Electron cloud MDs in Run 3

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

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

• e-cloud instabilities at injection energy
  o Characterization measurements
  o 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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• **Incoherent effects**
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**

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**

### Observations

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

Trains of 12 bunches

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

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**Sector 81** (characterization from 2018 MD)
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
  o Will also allow characterizing the behavior of amorphous carbon coating applied in stand-alone magnets during LS2
  o Useful test for the new diagnostics (e.g. flow-meters, RF transmission)
  o 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)
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 $1.8 \times 10^{11}$ p/bunch in 2022.
  - Test full HL-LHC beam at 450 GeV by 2024 ($2.3 \times 10^{11}$ p/bunch, 2760b).
- Useful also to study RF heating in several accelerator components.

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

More details at [https://indico.cern.ch/event/788818](https://indico.cern.ch/event/788818)
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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:

\[ \rightarrow \] Need a **consistent and complete set of experimental data** to validate the models

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**For more info:**

X. Buffat, “Transverse Instabilities”, [Evian19](#)

L. Sabato and G. Iadarola: “Single bunch instabilities at injection energy”, [e-cloud meeting #71](#)
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*
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 $\sim 1.8 \times 10^{11}$ p/bunch already in 2022, to have time, if needed, to develop and test mitigation measures during Run 3

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For more info: L. Sabato and G. Iadarola: “Single bunch instabilities at injection energy”, e-cloud meeting #71
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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](https://indico.cern.ch/event/859514)
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

**Fill 6966 Loss Rates at 2.6h for B1**
FT started on Mon, 23 Jul 2018 23:29:02

\[ \beta^* = 25 \text{ cm}, \phi = 130 \text{ \mu rad (single beam)} \]

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](https://indico.cern.ch/event/859514)
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

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<th>Topic</th>
<th>2021</th>
<th>2022-2024</th>
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<tbody>
<tr>
<td>Heat load characterization</td>
<td>2.5 shifts (after 2 months of operation)</td>
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<tr>
<td>Heat loads - higher bunch intensity</td>
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<td>2 shifts / year</td>
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<tr>
<td>Heat loads – hybrid schemes</td>
<td></td>
<td>1 shift (once)</td>
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<tr>
<td>Instabilities characterization and diagnostics (~1e11 p/b)</td>
<td>1 shift before scrubbing</td>
<td>1.5 shift / year</td>
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<tr>
<td></td>
<td>1 shift after two months of operation</td>
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<tr>
<td>Instabilities bunch intensity dependence (&gt; 1.8 e 11 p/b)</td>
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<td>2 shifts / year</td>
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<tr>
<td>Incoherent effects</td>
<td>1 shifts (after 2 months of operation)</td>
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Thanks of your attention!