Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Electron cloud status

L. Mether

Acknowledgements: S. Arsenyev, I. Bellafont, R. Kersevan, D. Schulte

4th EuroCirCol meeting
KIT
October 17th – 18th, 2018

Studies done so far

Previous studies

E-cloud studies for 25 ns, 12.5 ns and 5 ns beams:

- Build-up in arc dipoles, quadrupoles, drifts
- Effect of photoelectrons
- Beam dynamics simulations to confirm instability thresholds in dipoles

Studies performed considering

- Main chamber of beam screen (2015 version)
- LHC co-laminated Cu surface

Presented at FCC Week

Studied effect on electron cloud build-up of

- Beam screen geometry
- Updated bunch train pattern and other parameters
- Photoelectrons according to distribution from ray tracing

Determined cloud distribution for coatings

SEY model

The predictions from e-cloud simulations rely on confidence in the SEY models used

- We use the Cimino-Collins SEY model, parameterising measured SEY curves of the LHC beam screens:

$$\delta(E) = \boxed{\delta_{\text{elas}}(E)} + \boxed{\delta_{\text{true}}(E)}$$

$$\delta_{\text{elas}}(E) = R_0 \left(\frac{\sqrt{E} - \sqrt{E+E_0}}{\sqrt{E} + \sqrt{E+E_0}} \right)^2$$

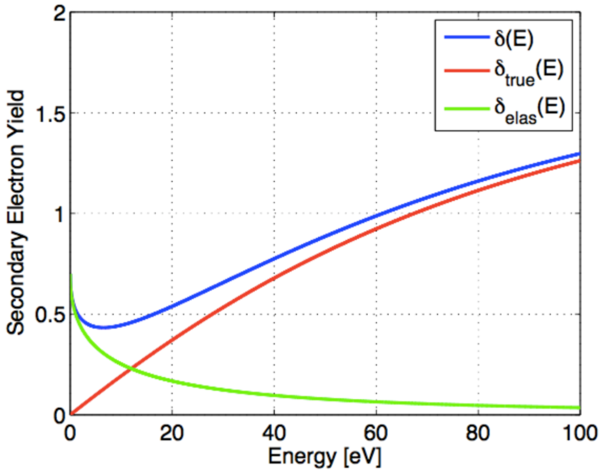
with:

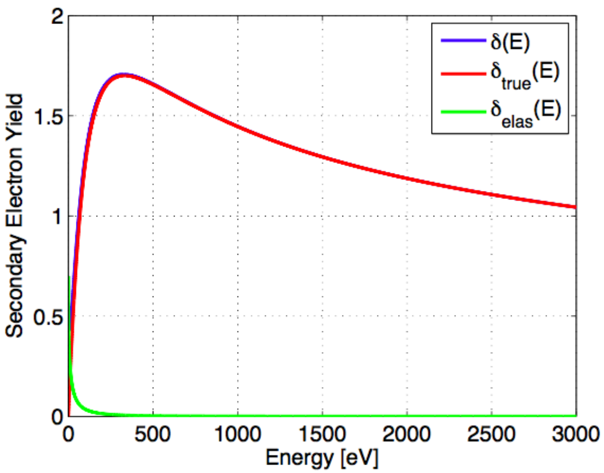
$$R_0 = 0.7 \qquad E_0 = 150 \text{ eV}$$

$$\delta_{\text{true}}(E) = \delta_{\max} \frac{s \dfrac{E}{E_{\max}}}{s - 1 + \left(\dfrac{E}{E_{\max}} \right)^s}$$

with:

$$s = 1.35 \qquad E_{\max} = 332 \text{ eV}$$





R. Cimino et al., Phys. Rev. Lett. 93, 014801

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- Dependence on incidence angle:

$$E_{\max}(\theta) = E_{\max}(\theta = 0)\,(1 - 0.7\,(1 - \cos\theta))$$

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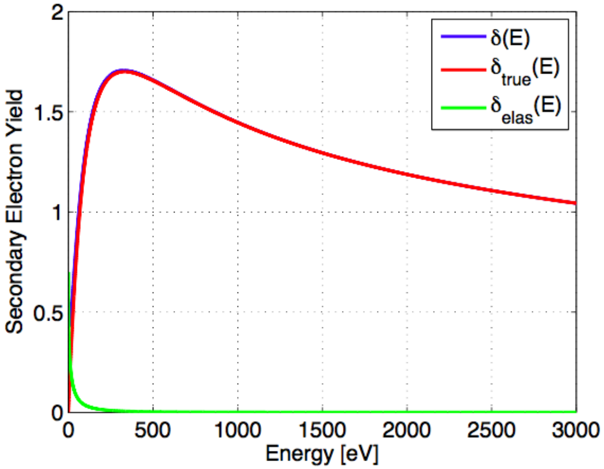

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New SEY measurements on LHC beam screens at different stages of surface conditioning and comparison with SEY model in simulations are on-going

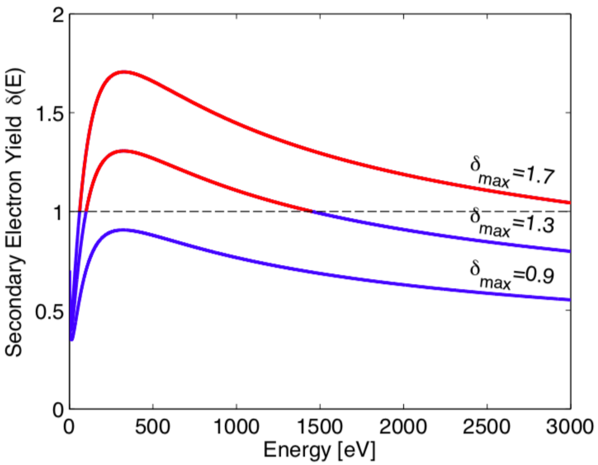
R. Cimino et al., Phys. Rev. Lett. 93, 014801

Multipacting threhsolds

With the updated parameters for the FCC Week, we could identify the multipacting thresholds, i.e. the maximum secondary emission yield, δ_{max}, without build-up

FCC-hh multipacting thresholds

	25 ns		12.5 ns		5 ns	
E [TeV]	3.3	50	3.3	50	3.3	50
Dipole	1.5	1.5	1.1	1.1	1.5	1.5
Quad	1.1	1.2	1.0	1.0	1.1	1.0
Drift	2.0	2.0	1.3	1.3	1.6	1.6



HE-LHC multipacting thresholds

	25 ns		12.5 ns		5 ns	
E [TeV]	1.3	13.5	1.3	13.5	1.3	13.5
Dipole	1.55	1.45	1.2	1.15	1.0	1.0
Quad	1.4	1.45	1.05	1.1	1.1	1.05

HE-LHC simulations with HL-LHC bunch train pattern

Secondary emission yield

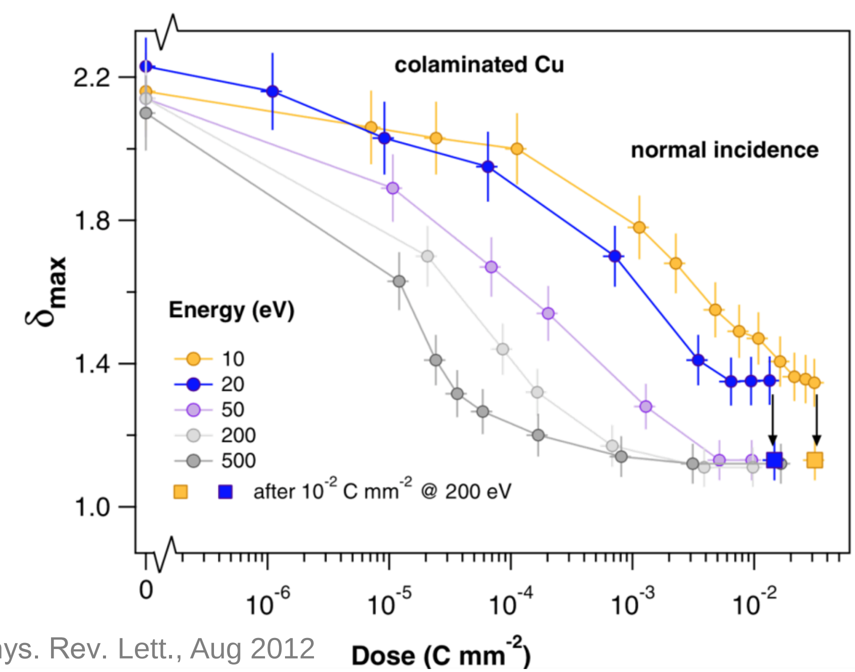
The maximum secondary emission yield of an as-received LHC beam screen is around 2.0

The surface is conditioned by electron irradiation

→ In the machine electron clouds should condition the surface, “scrubbing”

- In the lab irradiated surfaces reach SEY ~ 1.15
- In the LHC some of the surfaces seem to not condition to the expected extent (after Long Shutdown 1), and some half-cells may have SEY as high as 1.6 (on average)

As long as this phenomenon is not fully understood, we cannot rely on scrubbing for low SEY, and should use beam screen coatings



R. Cimino, V. Baglin et al., ” Phys. Rev. Lett., Aug 2012

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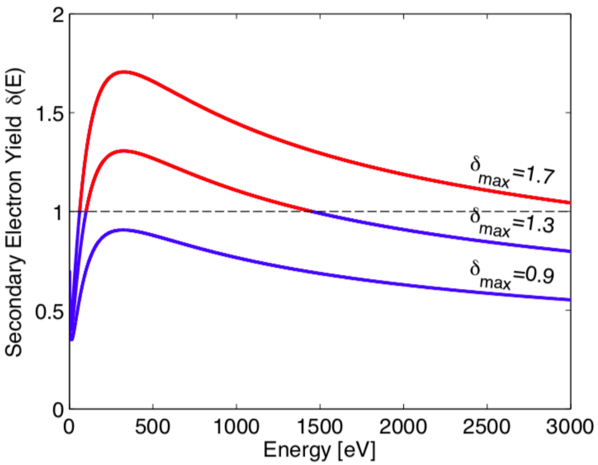

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HE-LHC simulations with HL-LHC bunch train pattern

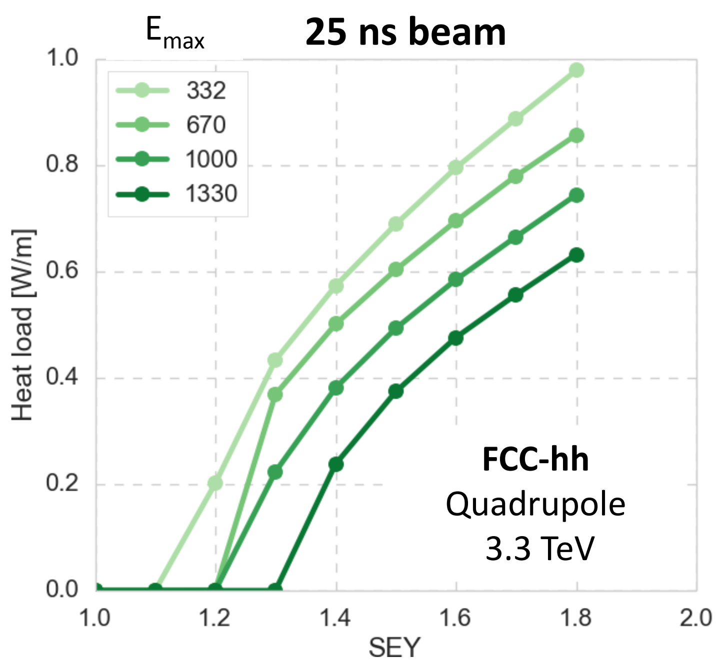
Coating materials

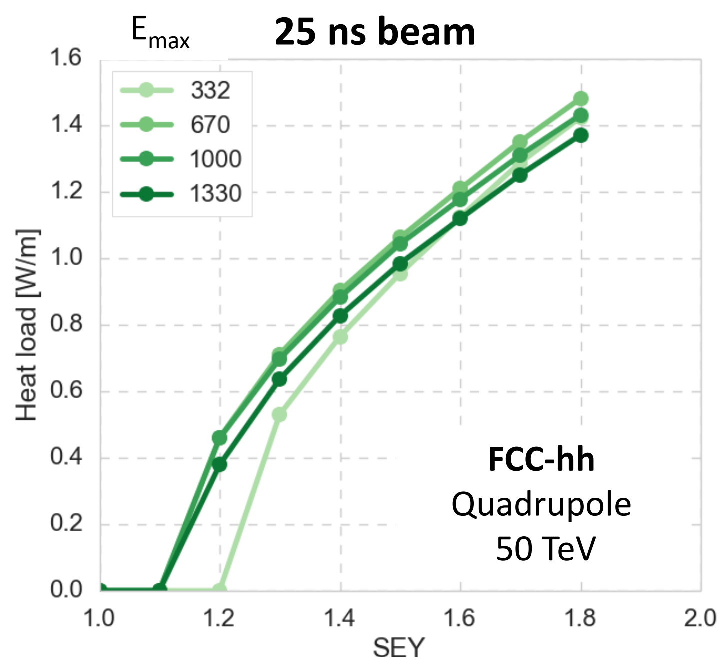
Considered options for surface coating:

- Amorphous carbon (a-C) coatings, with maximum SEY around 1.0 – 1.05
- Laser treated surfaces (LASE), with maximum SEY below 1.0, E_{max} at high energy

We cannot determine which coating is viable in any given case without detailed SEY models for the coating materials to use in simulations

- To illustrate the possible effects, we shift only E_{max} in the SEY model:





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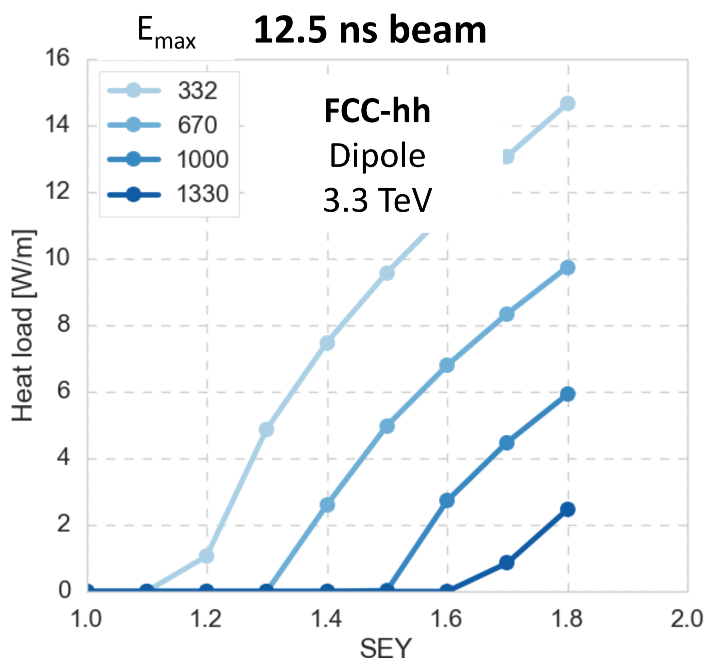

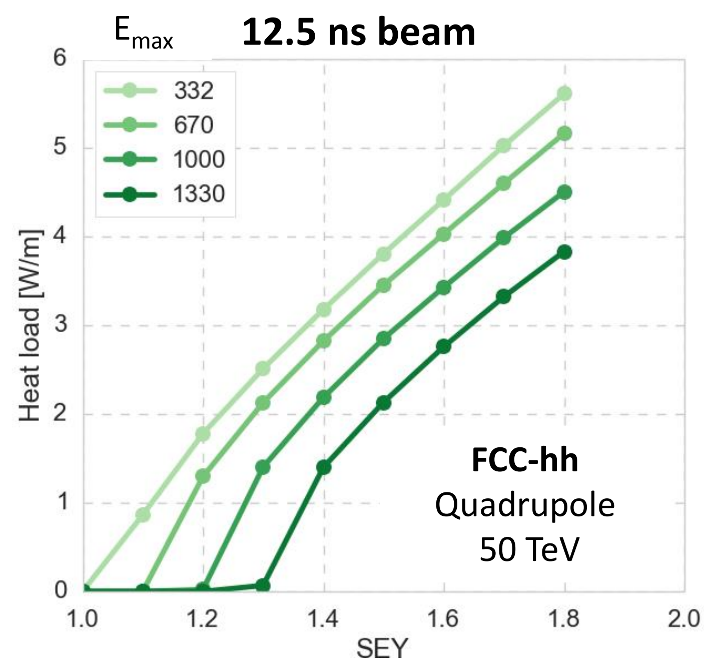

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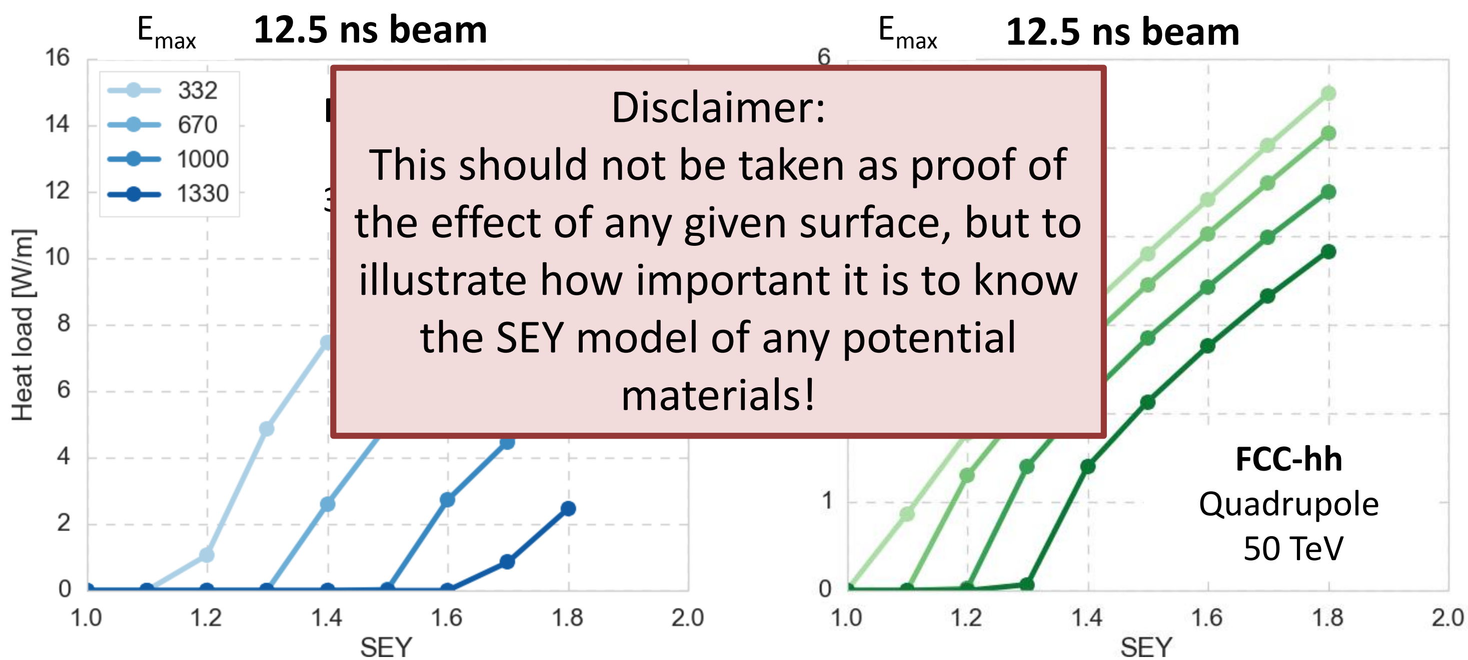


Disclaimer:
This should not be taken as proof of the effect of any given surface, but to illustrate how important it is to know the SEY model of any potential materials!

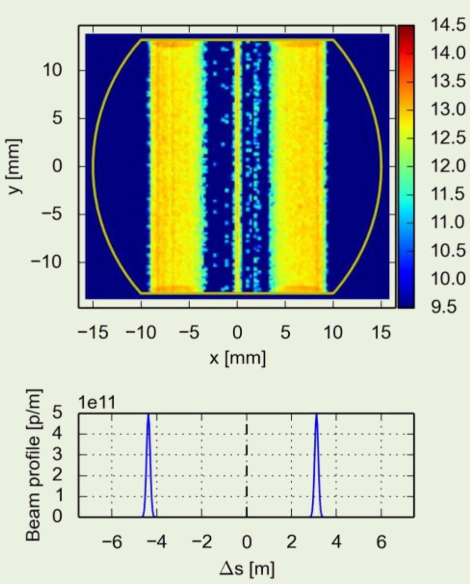
Baseline scenarios

A baseline scenario has been identified for the 25 ns beam:

- Considering the 2018 beam screen and 80b+17e bunch train pattern
- Sufficient e-cloud suppression with a-C/(LASE) beam screen coating in dipoles and quadrupoles, no coating in drifts

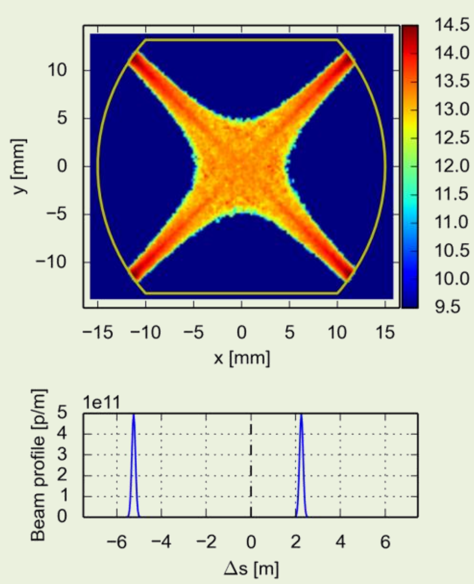
Dipole

The coating should cover the full top and bottom of the chamber



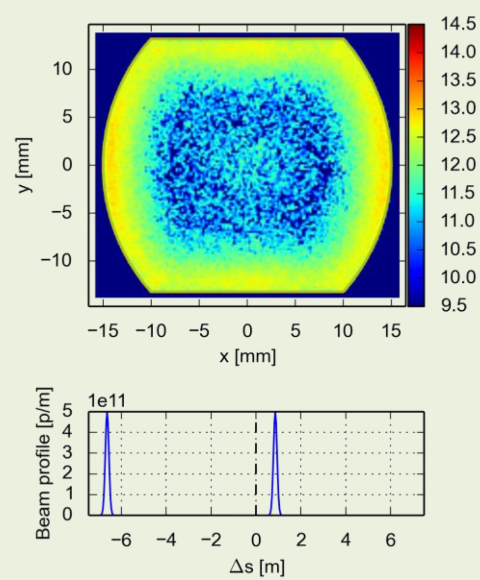
Quadrupole

Coating is required at 45° to the horizontal plane



Drift

Multipacting on all sides, hot spots along axes, but threshold high enough that coating should not be necessary



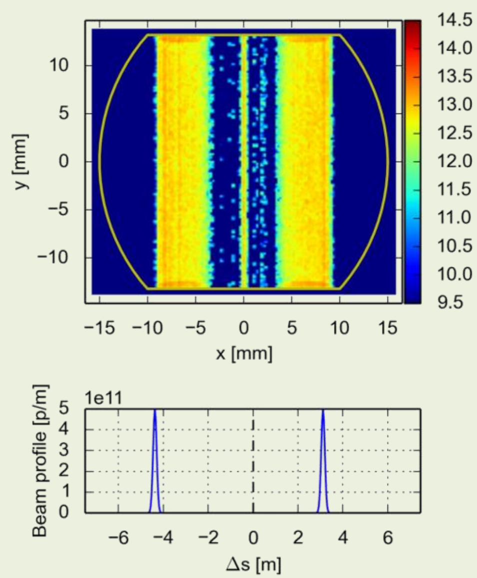
Baseline scenarios

For the alternative beam configurations (12.5 and 5 ns):

- With the 2018 beam screen and 80b+17e equivalent bunch train pattern
- Tighter constraints on the beam screen coating, in particular in quadrupoles
- Coating to be considered also in drifts, if possible

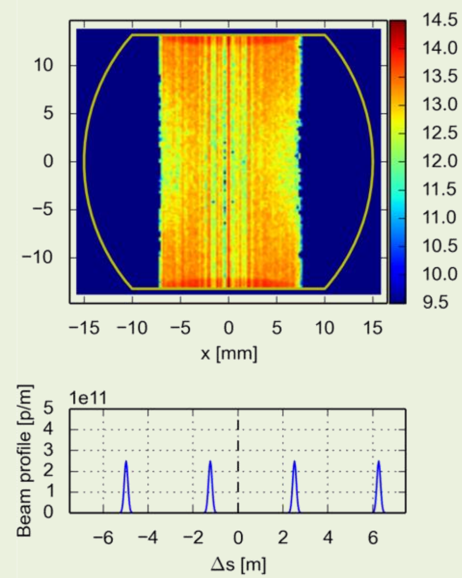
25 ns

Bunch intensity 1×10^{11} p



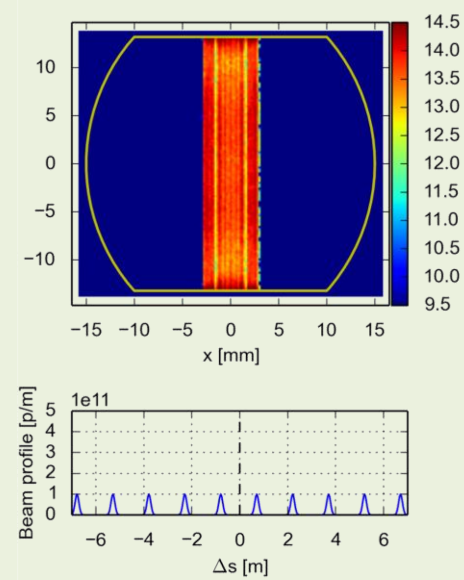
12.5 ns

Bunch intensity 5×10^{10} p



5 ns

Bunch intensity 2×10^{10} p



Milestone

The studies done up to now were summarized in the EuroCirCol WP2 Milestone 2.4, submitted at the end of September

EuroCirCol

ANALYSIS OF ELECTRON CLOUD EFFECTS AND MITIGATION OPTIONS

EuroCirCol-P1-WP2-M2.4

Date: Error! Not a valid bookmark self-reference.

Grant Agreement No: 654305

EuroCirCol

European Circular Energy-Frontier Collider Study

Horizon 2020 Research and Innovation Framework Programme, Research and Innovation Action

MILESTONE REPORT

ANALYSIS OF ELECTRON CLOUD EFFECTS AND MITIGATION OPTIONS

Document identifier:	EuroCirCol-P1-WP2-M2.4
Due date:	End of Month 40 (October 1, 2018)
Report release date:	**Error! Not a valid bookmark self-reference.**
Work package:	WP2 (Arc lattice design)
Lead beneficiary:	CEA
Document status:	IN WORK | RELEASED

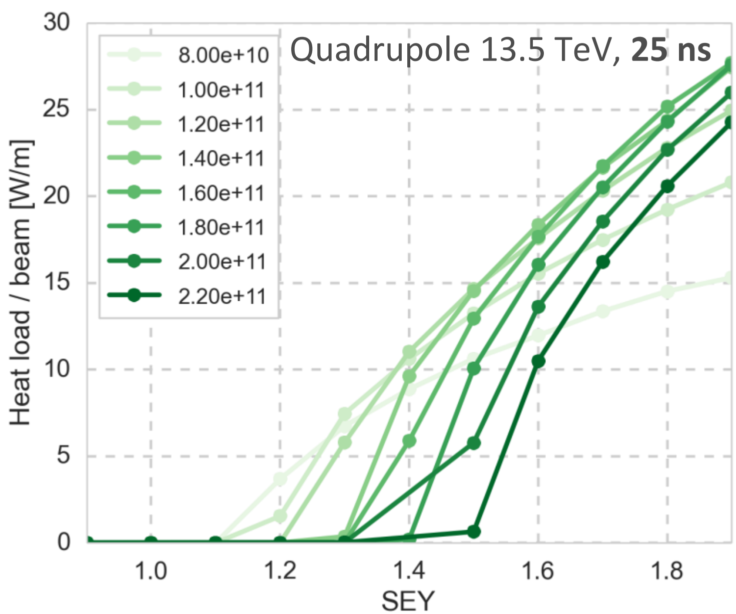
Abstract:

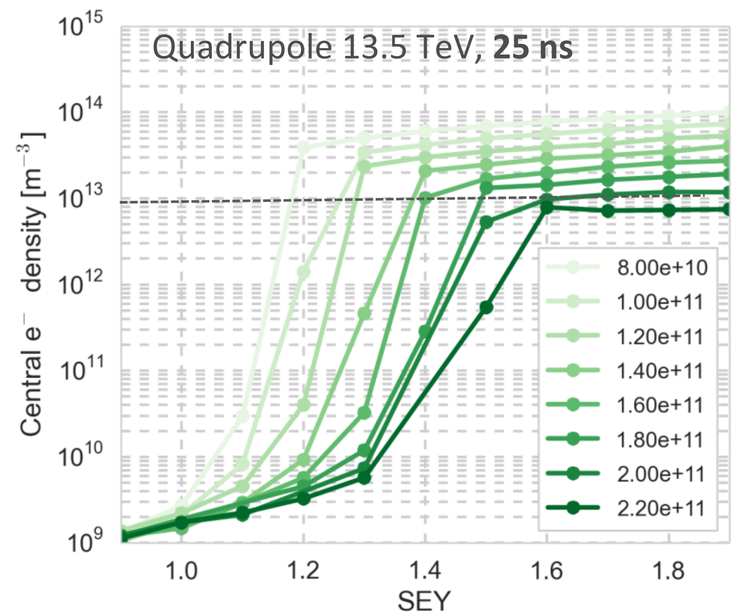
This report reviews the results of electron cloud studies using computer simulations. Different beam screen geometries, beam configurations, photoelectron emission scenarios and surface treatments are considered. Implications for beam screen and overall collider design are discussed and a baseline mitigation strategy is identified.

Evolution during a fill

E-cloud effects don't scale linearly with intensity → some effects may get worse with the intensity burn-off during luminosity production fills

- A scan for **HE-LHC** decreasing intensity and emittance in uniform steps shows a significant effect for the 12.5 and 25 ns beams, in particular in the quadrupoles (also dipoles for 12.5 ns)





The multipacting threshold decreases significantly with decreasing intensity, and the central density approaches the instability threshold

Evolution during a fill

E-cloud effects don't scale linearly with intensity → some effects may get worse with the intensity burn-off during luminosity production fills

- A scan for **HE-LHC** decreasing intensity and emittance in uniform steps shows a significant effect for the 12.5 and 25 ns beams, in particular in the quadrupoles (also dipoles for 12.5 ns)

- This effect should be taken into account when considering the need for coating:

Multipacting thresholds from build-up simulation

	5 ns	12.5 ns	25 ns	5 ns	12.5 ns	25 ns	5 ns	12.5 ns	25 ns
	Injection 1.3 TeV			Flat top 13.5 TeV			Flat top with intensity and emittance scan		
Dipole	1.0	1.2	1.55	1.0	1.15	1.45	1.0	1.1	1.4
Quadrupole	1.1	1.05	1.4	1.05	1.1	1.45	1.0	1.0	1.1

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Quadrupole	1.1	1.05	1.4	1.05	1.1	1.45	1.0	1.0	1.1

This effect has not been studied for FCC-hh

- Extrapolations from (HL-)LHC and HE-LHC studies suggest it is less important at the FCC-hh bunch intensities, to be confirmed with simulations

Further studies

- Updated simulations with photoelectron production
  - Based on detailed data from ray tracing studies (data provided)
  - Using data of photoelectron production from experimental studies, if available
- Beam stability studies in quadrupoles (probing the low-SEY range)
  - Requires saved electron distributions from dedicated build-up simulations
- Simulations for different beam screen coatings
  - Requires detailed information on secondary emission yield of surfaces
- Updates build-up simulations for LHC beam screen surface
  - If/when needed after results from new measurements

Extra slides

FCC-hh beam screen

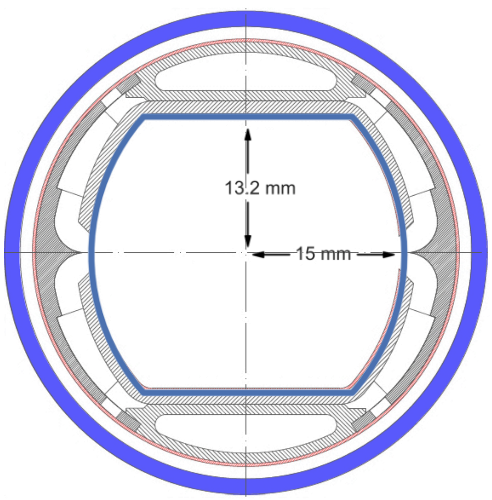
The effect of the beam screen geometry on electron cloud multipacting has been studied in simulations for the three geometries below.

2015 → 2017

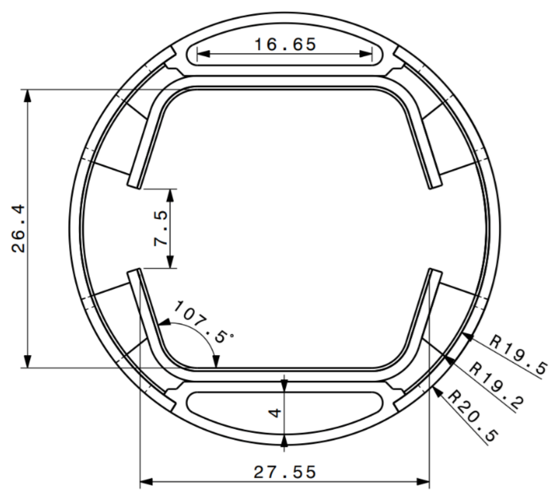
- Larger slit, saw-tooth surface at SR impact point, straight edges
- Impact expected mainly in the drifts, due to the cloud distribution in magnetic fields

2017 → 2018

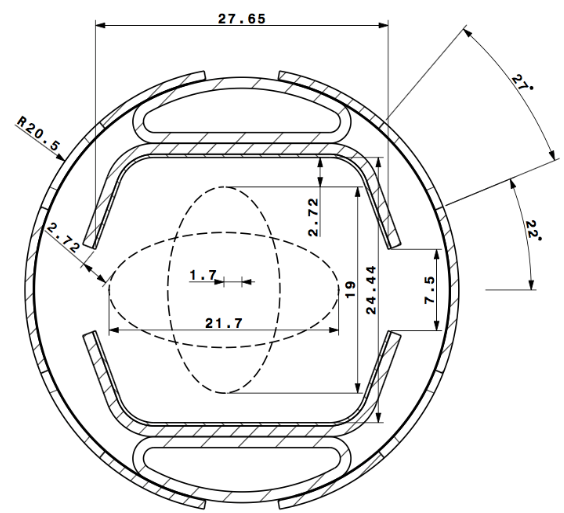
- Smaller vertical aperture (by 2 mm) for manufacturing purposes
- Could impact results also in dipoles and quadrupoles



2015



2017



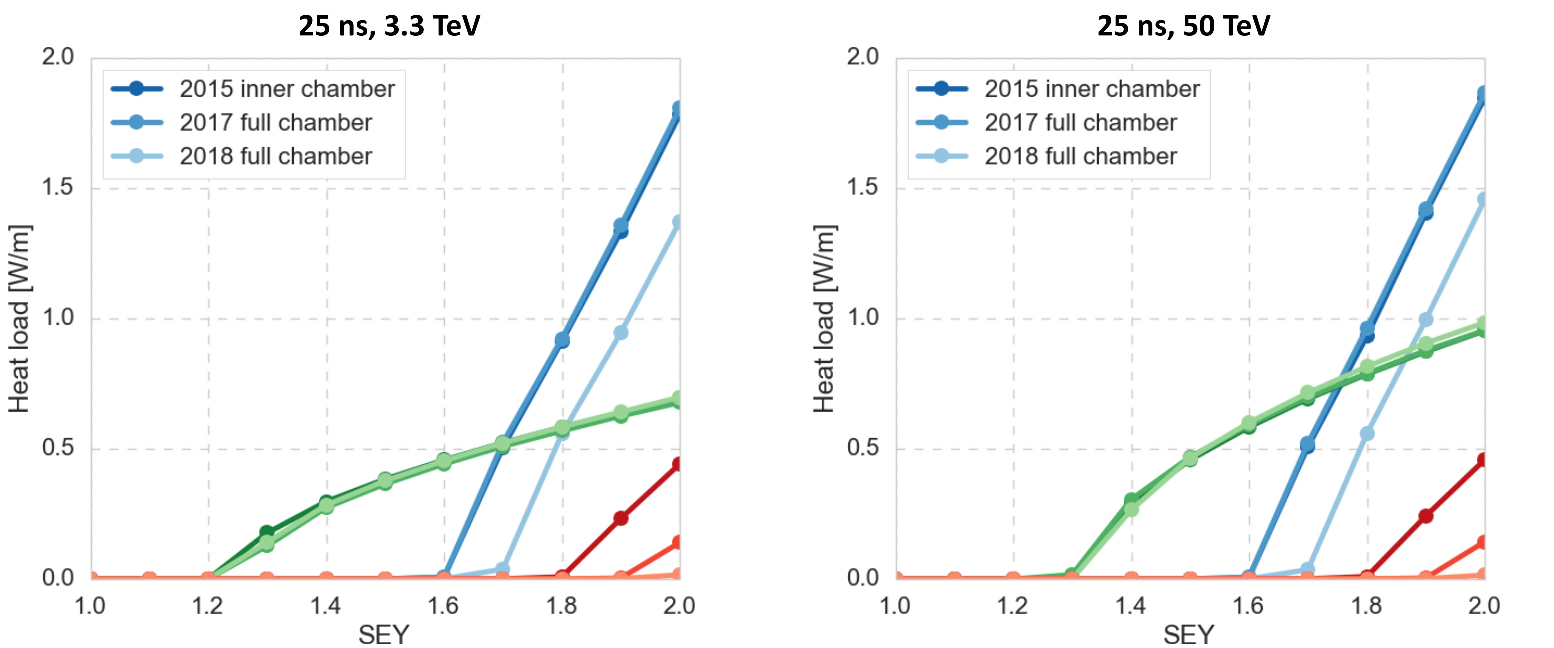
2018

C. Garion, J. Fernandez Topham et al

FCC-hh beam screen

The effect of the beam screen geometry on electron cloud multipacting has been studied in simulations for the three geometries below.

- There are some differences in the multipacting thresholds for the different designs, but not significant enough to set preferences between the geometries
- For further studies the 2018 design is used



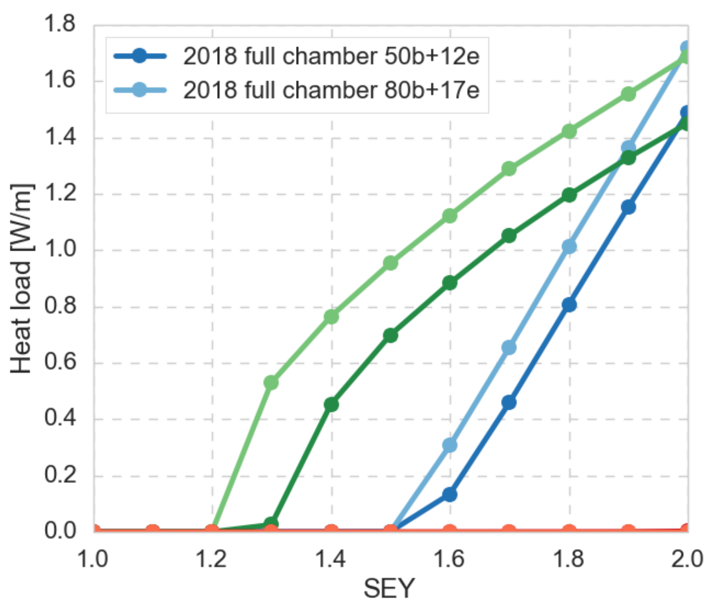
Scaled to device length in arc cells

Bunch train pattern

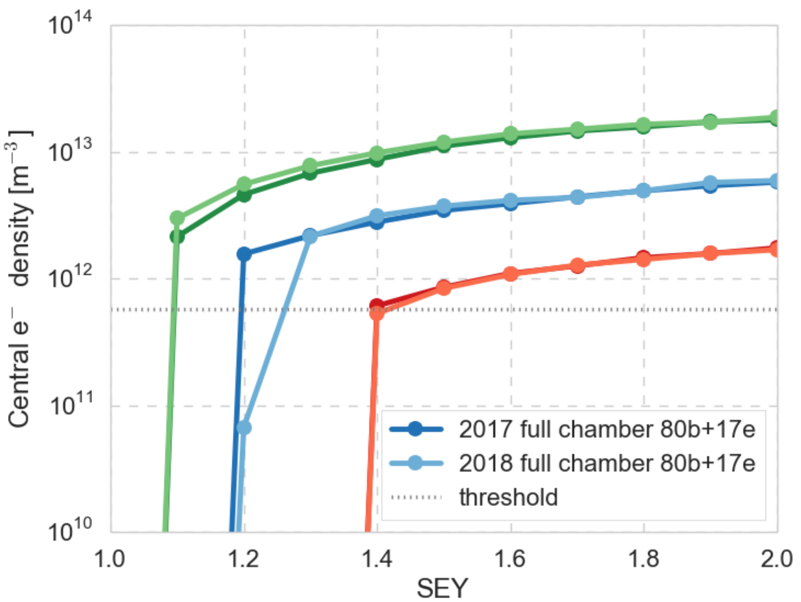
The effect of the bunch train pattern has been studied in simulations: previously used 50b + 12e slots for the 25 ns beam → 80b + 17e slots

- Lower multipacting thresholds in the dipoles and quadrupoles
- For the alternative bunch spacings the lower thresholds are particularly constraining

25 ns, 50 TeV



12.5 ns, 50 TeV

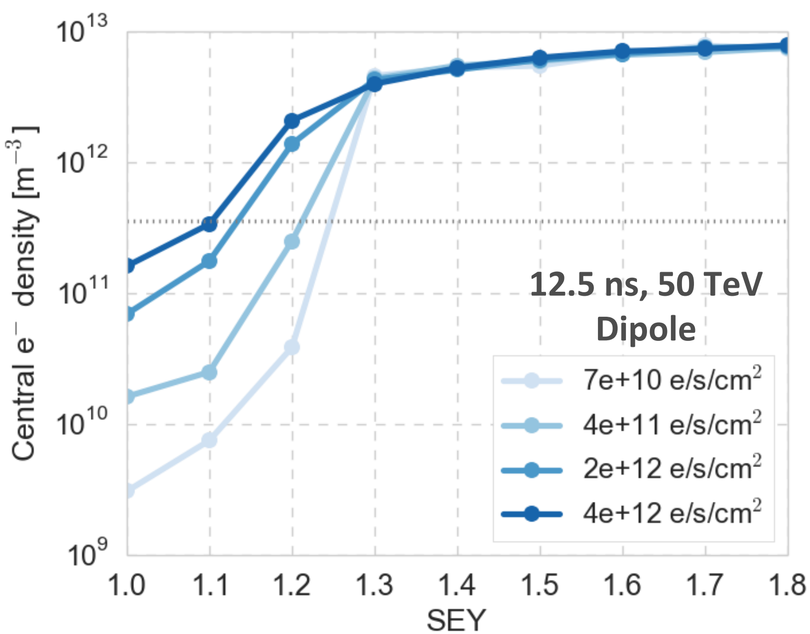


Scaled to device length in arc cells

Photoelectrons

Studies show that photoelectrons could raise the central density above the instability threshold below the multipacting threshold, depending on their production rate

- In **FCC-hh** this is especially the case for the 12.5 and 5 ns beams



Detailed knowledge of the photoelectron yield as a function of photon energy and incidence angle would be necessary to predict the production rate,

unless there is a sufficient margin so that even a very high yield cannot cause problems

Photoelectrons with FCC-hh beam screen

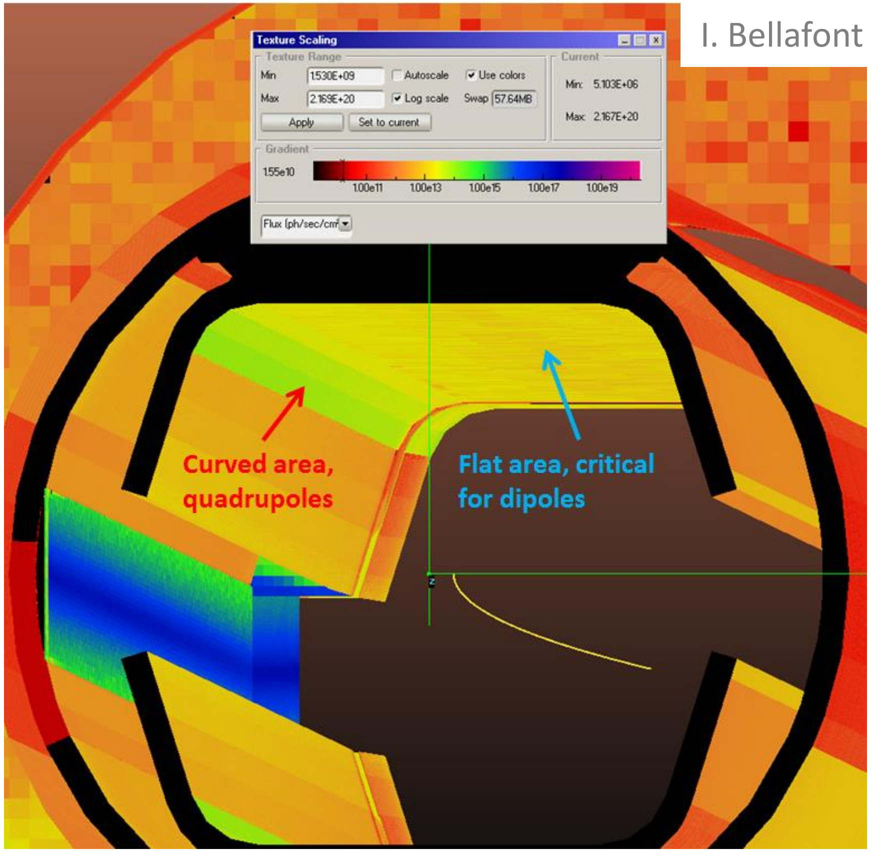
Photon absorption patterns have been studied with ray-tracing simulations (I. Bellafont)

To model photoelectron production in this complex geometry in the e-cloud simulations, the possibility to assign a photoelectron yield to each segment (of arbitrary length) of the chamber walls was implemented

Photoelectron distributions based on ray-tracing studies used in the e-cloud simulations:

- Conservative estimate (10% yield): photoelectron flux $5\times10^{10} - 5\times10^{11}$ e/cm^2/s in main chamber
- LASE estimate : photoelectron flux $10^9 - 10^{10}$ e/cm^2/s in main chamber

I. Bellafont



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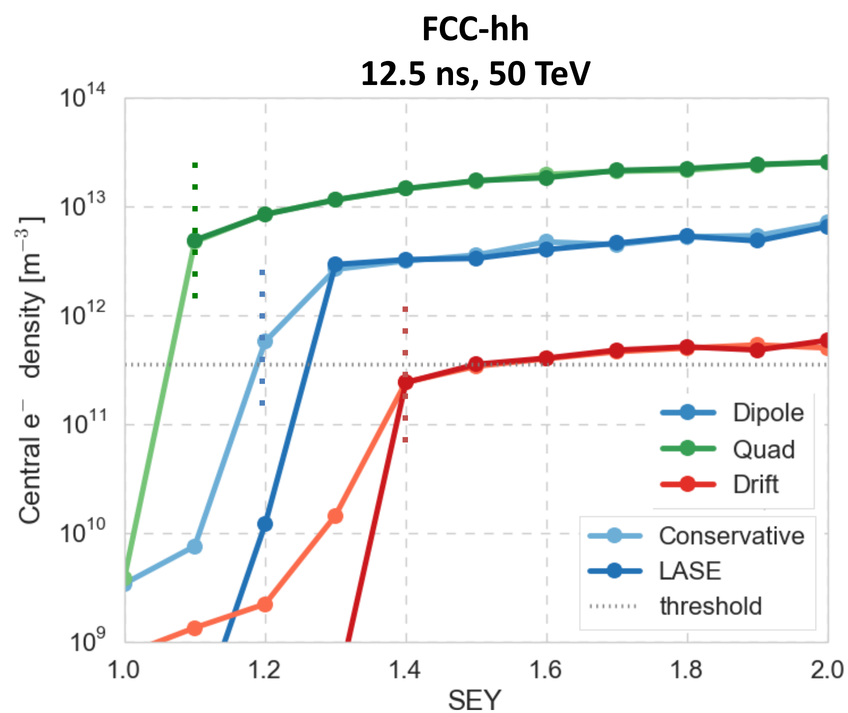

Simulations confirm that both cases are viable

- Central electron densities remain below the instability threshold for all bunch spacings when the SEY is below the multipacting threshold