Heat load due to e-cloud in the HL-LHC triplets

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Many thanks to:
H. Bartosik, R. De Maria, R. Tomas, L. Tavian
• **Present inner triplets**
  o Layout and optics
  o PyECloud simulations
  o Heat load measurements and estimate of the SEY

• **Inner triplets for the HL-LHC upgrade**
  o Layout and optics
  o Heat load estimates from PyECloud simulations
• **Present inner triplets**
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Machine layout and optics near IP1

IP1, 4 TeV, $\beta^* = 0.6$ m
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The longitudinal direction

The delay between two following bunch passages changes along the machine elements

- Locations of long range encounters spaced by half the bunch spacing
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Quite a **challenging simulation scenario**:

- **Two beams** with:
  - Different **transverse position** (off center)
  - Different **transverse shape**
  - **Arbitrarily delayed** with respect to each other (no real bunch spacing)
PyE mamma simulations for the inner triplets

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- **Quadrupolar** magnetic field

- **Non elliptical chamber**
PyE CLOUD simulations for the inner triplets

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Beam properties (delay, position, size) changing along the structure:

- Simulated **10 slices per magnet**
- **SEY = 1.0, 1.1, ... , 2.0**
- **50 ns and 25 ns**
PyECL OUD simulations for the inner triplets

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- **50 ns and 25 ns**

Required the introduction of new features in PyECL OUD

~1000 simulations, ~48 h for two bunch trains, ~120 GB of sim. data
Simulated scenarios

25 ns beam – $1.15 \times 10^{11}$ ppb

| 72 | 8  | 72 | 8  | 72 | 38 | 72 | 8  | 72 | 8  | 72 | 8  | 38 |

50 ns beam – $1.65 \times 10^{11}$ ppb

| 36 | 4  | 36 | 4  | 36 | 4  | 36 | 19 | 36 | 4  | 36 | 4  | 36 | 19 |

Other beam parameters:

- Beam energy: **4 TeV**
- Transverse emittance: **2.4 μm**
- Bunch length: **1.3 ns**
- Optics with $\beta^* = 0.6$ m
A look to the EC buildup

Few snapshots of the **electron distribution** (50 ns spacing)
The presence of two beams **enhances the multipacting efficiency**, especially far enough from the locations of the long range encounters.
A look to the EC buildup

The presence of two beams **enhances the multipacting efficiency**, especially far enough from the locations of the long range encounters.

![Graphs showing EC buildup with two beams](image-url)
Heat load density along the triplet - 50 ns

Locations of long range encounters

Remarks:

• EC much weaker close to long range encounters
• Modules with the same beam screen behave very similarly
Heat load density along the triplet - 50 ns

The presence of the two beams leads to an important \textbf{lowering of the multipacting threshold} w.r.t. the single beam case (dashed)

**Remarks:**

- EC much weaker close to \textbf{long range encounters}
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Heat load density along the triplet - 25 ns

Remarks:

• EC much weaker close to long range encounters
• Modules with the same beam screen behave very similarly
Heat load density along the triplet - 25 ns

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- Modules with the same beam screen behave very similarly

As in the other quardupoles in the LHC, the multipacting threshold is already quite low even for a single beam with 25 ns spacing
The presence of the two beams leads to an important lowering of the multipacting threshold w.r.t. the single beam case (dashed).

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Heat load density along the triplet - 25 ns

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Heat load density along the triplet - 25 ns

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- Modules with the same beam screen behave very similarly

The presence of the two beams leads to an important lowering of the multipacting threshold w.r.t. the single beam case (dashed)
Average heat load density – 50 ns vs. 25 ns

For each triplet we get:

Remarks:

• Above threshold values are very similar → enhancement from hybrid spacings much stronger on the 50 ns than on 25 ns
• **Present inner triplets**
  - Layout and optics
  - PyECLoud simulations
  - Heat load measurements and estimate of the SEY

• **Inner triplets for the HL-LHC upgrade**
  - Layout and optics
  - Heat load estimates from PyECLoud simulations
Machine observations – 50 ns

fill 3286 started on Wed, 14 Nov 2012 00:14:11

No big change during ramp and squeeze

Data provided by L. Tavian
No big change during ramp and squeeze
Heat load much higher than in two-aperture quadrupoles
Machine observations – 25 ns (4 TeV)

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No big change during ramp and squeeze
Machine observations – 25 ns (4 TeV)

No big change during ramp and squeeze
Machine observations – 25 ns (4 TeV)

fill 3429 started on Thu, 13 Dec 2012 18:16:27

Heat load similar to two-aperture quadrupoles
Comparison against simulations

1.2 < $SEY_{\text{max}}$ < 1.3

is compatible with the observations
For the estimated SEY value we do not expect nor observe EC in the triplets with only one beam with 50 ns spacing circulating in the LHC.
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  o Layout and optics
  o PyECLOUD simulations
  o Heat load measurements and estimate of the SEY

• **Inner triplets for the HL-LHC upgrade**
  o Layout and optics
  o Heat load estimates from PyECLOUD simulations
Optics, layout and apertures

Present

IP1, 4 TeV, $\beta^* = 0.6$ m

HiLumi

IP1, 7 TeV, $\beta^* = 0.15$ m
For the moment, only quadrupoles have been simulated.
Optics, layout and apertures

**Present**

- **IP1, 4 TeV, \( \beta^* = 0.6 \) m
- **IP1, 7 TeV, \( \beta^* = 0.15 \) m

**HiLumi**

- **IP1, 4 TeV, \( \beta^* = 0.6 \) m
- **IP1, 7 TeV, \( \beta^* = 0.15 \) m

*3R1 7000.0 GeV (2sigma beam shape)*

*5R1 7000.0 GeV (2sigma beam shape)*
Optics, layout and apertures

Present

IP1, 4 TeV, $\beta^*$ = 0.6 m

HiLumi

IP1, 7 TeV, $\beta^*$ = 0.15 m
Optics, layout and apertures

Present

Q1  
Q2 (A/B)  
Q3  
D1

IP1, 4 TeV, $\beta^* = 0.6$ m

HiLumi

IP1, 7 TeV, $\beta^* = 0.15$ m

B2R1 7000.0 GeV (2sigma beam shape)

Present

HiLumi
Optics, layout and apertures

Present

Q1

Q2 (A/B)

Q3

D1

IP1, 4 TeV, $\beta^* = 0.6$ m

Beta function [m]

4

3

2

1

0

0

20

40

60

80

100

Beam position [mm]

0

0

2

4

6

8

10

Beta function [m]

2.5e+04

2e+04

1.5e+04

1e+04

5e+03

0

b1H, b2V

b2H, b1V

b1H

b1V

b2H

b2V

HiLumi

Q1 (A/B)

Q3 (A/B)

D1

Q2 (A/B)

IP1, 7 TeV, $\beta^* = 0.15$ m

Beta function [m]

2.5e+04

2e+04

1.5e+04

1e+04

5e+03

0

b1H, b2V

b2H, b1V

b1H

b1V

b2H

b2V

Beam position [mm]

0

0

1

2

3

4

5
**Optics, layout and apertures**

**Present**

- IP1, 4 TeV, $\beta^* = 0.6$ m
- IP1, 7 TeV, $\beta^* = 0.15$ m

**HiLumi**

- IP1, 7 TeV, $\beta^* = 0.15$ m
Present

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Simulated scenario

25 ns beam – $2.20 \times 10^{11}$ ppb

Other beam parameters:

• Beam energy: 7 TeV
• Transverse emittance: 2.5 μm
• Bunch length: 1.0 ns
• Optics with $\beta^* = 0.15$ m
A look to the EC buildup – HiLumi triplets

Few snapshots of the electron distribution $\rightarrow$ much wider stripes for HiLumi triplets
Heat load along the triplet

Present triplets

HiLumi triplets

Locations of long range encounters
Bunch intensity is larger but also chamber is wider

→ energy of multipacting electrons is quite similar
Bunch intensity is larger but also chamber is wider

→ **energy of multipacting electrons** is quite similar
→ **number of impacting electrons** about x2 larger

**Present triplets**

- 25 ns - 576 bunches
- Only e\(^{-}\) with En > 50eV are considered

**HiLumi triplets**

- 25 ns - 576 bunches
- Only e\(^{-}\) with En > 50eV are considered
Bunch intensity is larger but also chamber is wider

- energy of multipacting electrons is quite similar
- number of impacting electrons about x2 larger
- Total heat load about x2 larger

- **Present triplets**
  - 25 ns - 2800 bunches

- **HiLumi triplets**
  - 25 ns - 2800 bunches

**SEY**

- **SEY\text{max}** in the present triplets at the end of 2012

**Heat loads**

- **D1 and correctors not included!**
Summary and conclusions

• Simulations show a strong enhancement of the EC due to the presence of the two beams → **extremely low multipacting thresholds** ($SEY_{th} < 1.1$ for 25 ns beams)

• Comparing measured heat load against simulation we infer $SEY_{max} = \sim 1.3$ for the **present triplets** (crosschecked in different beam conditions)

• Simulations for the **HiLumi scenario** show x2 stronger heat load w.r.t. the present scenario ($SEY_{max} = \sim 1.3 \rightarrow HL = \sim 500 \, W$ – D1 and correctors to be added)

• Heat load could be strongly reduced by **EC mitigation strategies**:
  - **Low SEY coating** (but we need $SEY_{max} < 1.1$ to have full suppression)
  - **Clearing electrode** (EC localized in a region where there should be enough aperture to place a polarized plate/wire)
Thanks for your attention!
Machine layout and optics near IP1 - present

Separated beam pipes

Common beam pipe

Separated beam pipes

IP1

1e3
Beta function [m]

-400 -200 0 200 400
s [m]

b1H, b2V
b2H, b1V

Beam position [mm]

-400 -200 0 200 400
s [m]

b1H
b1V
b2H
b2V

IP1, 4 TeV, $\beta^* = 0.6$ m

Beam size [mm]
Machine layout and optics near IP1 - HiLumi

Separated beam pipes → Common beam pipe ← Separated beam pipes

IP1, 4 TeV, $\beta^* = 0.6$ m
Machine layout and optics near IP1 - present

IP1, 4 TeV, $\beta^* = 0.6$ m
Machine layout and optics near IP1 - HiLumi

[Diagram showing the machine layout and optics near IP1]

- B2L1, A2L1, 3L1, 1L1, 1R1 (A/B), 2R1 (A/B), 3R1 (A/B)

Graphs showing:
- Beta function [m]
- Beam position [mm]
- Beam size (rms) [mm]

**IP1, 4 TeV, $\beta^* = 0.6$ m**
The longitudinal direction

The **delay between two following bunch passages** changes along the machine elements

- Locations of **long range encounters** spaced by half the bunch spacing
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A look to the EC buildup – present triplets

Few snapshots of the electron distribution
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