200 MHz option for HL-LHC: e-cloud considerations (heat load aspects)

G. Iadarola and G. Rumolo

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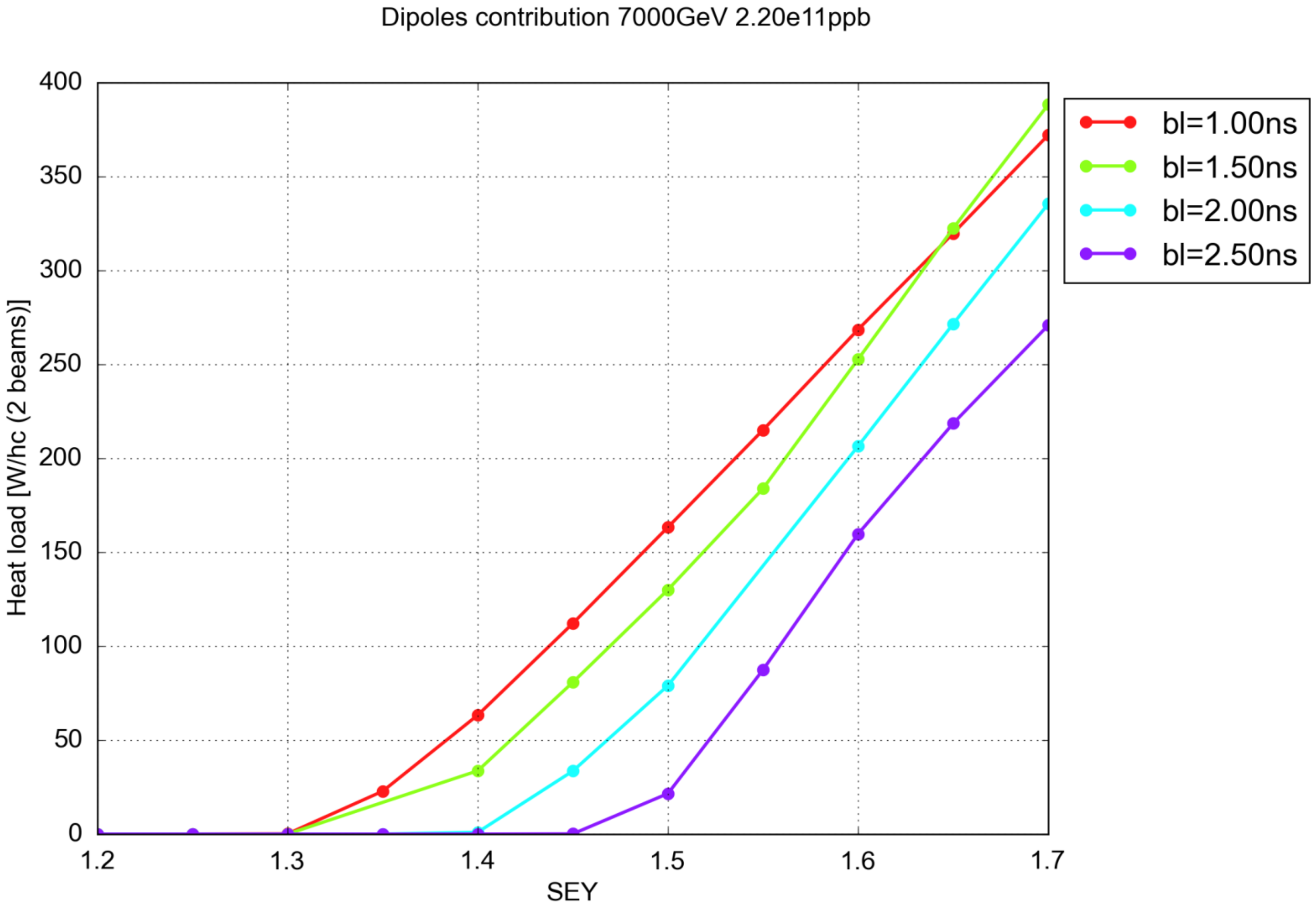
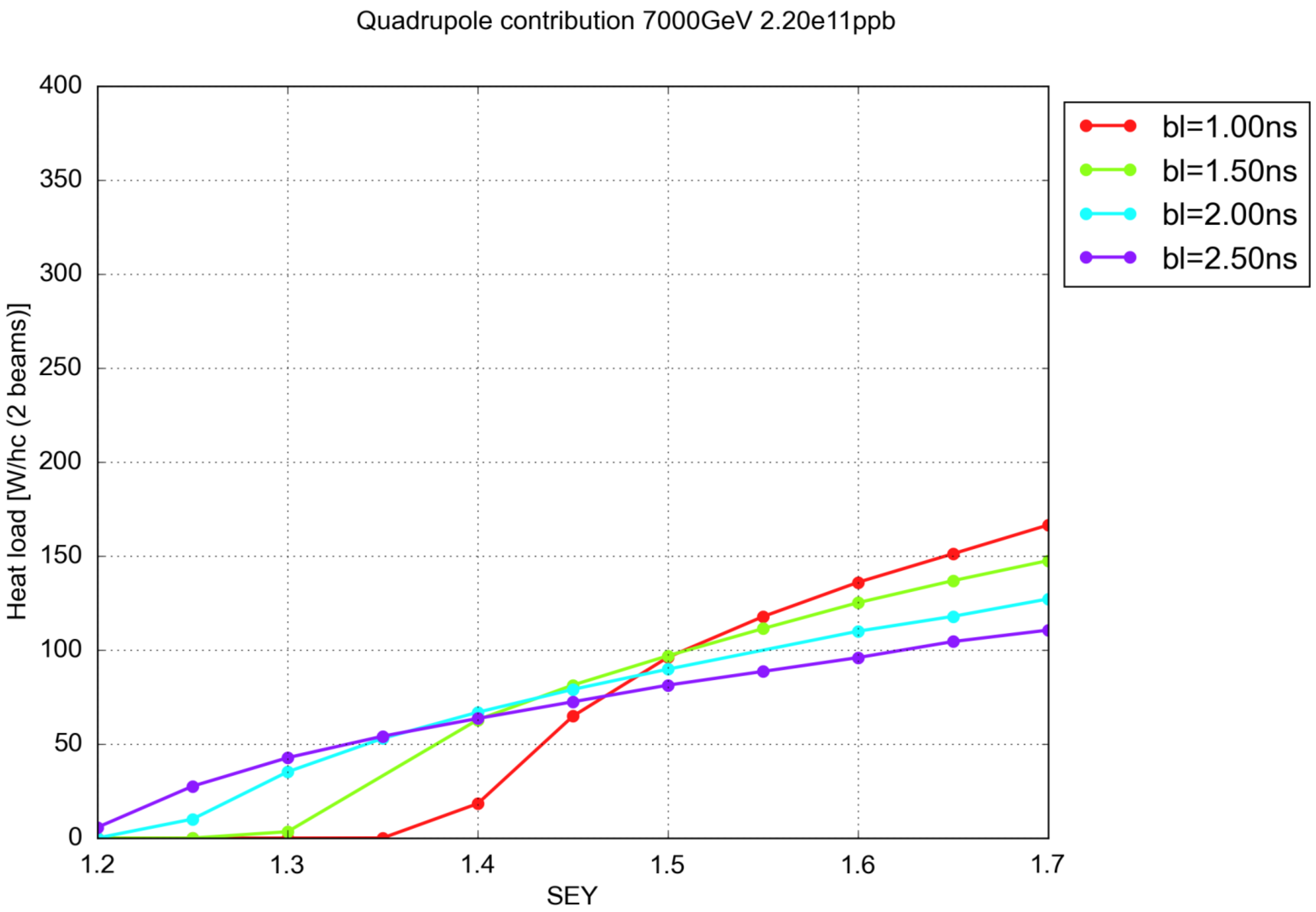
e-cloud dependence on bunch length – arc dipoles

- Heat load decreasing with bunch length for all values of SEY
- Significant change of the multipacting threshold



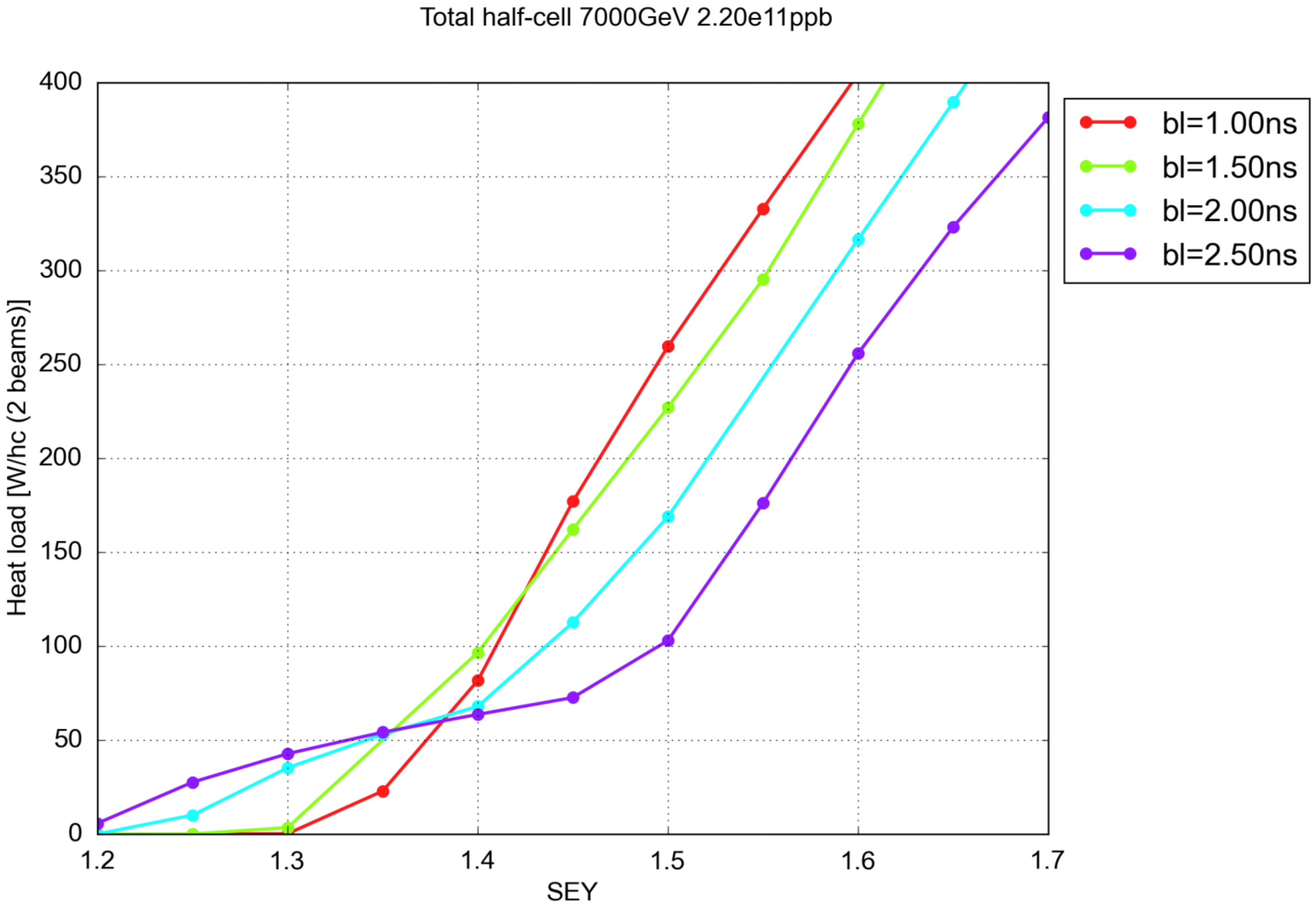
e-cloud dependence on bunch length – arc quadrupoles

- Heat load decreasing with bunch length only for large values of SEY
- Multipacting threshold **decreasing for longer bunches**



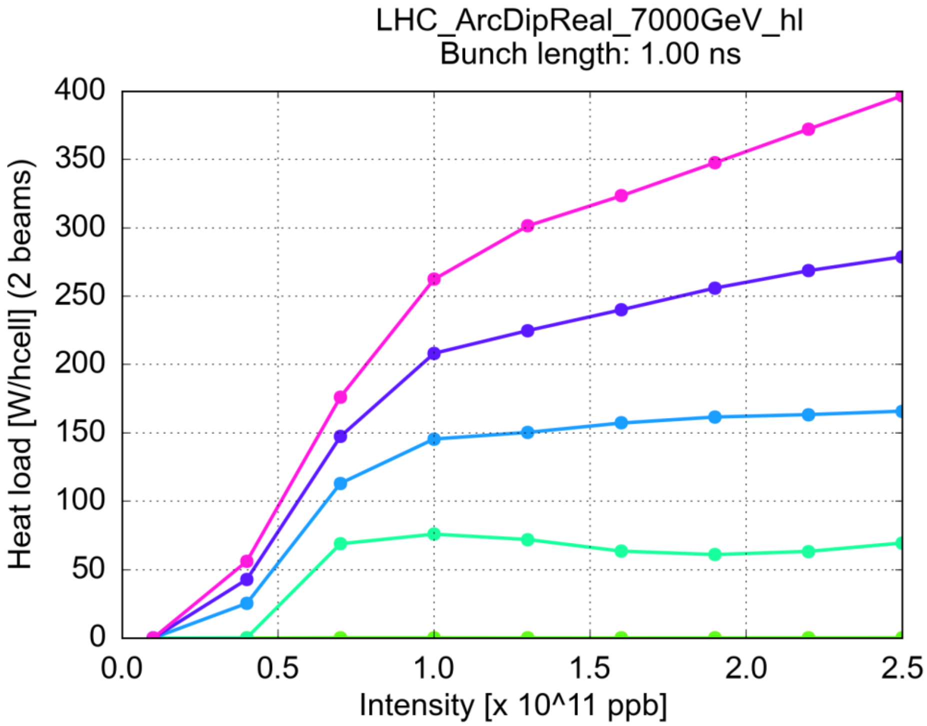
e-cloud dependence on bunch length – half cell

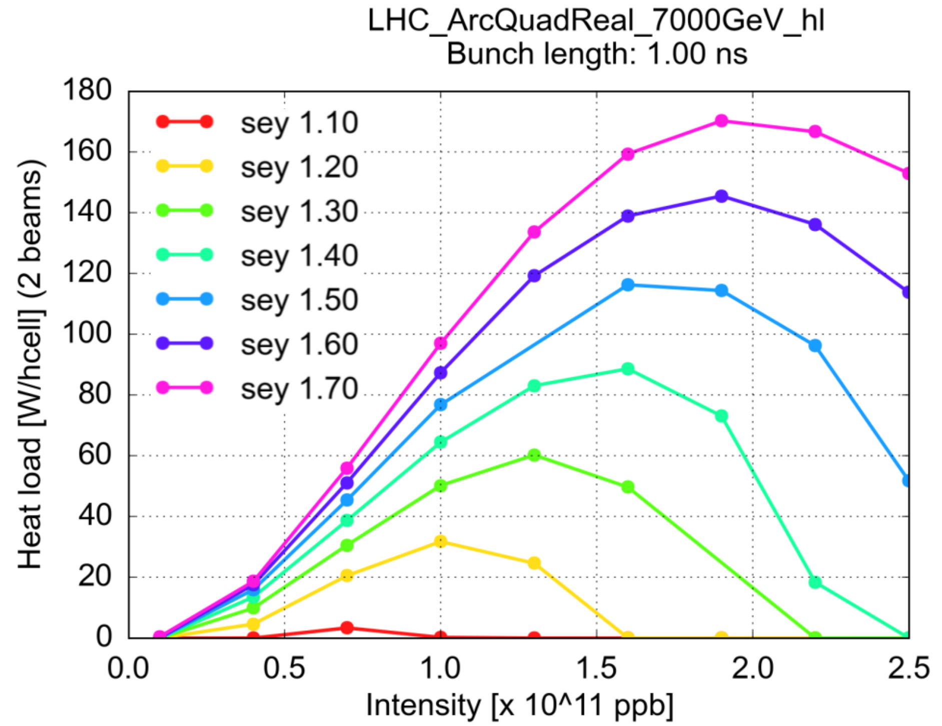
- In the region where heat loads from e-cloud are worrying, longer bunches are beneficial



e-cloud dependence on bunch intensity

- Heat load scales **non monotonically with bunch intensity**
  - → Start of fill might not be the most critical moment





e-cloud dependence on bunch intensity

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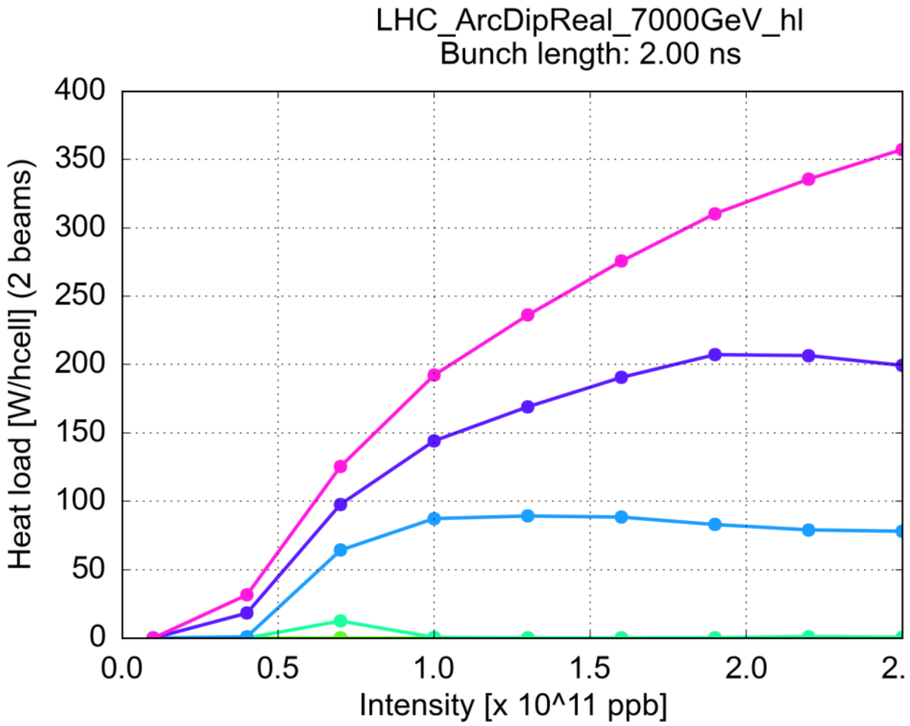
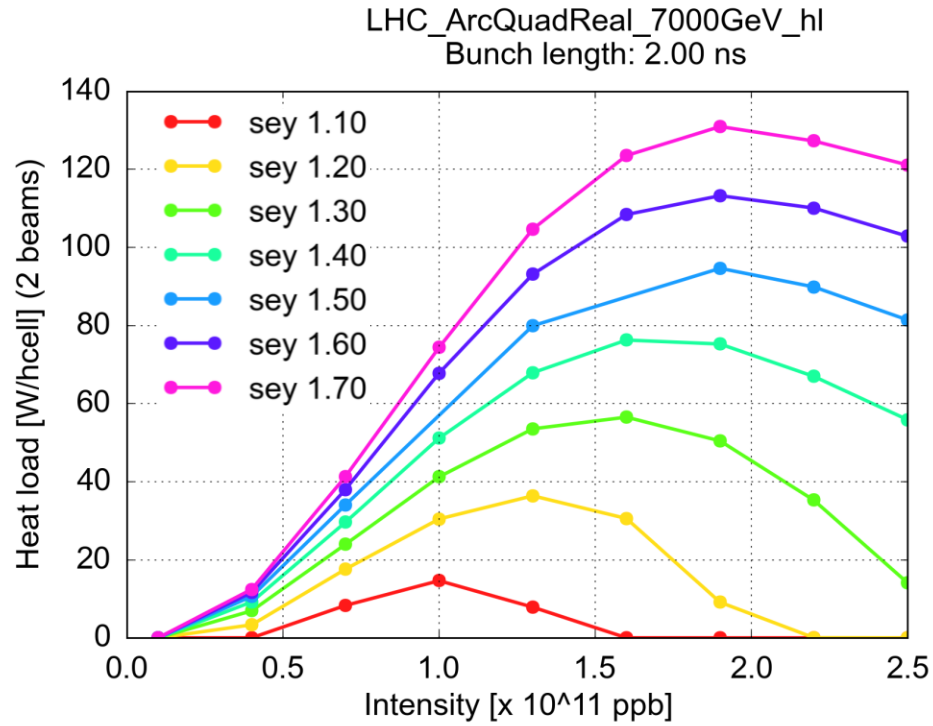




Estimation approach

Evolution of the heat load during the fill is the **result of different factors**:

- Heat load **sharing between dipoles and quadrupoles**
- Dependence on **bunch intensity** (start of fill is not necessarily the critical point)
- Dependence on **bunch length**
- Contribution of **synchrotron radiation and impedance**

Built **python module** to **estimate evolution of the heat load during the fill**:

- **Simple formulas** (same as for online displays) for **impedance and synchrotron radiation**
- **Interpolation over a database** of build-up simulations of the e-cloud contributions. **Simulations available for:**
    - **Dipoles** and **quadrupoles**
    - **Intensity** in [0.1, … , 2.5] x 10^{11} p/bunch
    - **Bunch length** in [0.5, … , 3.5] ns
    - **SEY** in [1.0, … , 2.0]

Considered scenarios

Considered two possible situations with respect to e-cloud

- e-cloud **suppression in the dipoles is achieved**: SEY_{dip} = SEY_{quad} = **1.30**
- e-cloud **suppression in the dipoles is not achieved**: SEY_{dip} = SEY_{quad} = **1.40**

For each case we simulated a fill for the **HL-LHC baseline (400 MHz)** and **two 200 MHz cases** (fast recapture, long bunches kept along the fill)

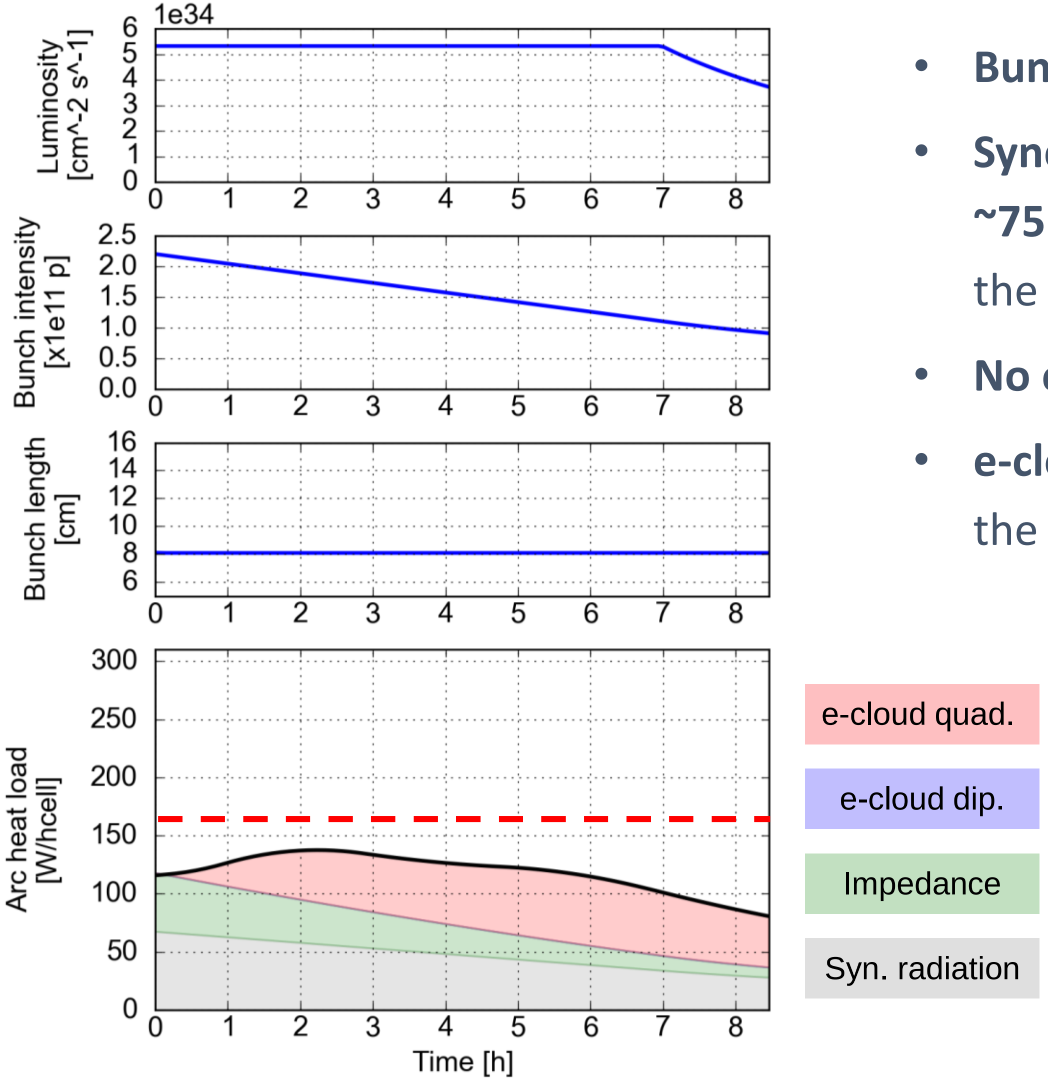
Scenario 1:
e-cloud suppression achieved in dipoles

$SEY_{dip} = SEY_{quad} = \mathbf{1.30}$

Scenario 1 – e-cloud suppression achieved in dipoles

Assumption: $SEY_{dip} = SEY_{quad} =$ **1.30**

HL-LHC baseline (400 MHz)

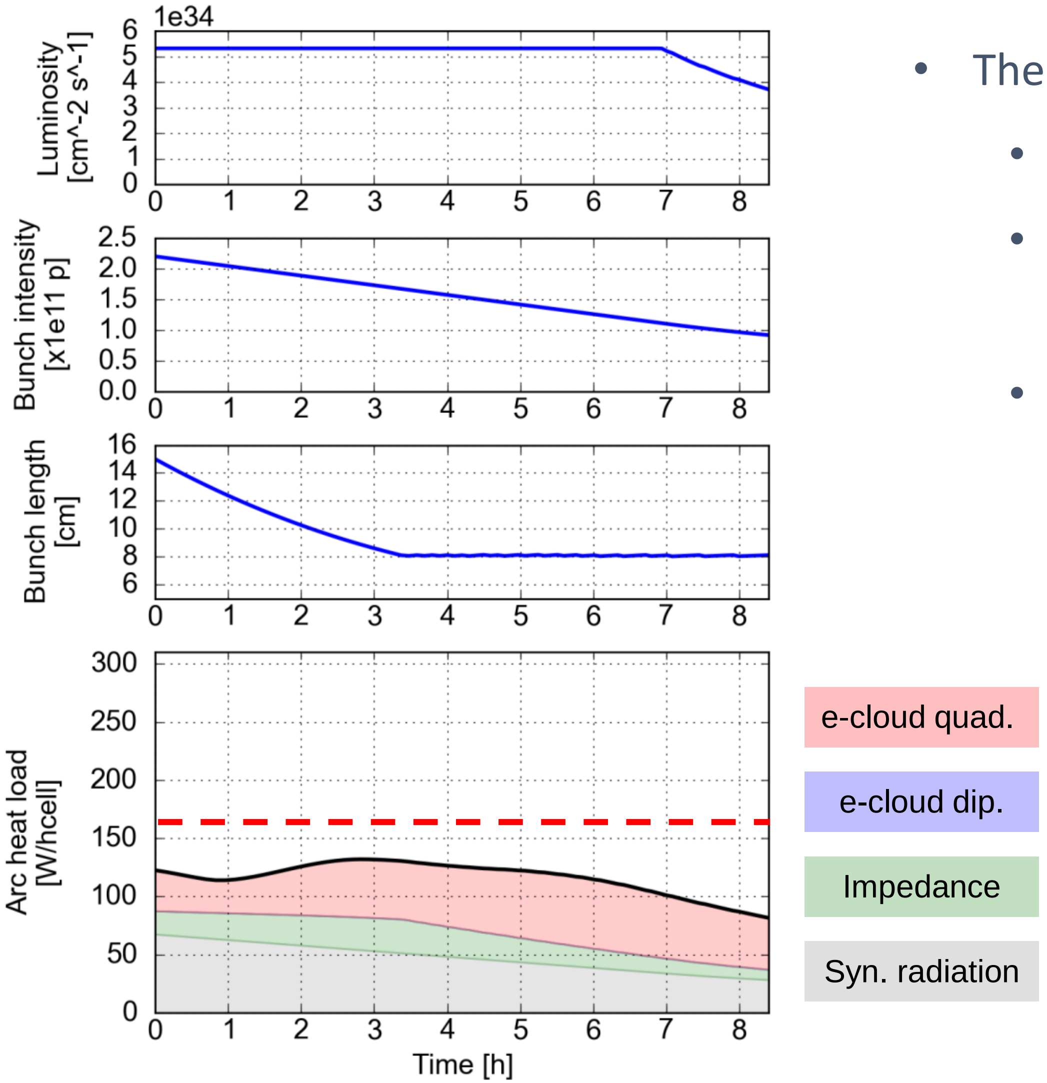


- **Bunch length** is kept constant at 8 cm
- **Synchrotron radiation and impedance** take **~75 %** of the available cooling capacity at the beginning of the fill
- **No e-cloud in dipoles** all along the fill
- **e-cloud in the quadrupoles** appears with the decrease in intensity

Scenario 1 – e-cloud suppression achieved in dipoles

Assumption: $SEY_{dip} = SEY_{quad} =$ **1.30**

200 MHz option, fast recapture

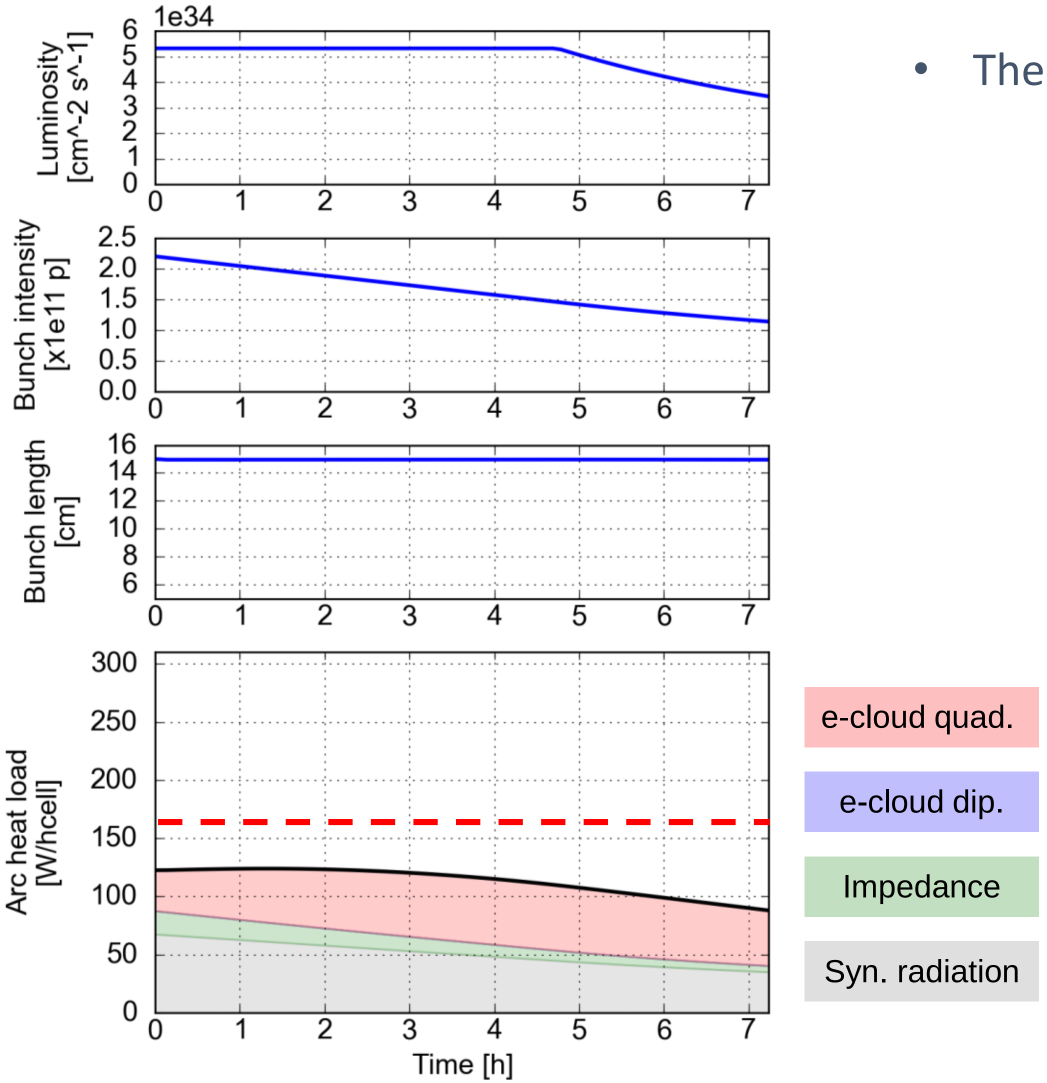


- The picture does not change significantly
  - No e-cloud in dipoles all along the fill
  - Bunches are already short when the "critical" intensity is achieved
  - Impedance contribution is reduced at the beginning of the fill

Scenario 1 – e-cloud suppression achieved in dipoles

Assumption: $SEY_{dip} = SEY_{quad} = $ **1.30**

200 MHz option, constant bunch length



- The picture does not change significantly

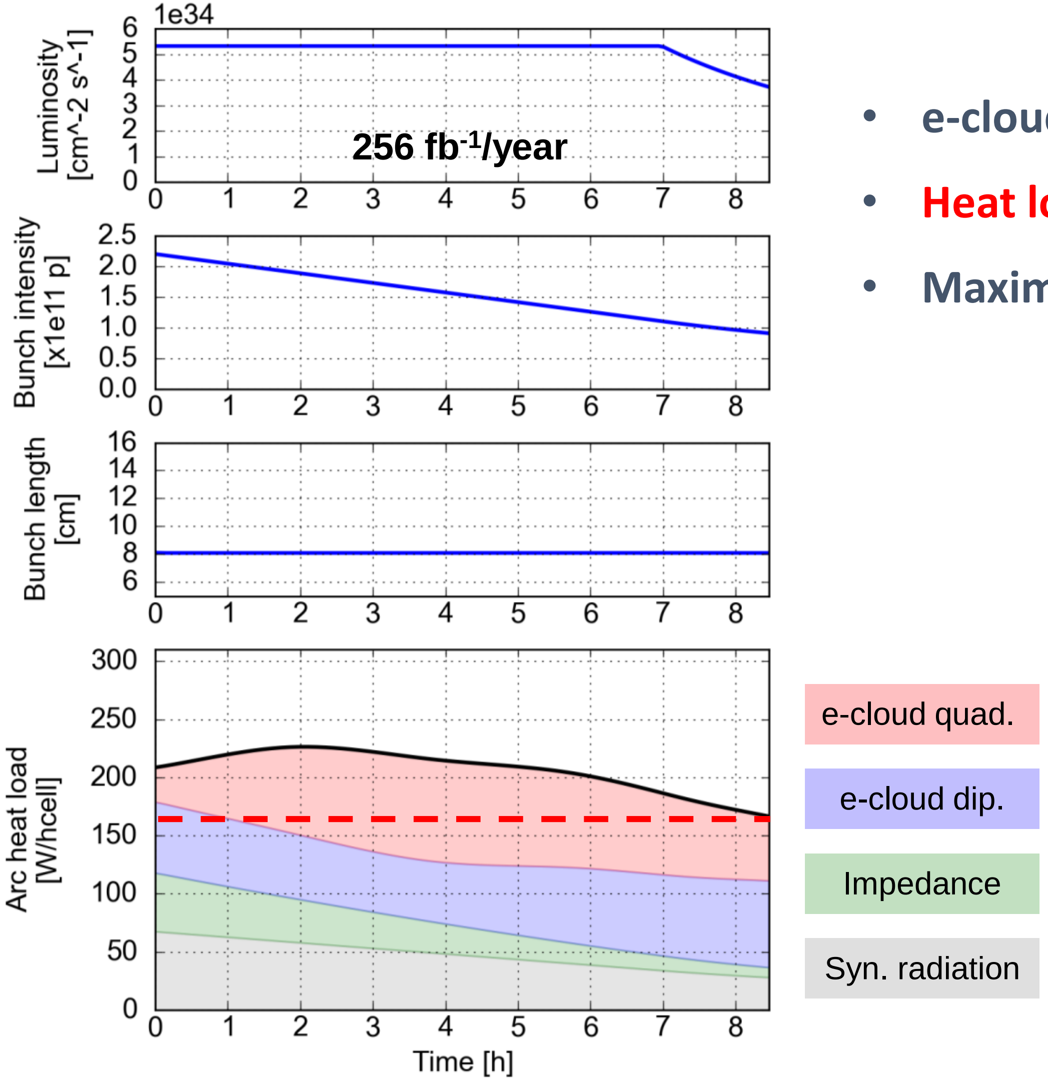
Scenario 2:
e-cloud suppression not achieved in dipoles

$SEY_{dip} = SEY_{quad} = \mathbf{1.40}$

Scenario 2 – e-cloud suppression not achieved in dipoles

Assumption: $SEY_{dip} = SEY_{quad} = \mathbf{1.40}$

HL-LHC baseline (400 MHz)

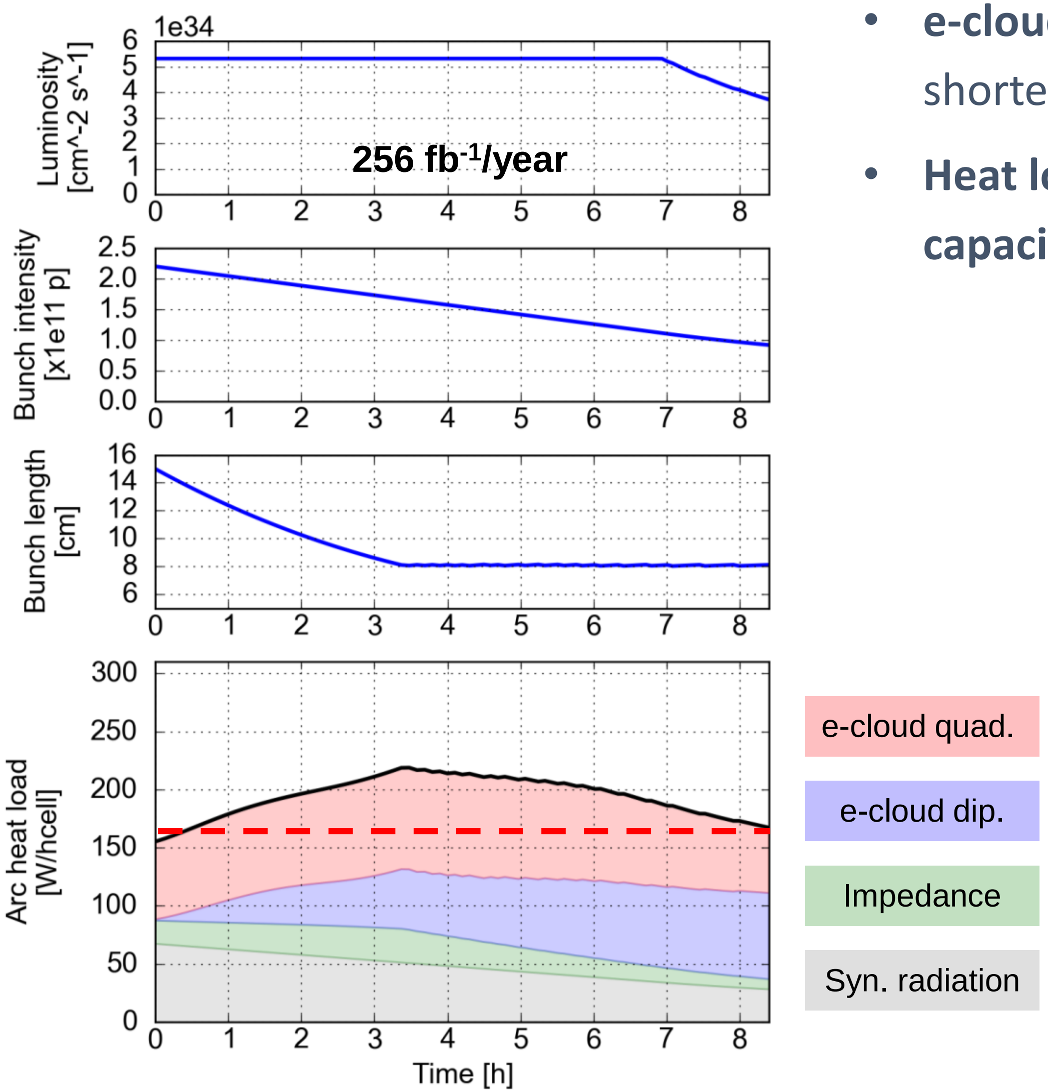


- **e-cloud in dipoles** all along the fill
- **Heat load exceeds the available cooling capacity**
- **Maximum** heat load reached later **during the fill**

Scenario 2 – e-cloud suppression not achieved in dipoles

Assumption: $SEY_{dip} = SEY_{quad} = \mathbf{1.40}$

200 MHz option, fast recapture

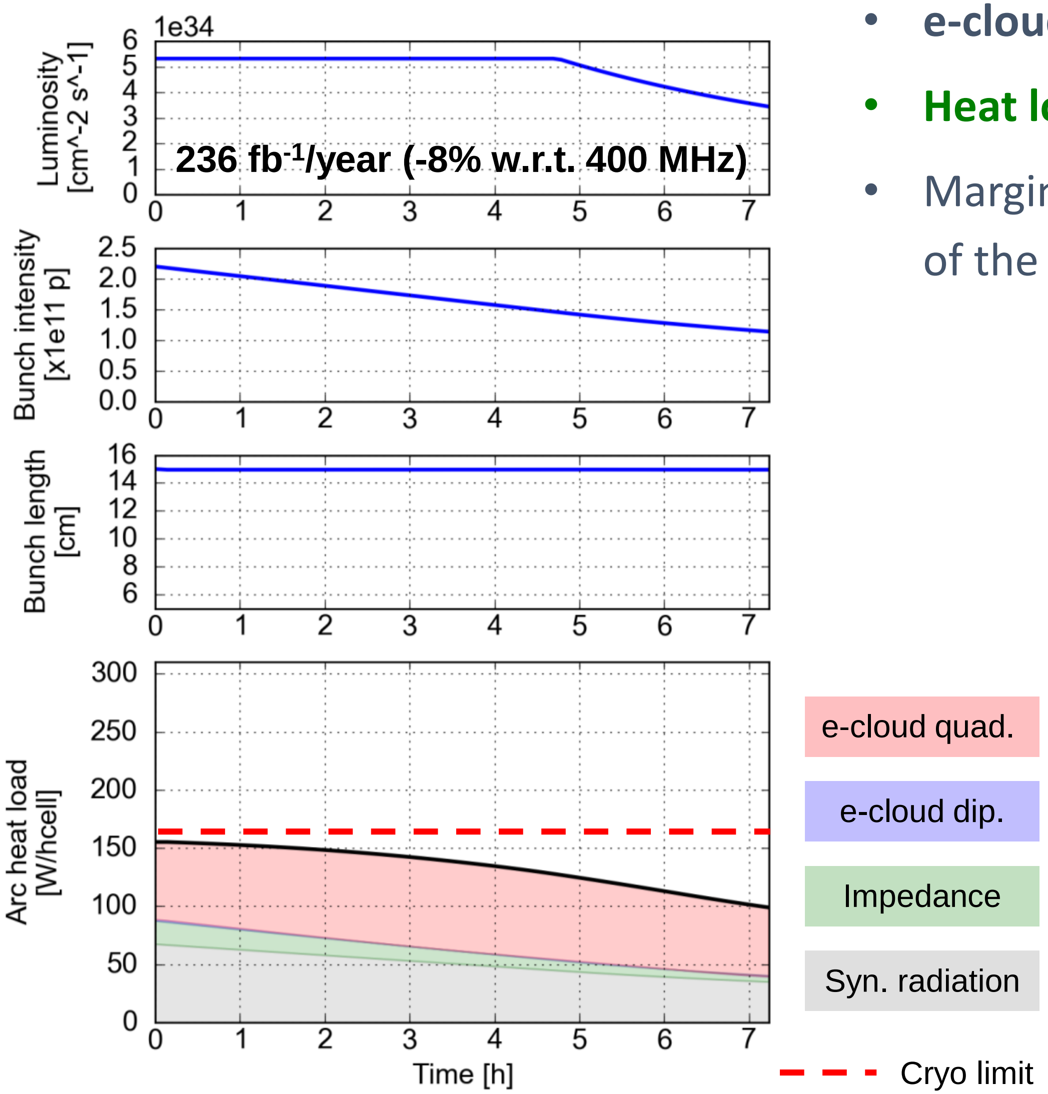


- **e-cloud in dipoles** develops when bunches are shortened
- **Heat load still exceeds the available cooling capacity**

Scenario 2 – e-cloud suppression not achieved in dipoles

Assumption: $SEY_{dip} = SEY_{quad} = \mathbf{1.40}$

200 MHz option, constant bunch length

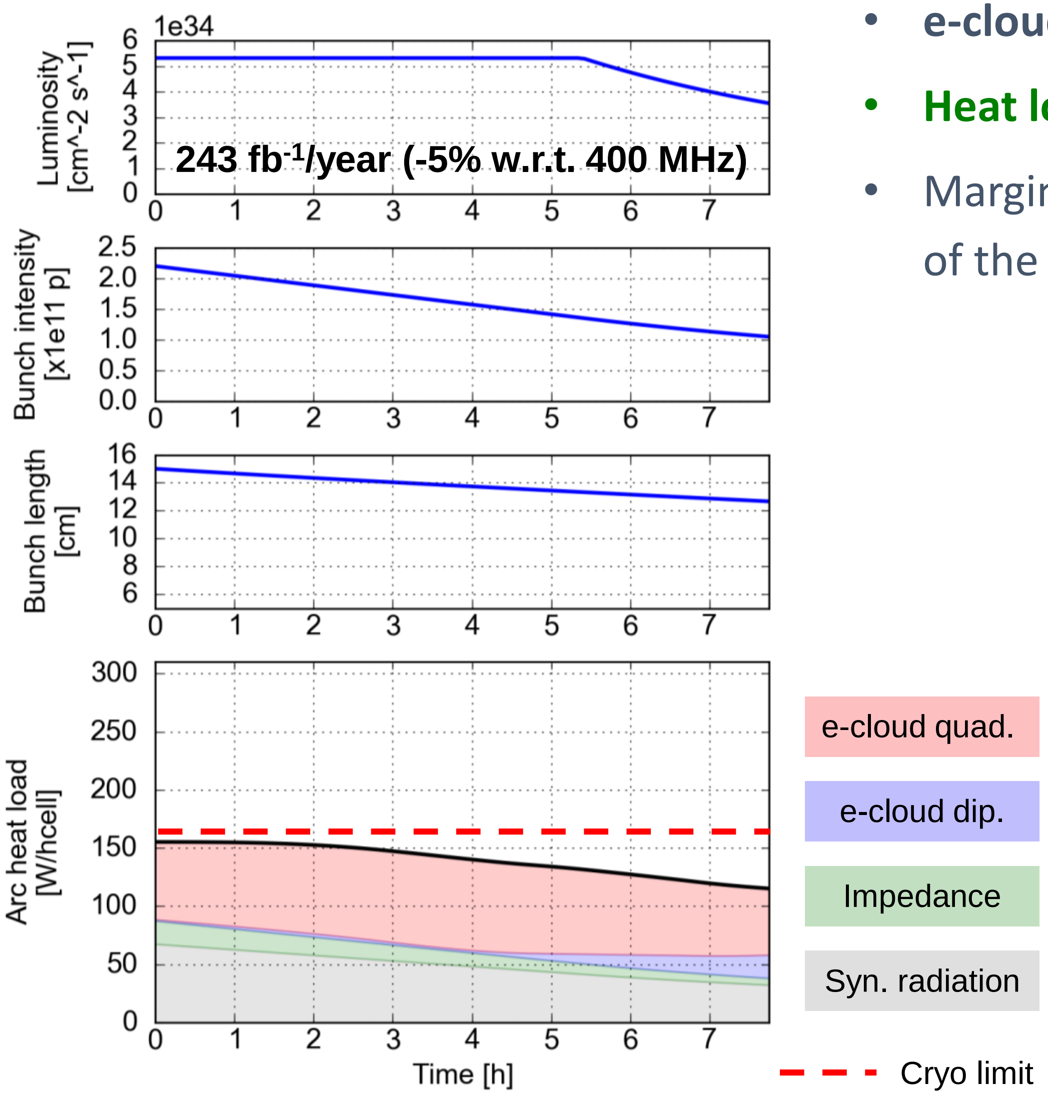


- **e-cloud in dipoles** is suppressed
- **Heat load within the cryogenics limit**
- Margin to shorten the bunches towards the end of the fill to optimize performance

Scenario 2 – e-cloud suppression not achieved in dipoles

Assumption: $SEY_{dip} = SEY_{quad} = \mathbf{1.40}$

200 MHz option, "natural" shortening



- **e-cloud in dipoles** is suppressed
- **Heat load within the cryogenics limit**
- Margin to shorten the bunches towards the end of the fill to optimize performance

Summary and conclusions

- A simple tool has been developed to evaluated the evolution of the heat loads on the arc beam screen during a physics fill
- The baseline HL-LHC scenario has been compared with different 200 MHz operation modes
- **200 MHz becomes very interested in the case where the e-cloud in the dipole magnets is not suppressed** (SEY>=1.4)
    - In this case heat load **exceeds the available capacity for the 400 MHz scenario**
    - The increase in bunch length given by **the 200 MHz RF, is sufficient to suppress the e-cloud in the dipoles** and bring the heat load within the available capacity
    - **Long bunches have to be kept** at least for the first part of the fill
    - **Bunch length evolution can be optimized** to maximize luminosity within the allowed heat load → need to be setup
    - After **long shutdowns**, 200 MHz operation would mitigate the luminosity loss due the **SEY recovery**

Thanks for your attention!