Filling schemes and e-cloud constraints

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With valuable input from:
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2016 vs 2017: what changes?

- **SPS beam dump will be replaced** (fingers crossed) → **more intensity per injection** (see talks by Hannes and Chiara):
  - → **Standard scheme:** 288b per injection (4x72b)
  - → **BCMS scheme:** 144b per injection (3*48b) - more?

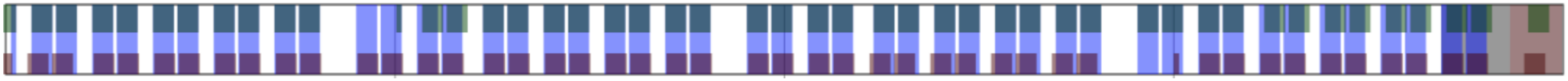
- Improved **vacuum in MKI** regions:
  - → Possible to **increase the bunch intensity** (up to ~1.3e11 p/bunch)

- Improved **rise-time** in both **LHC and SPS injection kickers** (see talk by Wolfgang):
  - → **200 ns** spacing between PS batches (225 used in 2016)
  - → **800 ns** spacing between SPS injections (900 used in 2016)

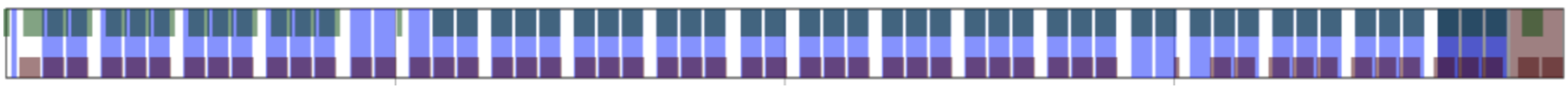
In the following we will also assume that the **Abort Gap Keeper Length** is adjusted to the actual train length (as done in 2016)

Filling schemes

BCMS 2016: 2220b, 96 b/injection (2x48) T_{MKI} = 900 ns, T_{SPS} = 225 ns



BCMS 2017: 2556b, 144 b/injection (3x48) T_{MKI} = 800 ns, T_{SPS} = 200 ns



15% more bunches w.r.t. BCMS 2016

Standard 2017: 2760b, 288 b/injection (4x72) T_{MKI} = 800 ns, T_{SPS} = 200 ns (~40% lower brightness)

7% more bunches w.r.t. BCMS 2017

Thanks to C. Schwick and J. Boyd

Sensitivity to constraints

A few **Frequently Asked Questions** when discussing filling schemes for 2017:

- What if **200ns gap from the SPS is not available**?
  - → We get **~6% less** collisions in IP1&5 **for BCMS**
  - → **No impact** for the **standard** scheme (less than 1%)
- What if we could have **more than 144b per injection in BCMS**?
  - → For the extreme case injection of 288b (6x48b) we get 2748b., i.e. **7.5% more collisions in IP1&5,** w. r. t. BCMS-144bpi but only **3% more in IP8**
- What if we use **4x80b per injection**?
  - → We could get **~2% more** collisions in IP1&5 w.r.t. standard (4x72b)

For more combinations:

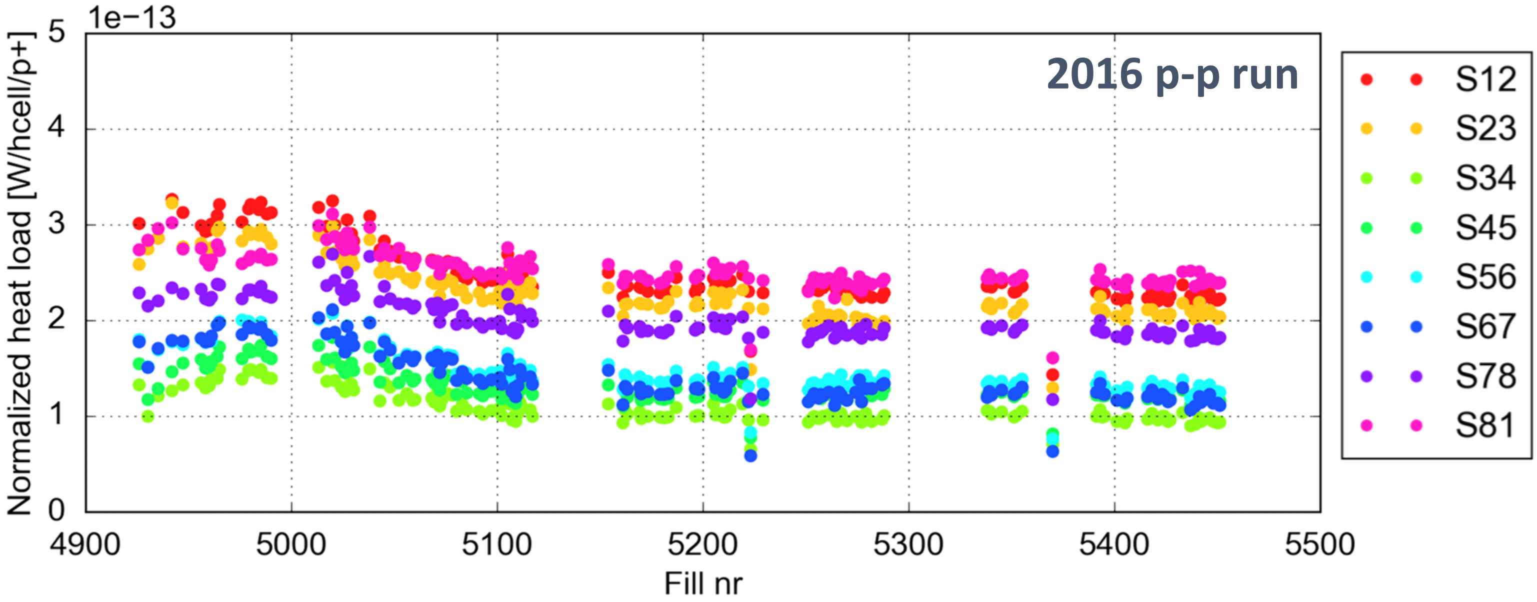
- See full table by Christoph and Jamie
- Or bother them by e-mail as I usually do ☺

I will not consider explicitly these scenarios for heat load estimations:

→ values can be simply scaled with number of bunches for the same beam flavor

Scheme	Injection	AGK	Inj. sp.	Batch sp.	Bunches	IP1/5	IP2	IP8
Nominal	4x72b	31181	900ns	225ns	2748	2736	2476	2538
Nominal	4x72b	31181	900ns	200ns	2760	2748	2460	2540
Nominal	4x72b	31181	800ns	225ns	2760	2748	2488	2563
Nominal	4x72b	31181	800ns	200ns	2760	2748	2494	2572
Nominal	4x80b	30911	900ns	225ns	2744	2732	2452	2537
Nominal	4x80b	30911	900ns	200ns	2744	2732	2460	2547
Nominal	4x80b	30911	800ns	225ns	2812	2800	2522	2570
Nominal	4x80b	30911	800ns	200ns	2812	2800	2246	2606
Nominal	4x80b	30911	900ns	225ns	2744	2732	2452	2537
Nominal	4x80b	30911	900ns	200ns	2744	2732	2460	2547
Nominal	4x80b	30911	800ns	225ns	2812	2800	2522	2570
Nominal	4x80b	30911	800ns	200ns	2812	2800	2246	2606

Heat load estimates: the recipe



We assume that the **scrubbing status** is the same as at the end of 2016 (given the very slow conditioning observed at the end 2016, see talk by Lotta)

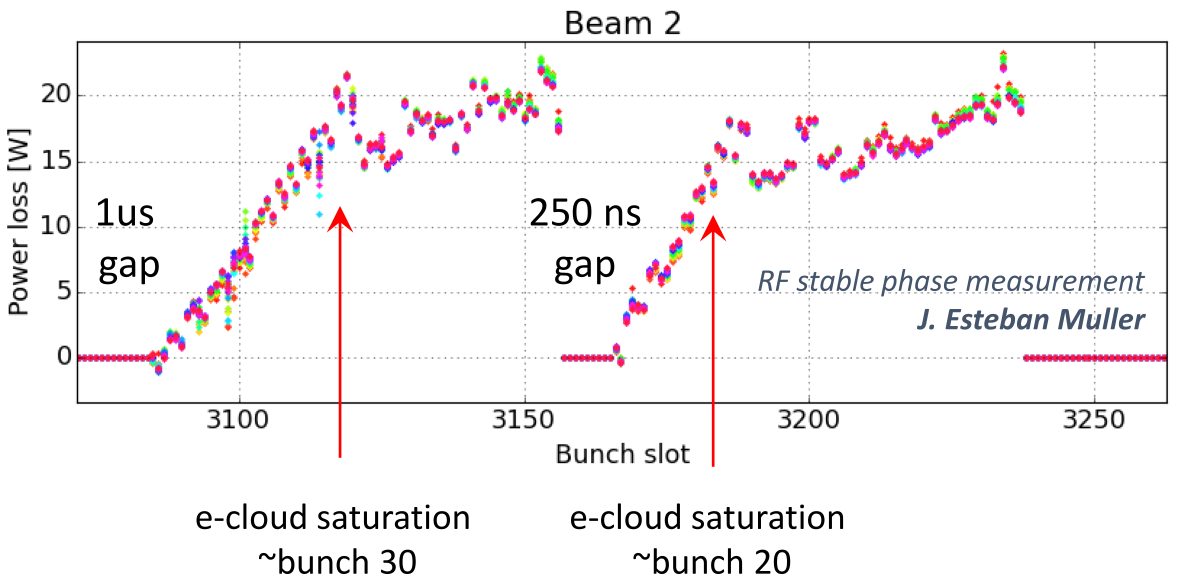
- Might not be true right at the beginning of the year due to **S12 recovery** (but differences among sectors are not understood, thermal cycle might also be beneficial, fingers crossed…)

Heat loads are **estimated for the worst Sector 81**, starting from measured values at the end of 2016. Two effects need to be taken into account:

- **Filling pattern** (train length, number of gaps)
- **Bunch intensity**

Heat load estimates: impact of the filling scheme

The **impact of the filling scheme** can be estimated knowing the **e-cloud rise-time** from the RF stable phase measurements



Basically:

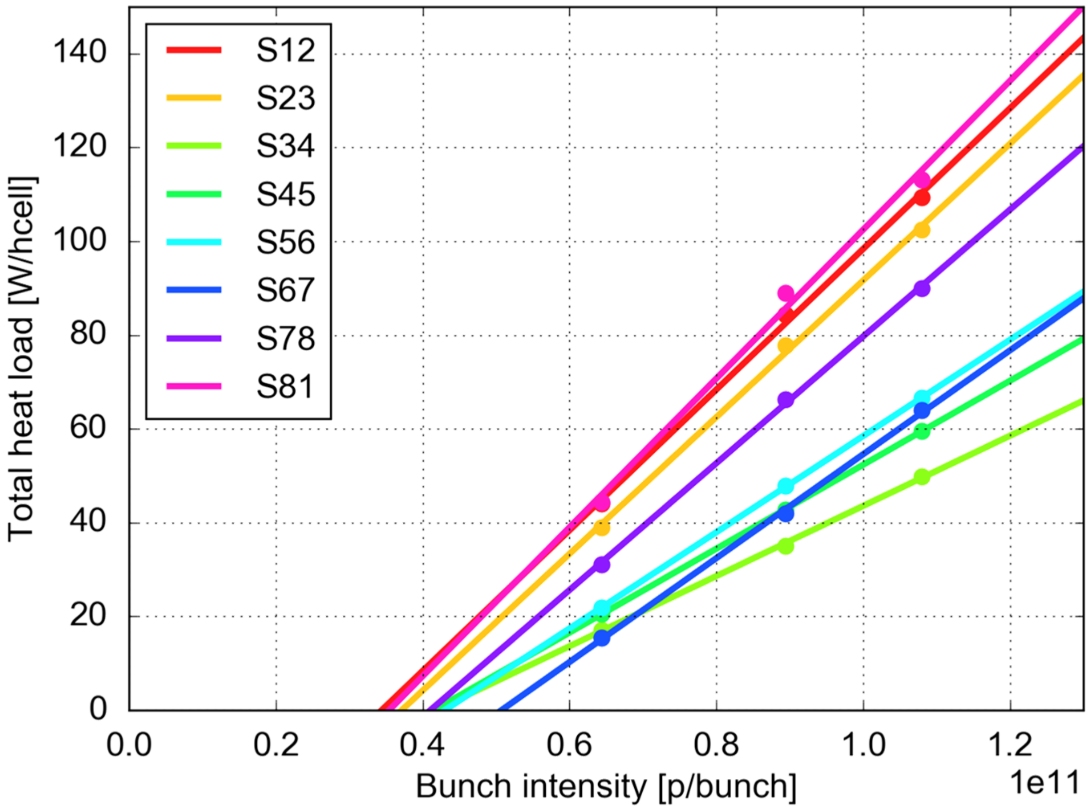
- Bunches at the head of the train generate very little heat load
- Bunches at the tail of long trains generate a significant heat load

→ Heat load is **minimized** with filling schemes having **short trains and lots of gaps**, of course clashing with the maximization of number of bunches → optimum to be found

Heat load estimates: impact of the filling scheme

Intensity dependence measured in MD in 2016 keeping the same bunch length and filling scheme

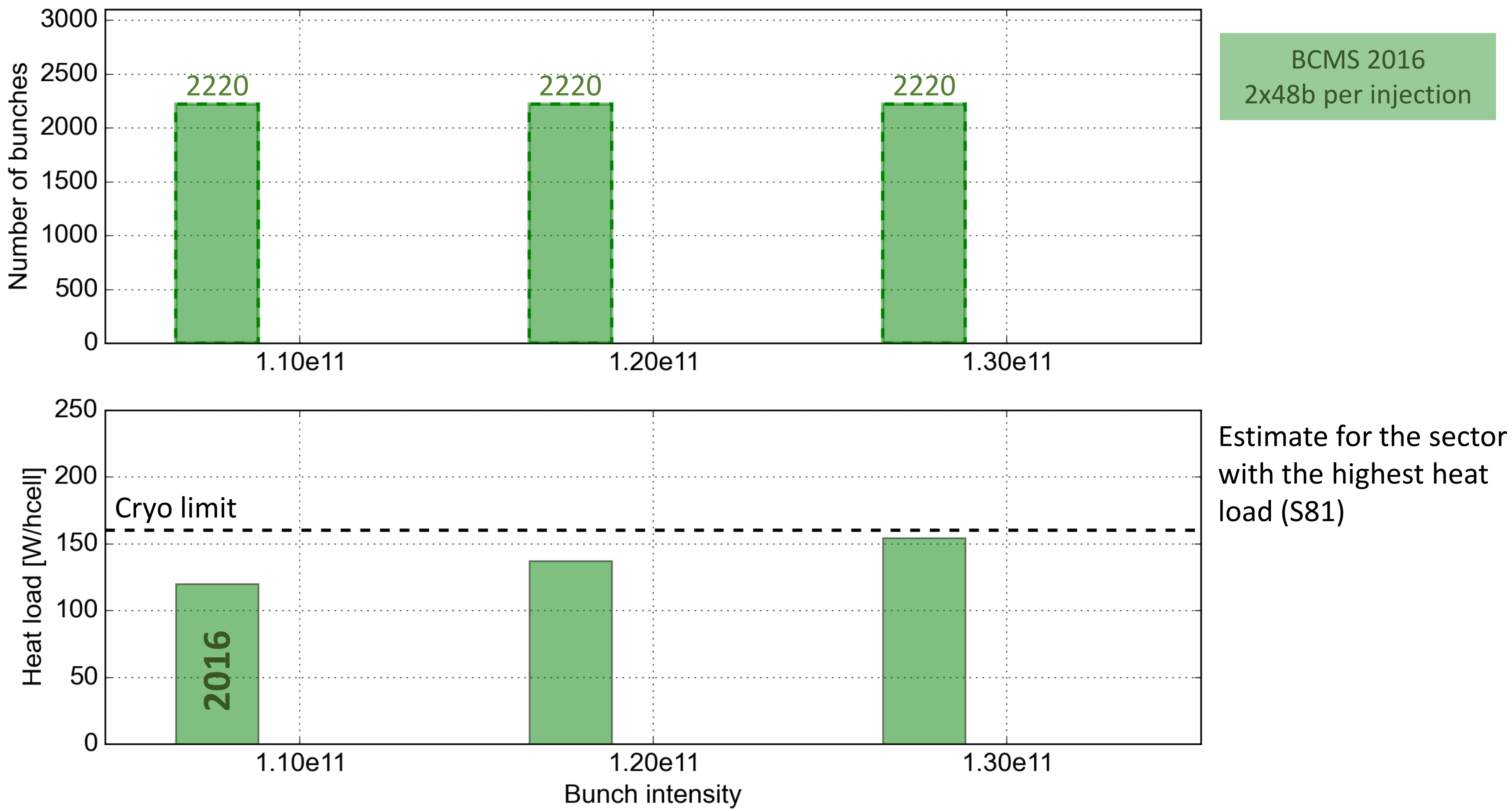
- Measured points are fitting quite well with **linear dependence** with **intensity threshold** in the range 0.4 to 0.7 x 10^{11} p/bunch
- **Dependence is quite steep** → effect can be sizable when increasing the bunch charge from 1.1 x 10^{11} p/bunch to 1.3 x 10^{11} p/bunch



Heat load estimates: BCMS vs standard

Case 1: "BCMS 2016", 2220b., 2x48b per injection (in case SPS dump is not replaced)

- → Some margin w.r.t. cryo cooling capacity for 1.1 x 10^{11} p/bunch (as in 2016)
- → **Bunch intensity could be increased up 1.3 x 10^{11} p/bunch** without limitations on the number of bunches



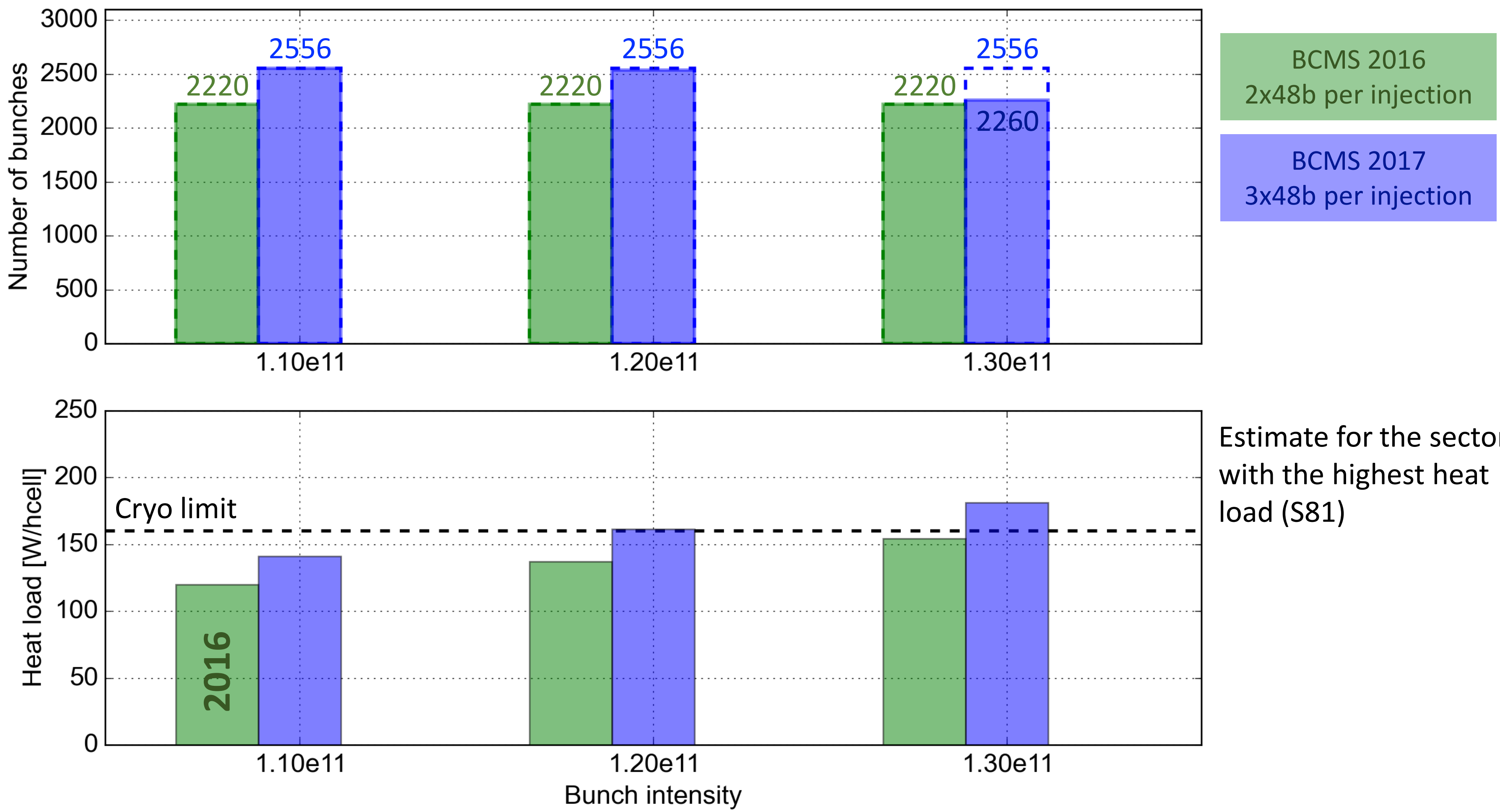
Heat load estimates: BCMS vs standard

Case 2: "BCMS 2017", 2556b., 3x48b per injection

→ Still **within the cryo capacity** limit for bunch intensities up to **1.2x10^{11} p/bunch**

→ Limit is exceeded by 10% if the bunch intensity is increased to 1.3x10^{11} p/bunch

Dashed bars: max. allowed by filling scheme, **Full bars:** max. allowed by heat load limit

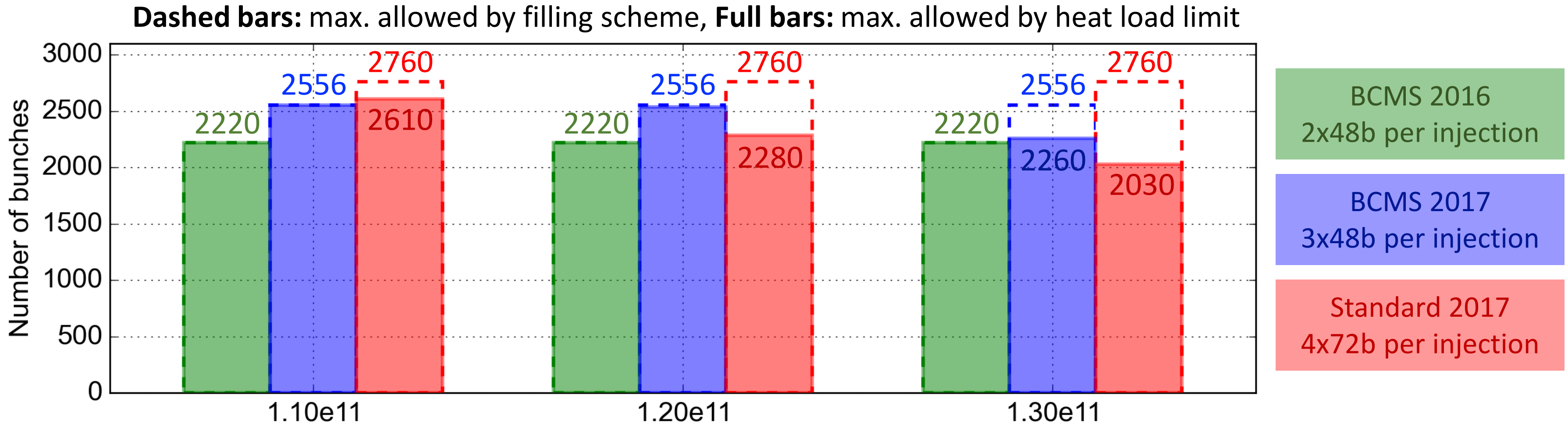


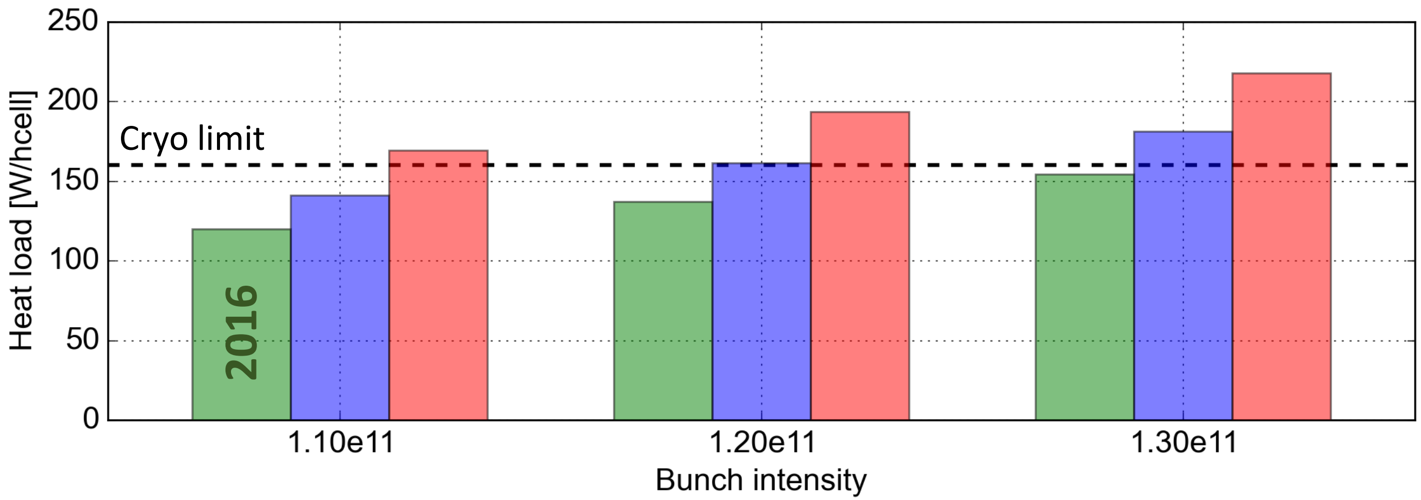
Heat load estimates: BCMS vs standard

Case 3: "Standard 2017", 2760b., 4x72b per injection

→ Cryo capacity **limit is already reached** for a bunch intensity of **1.1×10^{11} p/bunch**

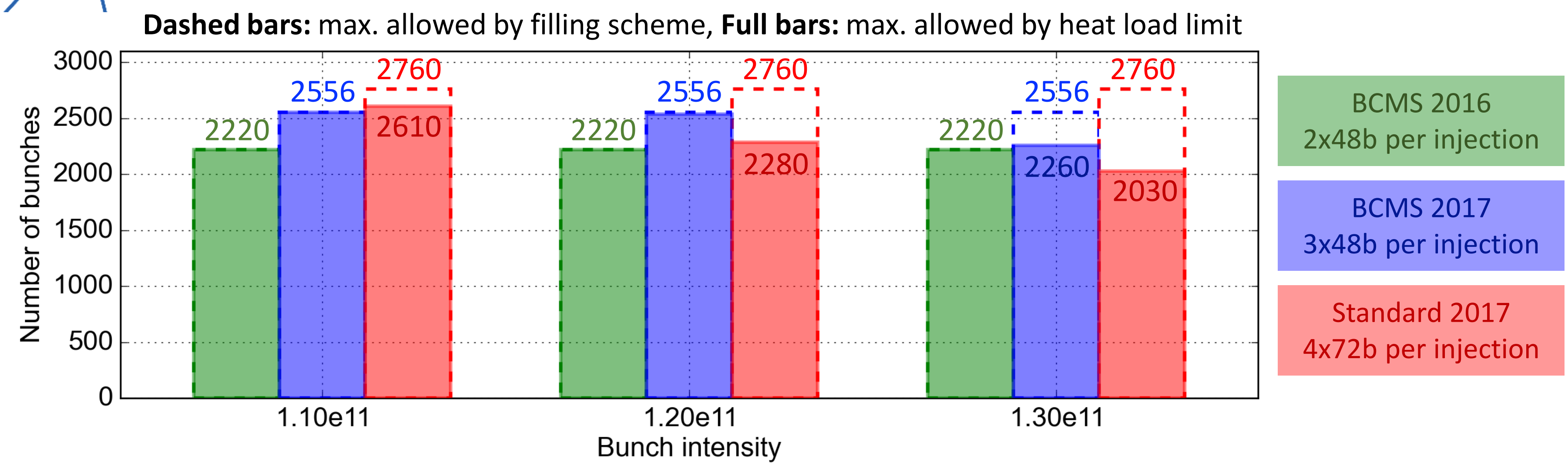
→ For larger bunch intensity the standard scheme is **limited to a number of bunches that is even lower than BCMS**





Estimate for the sector with the highest heat load (S81)

Heat load estimates: BCMS vs standard



Assuming end-2016 scrubbing status, **standard scheme does not really allow for a larger number of bunches → BCMS seems to be the natural choice for 2017** (for detailed performance comparison see talk by Yannis). Moreover:

- **Intensity ramp-up** will most likely be **fast** (2016-like)
- It will be easier to deal with **S12 recovery** if needed

But most likely **we will not see more conditioning than in 2016** → not much impact on Run 2 performance, but **heat loads will come back as a performance limitation for Run 3 and HL-LHC**

Scrubbing Requirements for 2017

- Experience from **the 2015-16 Year End Technical Stop** (YETS)
  - **Deconditioning clearly observed**: in the first few fills it was quite difficult to stabilize the beam (see presentation by Lotta)
  - **Reconditioning very fast:** ~24h at 450 GeV
  - This suggests to allocate **1-2 days for scrubbing at the beginning of each year**, mainly to recover the beam stability

- Situation for the **2016-17 EYETS** will be different since **Sector 12** will be warmed-up to replace the dipole with the inter-turn short:
  - Based on the LS1 experience we have to assume that the **SEY will be reset** (scrubbing preservation might be better thanks to the larger accumulated dose but no direct experience is available on these effects)
  - Nevertheless scrubbing in **S12 will be more efficient than in 2015** since:
    - → It will **be easier to preserve the beam quality**: only 1/8 of the arcs with high SEY and improved knowledge on how to stabilize the beams
    - → Better management of **heat load transients from the cryogenics** (feedforward, cryo-maintain levels)

Scrubbing Requirements for 2017

Time requirements:

- **7 days** (as allocated in the present schedule)
  - → For **S12 reconditioning** we might want to start gently (short trains)
  - → Intensity increase will also be limited by **conditioning time in MKI2D** which was exchanged before the ion run (has not seen any high intensity yet)

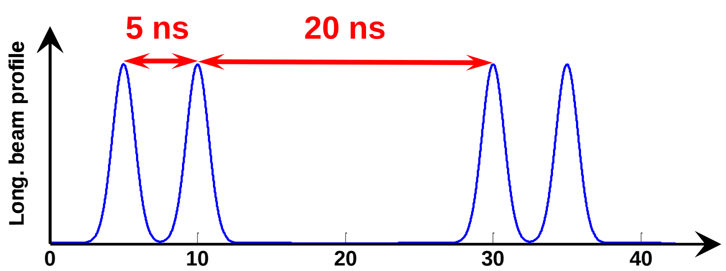
Beam requirements:

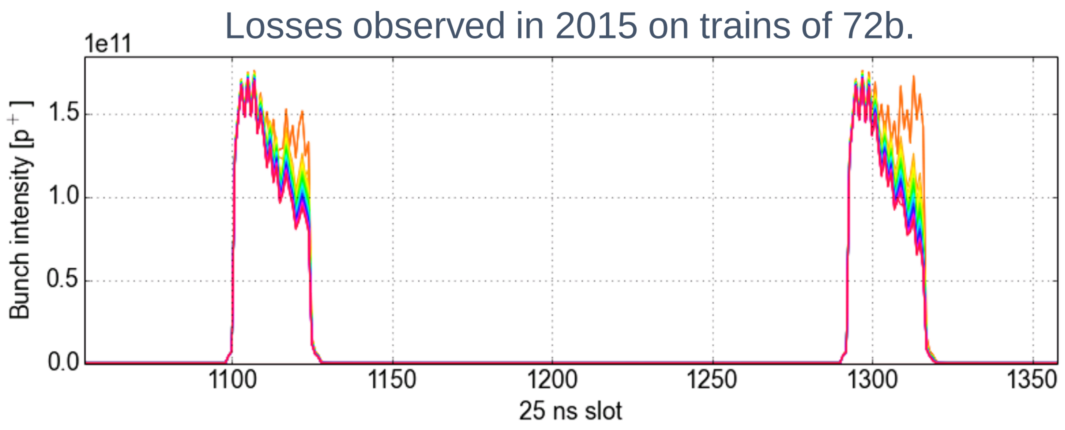
- **25 ns**, standard production scheme, **4x72b per injection**
  - → This period will also provide an indication on the **scrubbing efficiency** that can be obtained **with long trains** (important, in particular for Run 3 and HL-LHC, especially if BCMS is chosen for physics production)

Possible tests with doublet beams

- Doublets **could not be used in 2016** due to limitations from the SPS beam dump
- In 2015, due to strong transverse instabilities, it was possible to **accumulate only trains of 24 doublets** (up to ~250 doublets in total)
- This schemes becomes interesting only if it is possible to store significantly **more bunches** (>1000 doublets) and in **longer trains** (48-72 doublets/train)

- We plan to **restart these studies in MD** (need ~24h slot including necessary setup). **Main goals:**
  - Identify optimal settings to **stabilize the beam** (Q', octupoles, ADT, profiting of e-cloud tunes)
  - Assess **the achievable beam intensity**
- In case of positive outcome, we could think of **longer test period** to probe the **scrubbing efficiency** (in 2017 or later)

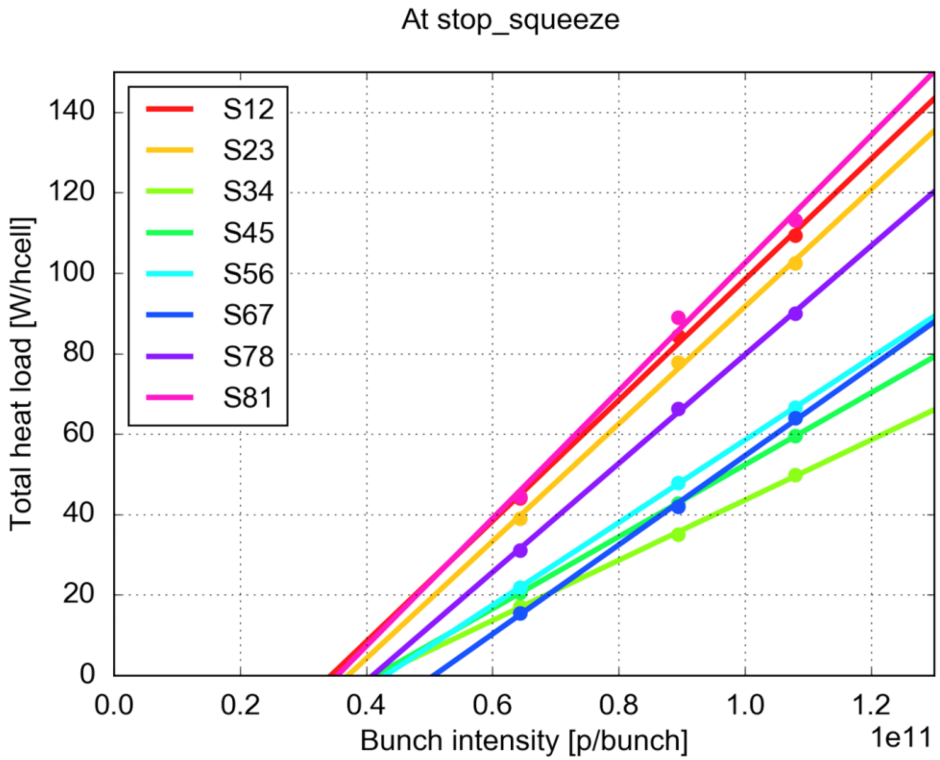


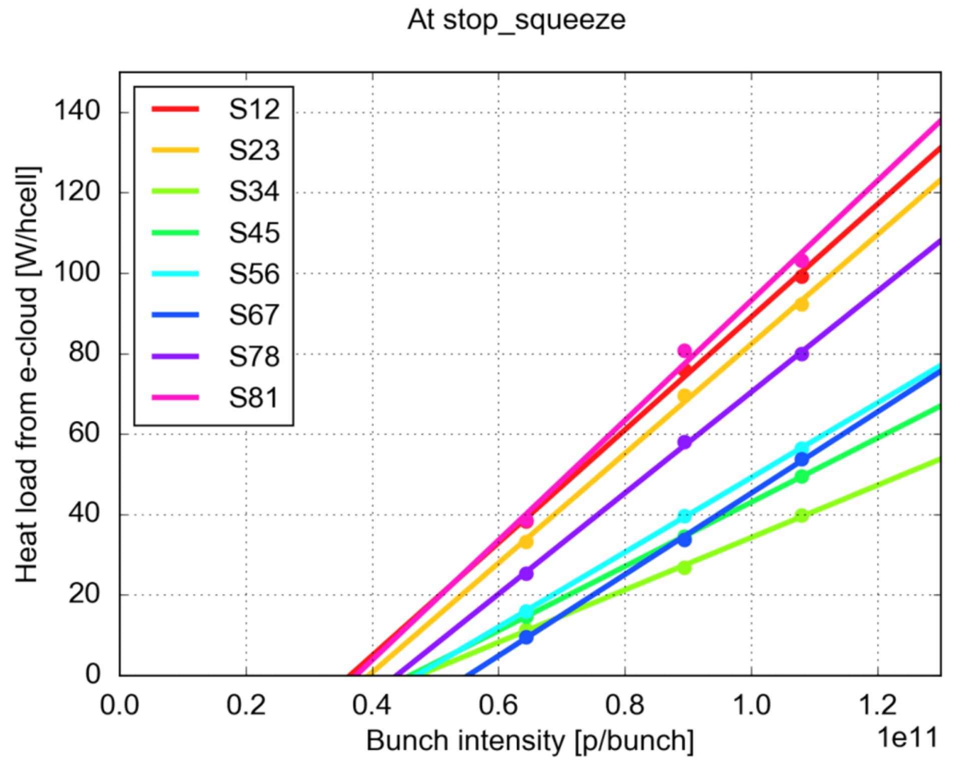


Summary

- In 2017 it should be possible to **increase the number of bunches in the LHC** (thanks to SPS dump replacement, better kicker rise-times). From "filling scheme constraints":
  → **2556** bunches for **BCMS** (up to 2748b. in case longer injected trains are allowed)
  → **2760** bunches for the **standard scheme**
- **Limitations from e-cloud** are quite different for the two schemes. Assuming same situation as end-2016:
  → **BCMS shows no limitation** on the number of bunches up to **1.2 p/bunch**
  → **Standard scheme** is limited to **same or less bunches than BCMS** (already at 1.1e11)
- **BCMS seems to be the natural choice for 2017** allowing for faster ramp-up and easier recovery for S12
  → But most likely we will not see more conditioning than in 2016
  → Not much impact on Run 2 performance, but **not enough for Run 3 and HL-LHC**
- **2017 scrubbing run: 7 days**, 25 ns beams in long trains (**288b/injection**). Goals:
  → Recover scrubbing in **S12** and conditioning of exchanged **MKI2D**
  → Probe **scrubbing efficiency with long bunch trains**
- Studies with **doublets** to be **restarted in MDs** to evaluate **stability** margins and **intensity reach** → if promising, follow-up with longer period to assess the scrubbing efficiency

Thanks for your attention!


At stop_squeeze
Total heat load [W/hcell]
Bunch intensity [p/bunch]
1e11
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
20
40
60
80
100
120
140
S12
S23
S34
S45
S56
S67
S78
S81


At stop_squeeze
Heat load from e-cloud [W/hcell]
Bunch intensity [p/bunch]
1e11
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
20
40
60
80
100
120
140
S12
S23
S34
S45
S56
S67
S78
S81