Electron cloud MDs in Run 3

G. Iadarola for the e-cloud team and the heat load task force

LHC MD Day 2020

Outline

- **Introduction**

- **Heat loads on cryogenic beam-screen**
    - Characterization of ring after LS2
    - Measurements with LIU beams
    - Validation of backup schemes

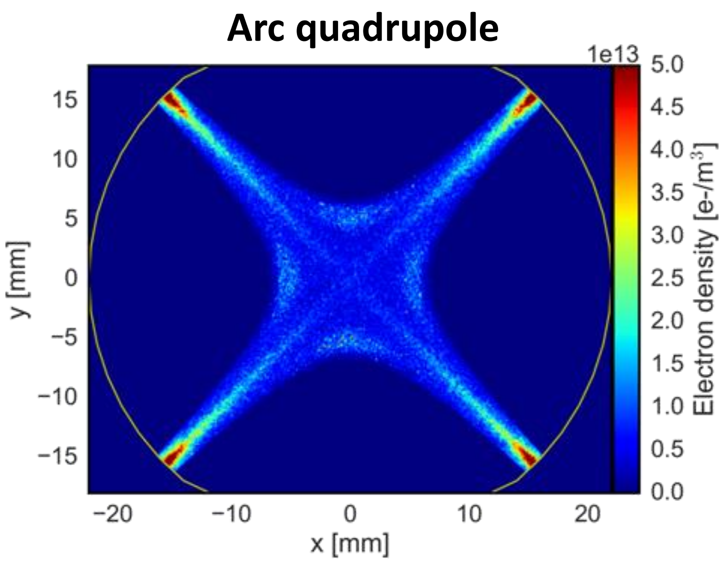
- **e-cloud instabilities at injection energy**
    - Characterization measurements
    - Tests with LIU beams

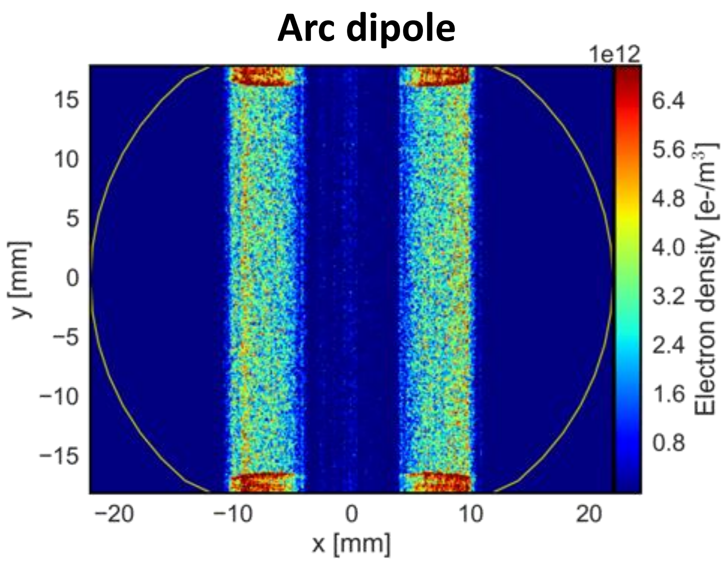
- **Incoherent effects**

Run 2 marked an **important milestone** with respect to **e-cloud effects** in the LHC, i.e. the **usage of the 25 ns bunch spacing** for most of the p-p physics operation

- With 25 ns spacing **e-cloud effects are much stronger than with 50 ns** spacing (used for luminosity production in Run 1)

- Even after years of conditioning (mostly parasitic during high-intensity operation) **effects of the e-cloud remained very visible**:
  - **Heat loads** in cryogenic magnets (with puzzling differences among sectors)
  - **Impact on beam quality** (instabilities, losses, emittance growth)





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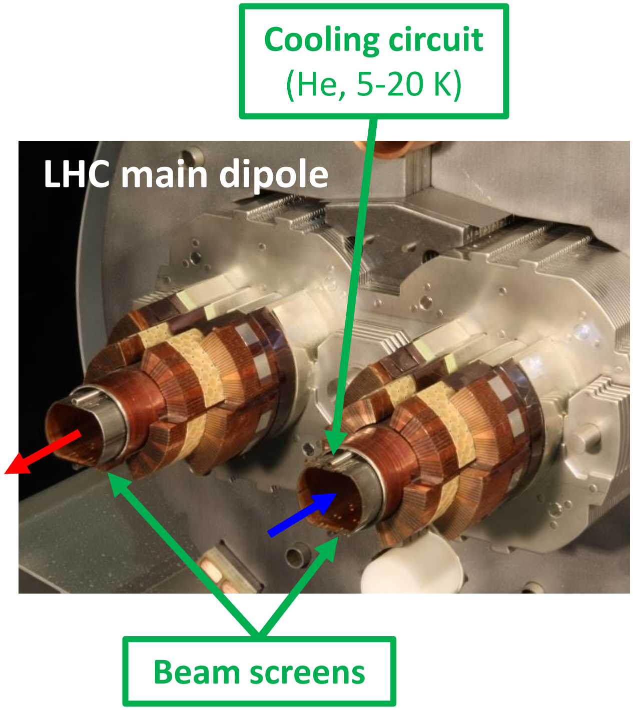
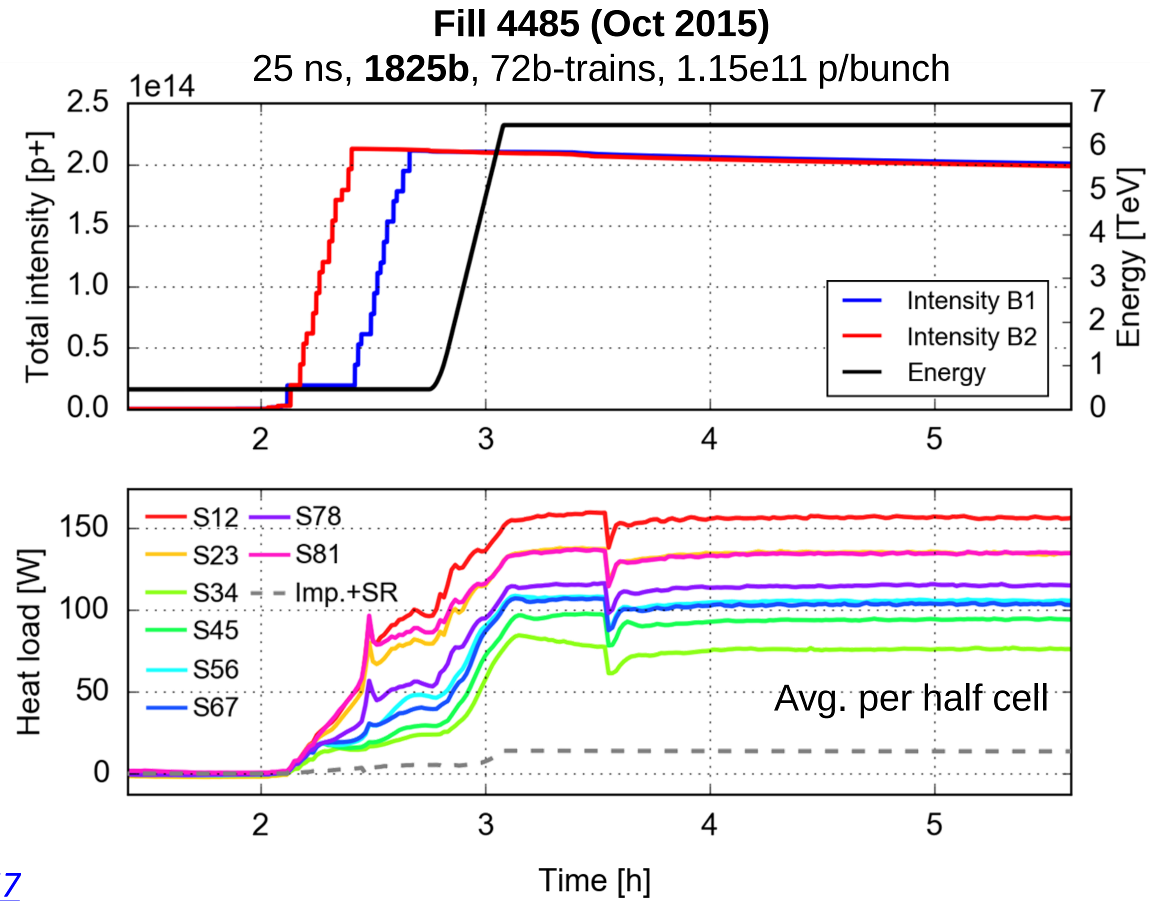
Heat loads on the arc beam-screens

- Electrons deposit **energy on the beam screens** of the LHC arc magnets
  - → **Heat load** that needs to be absorbed by the **cryogenics system**
  - → For some sectors at the **limit of the design cooling capacity** (160 W/half-cell)
- Large **differences observed among sectors**: unexpected!
  - → Object of investigation by dedicated **task force**





For more details see CERN-ACC-NOTE-2019-0057

Heat loads: underlying mechanisms

Tests done in **MD were fundamental** to **characterize the source of heating**

- We reviewed the **mechanisms** that can **transfer energy** from the beam to the beam-screen and evaluated their **compatibility with observations**

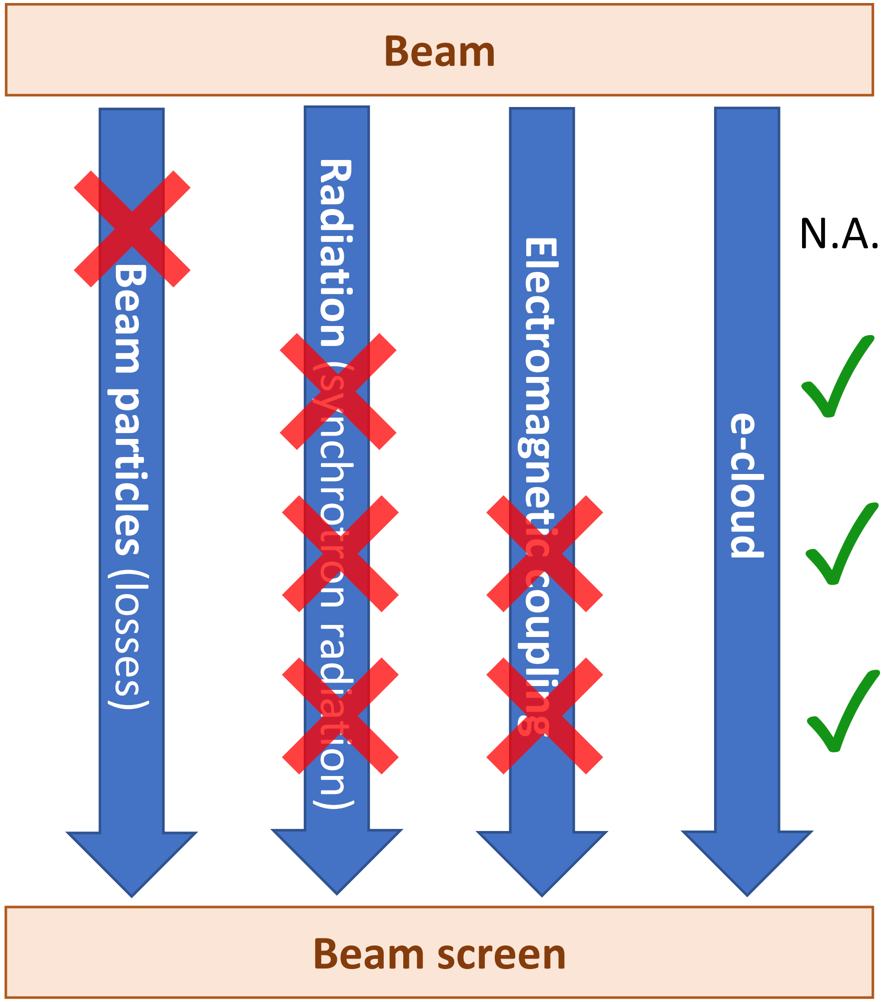
<u>**Observations**</u>

Total power associated to **intensity loss is less than 10% of measured heat load**

Heat load **increases only moderately during the energy ramp**

Heat loads with **50 ns are >10 times smaller than with 25 ns**

Measured **dependence on bunch intensity** and **bunch length**



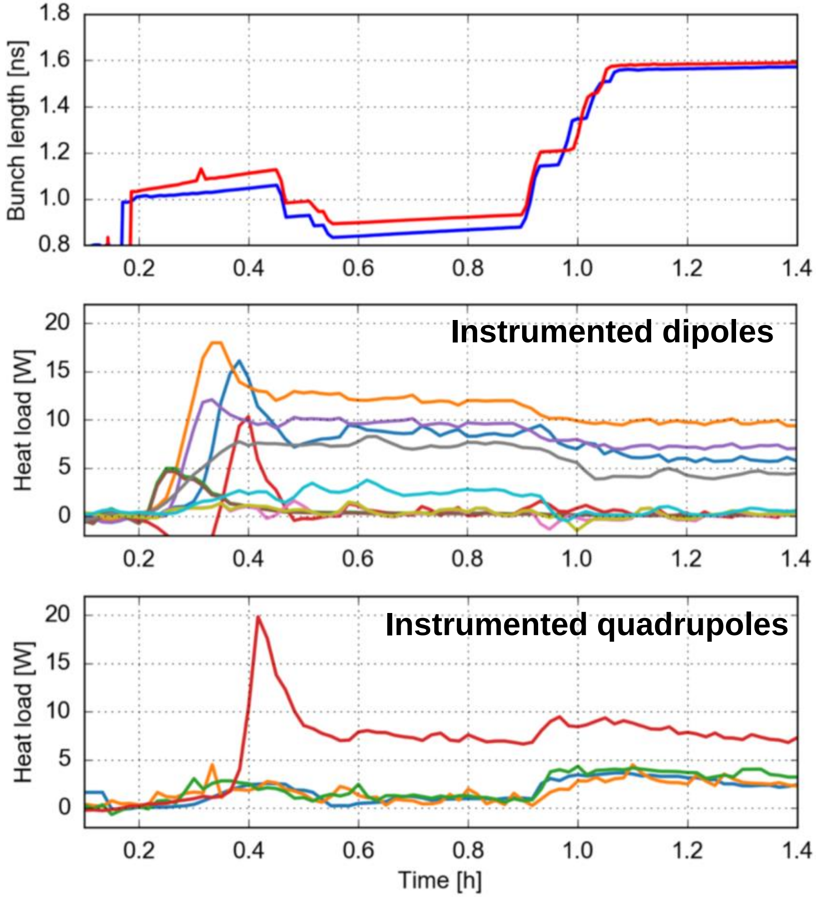
✓ **= Good quantitative agreement**

✗ **= Excluded**

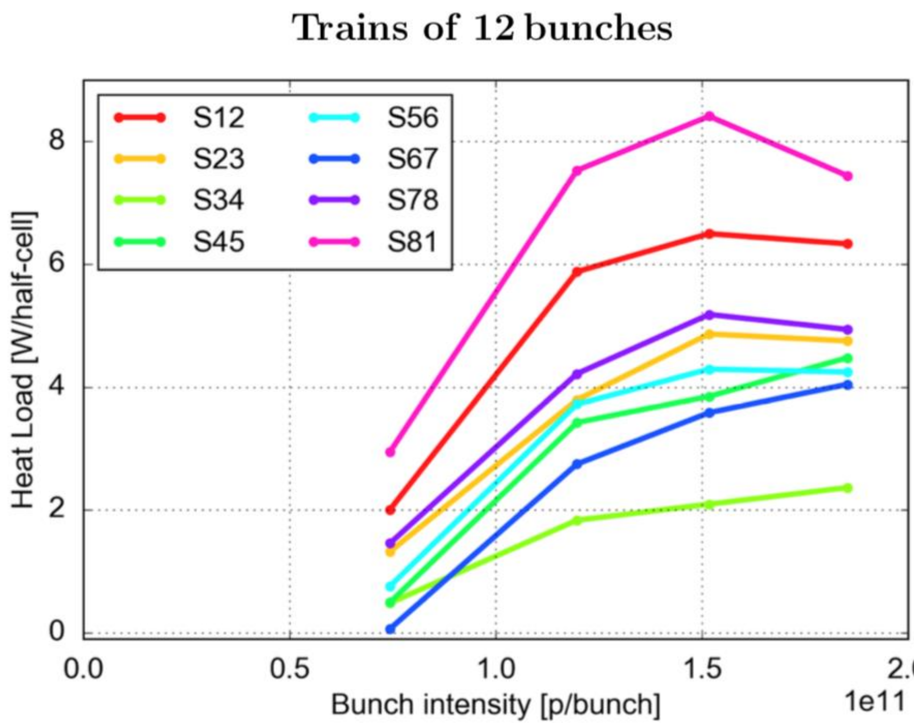
For more details see [CERN-ACC-NOTE-2019-0057]

A couple of highlights from Run 2 MDs

Confirmed different behavior w.r.t. bunch length in dipoles and quadrupoles



Confirmed non-monotonic behavior w.r.t. bunch intensity

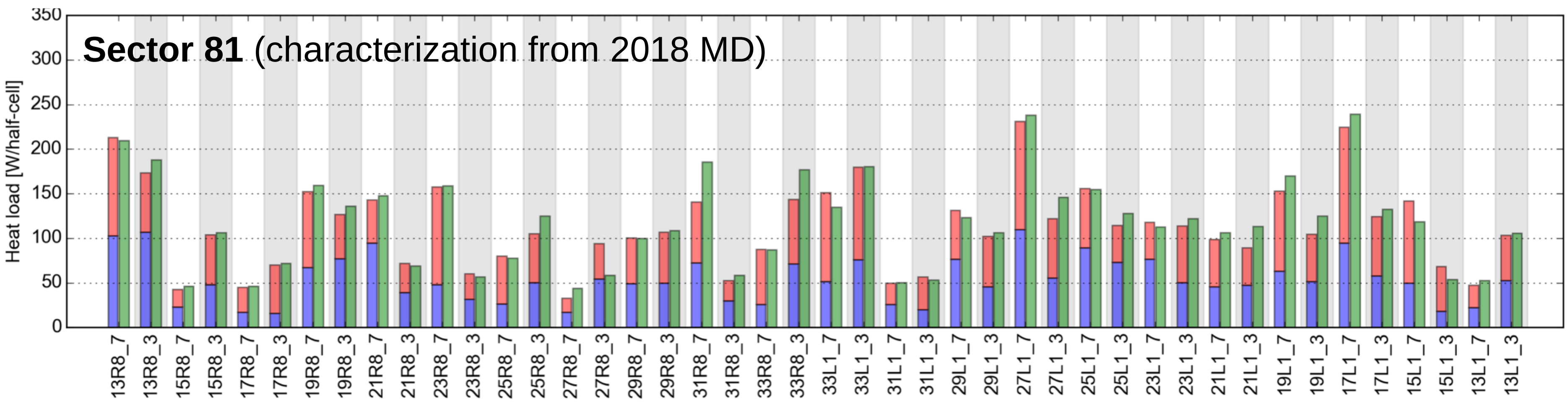


For more details see [CERN-ACC-NOTE-2019-0057]

Heat load MDs in Run 3: ring characterization

The first objective will be to **identify changes in the beam screen surfaces** that took place **during LS2** (as strong changes were observed after LS1)

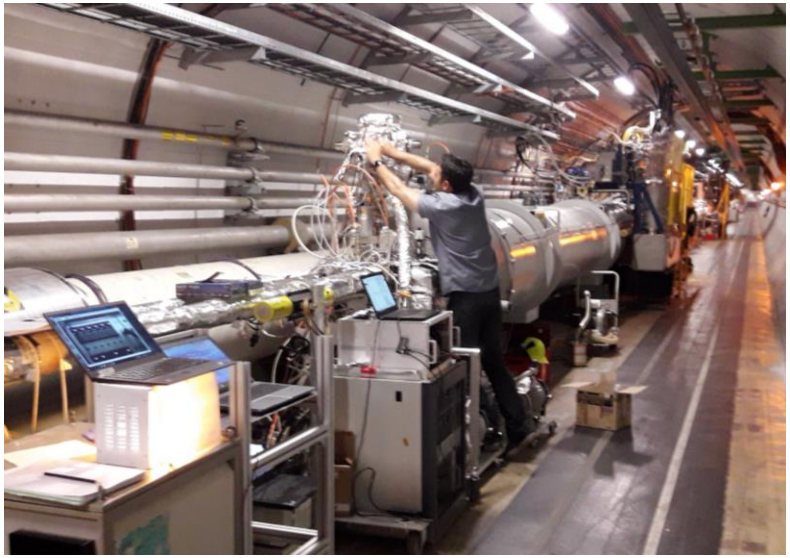
- Needs **two fills (top-energy) with B1 and B2 alone** to build the **cell-by-cell heat load maps**

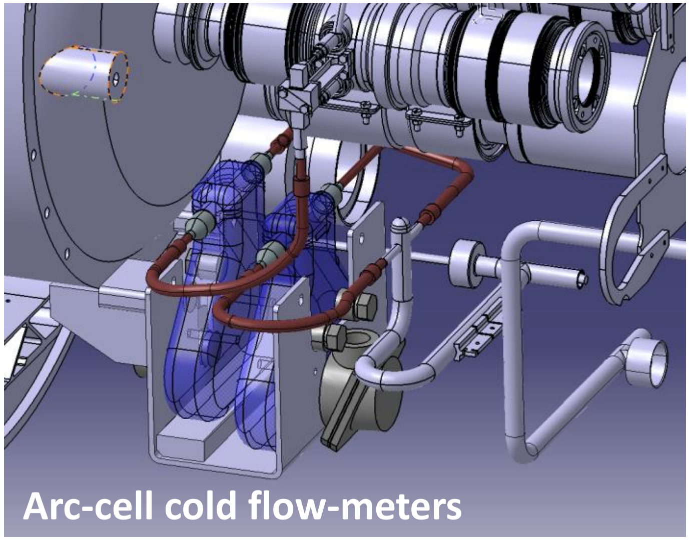


Heat load MDs in Run 3: ring characterization

The first objective will be to **identify changes in the beam screen surfaces** that took place **during LS2** (as strong changes were observed after LS1)

- Needs **two fills (top-energy) with B1 and B2 alone** to build the **cell-by-cell heat load maps**
  - Will also allow characterizing the behavior of **amorphous carbon coating** applied in stand-alone magnets during LS2
  - Useful test for the **new diagnostics** (e.g. flow-meters, RF transmission)
  - To be performed **after machine re-conditioning** (end of 2021 proton run)
- **Dependence of heat load on bunch length** in newly instrumented half-cells should also be measured (450 GeV)

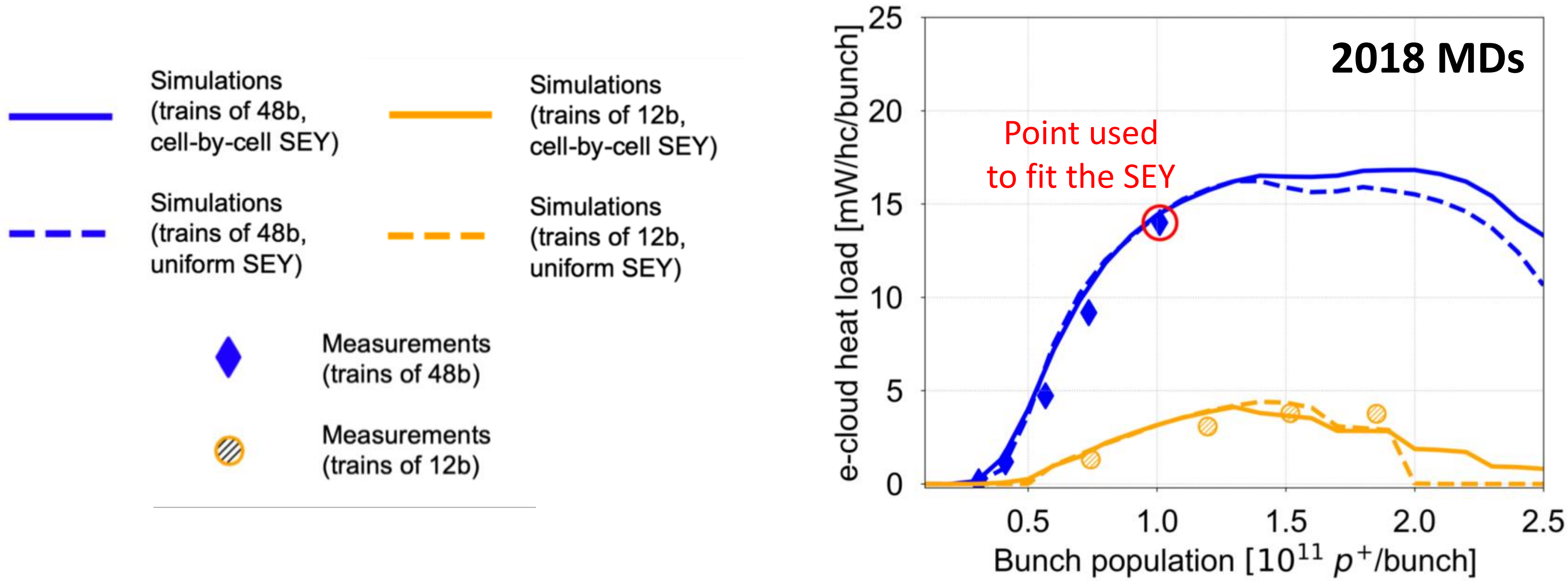




Heat load MDs in run 3: dependence on bunch intensity

The **dependence of the heat loads on bunch intensity** is a key factor for performance in Run 3 and for HL-LHC

- With the available models, **simulations foresee a relatively favourable behavior**
- Due to intensity limitations in the injectors, this dependence could be **tested only with short bunch trains (12b) in Run 2**
- Direct tests with **longer bunch trains (48b or more) with high bunch intensity** should take place in Run 3 (LIU beams):
    - Aiming at **1.8 x 10^{11} p/bunch in 2022**
    - Test **full HL-LHC beam at 450 GeV by 2024** (2.3 x 10^{11} p/bunch, 2760b)
- Useful also to study **RF heating** in several accelerator components



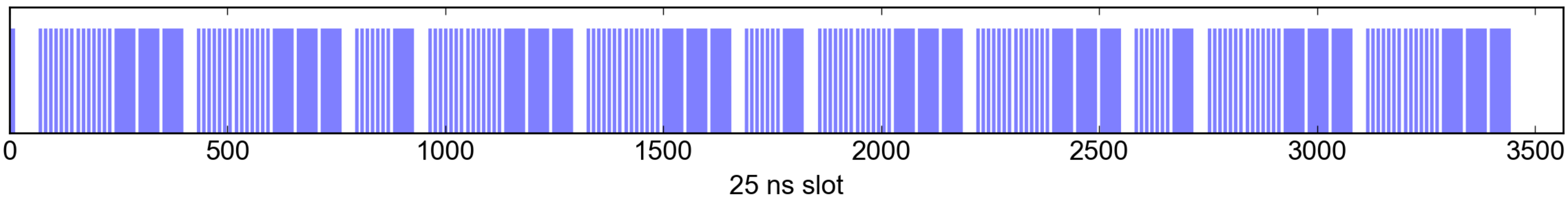
For more details see CERN-ACC-NOTE-2019-0057

Heat load MDs in run 3: backup schemes

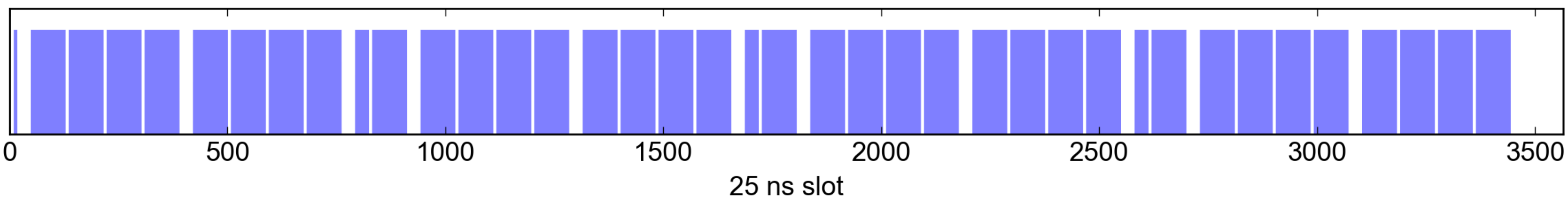
In case of strong limitations from the e-cloud heat loads, **hybrid schemes mixing 25 ns and 8b+4e** trains will have to be used:

- To optimize the number of bunches we **need to combine the trains already in the SPS**
- Production and injection of this type of patterns have never been done and **should be tested in Run 3**
- The same approach can be used to **push the number of bunches** in the **nominal scheme**

Hybrid scheme 25ns_2372b_2360_1784_2216_256bpi_12inj_800ns_bs200ns_run3study



(80+32)b scheme 25ns_2904b_2896_2656_2734_320bpi_12inj_800ns_bs200ns_4x80b_opt



More details at https://indico.cern.ch/event/788818

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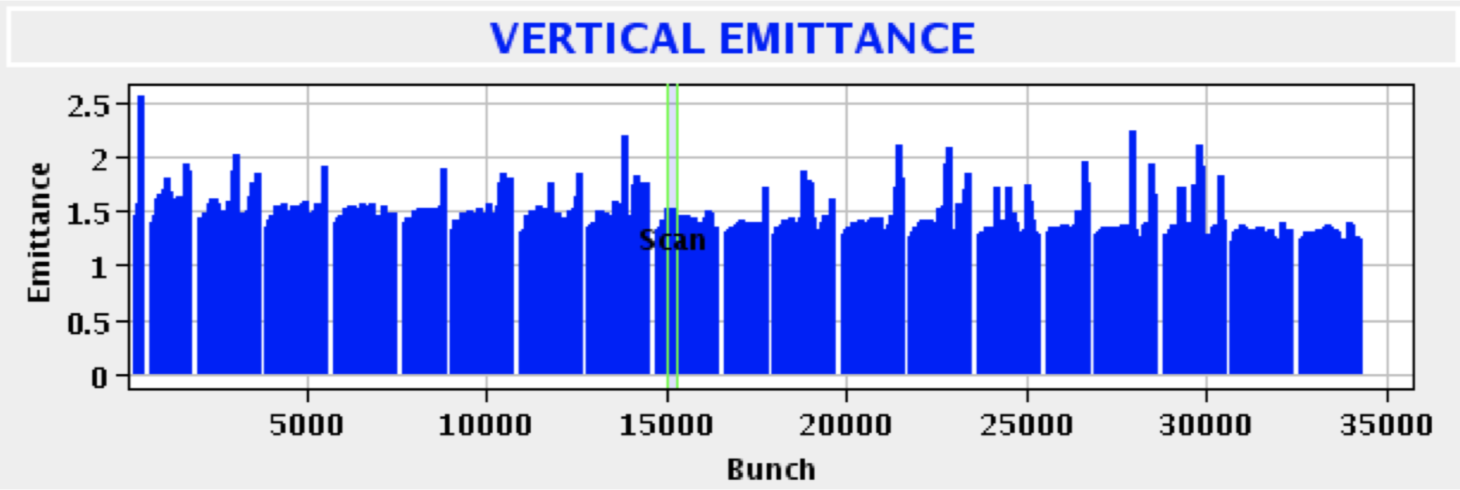
Instabilities at injection energy

In Run 2 **weak instabilities were often taking place at injection energy**:

- Contained with a high chromaticity (15-20) and octupole current (~50A)
- A potential concern for future intensities

Significant **advances on simulation models** made during LS2:

→ Need a **consistent and complete set of experimental data** to validate the models



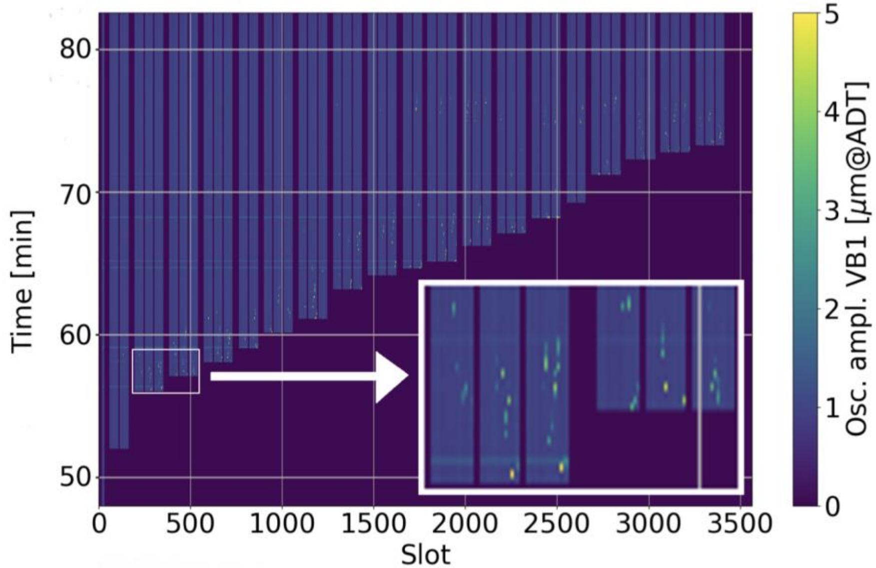
For more info: X. Buffat, "Transverse Instabilities", Evian19
L. Sabato and G. Iadarola: "Single bunch instabilities at injection energy", e-cloud meeting #71

Instabilities at injection energy – characterization MDs

Goals for **stability MDs with nominal intensity** at 450 GeV:

- **Characterize** instabilities single-bunch and coupled-bunch instabilities w.r.t. **chromaticity, octupoles and ADT settings, RF settings**
- Measure **bunch-by-bunch tune shift** exciting individual bunches with the ADT (possibly use also BTF measurements)
- **Optimize diagnostics** (e.g. instability trigger settings, gate of HeadTail monitor on most sensitive bunches) → for deployment in operation

It would be useful to collect some data **already at the beginning of 2021** - before scrubbing - when instabilities are stronger (data easier to compare against simulations)

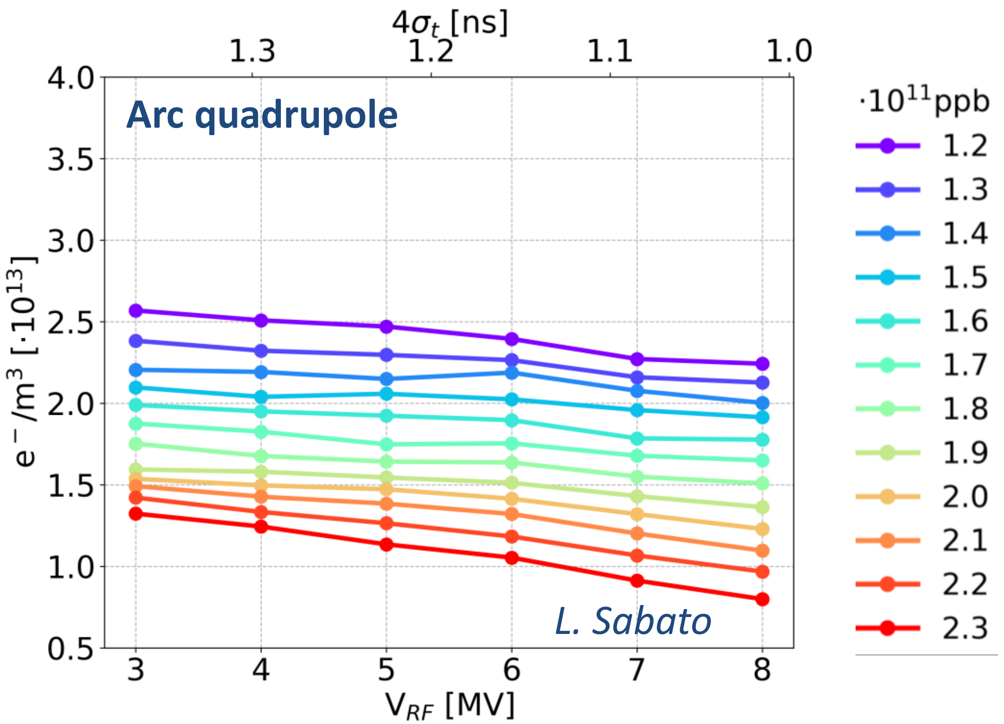


For more info: X. Buffat, "Transverse Instabilities", Evian19

Instabilities at injection energy – bunch intensity scaling

Also with respect to instabilities, **e-cloud simulations predict a favorable behavior when increasing the bunch intensity**

- This feature **needs to be tested experimentally during Run 3** (checking limits w.r.t. octupoles, chromaticity, damper gain)
- It would be useful to perform first tests with **~1.8 x 10^{11} p/bunch already in 2022**, to have time, if needed, to develop and test mitigation measures during Run 3



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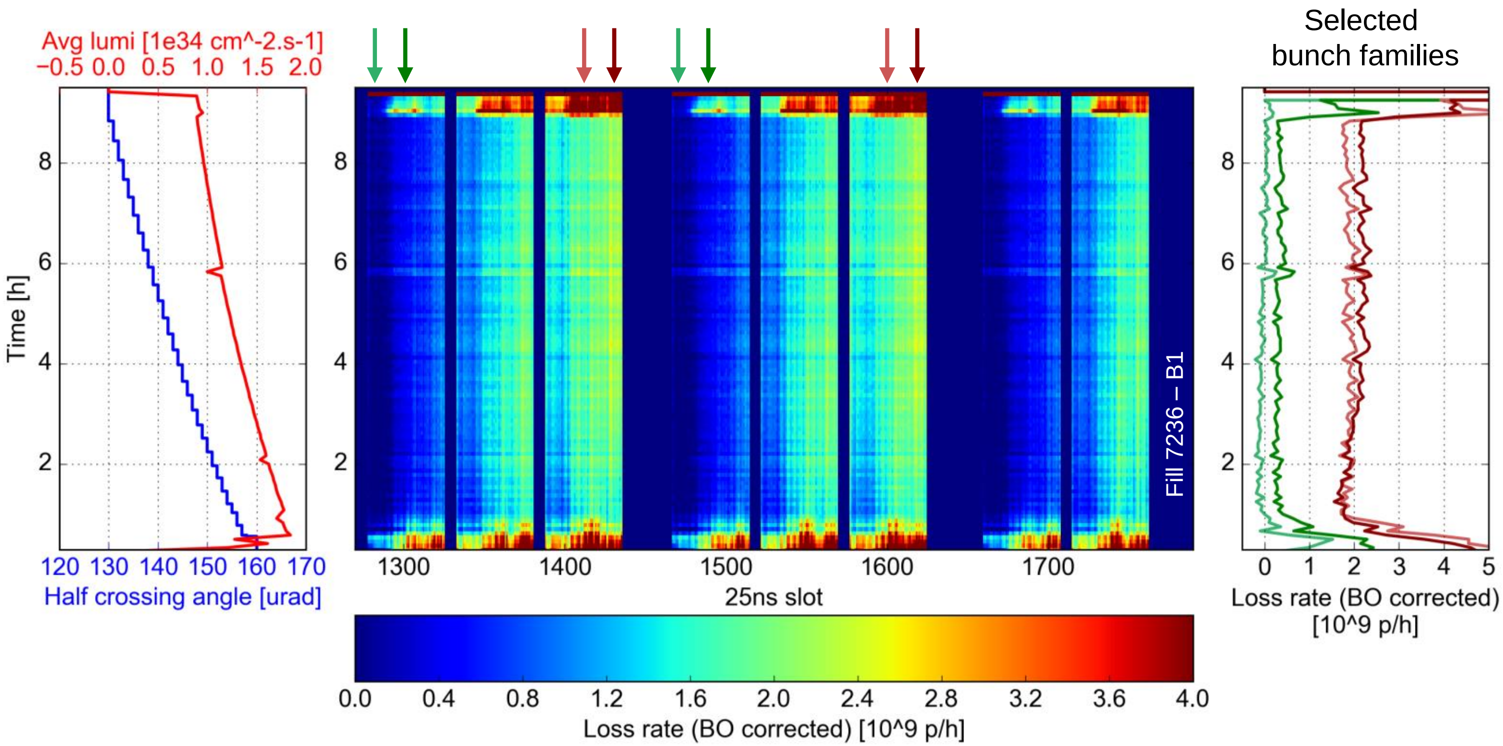
Incoherent effects

Even when the beam is kept stable the **e-cloud is the source of incoherent effects** which lead to significant **beam degradation**

- Beam **losses** and transverse emittance **blow-up**
- Visible at **injection** energy and in **collision**

Significant work being done during LS2 to develop **methods and tools** allowing to reliably model these effects

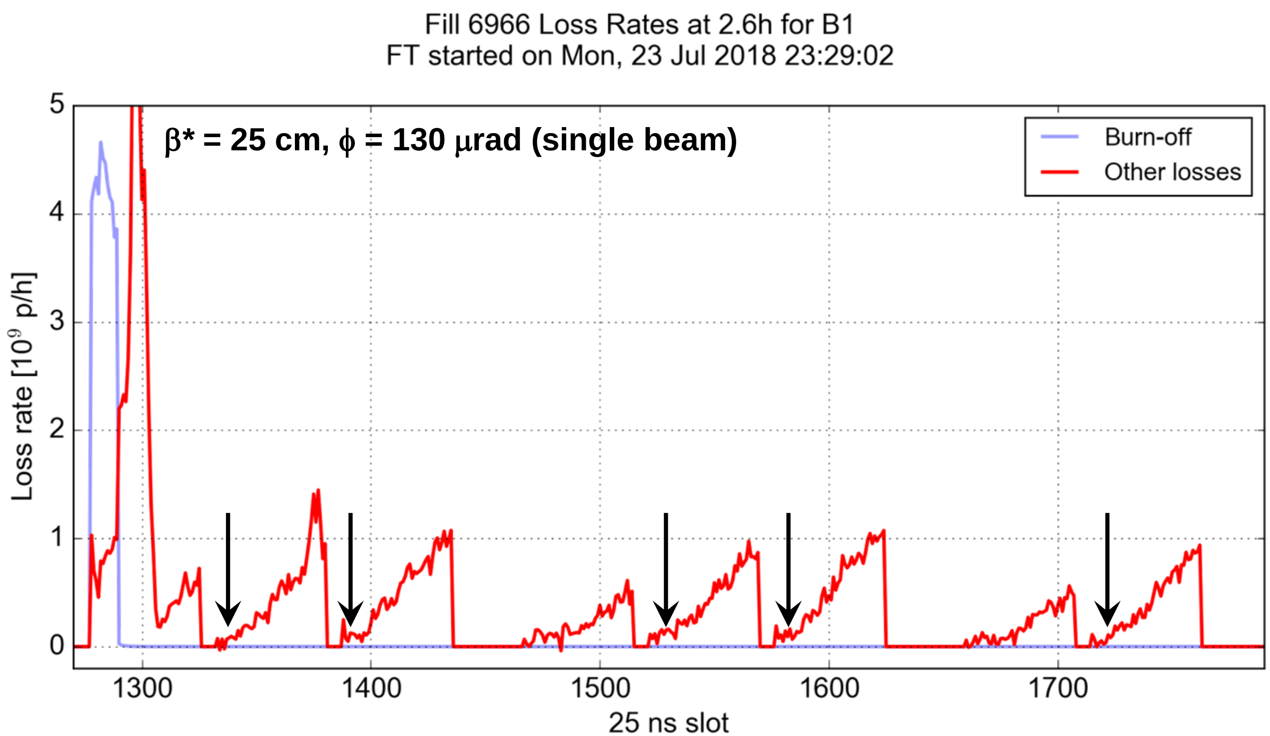


More info at https://indico.cern.ch/event/859514

Incoherent effects

Main goals for Run 3 MDs on **e-cloud incoherent effects**:

- Study the dependence of **lifetime/emittance blow-up on the machine settings at 450 GeV**
  - Explore **tune space below the diagonal** (will provide information on the effect of dipoles and quadrupoles separately)
- Study the **dependence on the bunch intensity** as LIU beams become available
  - Collect data with **one circulating beam at high energy** to disentangle the effect of beam-beam



2018 MDs allowed identifying **e-cloud in the triplet** as the main source of the losses in collisions

More info at https://indico.cern.ch/event/859514

Summary

Several tests and studies ahead of us, **main objectives**:

- **Heat loads:**
  - Characterize the **impact on LS2** on the heat loads
  - Study the **dependence on bunch intensity** with LIU beams
  - Test **“hybrid schemes”** based on advanced pattern from the SPS
- e-cloud induced **instabilities** and **incoherent effects:**
  - Characterize the behavior with respect to **tune, Q’, octupoles, ADT, RF settings**
  - Study the **dependence on bunch intensity** with LIU beams (instability thresholds vs Q’/octupoles, lifetime at high energy)
  - **Optimize diagnostics** (triggers, gating) to better capture instabilities at injection

A first thought on time requirements

Topic	2021	2022-2024
Heat load characterization	2.5 shifts (after 2 months of operation)	
Heat loads - higher bunch intensity		2 shifts / year
Heat loads – hybrid schemes		1 shift (once)
Instabilities characterization and diagnostics (~1e11 p/b)	1 shift before scrubbing 1 shift after two months of operation	1.5 shift / year
Instabilities bunch intensity dependence (> 1.8 e 11 p/b)		2 shifts / year
Incoherent effects	1 shifts (after 2 months of operation)	1 shift / year

Thanks of your attention!