e-cloud effects in the 2012 instabilities

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Many thanks to:
R. De Maria, E. Metral, J. Hulsmann, L. Tavian, C. Zannini
The “multipacting threshold” for 50 ns beams is significantly higher than for 25 ns.

With 50 ns beams we could restart the operation in 2012 without a dedicated scrubbing run, thanks to the scrubbing accumulated in 2011 in 4 days of scrubbing with 50 ns beams + 2 days of tests with 25 ns beams.

PyECLoud simulations
The “multipacting threshold” for 50 ns beams is significantly higher than for 25 ns.

In 2012, heat load measurements on the arc beam screens showed no evidence of e-cloud with 50 ns beams.

Heat load measurements from cryogenics:
- Estimation (impedance + synchrotron rad.)

Thanks to L. Tavian and C. Zannini.

As expected from simulations, a **significant heat load** could instead be measured in the **inner triplets** only in the presence of the **two counter-rotating beams in the same chamber** (hybrid spacing).

**Two beams**

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

**One beam**

fill 3145 started on Tue, 09 Oct 2012 20:51:15

See also: G. Iadarola et al., *Heat load analysis for inner triplet and stand alone modules*, LBOC 28/10/14
Different PyECLoud simulations had to be run for different longitudinal positions along the triplets in order to account for the different beam positions, beam size and for the different delays between the two beams.

→ Inferred values are very low: $1.1 < \text{SEY} < 1.2$

See also: G. Iadarola et al., *Heat load analysis for inner triplet and stand alone modules*, LBOC 28/10/14
In 2012 the e-cloud in the Inner Triplet was considered as a possible ingredient to explain the instabilities observed at the end of the squeeze, taking into account that the effect is enhanced by the local beta-function.

Detailed beam dynamics studies launched at the end of last year to evaluate the risk taken when moving from $\beta^*=80$ cm to $\beta^*=40$ cm:

- Intrinsic modularity of PyHEADTAIL fundamental for these studies.
- Still many features had to be developed and tested (proved to be quite tricky...)

See also: G. Iadarola et al., Analysis of electron cloud in the LHC triplets, e-cloud meeting 10/09/13.
To study the impact within a reasonable computational burden we focused on the evaluation of the **incoherent detuning introduced by the e-cloud**, as a measure of its capability of influencing the beam dynamics (footprint distortion)

→ **Position of the beam in the chamber** found to be a key ingredient due to the cross shaped distribution of the e-cloud induced by the quadrupolar field

See also: A. Romano et al., *Update on high energy tune footprint studies*, e-cloud meeting 03/06/16
Position of the beam in the chamber found to be a key ingredient due to the cross shaped distribution of the e-cloud in the quadrupolar field.

Effect would be very strong for zero crossing angle.

e-cloud in the triplet only, SEY=1.15, $\theta = 0 \mu$rad

6.5 TeV, $\beta^* = 40$ cm

See also: A. Romano et al., *Update on high energy tune footprint studies*, e-cloud meeting 03/06/16
- Position of the beam in the chamber found to be a key ingredient due to the cross shaped distribution of the e-cloud in the quadrupolar field
- Effect would be very strong for zero crossing angle
- But it becomes smaller when increasing the crossing angle

\[ \text{e-cloud in the triplet only, SEY=1.15, } \theta = 40 \ \mu\text{rad} \]

6.5 TeV, \( \beta^* = 40 \ \text{cm} \)

See also: A. Romano et al., *Update on high energy tune footprint studies*, e-cloud meeting 03/06/16
Position of the beam in the chamber found to be a key ingredient due to the cross shaped distribution of the e-cloud in the quadrupolar field.

Effect would be very strong for zero crossing angle.

But it becomes smaller when increasing the crossing angle.

e-cloud in the triplet only, SEY=1.15, $\theta = 80 \, \mu$rad

6.5 TeV, $\beta^* = 40 \, \text{cm}$

See also: A. Romano et al., Update on high energy tune footprint studies, e-cloud meeting 03/06/16
Position of the beam in the chamber found to be a key ingredient due to the cross shaped distribution of the e-cloud in the quadrupolar field.

Effect would be very strong for zero crossing angle.

But it becomes smaller when increasing the crossing angle.

- Position of the beam in the chamber
- Effect would be very strong for zero crossing angle
- But it becomes smaller when increasing the crossing angle

\[ e\text{-cloud in the triplet only, } \text{SEY}=1.15, \theta = 120 \, \mu\text{rad} \]

6.5 TeV, \( \beta^* = 40 \, \text{cm} \)

See also: A. Romano et al., *Update on high energy tune footprint studies*, e-cloud meeting 03/06/16
• **Position of the beam in the chamber** found to be a key ingredient due to the cross shaped distribution of the e-cloud in the **quadrupolar field**

• Effect would be **very strong for zero crossing angle**

• But it becomes **smaller when increasing the crossing angle → negligible for realistic values**

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e-cloud in the triplet only, $\text{SEY}=1.15$, $\theta = 160$ $\mu$rad

$6.5$ TeV, $\beta^* = 40$ cm

See also: A. Romano et al., *Update on high energy tune footprint studies*, e-cloud meeting 03/06/16
- **Position of the beam in the chamber** found to be a key ingredient due to the cross shaped distribution of the e-cloud in the **quadrupolar field**
- Effect would be **very strong for zero crossing angle**
- But it becomes **smaller when increasing the crossing angle** → negligible for realistic values

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**Tune footprint vs crossing angle - 2016**

- **e-cloud in the triplet only**, $SEY=1.15$, $\theta = 200 \, \mu\text{rad}$
- $6.5 \, \text{TeV}$, $\beta^* = 40 \, \text{cm}$

See also: A. Romano et al., *Update on high energy tune footprint studies*, e-cloud meeting 03/06/16
• **Position of the beam in the chamber** found to be a key ingredient due to the cross shaped distribution of the e-cloud in the quadrupolar field

• Effect would be **very strong for zero crossing angle**

• But it becomes **smaller when increasing the crossing angle** $\rightarrow$ negligible for realistic values

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**e-cloud in the triplet only,** $\text{SEY}=1.15$, $\theta = 280 \ \mu\text{rad}$

$6.5 \ \text{TeV}, \ \beta^* = 40 \ \text{cm}$

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See also: A. Romano et al., *Update on high energy tune footprint studies*, e-cloud meeting 03/06/16
• Position of the beam in the chamber found to be a key ingredient due to the cross shaped distribution of the e-cloud in the **quadrupolar field**

• Effect would be **very strong for zero crossing angle**

• But it becomes **smaller when increasing the crossing angle → negligible for realistic values**

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**e-cloud in the triplet only, SEY=1.15, $\theta = 400 \ \mu$rad**

6.5 TeV, $\beta^* = 40$ cm

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See also: A. Romano et al., *Update on high energy tune footprint studies*, e-cloud meeting 03/06/16
• **Position of the beam in the chamber** found to be a key ingredient due to the cross shaped distribution of the e-cloud in the **quadrupolar field**

• Effect would be **very strong for zero crossing angle**

• But it becomes **smaller when increasing the crossing angle → negligible for realistic values**

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**2016 configuration:**

- $\beta^*=40$ cm
- 6.5 TeV
- 1.15 p/bunch
- $\varepsilon_n=2.5$ um
- SEY = 1.15

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**Tune footprint vs crossing angle - 2016**

- **Average detuning**
- **r.m.s. tune spread**
• Position of the beam in the chamber found to be a key ingredient due to the cross shaped distribution of the e-cloud in the quadrupolar field
• Effect would be very strong for zero crossing angle
• But it becomes smaller when increasing the crossing angle → negligible for realistic values

→ In 2016 no evidence of the beam being more unstable at low $\beta^*$ both for $\theta = 185$ urad and for $\theta = 165$ urad, and with standard and high brightness beams.

2016 configuration:
$\beta^*$=40 cm
6.5 TeV
1.15 p/bunch
$\varepsilon_n$=2.5 um
SEY = 1.25
Simulations were performed also for the 2012 machine configuration finding very similar results:

- Detuning induced by the e-cloud much smaller than the one from the octupoles
- Difficult to imagine an impact on beam stability...

2012 configuration:
- $\beta^*=60$ cm
- 4 TeV
- 1.7 p/bunch
- $\epsilon_n=2.5$ um
- SEY = 1.25
• Simulations were performed also for the 2012 machine configuration finding very similar results

→ Detuning induced by the e-cloud much smaller than the one from the octupoles
→ Difficult to imagine an impact on beam stability...
• Simulations were performed also for the 2012 machine configuration finding very similar results

→ Detuning induced by the e-cloud much smaller than the one from the octupoles

→ Difficult to imagine an impact on beam stability...
• During operation with 50 ns beams in 2012 no e-cloud was detectable in the twin-bore magnets (arcs and LSS)

• A strong heat load instead was expected and observed on the inner triplet due to the presence of the two beams in the same chamber (hybrid spacing)

• The impact of the e-cloud in the triplet on the tune footprint is strongly mitigated by the crossing angle
  o For the 2012 and 2016 configurations the effect is very small

• Experience at $\beta^*=40$ seems to confirm these findings

Possible further studies

• Perhaps check the effect of the drifts and the dipole correctors (but densities at the beam location should be very small compared to the center of the quadrupoles)
Thanks for your attention!
Electric field probes in PyEC4PyHT

So far, the electric field gradient \( (G_{EC}) \) used to estimate the analytic detuning were computed manually at each beam slice and repeated for all simulations.

Routine used to estimate the analytic detuning:

- From the simulation we can get the full electric field map.