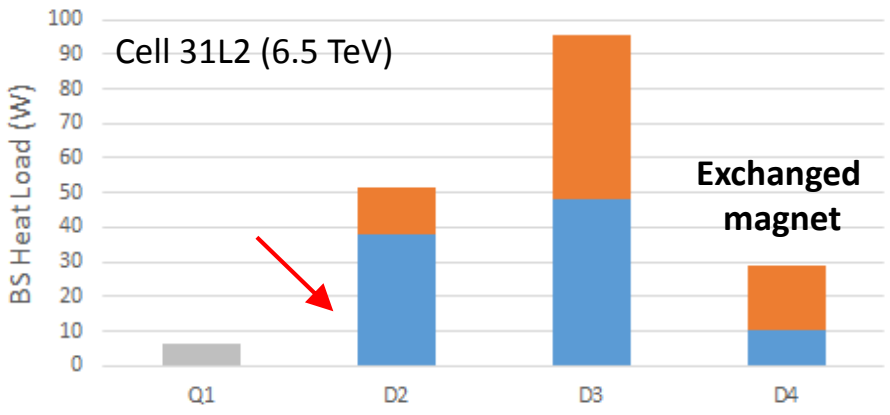
Quadrupole magnets: conditioning

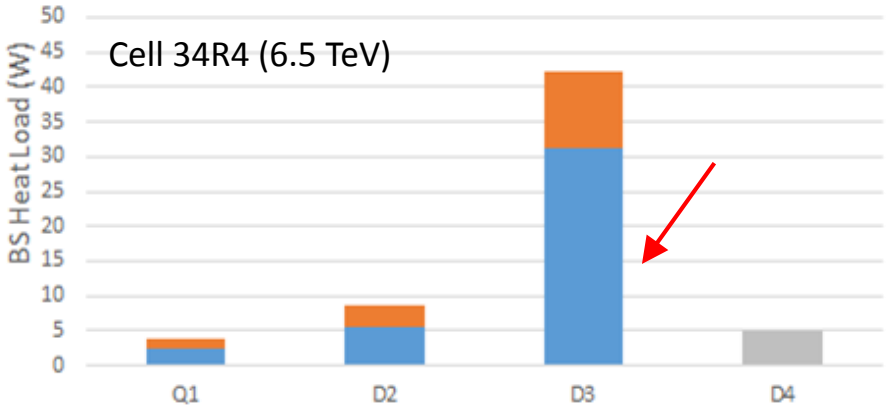


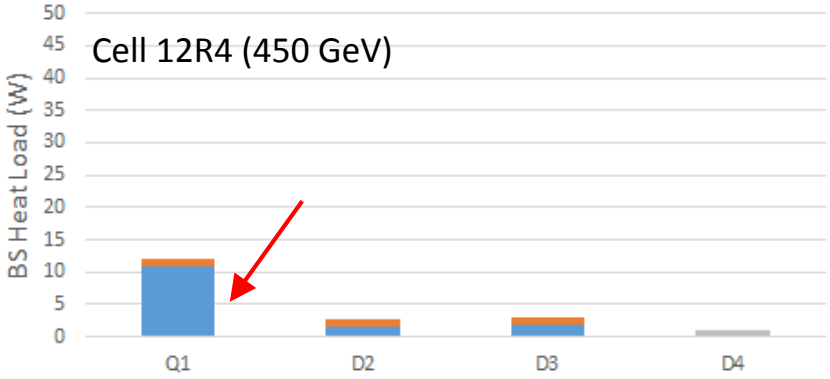
Quadrupole at 31L2 shows a **load much (x6) larger than the others** and does not seem to condition further

Distinction between the two apertures

- Temperature probes are installed on each cooling pipe → we can **disentangle the heat loads on the two aperture**
- In different high load magnets, heat load is found to be **strongly asymmetric between B1 and B2!**
- **Analysis by cryo team** confirmed that:
  - Asymmetry is **NOT due to a cryogenic hydraulic problem** in the cooling pipes
  - Asymmetry is **NOT observed with 50 ns beams**

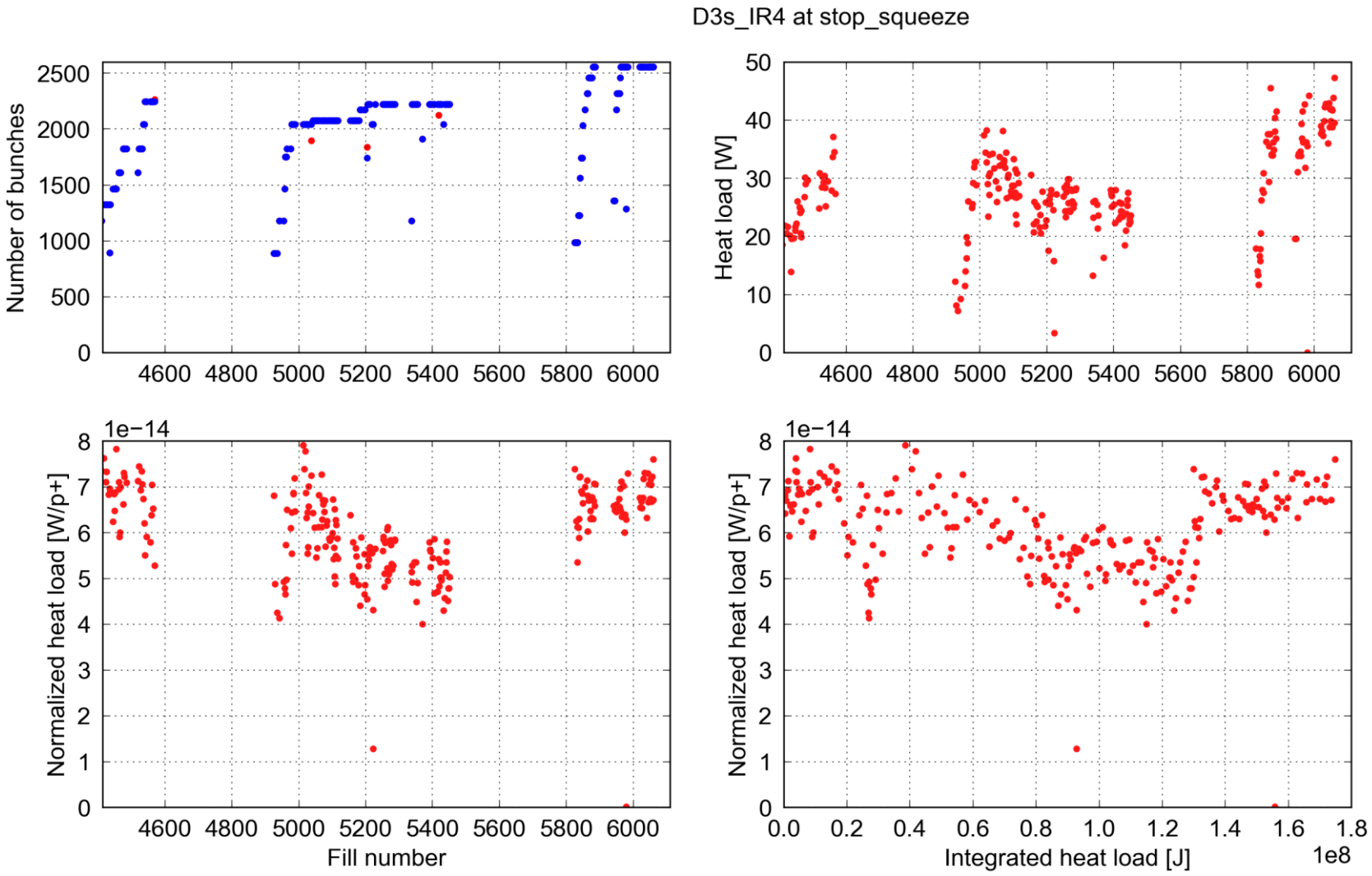






Observations from stand alone magnets

- Heat loads measured in **stand alone magnets** shows a similar picture



More information on stand alone magnets can be found here

Outline

- **Introduction**
  - Heat load observations
  - Differences between sectors and between cells
- **Can it be impedance heating?**
  - Observations with different bunch spacing
- **Were the differences always there?**
  - Heat loads with 25 ns in 2012
- **What is the impact of venting, thermal cycle and scrubbing?**
  - Experience with S12 (and others) after 2016-17 EYETS
- **Can we localize the heat deposition magnet by magnet?**
  - Analysis of measurements from instrumented cells and stand-alone magnets
- **Summary and conclusions**

Summary and conclusions

General features:

- **Large beam induced heat loads** are measured in the LHC in Run2. **Large differences** are observed between the arcs and between different cells

- Fills with different bunch pattern show that the difference in **heat load is observed only with 25 ns**
  - → This allows **excluding that the heat load is impedance driven** (analysis by the impedance team)
  - → The **only mechanism we could identify that matches** this distinctive dependence on the bunch spacing is **e-cloud**

Effect of long stops and thermal cycles

- Analysis of **2012 data** collected with **25 ns** beams showed that:
  - **Differences** between sectors **were not present before LS1**
  - At that time heat loads in sectors 12, 23, 78 and 81 were **significantly lower compared to present values** (there was a net degradation)

- **Deconditioning** was observed after the **thermal cycle of S12 in the EYETS** (2016-17)
  - **~4 days** of scrubbing were **sufficient to recover** the end-2016 state at 450 GeV
  - **No evolution observed thereafter** → impossible to get back to 2012 levels

- The effect of the 2016-17 warm-up on S12 could be easily reverted by scrubbing, the **effect of LS1 is somehow more permanent** → we need to understand why…
  - → Important to collect feedback from the equipment groups involved in the LS1 work in the arcs (e.g. magnets, vacuum)
  - → Any precaution that we could take to avoid further degradation in LS2?

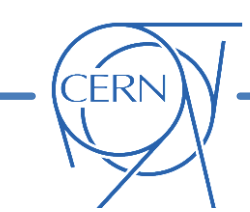
Summary and conclusions

Instrumented cells

- In several cases heat loads are **strongly asymmetric between the two apertures**
- Instrumentation **installed in cell 31L2 during the EYETS** is providing extremely interesting data:
  - The **exchanged dipole conditioned very rapidly**
  - **Other dipoles in the cell** (unchanged) **show significantly larger heat loads** (up to a factor of 10!) → we finally got a "bad magnet" under our spotlight
    - → **Analysis of the beam screens** in these high-load magnets **could provide important information** on the causes of observed differences **(LS2?)**
- In LS2 **sensors could be added in other cells** (the proposal agreed with cryo is to have at least one instrumented cell per sector)

Cryo calibrations excluded that differences are caused by a measurement artifact:

- A **further check** with beam could be made parasitically (on a few selected cells) working with **constant valve opening and regulating the temperature with the electric heaters**



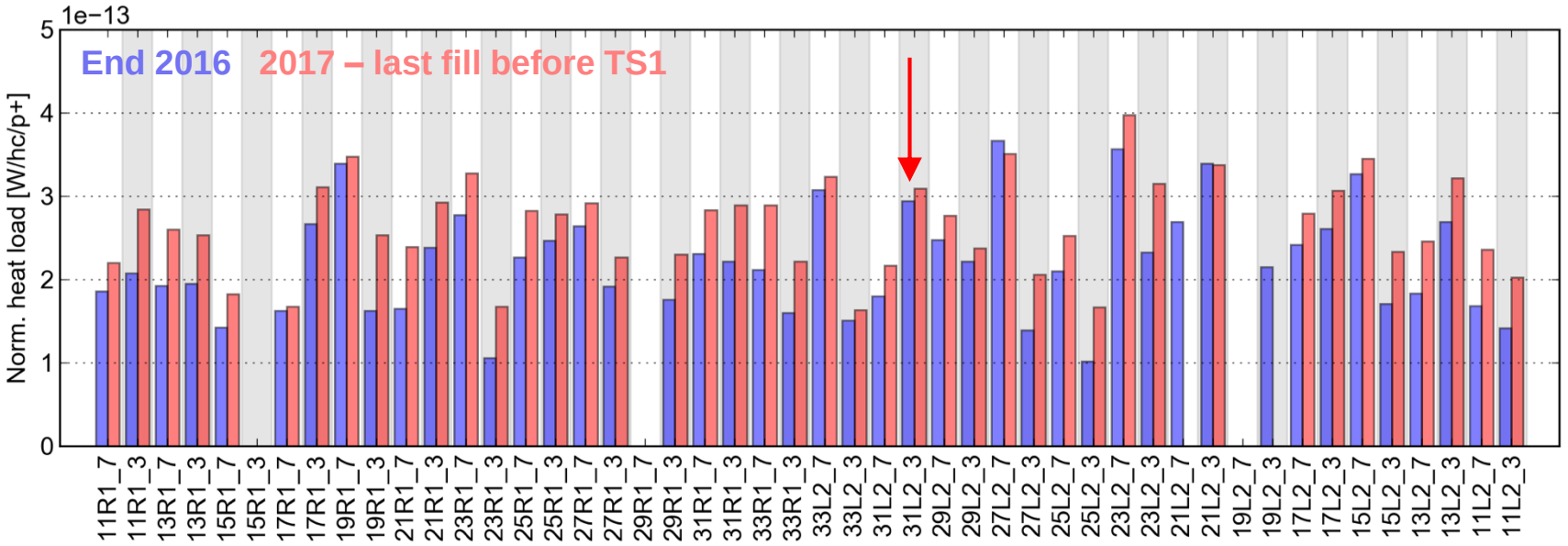
Thanks for your attention

What about the dipole that was taken out?

- No magnet-by-magnet diagnostics in 31L2 before the EYETS but:
  - **Total cell heat load** measured now is **extremely similar to end-2016 values**
  - Other cells show that **other magnets have practically recovered** the end-2016 conditioning state

→ This means that the **old magnet was behaving similarly to the newly installed one**

→ **The extracted magnet was a low-load magnet** (consistent with the fact that no issue was revealed by the lab analysis by TE-VSC)

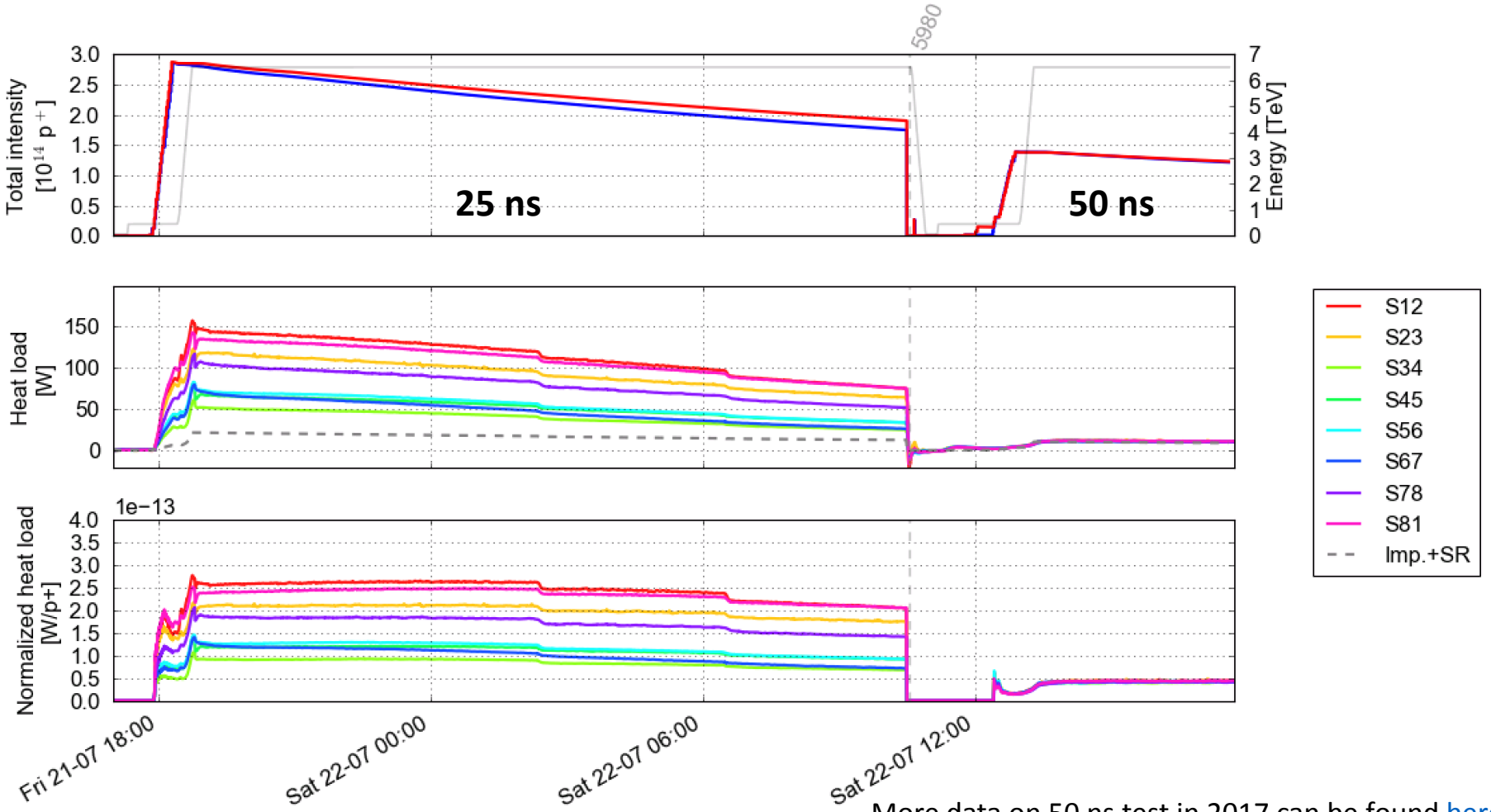


Test fill with 50 ns in 2017

Electron cloud suppression with 50 ns confirmed by heat load measurements on the beams-screens

→ Consistent with expectations from impedance and synchrotron radiation

→ Large **differences between sectors** observed with 25 ns are not visible **with 50 ns**



More data on 50 ns test in 2017 can be found here

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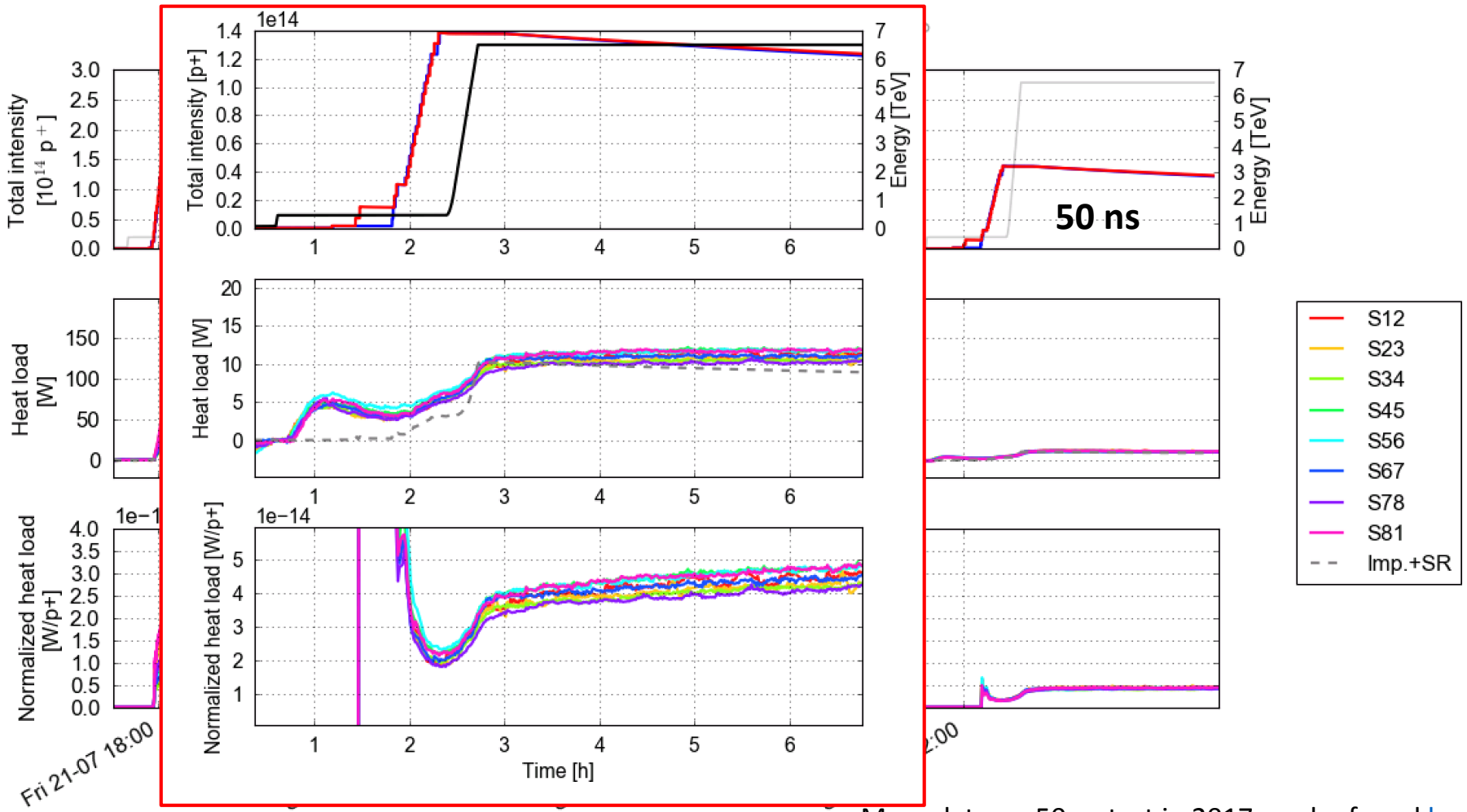

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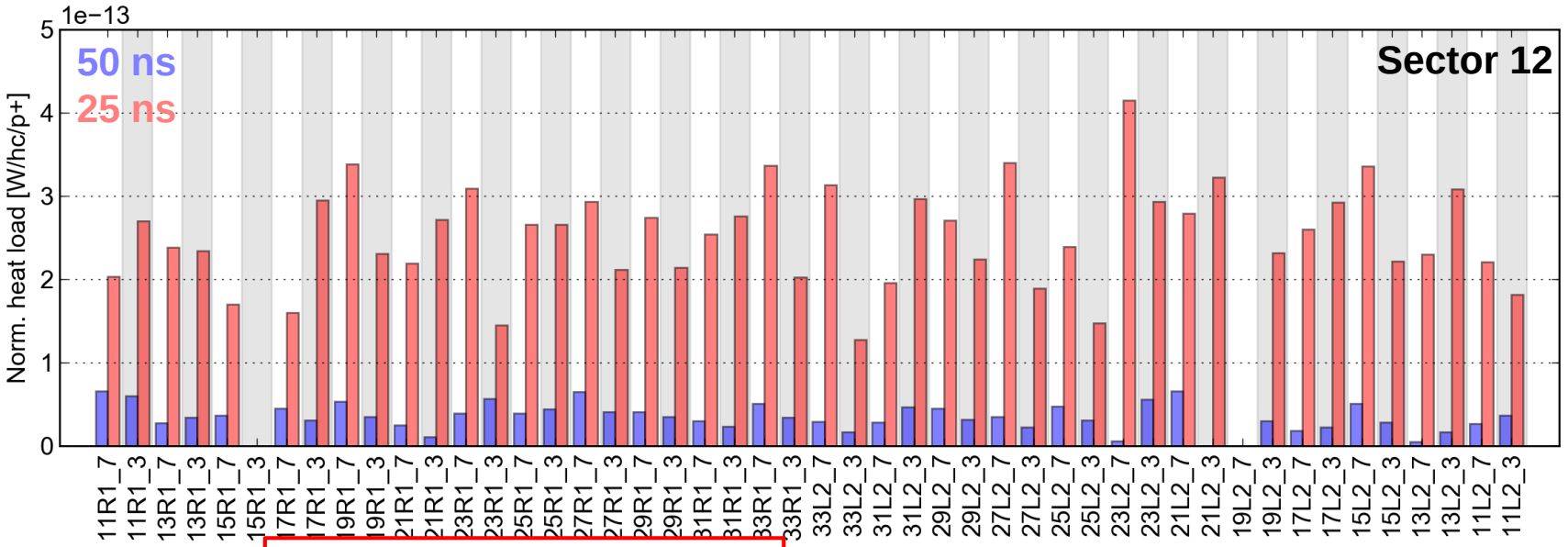
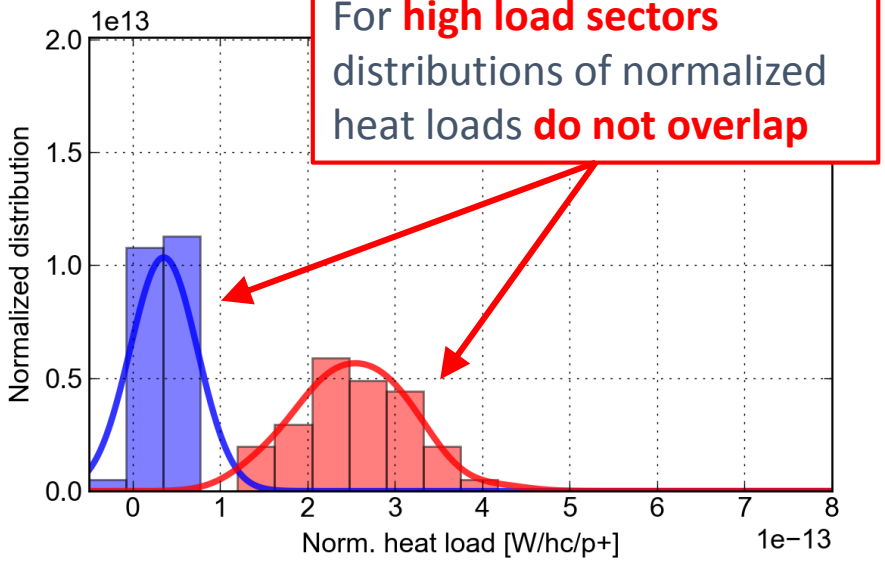
Cell-by-cell comparison

Reduction of normalized heat load is **observed in all cells**





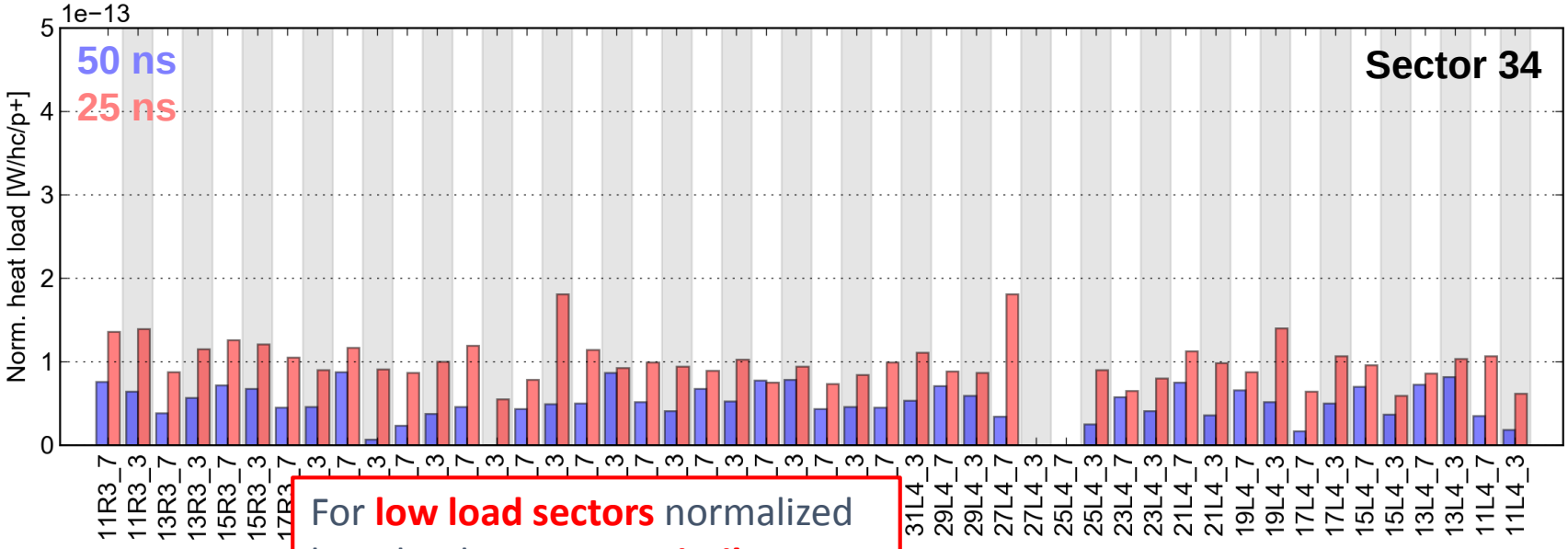
For **high load sectors** distributions of normalized heat loads **do not overlap**

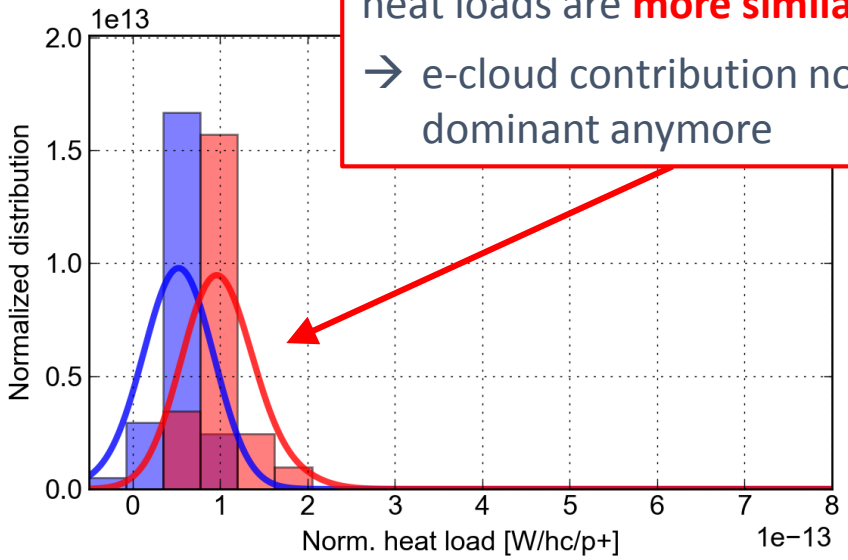
	50 ns	25 ns
Fill	5980	5979
Started on	22 Jul 2017 10:34	21 Jul 2017 15:41
T_sample [h]	3.00	3.30
Energy [GeV]	6499	6499
N_bunches (B1/B2)	1284/1284	2556/2556
Intensity (B1/B2) [p]	1.38e14/1.38e14	2.80e14/2.84e14
Bun.len. (B1/B2) [ns]	1.08/1.09	1.07/1.07
H.L. S12 (avg) [W]	9.72	142.57
H.L. S12 (std) [W]	4.55	33.44
H.L. exp. imped. [W]	4.33	9.20
H.L. exp. synrad [W]	5.87	12.01
T_nobeam [h]	0.63	2.00

More data on 50 ns test in 2017 can be found here

Cell-by-cell comparison

Reduction of normalized heat load is **observed in all cells**





For **low load sectors** normalized heat loads are **more similar**

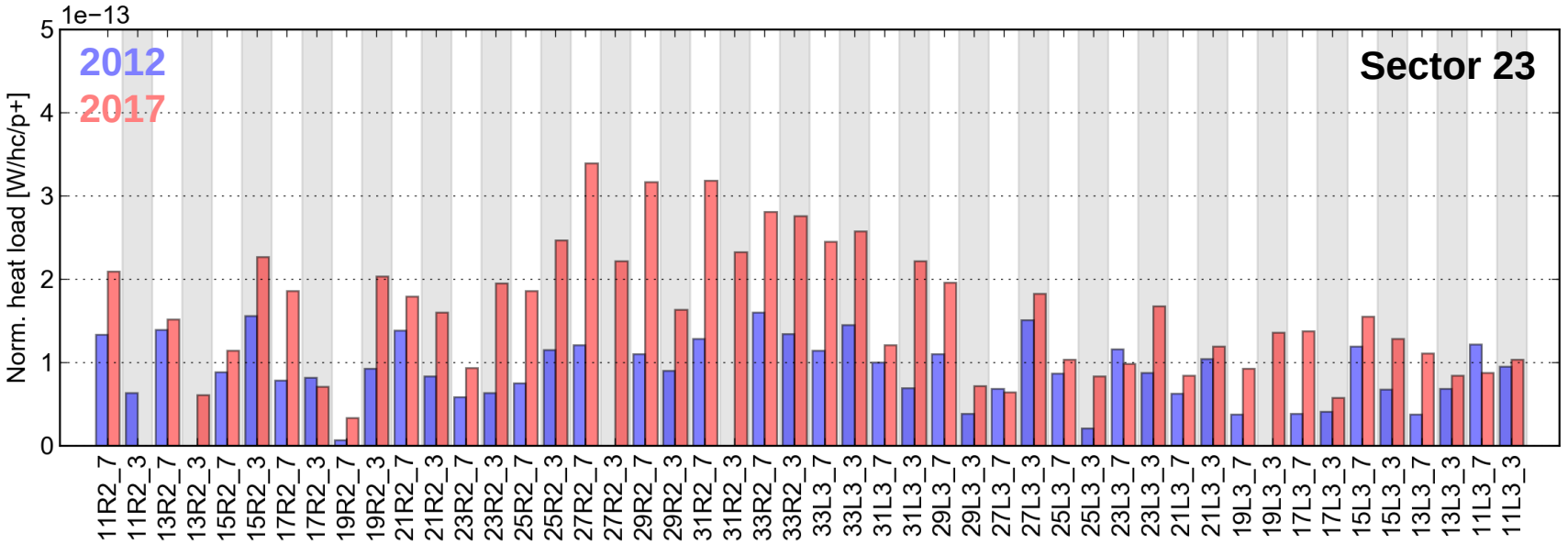
→ e-cloud contribution not dominant anymore

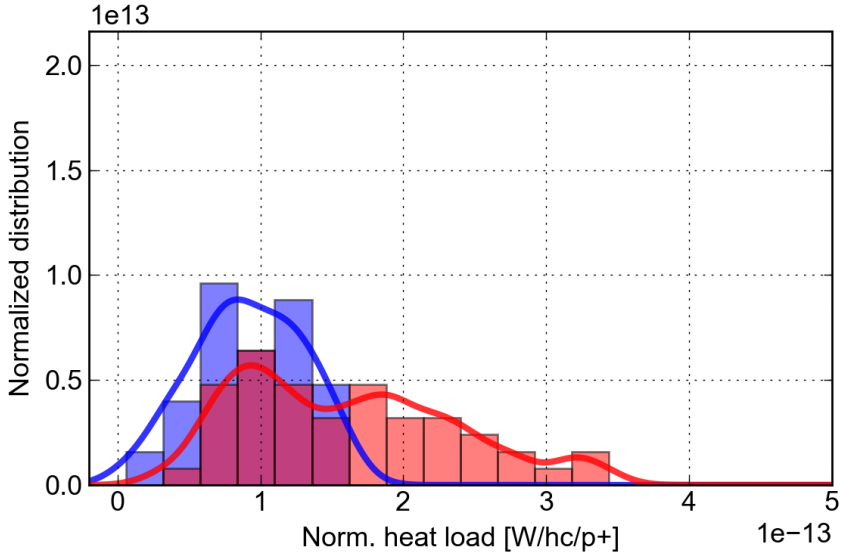
	50 ns	25 ns
Fill	5980	5979
Started on	22 Jul 2017 10:34	21 Jul 2017 15:41
T_sample [h]	3.00	3.30
Energy [GeV]	6499	6499
N_bunches (B1/B2)	1284/1284	2556/2556
Intensity (B1/B2) [p]	1.38e14/1.38e14	2.80e14/2.84e14
Bun.len. (B1/B2) [ns]	1.08/1.09	1.07/1.07
H.L. S34 (avg) [W]	13.98	56.41
H.L. S34 (std) [W]	6.18	14.79
H.L. exp. imped. [W]	4.33	9.20
H.L. exp. synrad [W]	5.87	12.01
T_nobeam [h]	0.63	2.00

More data on 50 ns test in 2017 can be found here

Was the difference always there? – situation before LS1

- In a high load sector, a large increase (up to a factor of 3) is observed on many of the cells

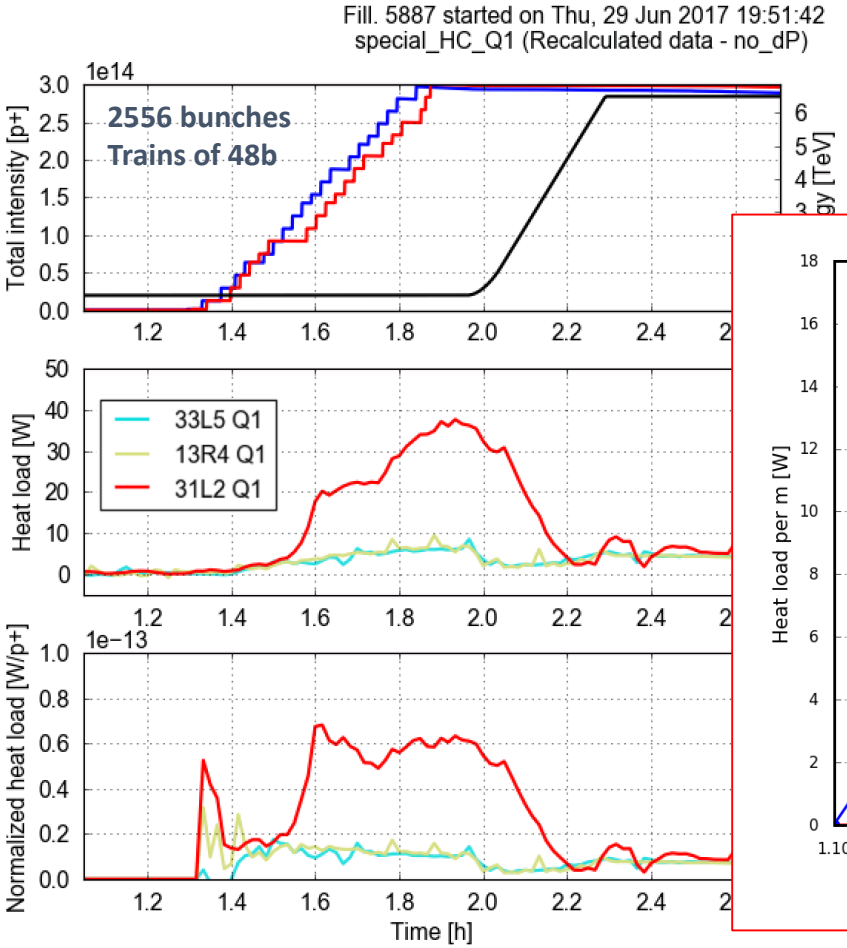




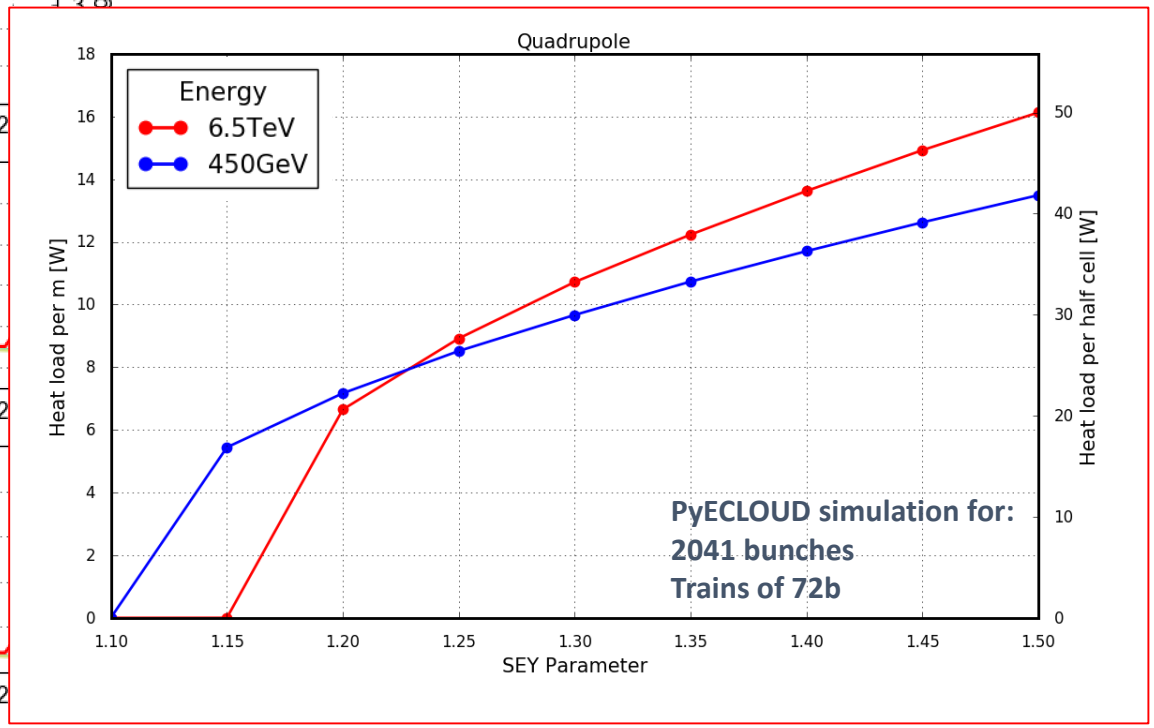
Fill	3439	5808
Started on	15 Dec 2012 08:53	11 Jun 2017 07:18
T_sample [h]	1.00	1.20
Energy [GeV]	450	450
N_bunches (B1/B2)	1164/1164	2820/2820
Intensity (B1/B2) [p]	1.27e14/1.27e14	2.86e14/2.93e14
Bun.len. (B1/B2) [ns]	1.26/1.23	1.18/1.26
H.L. S23 (avg) [W]	23.23	93.45
H.L. S23 (std) [W]	9.55	44.17
H.L. exp. imped. [W]	2.84	5.94
H.L. exp. synrad [W]	0.00	0.00
T_nobeam [h]	0.40	0.40

Quadrupole magnets: dependence on beam energy

- The instrumented quadrupole in 31L2 shows a peculiar behavior: **strong decrease of the heat load during the energy ramp**



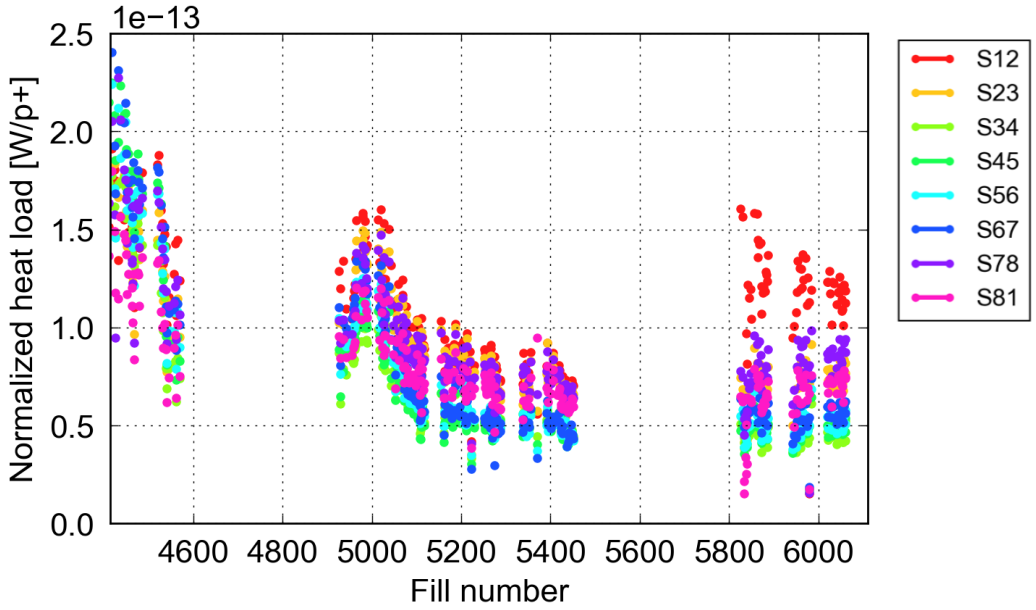
- Seems **consistent with (old) PyECLOUD simulations for low enough SEY**

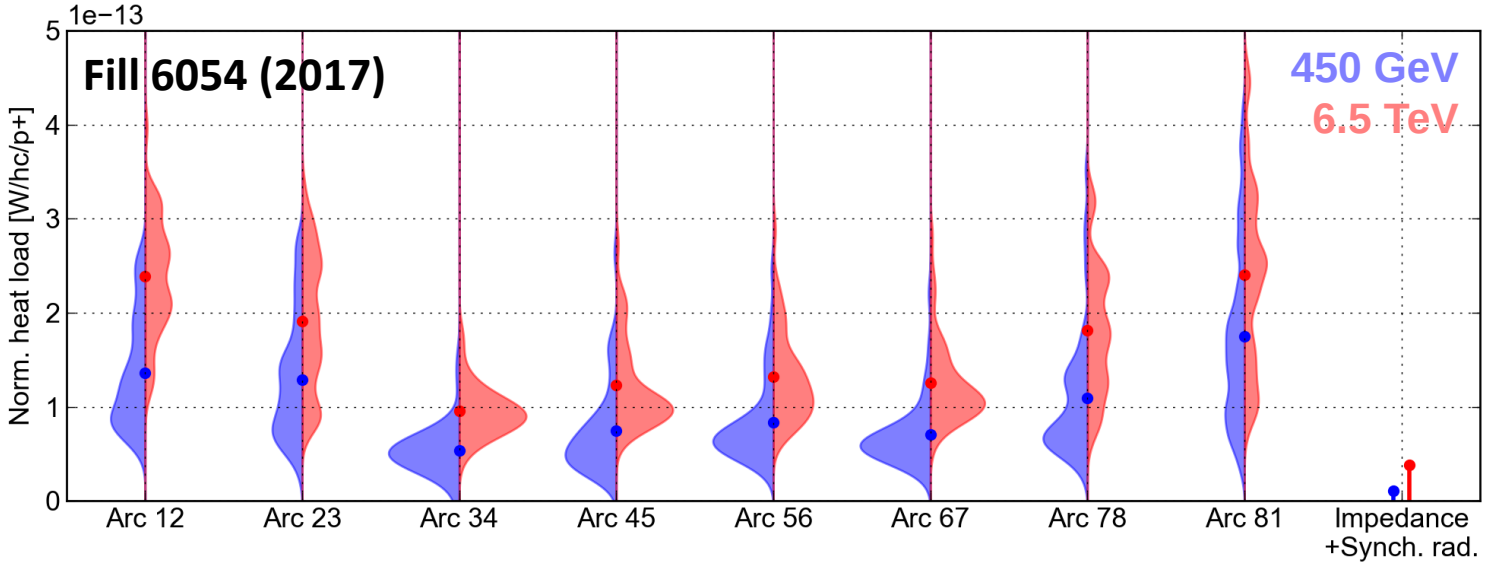


- A similar behavior was observed in the other devices in 2015

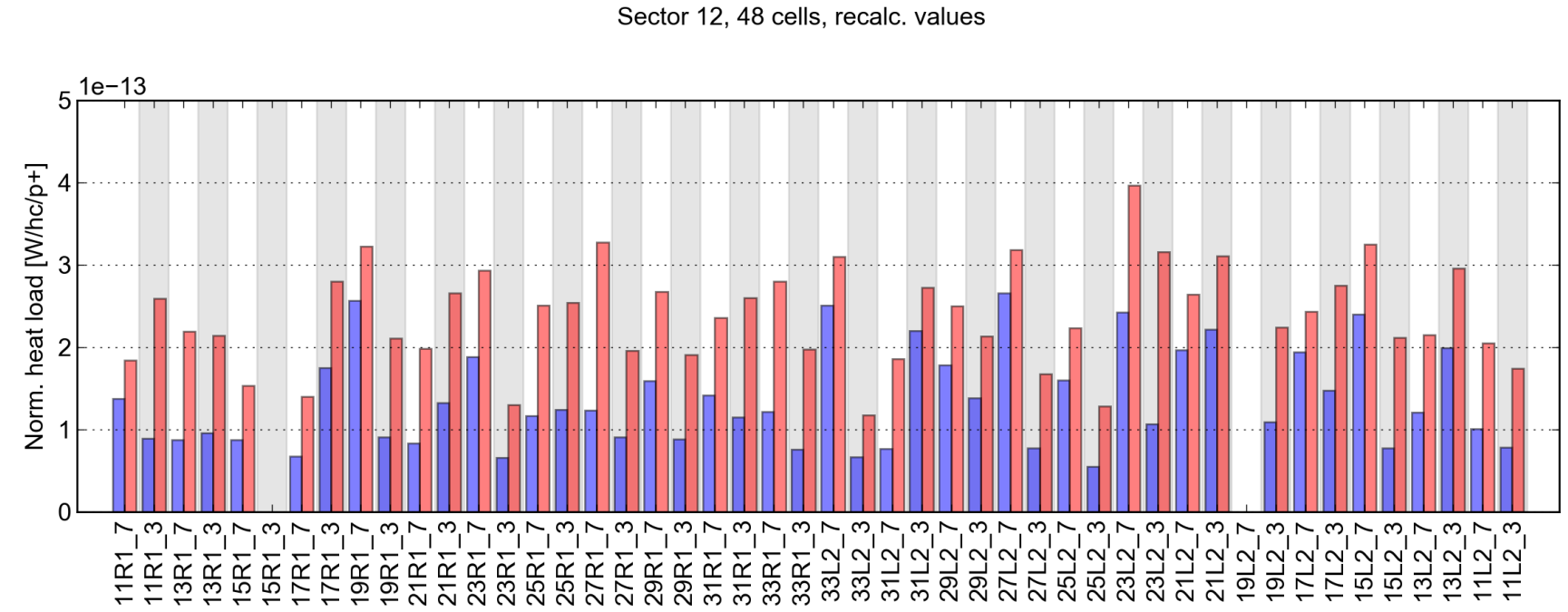
Detailed analysis of effect of energy

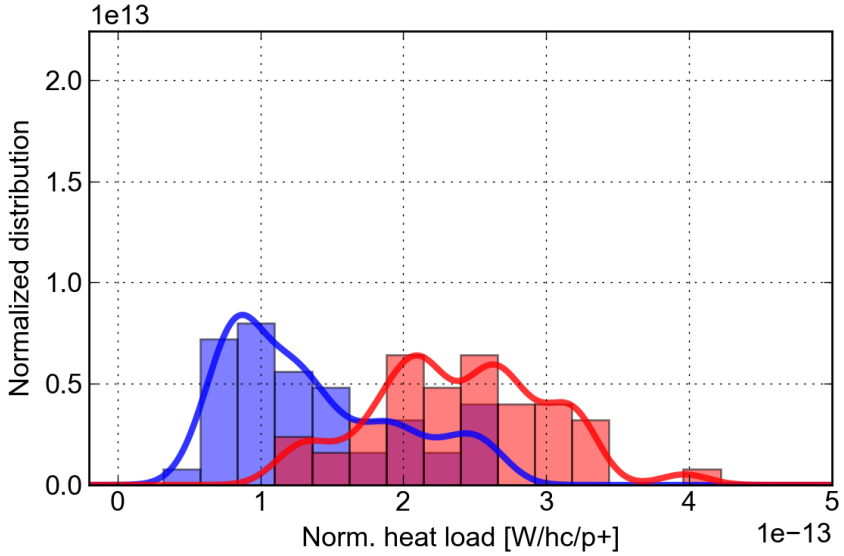
Heat load increase during the energy ramp





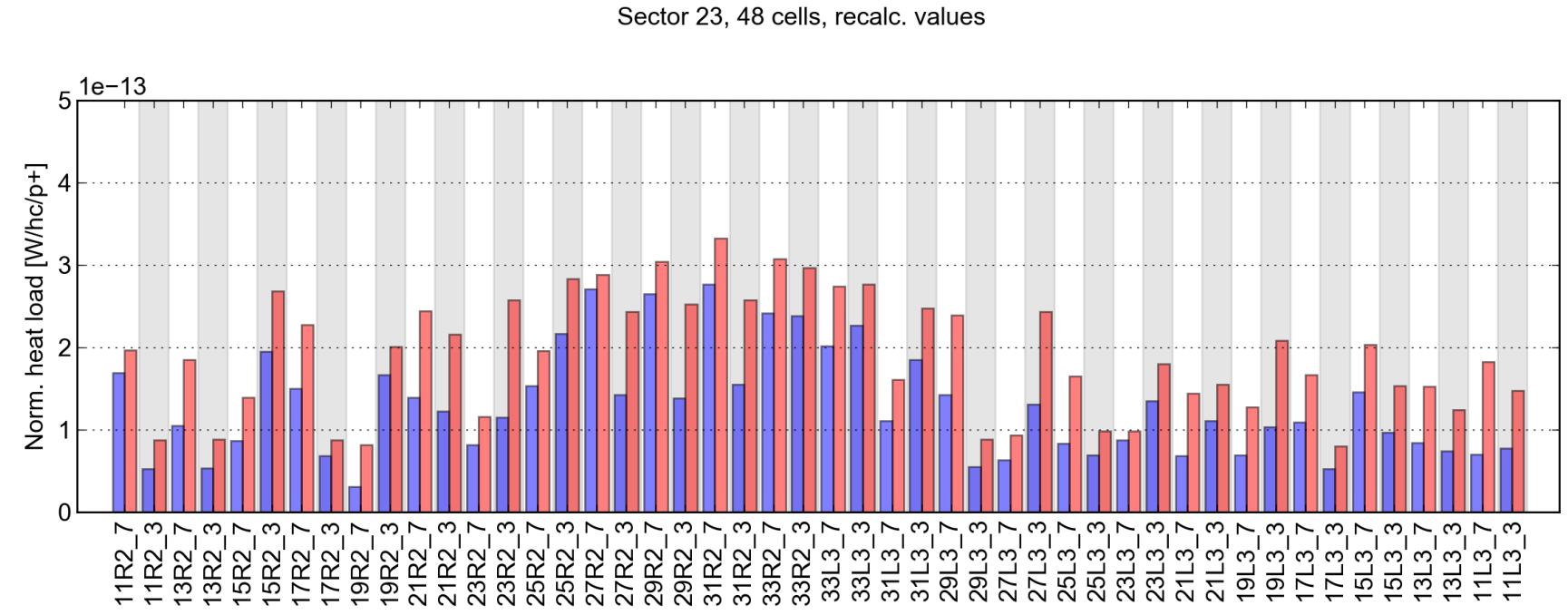
Detailed analysis of effect of energy

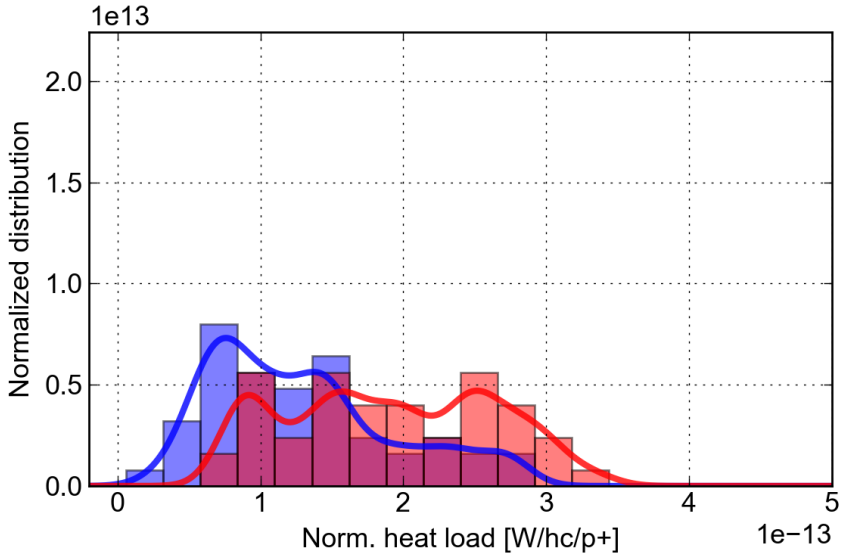




Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. S12 (avg) [W]	81.17	141.41
H.L. S12 (std) [W]	35.16	35.93
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
T_nobeam [h]	1.90	1.90

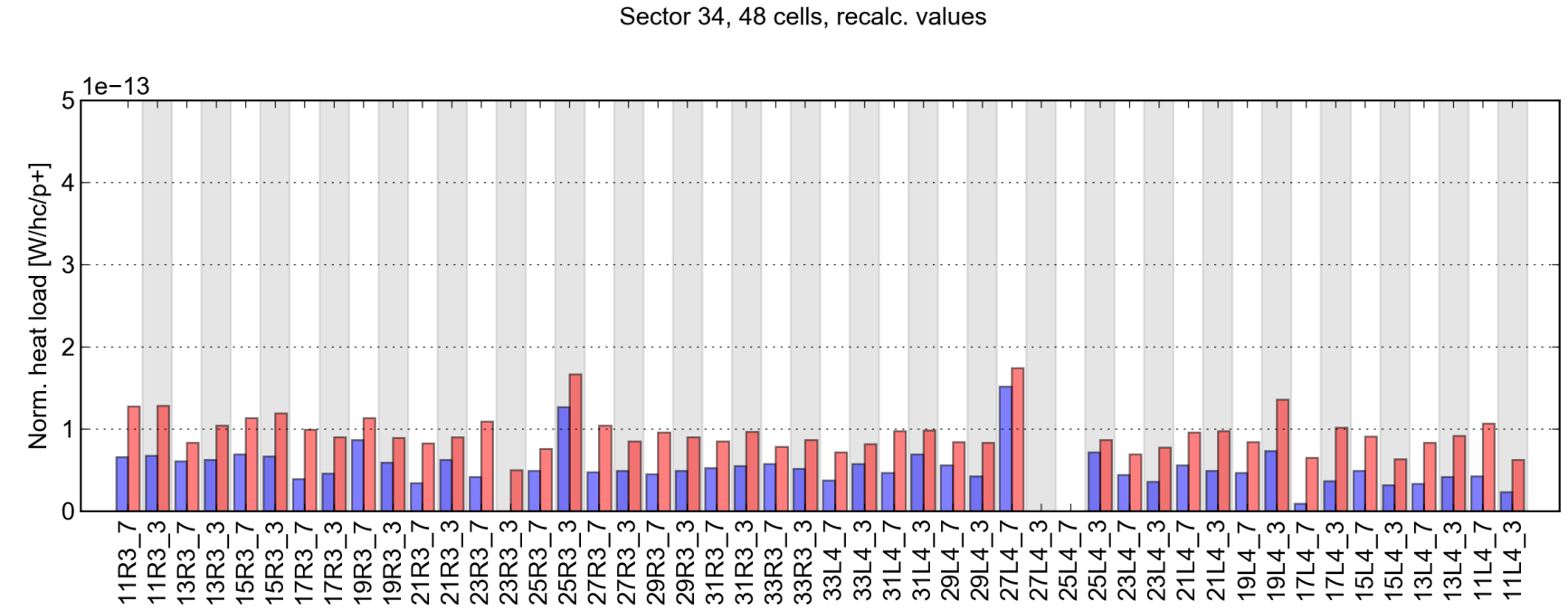
Detailed analysis of effect of energy

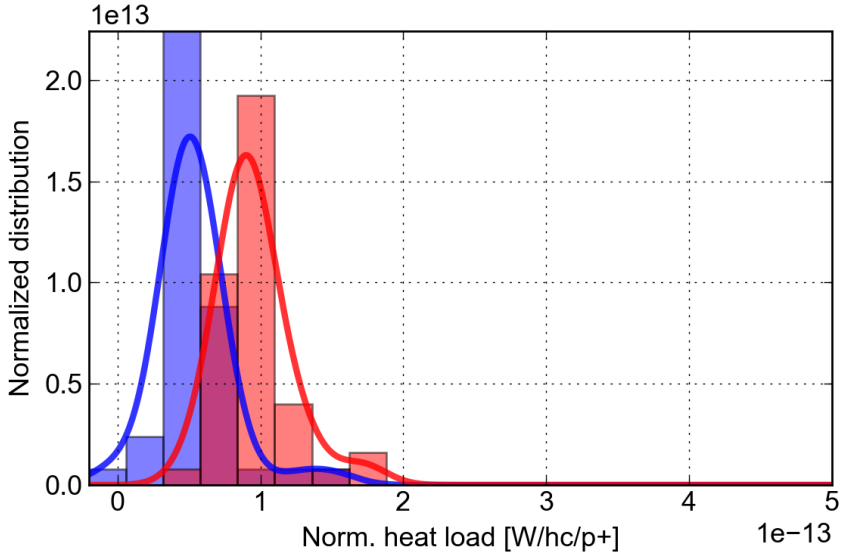




Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. S23 (avg) [W]	77.13	113.26
H.L. S23 (std) [W]	37.97	42.34
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
T_nobeam [h]	1.90	1.90

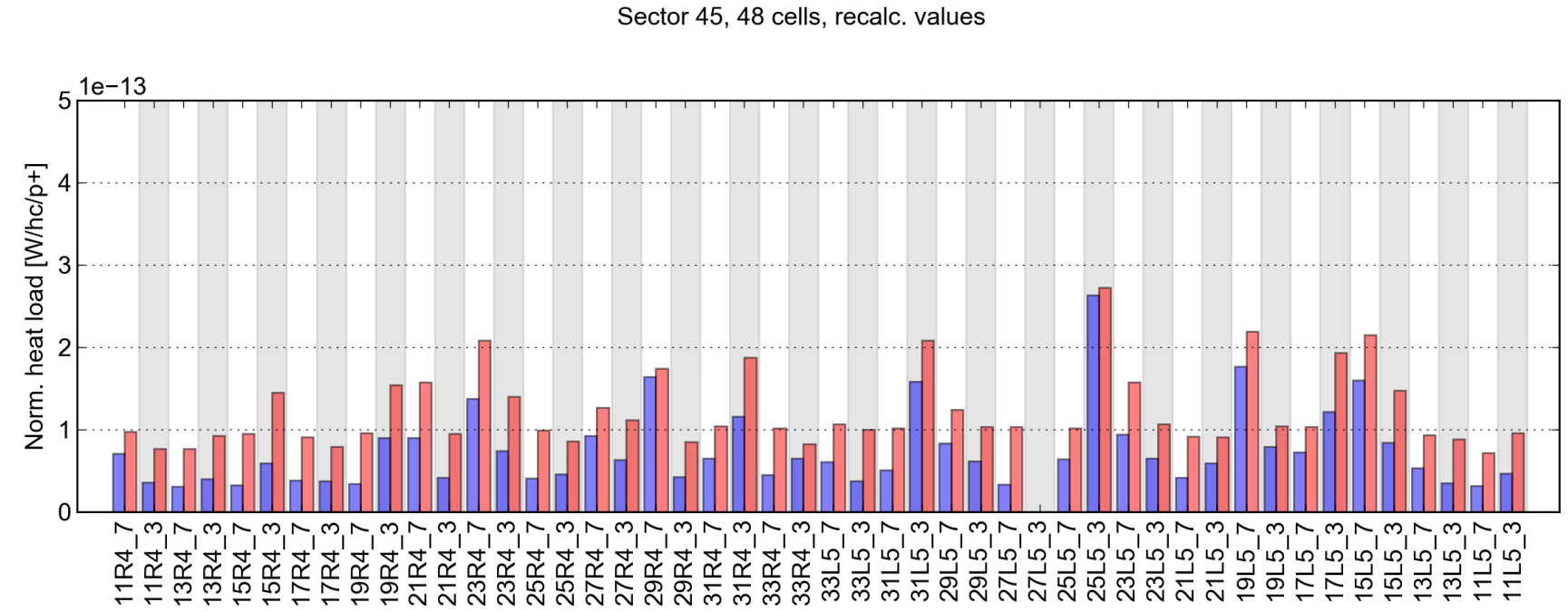
Detailed analysis of effect of energy

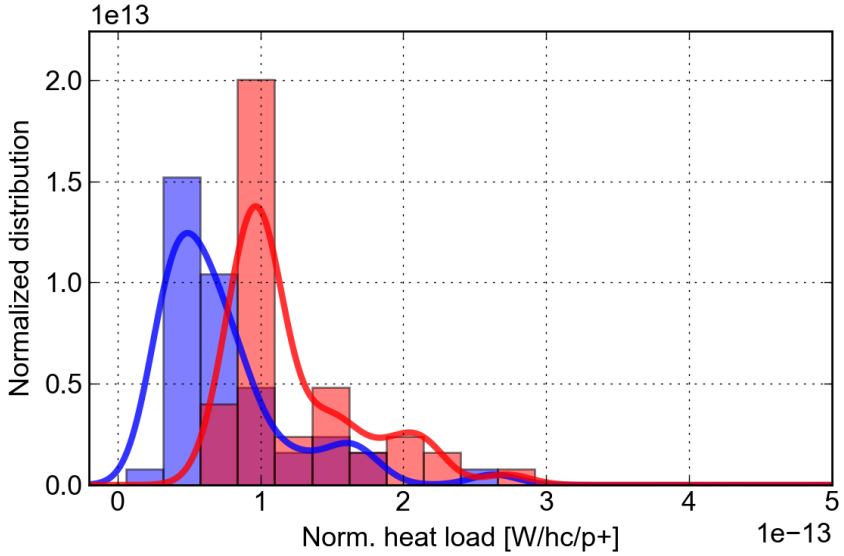




Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. S34 (avg) [W]	31.92	56.42
H.L. S34 (std) [W]	14.70	14.01
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
T_nobeam [h]	1.90	1.90

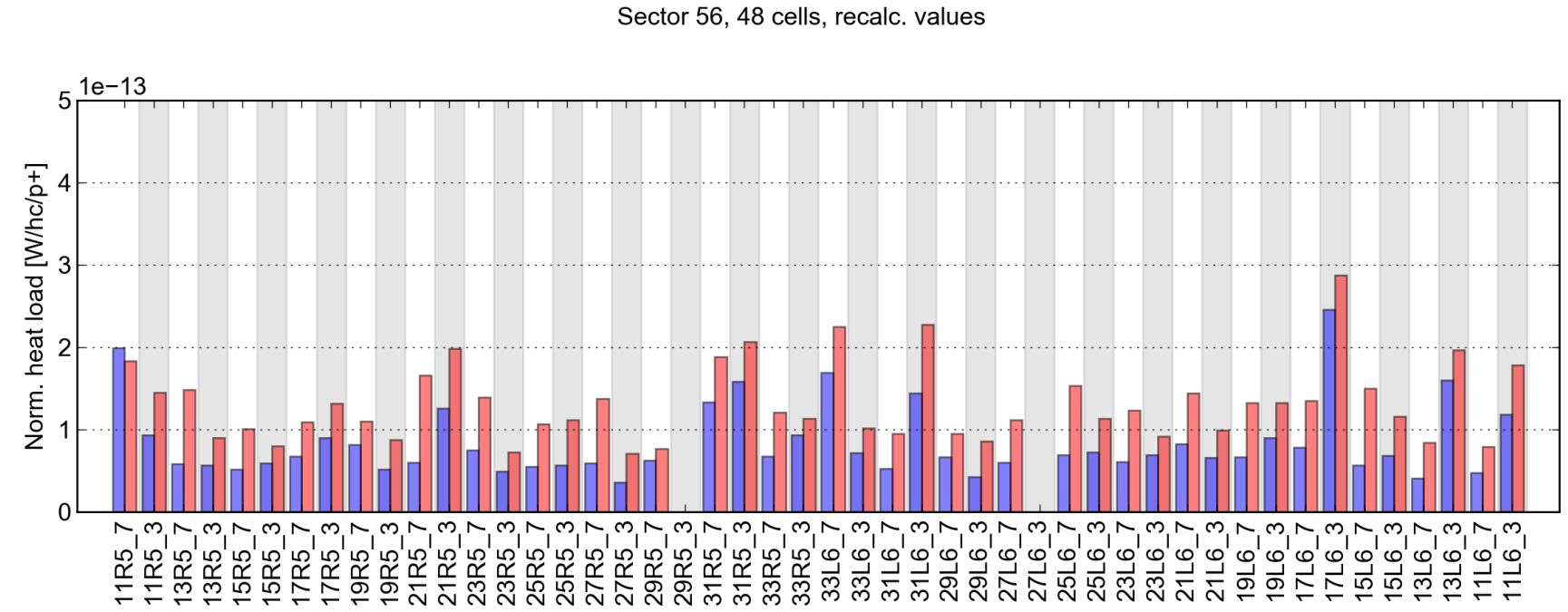
Detailed analysis of effect of energy

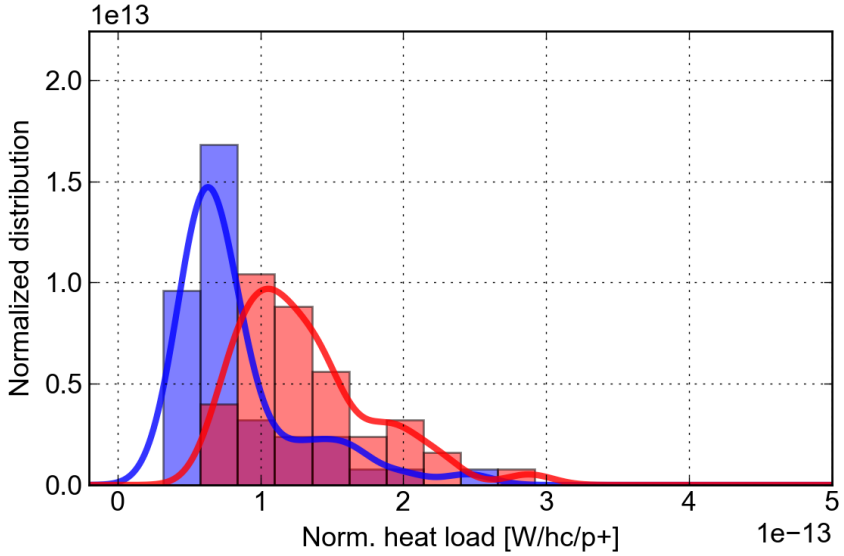




Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. S45 (avg) [W]	44.48	72.78
H.L. S45 (std) [W]	28.07	27.19
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
T_nobeam [h]	1.90	1.90

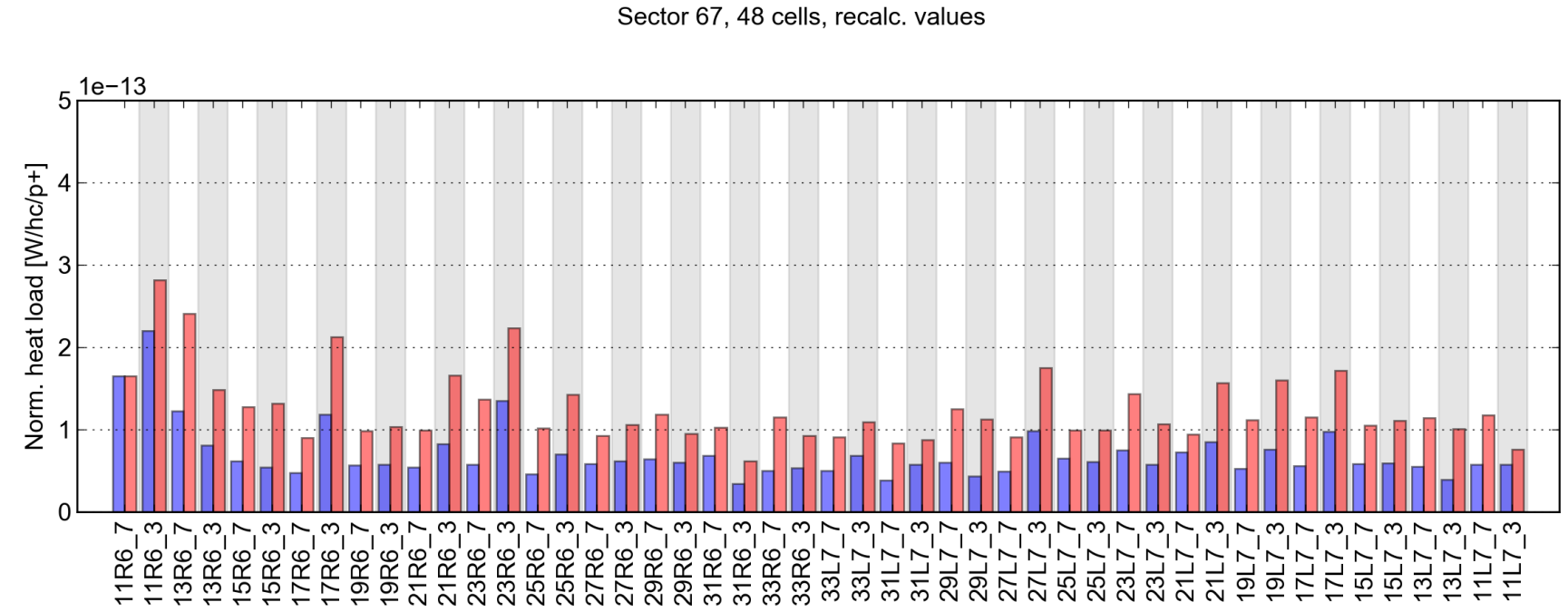
Detailed analysis of effect of energy

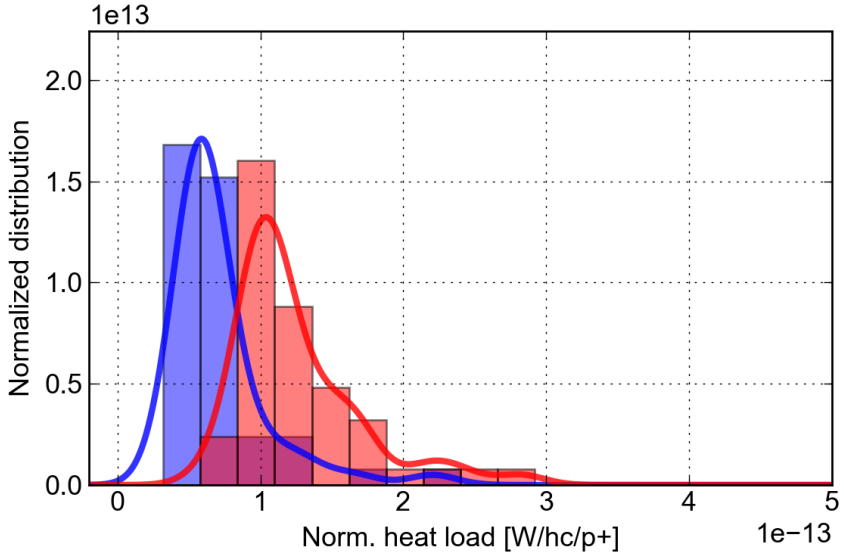




Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. S56 (avg) [W]	50.07	78.12
H.L. S56 (std) [W]	26.13	27.83
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
T_nobeam [h]	1.90	1.90

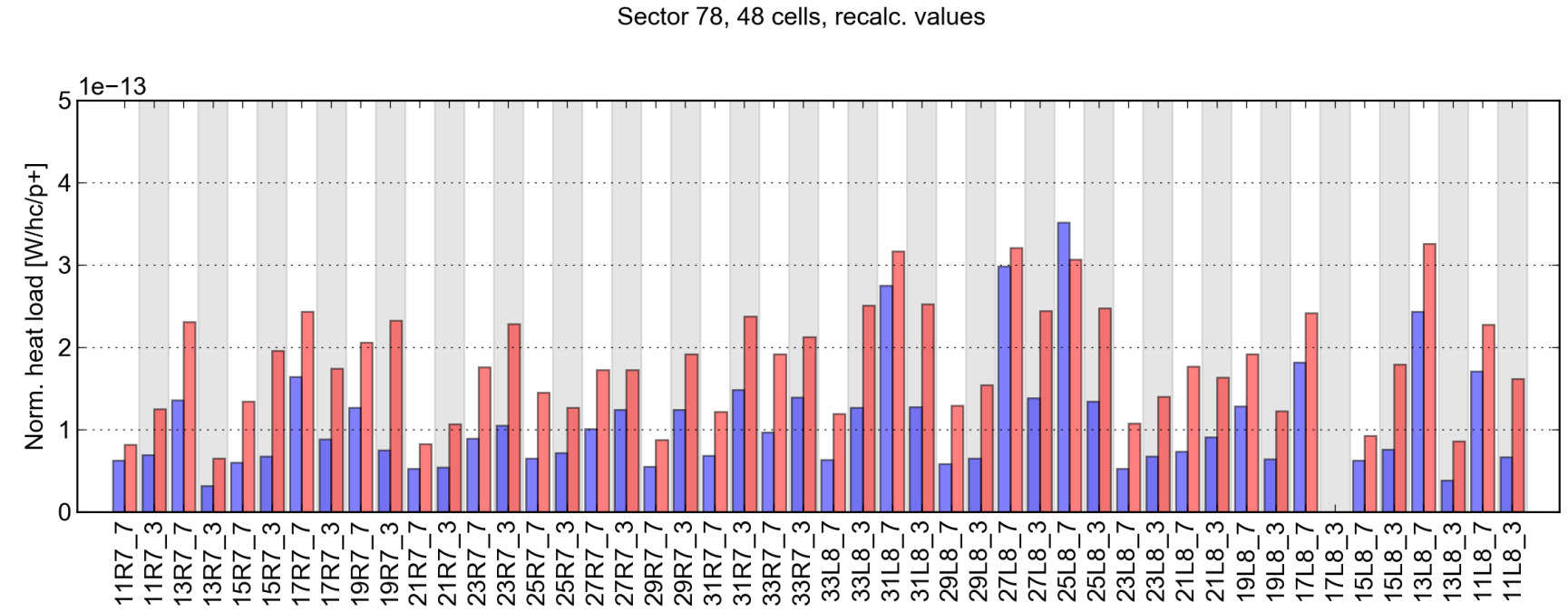
Detailed analysis of effect of energy

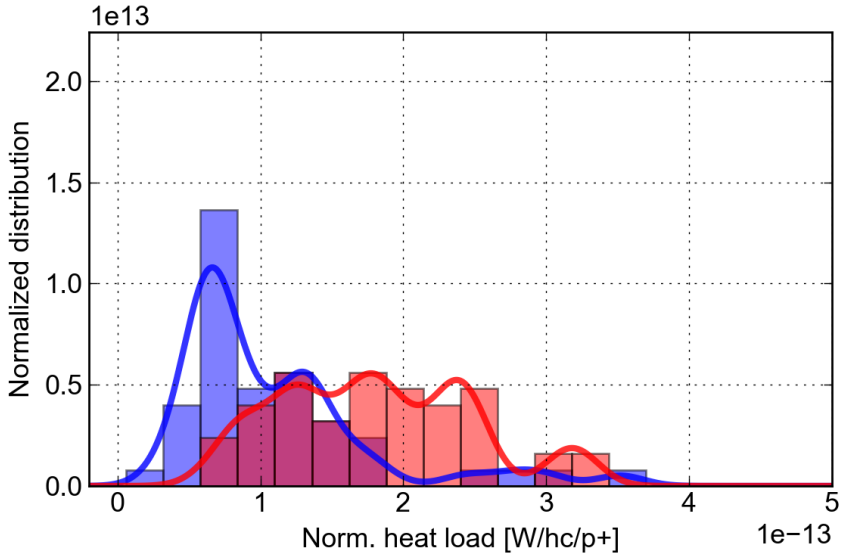




Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. S67 (avg) [W]	42.11	74.30
H.L. S67 (std) [W]	19.81	25.80
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
T_nobeam [h]	1.90	1.90

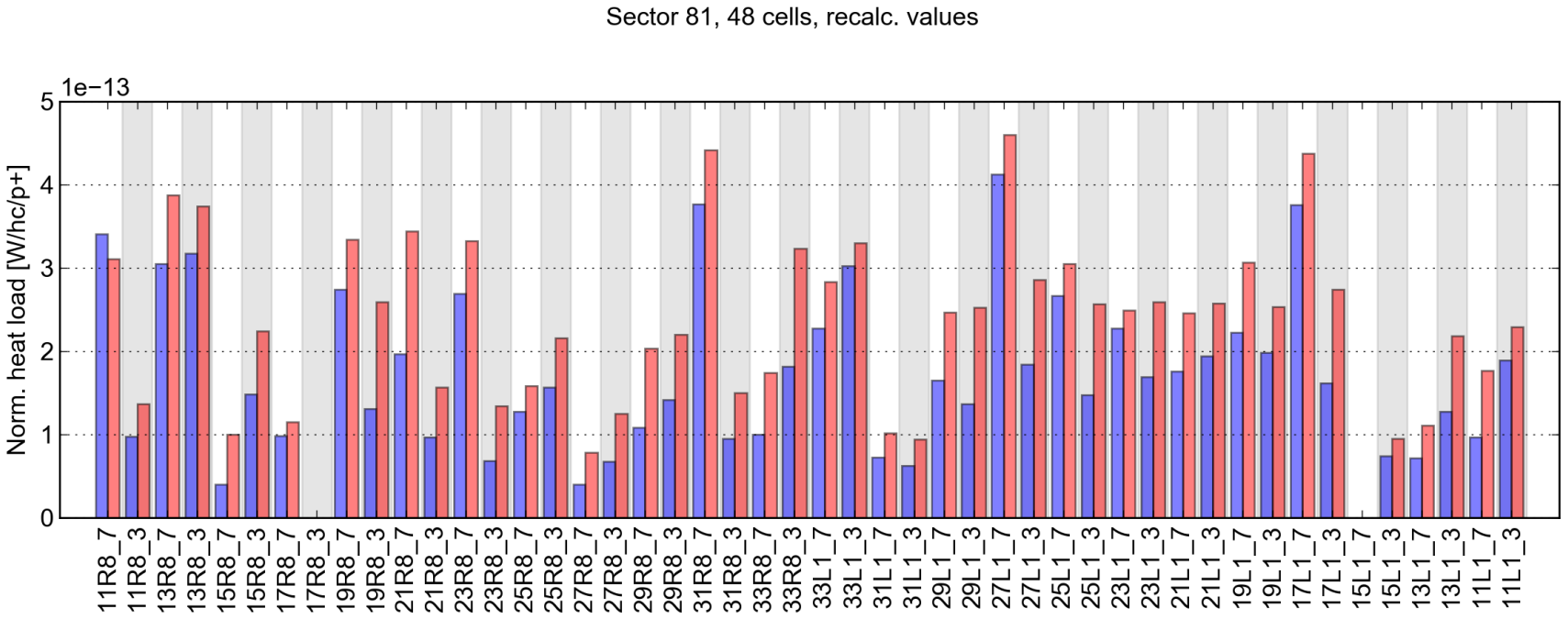
Detailed analysis of effect of energy

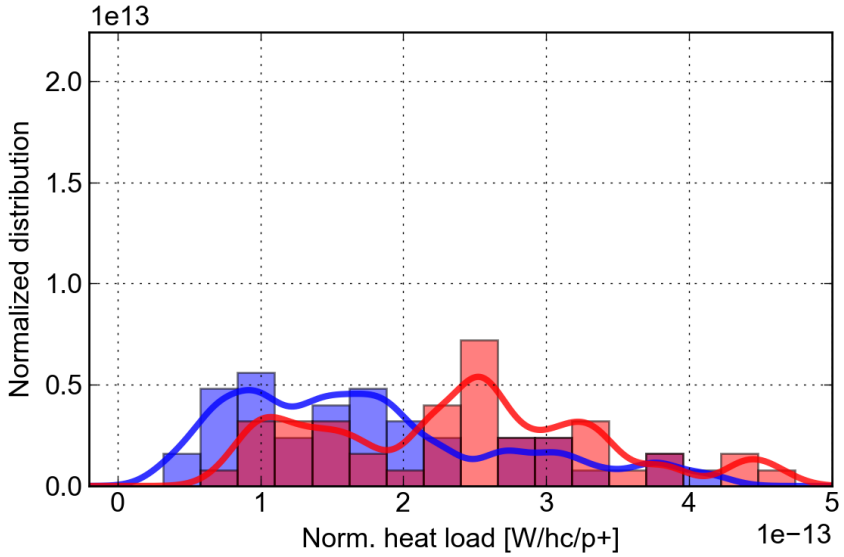




Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. S78 (avg) [W]	65.35	107.25
H.L. S78 (std) [W]	40.31	39.74
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
T_nobeam [h]	1.90	1.90

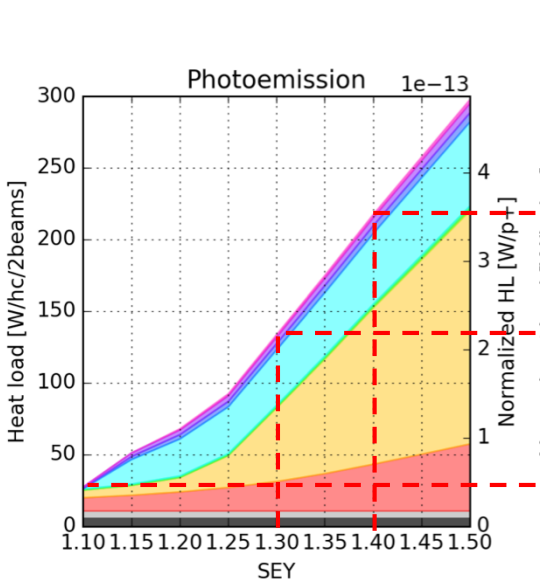
Detailed analysis of effect of energy

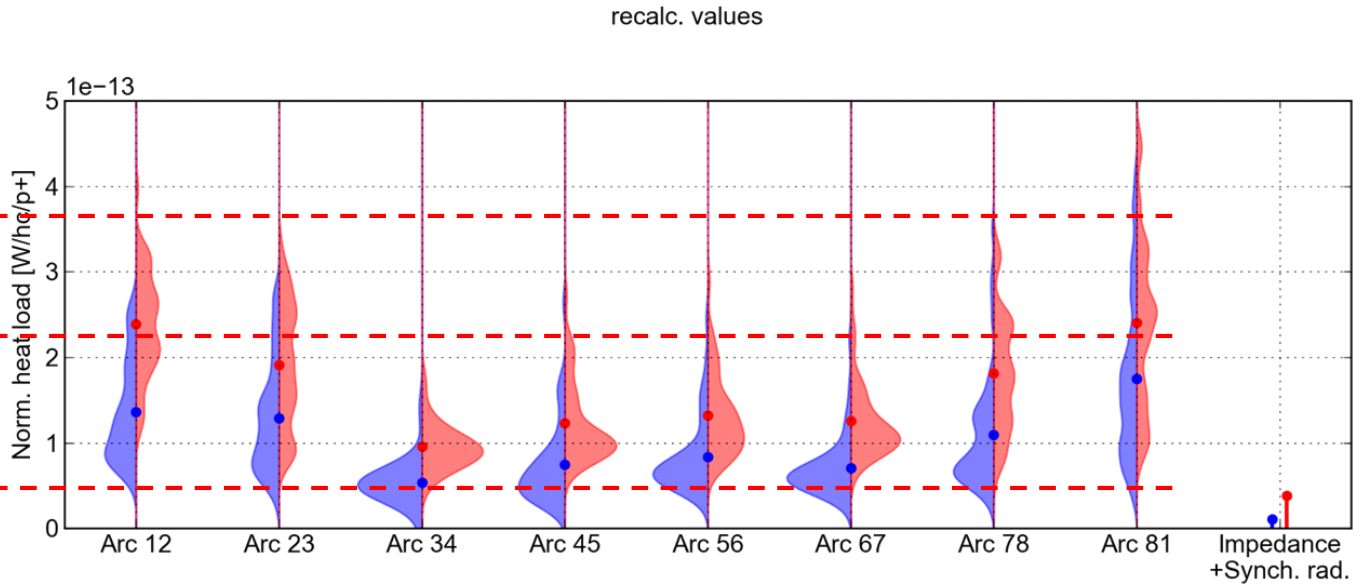


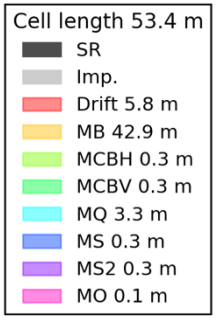


Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. S81 (avg) [W]	104.51	142.17
H.L. S81 (std) [W]	56.33	57.88
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
T_nobeam [h]	1.90	1.90

Comparison against simulations



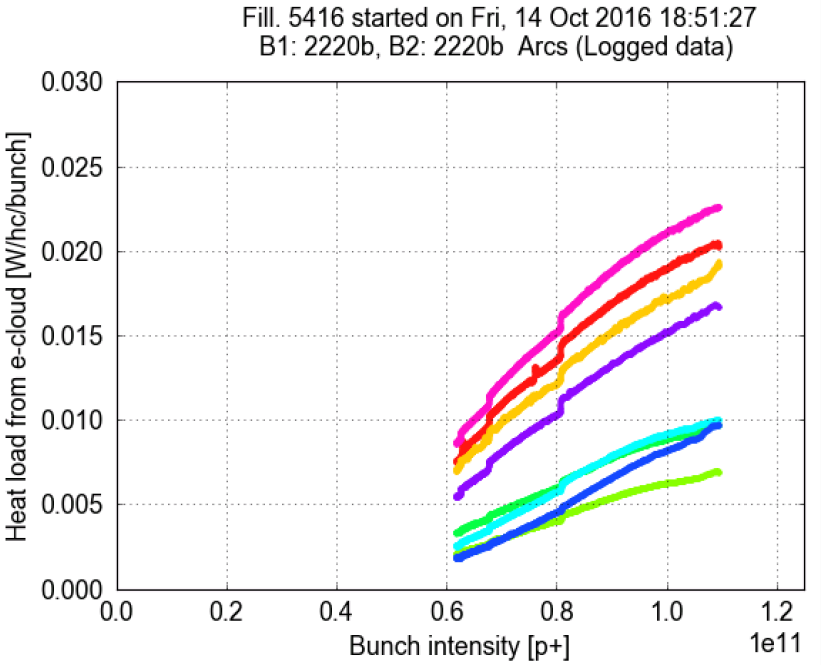




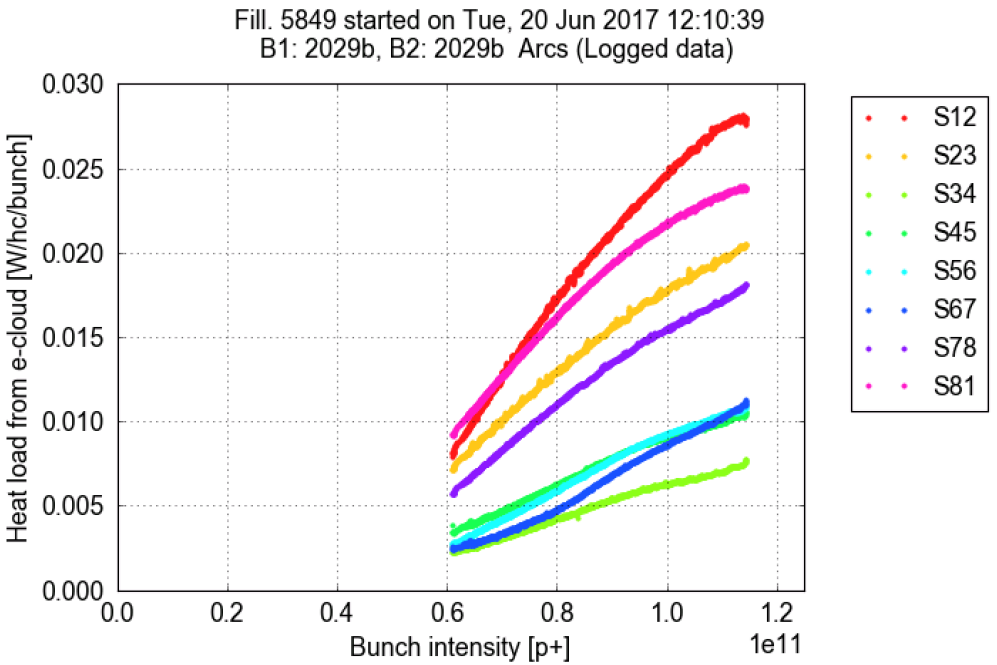
Fill	6054	6054
Started on	07 Aug 2017 14:15	07 Aug 2017 14:15
T_sample [h]	2.58	3.10
Energy [GeV]	450	6499
N_bunches (B1/B2)	2556/2556	2556/2556
Intensity (B1/B2) [p]	2.94e14/3.03e14	2.91e14/3.01e14
Bun.len. (B1/B2) [ns]	1.27/1.29	1.07/1.07
H.L. exp. imped. [W]	6.47	10.15
H.L. exp. synrad [W]	0.00	12.61
H.L. exp. imp.+SR [W/p+]	1.08e-14	3.84e-14
T_nobeam [h]	1.90	1.90

Dependence on bunch intensity from long fills

End 2016

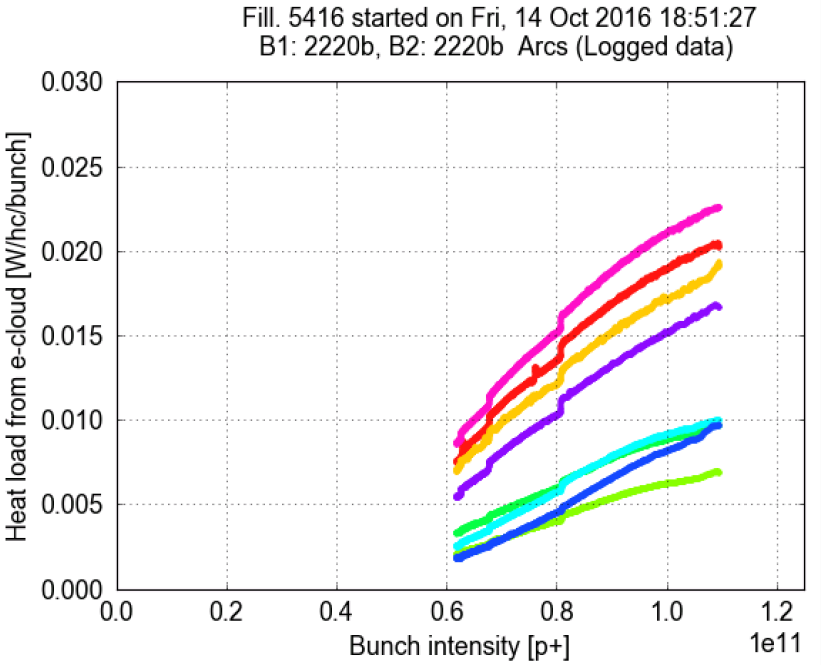


2017 (20/06)

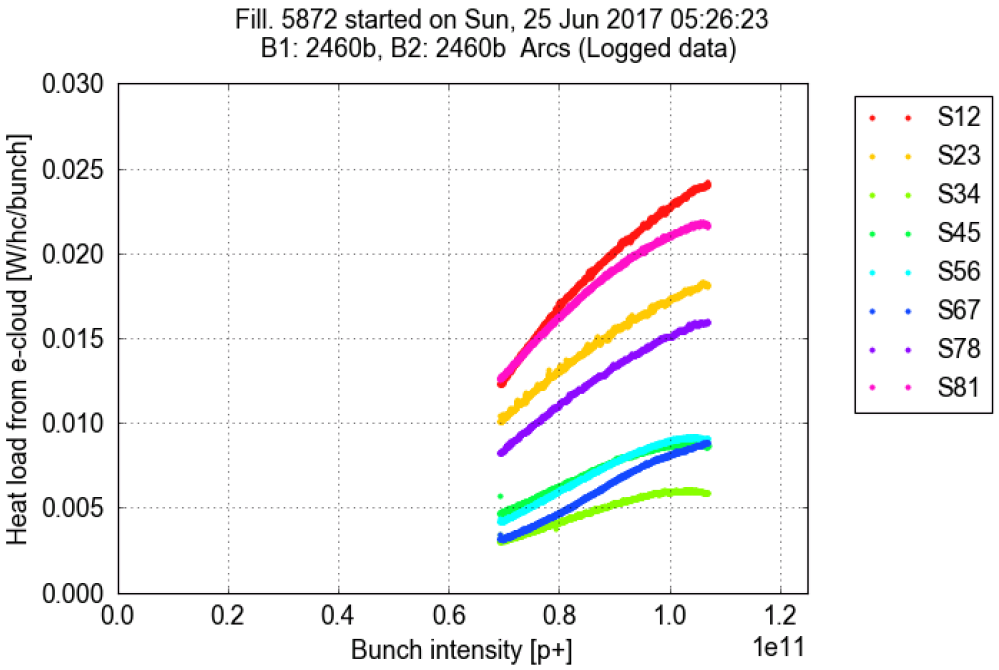


Dependence on bunch intensity from long fills

End 2016

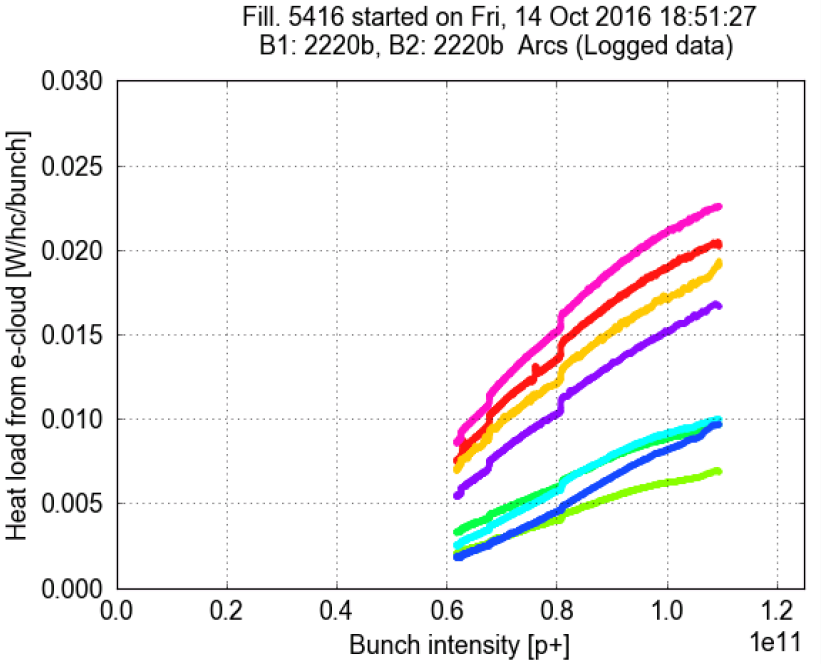


2017 (25/06)

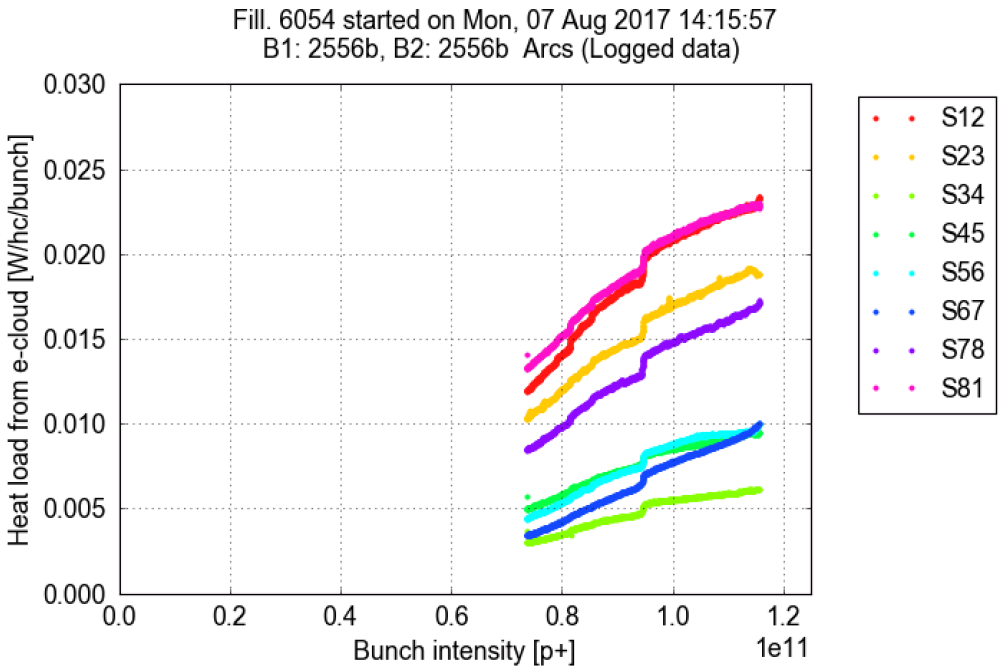


Dependence on bunch intensity from long fills

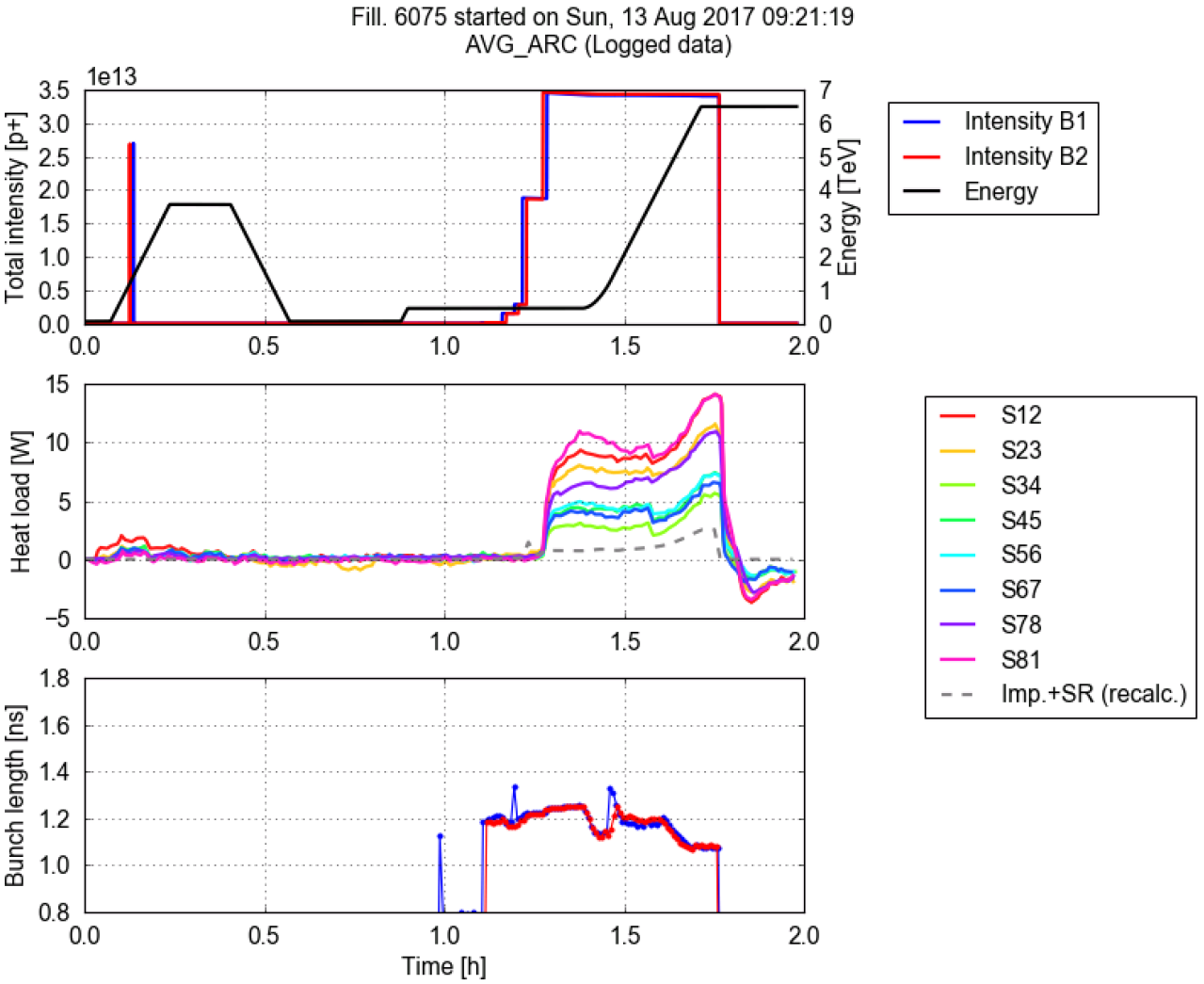
End 2016

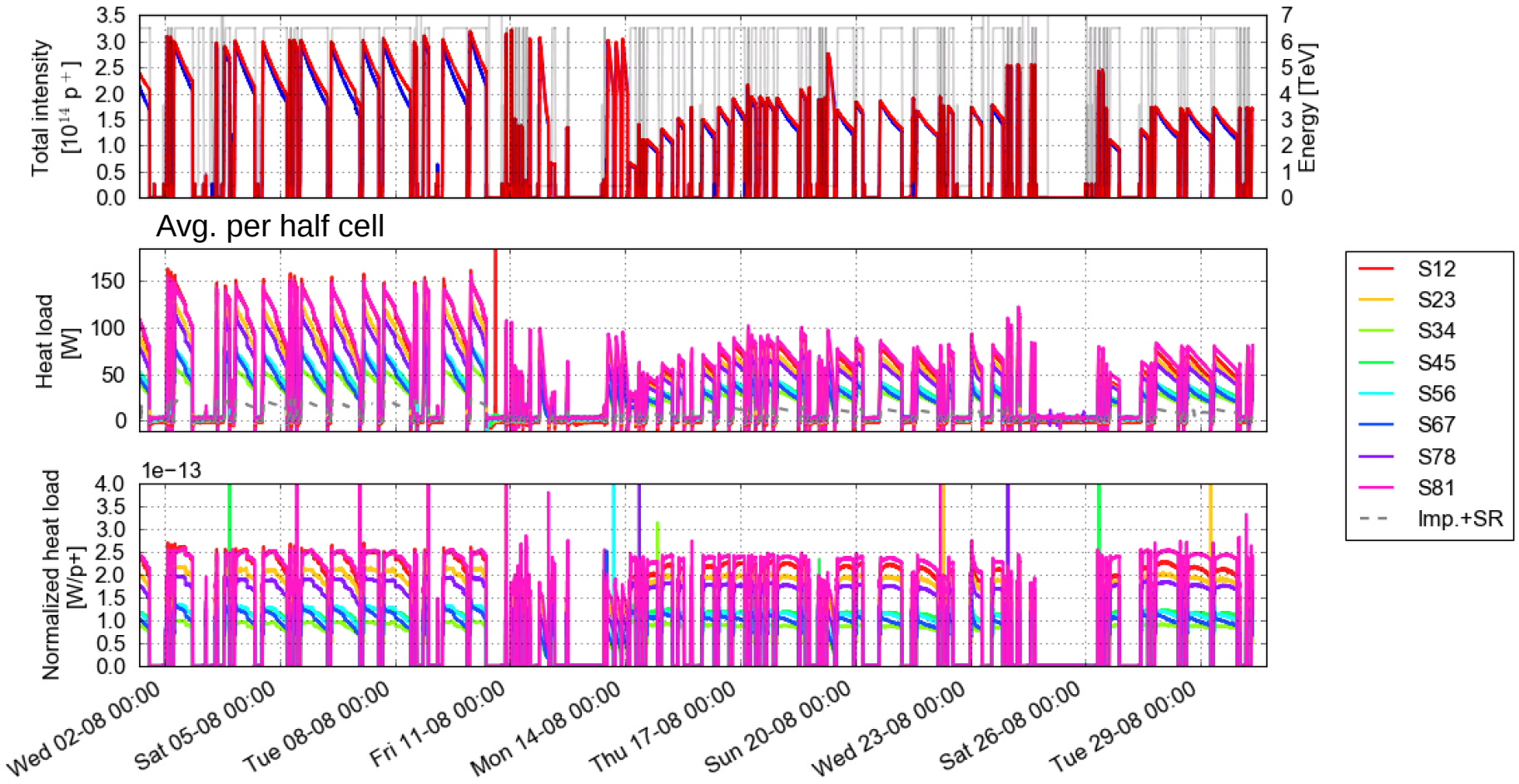


2017 (07/08)



A 25 ns fill with very low load




Total intensity
[10^14 p+]
Energy [TeV]
Avg. per half cell
Heat load
[W]
1e−13
Normalized heat load
[W/p+]
S12
S23
S34
S45
S56
S67
S78
S81
Imp.+SR
Wed 02-08 00:00
Sat 05-08 00:00
Tue 08-08 00:00
Fri 11-08 00:00
Mon 14-08 00:00
Thu 17-08 00:00
Sun 20-08 00:00
Wed 23-08 00:00
Sat 26-08 00:00
Tue 29-08 00:00