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

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Electron cloud

L. Mether

With contributions from: D. Astapovych, I. Bellafont, G. Iadarola, E. Wulff

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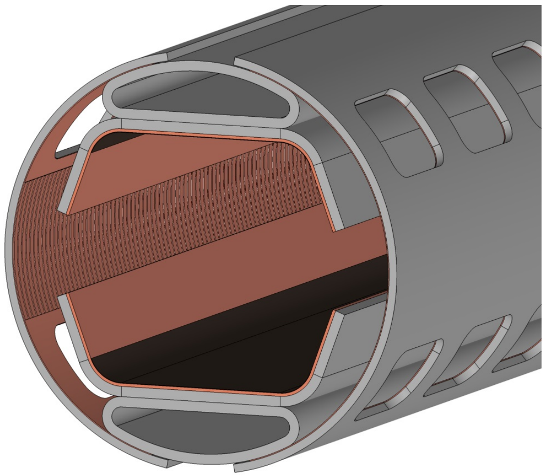
Electron cloud studies

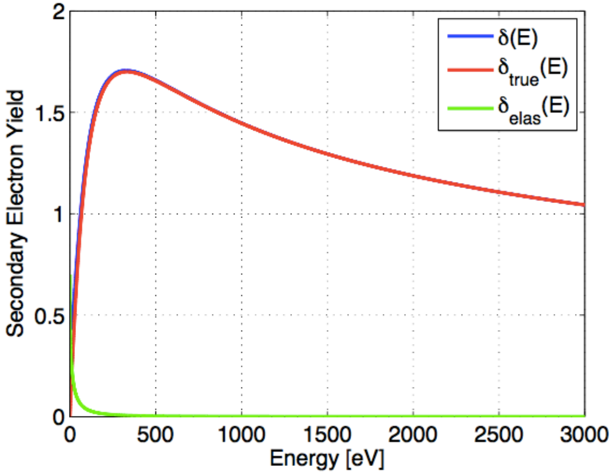
A baseline scenario for electron cloud mitigation (for CDR) has been identified based on

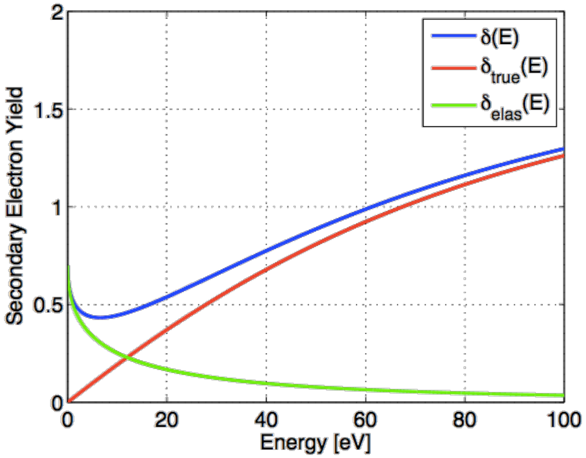
- Electron cloud build-up simulations in arc dipoles, quadrupoles and drifts
  - Full beam screen geometry
  - Trains of 80 bunches separated by 17 empty slots for the 25 ns beam
  - Secondary electron emission model for Cu co-laminated beam screen

- Estimations of the threshold electron density for single bunch instabilities

- Build-up studies with photoelectrons, using photoelectron distributions based on ray tracing simulations and measurements







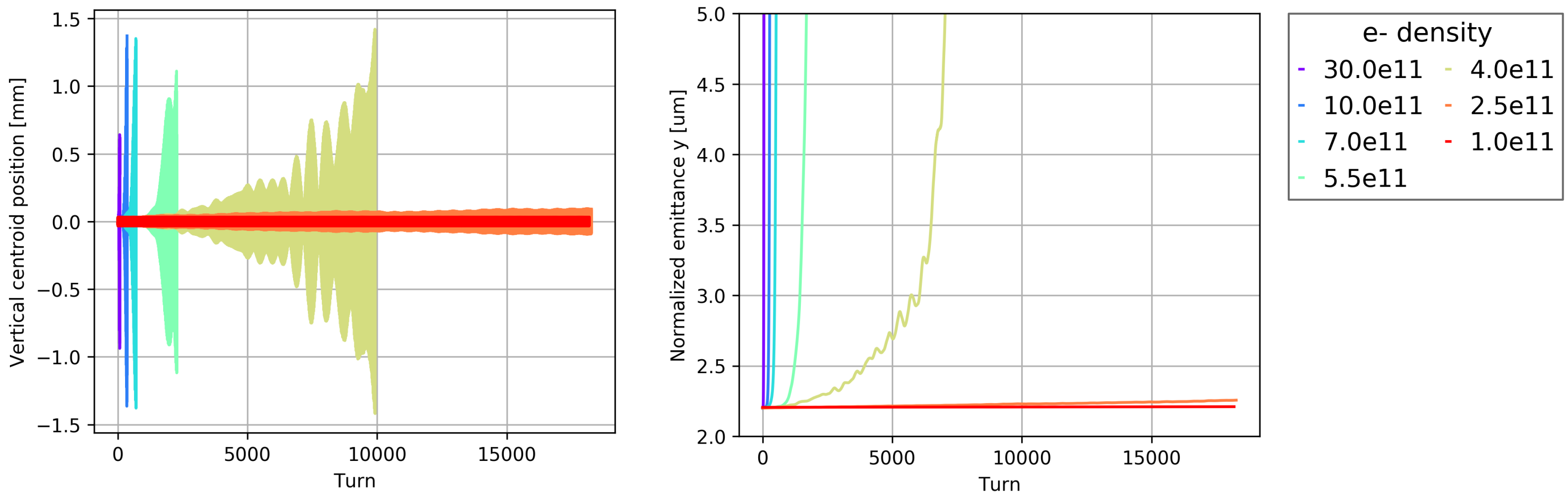
Single bunch stability

The threshold central electron density for instability has been estimated analytically:

K. Ohmi et al

$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_e\sigma_z/c}{\sqrt{3}KQr_0\beta L} \quad \text{with} \quad \omega_e = \sqrt{\frac{\lambda_p r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}, \qquad K = \omega_e\sigma_z/c, \quad Q = \min(\omega_e\sigma_z/c, 7)$$

As well as by single-bunch stability simulations in dipoles:



- The estimated density thresholds are independent of the bunch spacing for fixed beam brightness

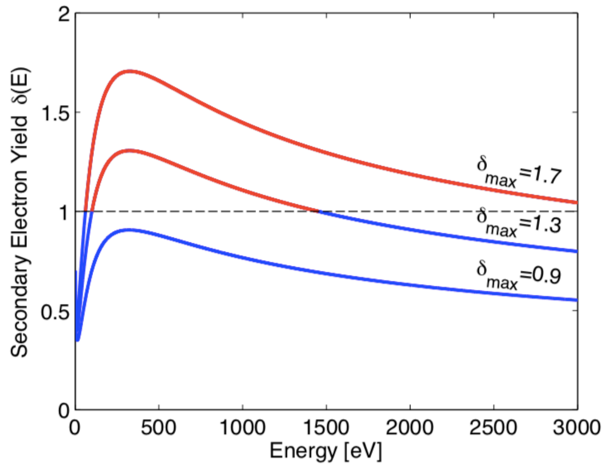
Threshold electron density

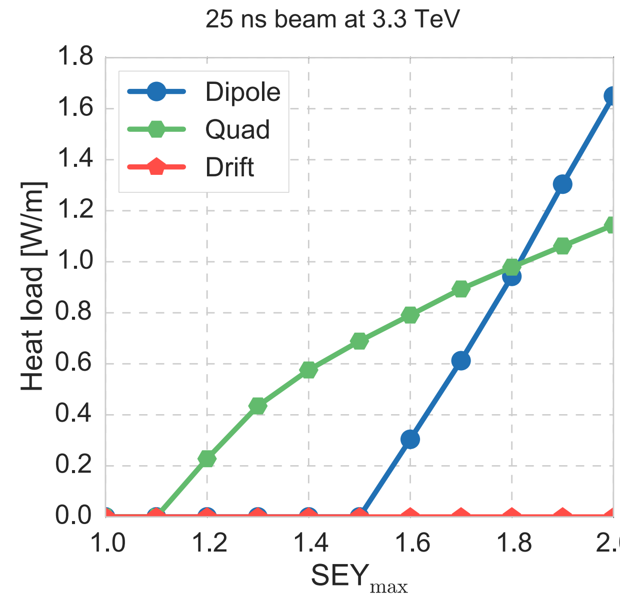
3.3 TeV	50 TeV
1 x 10^{11} m^{-3}	5 x 10^{11} m^{-3}

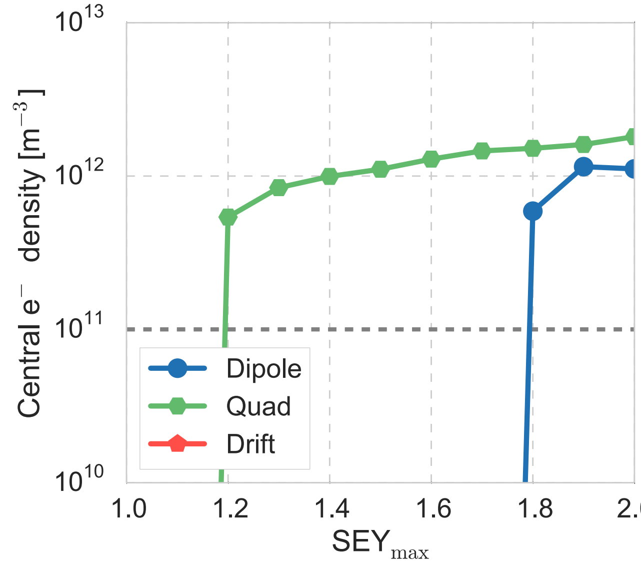
Electron cloud with 25 ns beam

Multipacting thresholds, i.e. maximum SEY (δ_{max}) without e-cloud build-up

	25 ns	
E [TeV]	3.3	50
Dipole	1.5	1.5
Quad	1.1	1.2
Drift	≥ 2.0	≥ 2.0







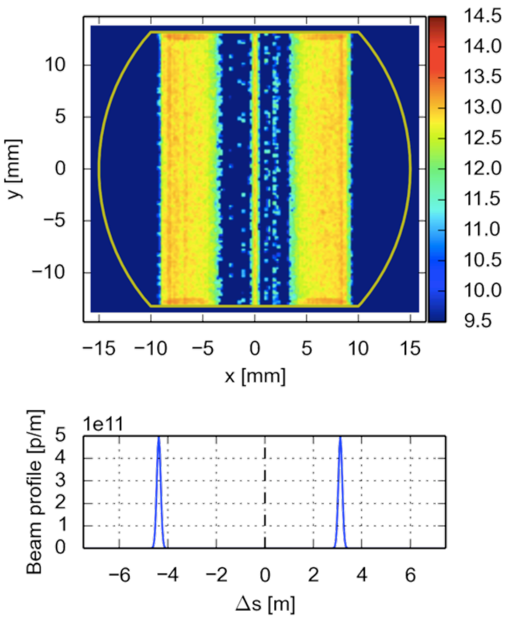
- Heat loads are moderate compared to the synchrotron radiation ~28.4 W/m
- Stability is more critical: in quadrupoles, the central densities exceeds the instability threshold above the multipacting threshold

Mitigation scenario for 25 ns beam

- Ensure e-cloud suppression with amorphous carbon coating in dipoles and quadrupoles
  - SEY ≤ 1.1
- No coating needed in drifts due to high multipacting threshold

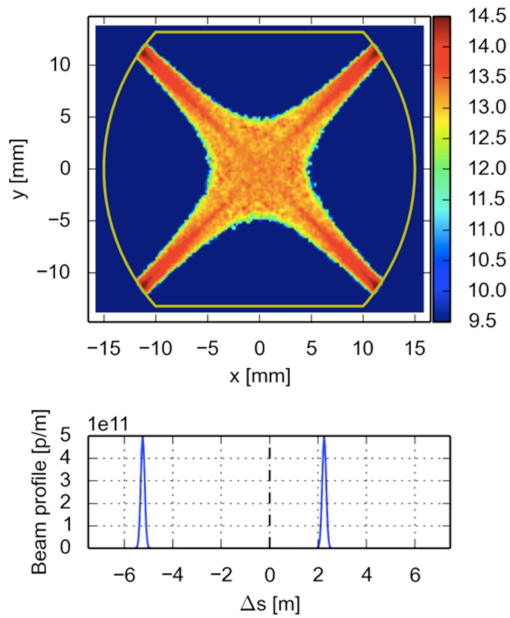
Dipole

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



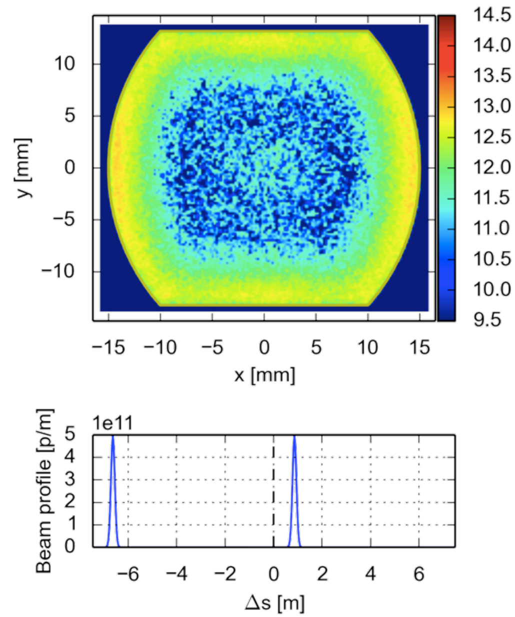
Quadrupole

Coating is required at 45° to the horizontal plane



Drift

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

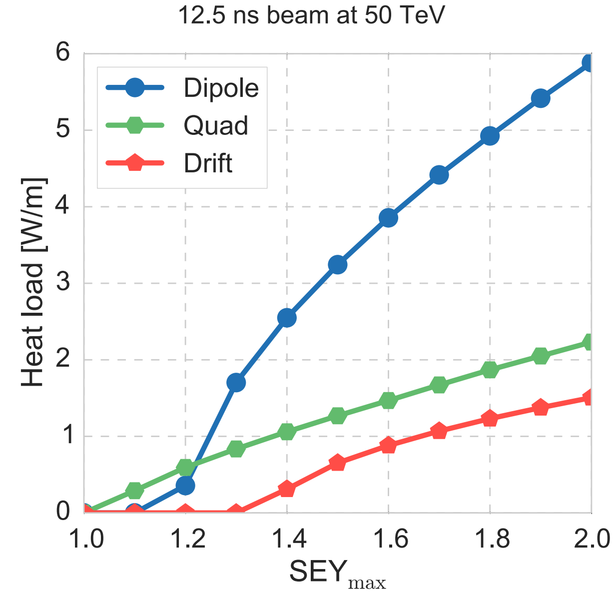


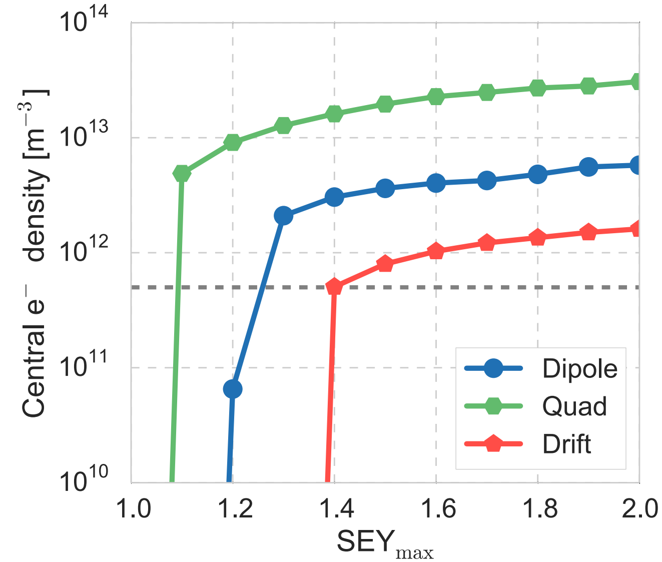
Electron cloud with alternative beams

Multipacting thresholds, i.e. maximum SEY (δ_{max}) without e-cloud build-up

	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

- Tighter constraints on the SEY for alternative beams, in particular for 12.5 ns
- Heat loads can be significant for unconditioned surfaces
- Stability is critical: the central densities exceed the instability threshold above the multipacting threshold



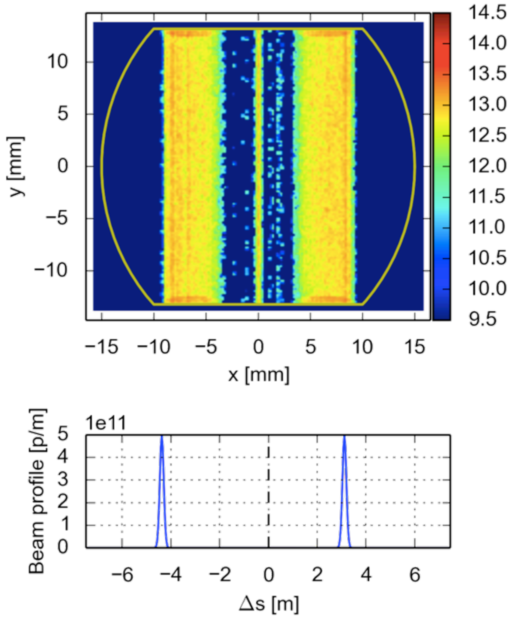


Mitigation scenario for alternative beams

- LASE surface treatments an option for decreasing the SEY beyond a-C
  - » Within constraints imposed by the impedance
- Coating or other mitigation scheme to be considered also in drifts

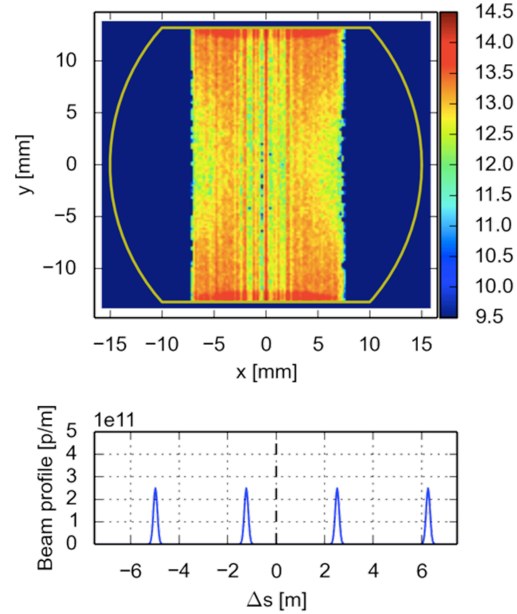
25 ns

Bunch intensity 1×10^{11} p



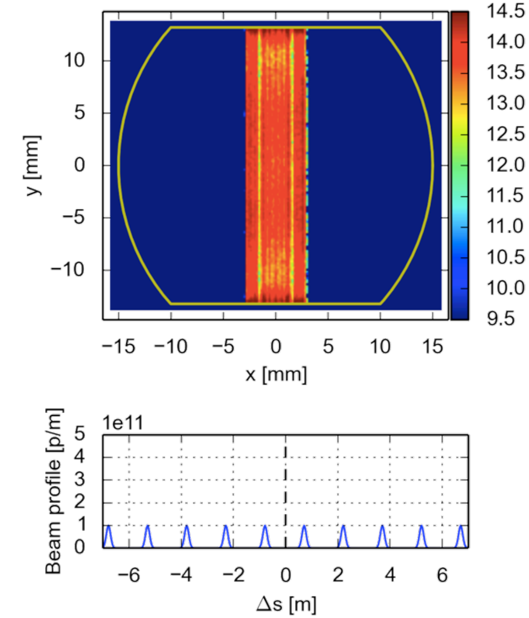
12.5 ns

Bunch intensity 5×10^{10} p



5 ns

Bunch intensity 2×10^{10} p

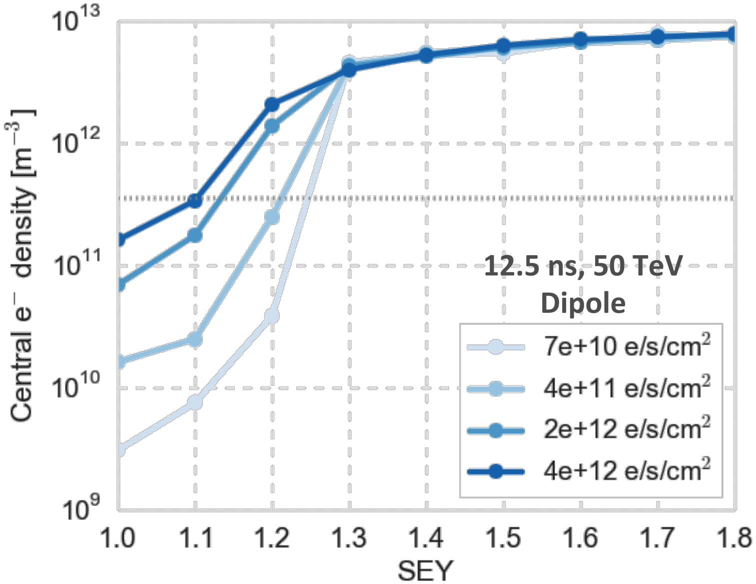


Photoelectrons

Preliminary studies showed that a high photoelectron yield could bring the central electron density above the instability threshold below the multipacting threshold

Constraints on the photoelectron flux were conveyed to the beam screen design team

The current beam screen with saw-tooth was found to be compatible in dipoles and quadrupoles



Build-up studies with photoelectron flux distributions based on ray-tracing studies were implemented in the build-up simulations and results presented at the FCC Week 2018

- Confirmed the viability of the current beam screen design in dipoles and quadrupoles
- Uncertainty on amount of photoemission in drifts

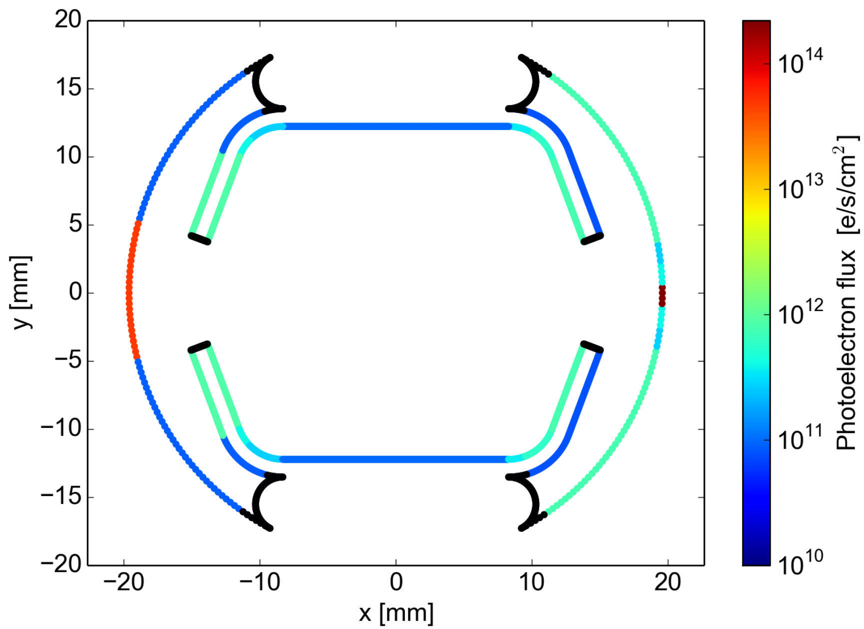
Photoelectron yield in arc magnets

New more detailed simulations with photoelectrons based on ray-tracing simulations as well as photoelectron yield measurements on Cu and LASE surfaces

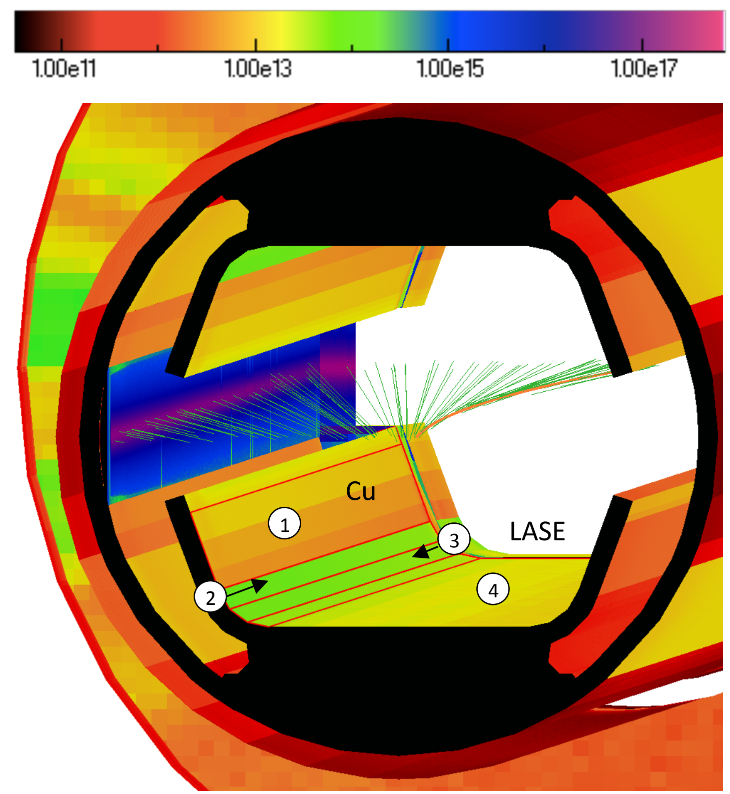
Two options for dipoles and quadrupoles:
- Cu photoelectron yield everywhere

I. Bellafont

Cu photoemission everywhere



SR photon flux (ph/s/cm²)



Pessimistic estimation, data for the most irradiated magnet. If using LASE on sawtooth, electron generation can be further reduced in the inner chamber

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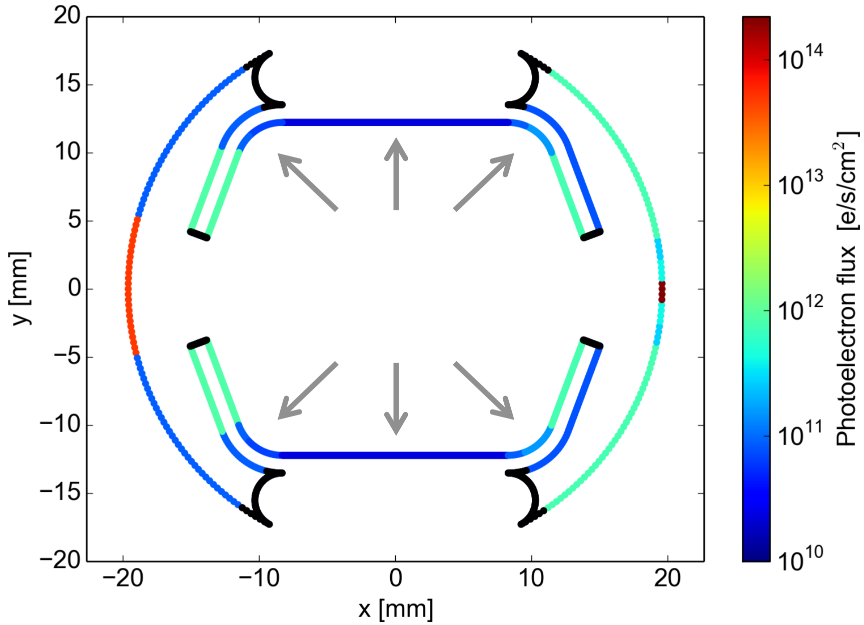
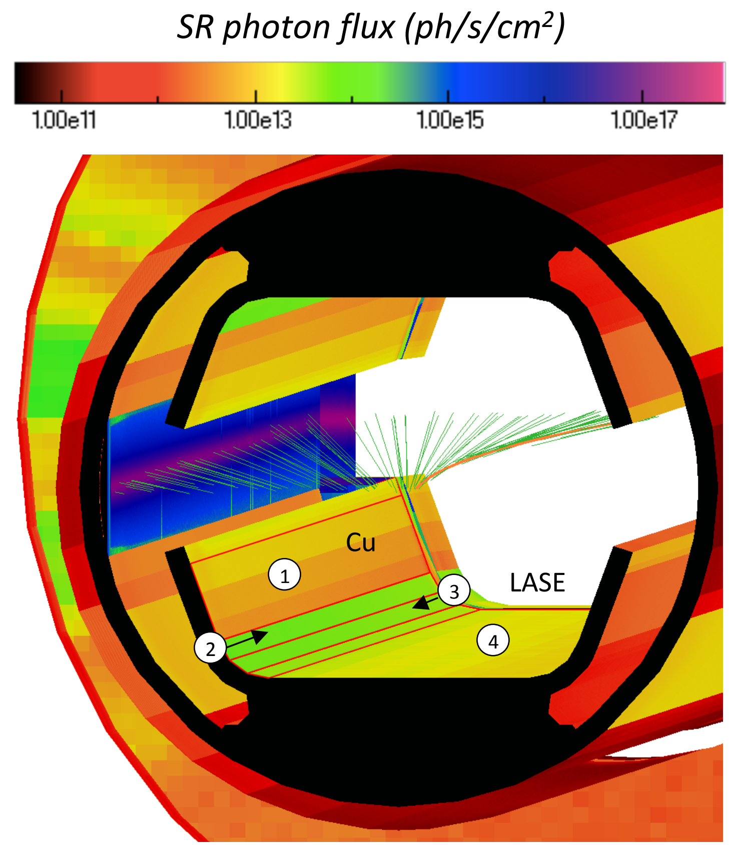
LASE photoemission in critical areas



NB! Still using SEY model based on Cu

I. Bellafont



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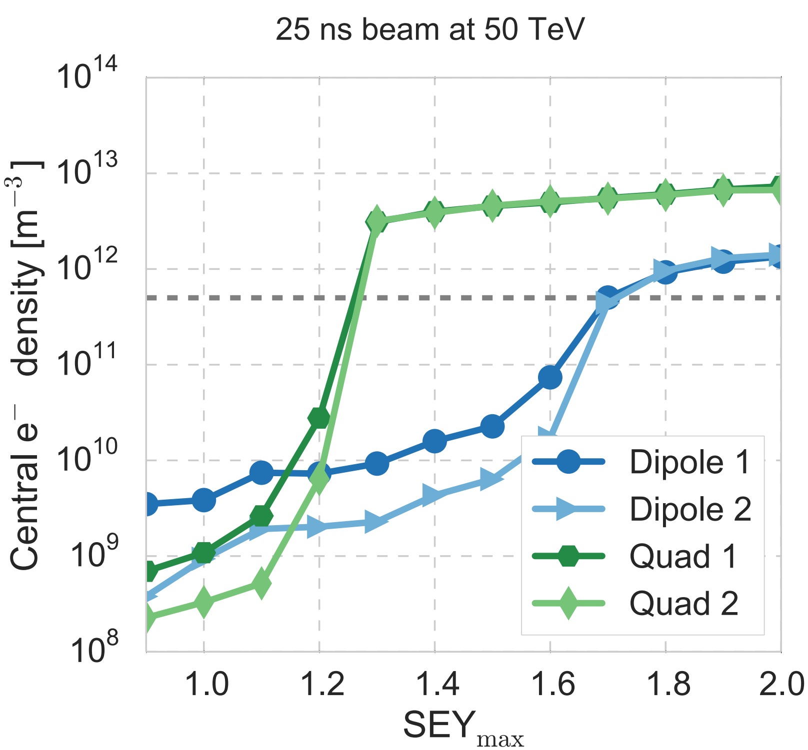
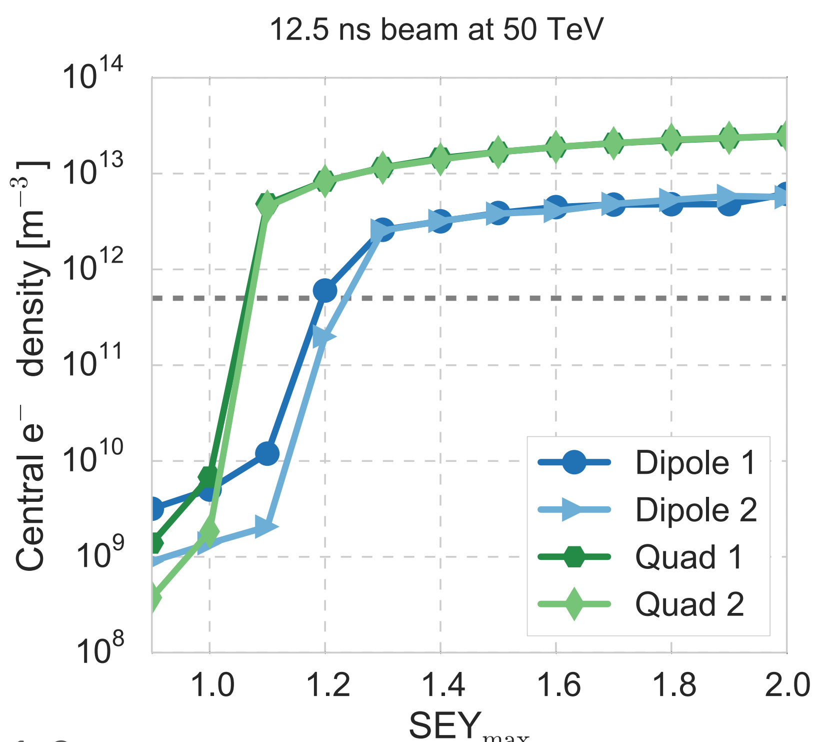
Effect of photoelectrons in arc magnets

New more detailed simulations with photoelectrons based on ray-tracing simulations as well as photoelectron yield measurements on Cu and LASE surfaces

Two options for dipoles and quadrupoles:
- Cu photoelectron yield everywhere
- LASE photoelectron yield in critical areas

No risk of beam instability below the multipacting threshold due to photoelectrons for any beam option





Case 1: Cu
Case 2: LASE

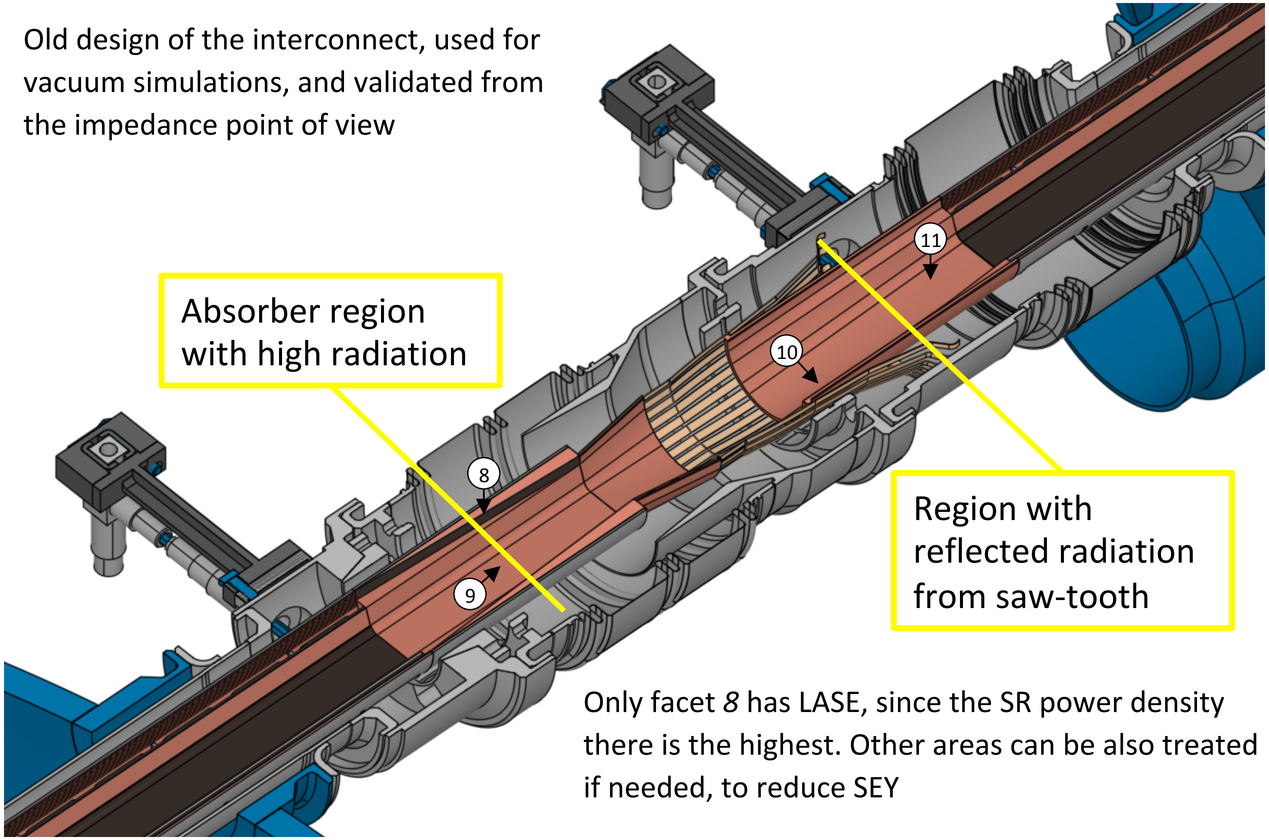
Photoelectron yield in drifts

New more detailed simulations with photoelectrons based on ray-tracing simulations as well as photoelectron yield measurements on Cu and LASE surfaces (WP4)

Two distinct areas are considered in the interconnections

I. Bellafont

Old design of the interconnect, used for vacuum simulations, and validated from the impedance point of view



Only facet *8* has LASE, since the SR power density there is the highest. Other areas can be also treated if needed, to reduce SEY

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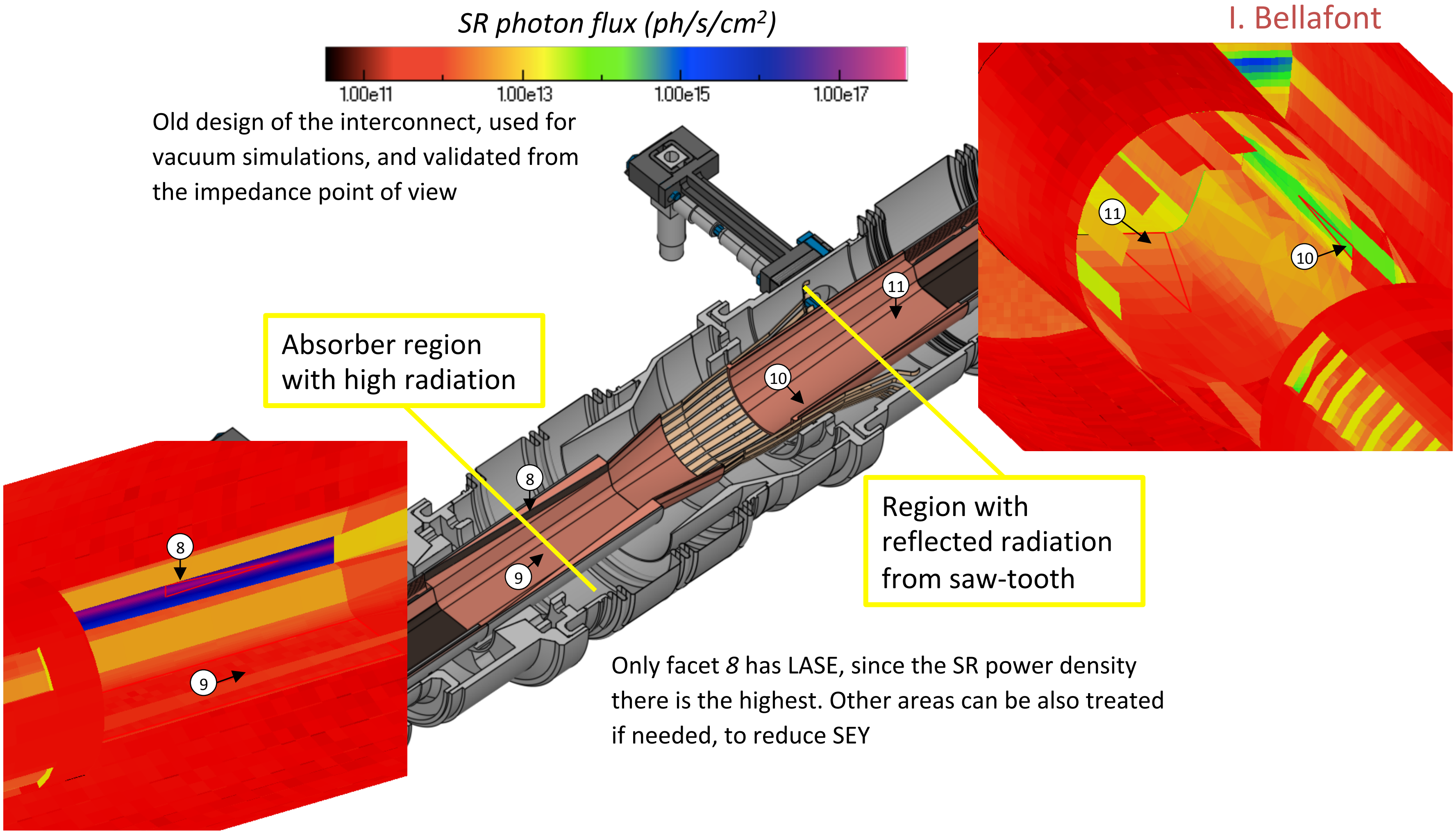

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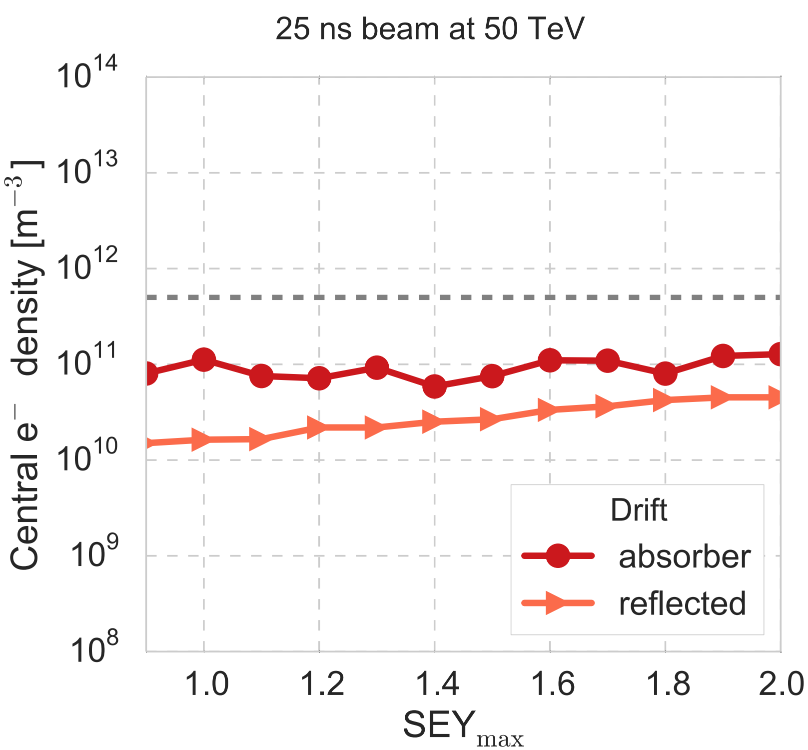
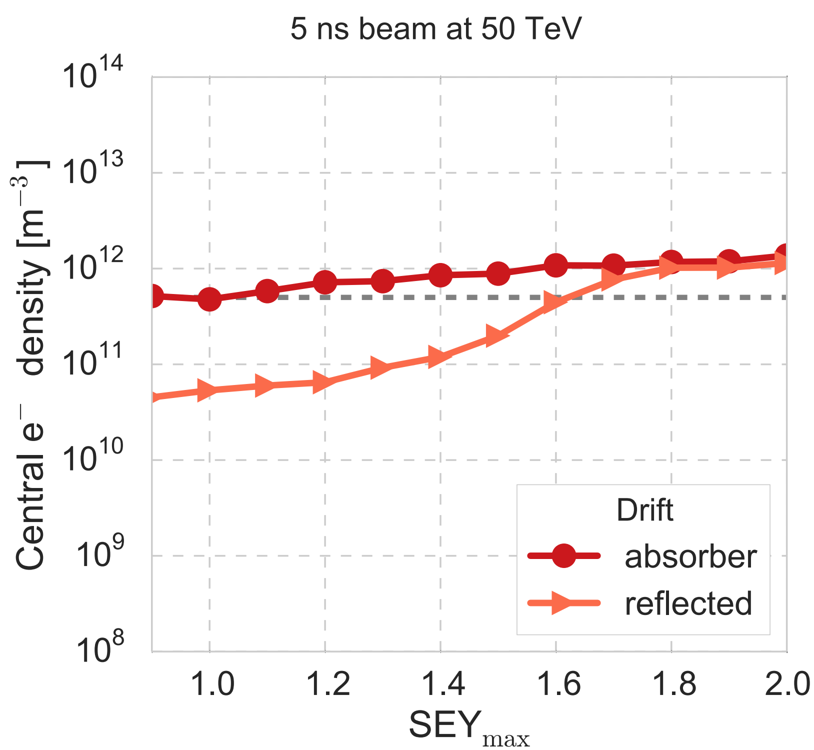
Two distinct areas are considered in the interconnections

Each region is assumed to cover 1/3 of the interconnection length

For the 5 ns beam the electron density in the absorber region may cause instabilities

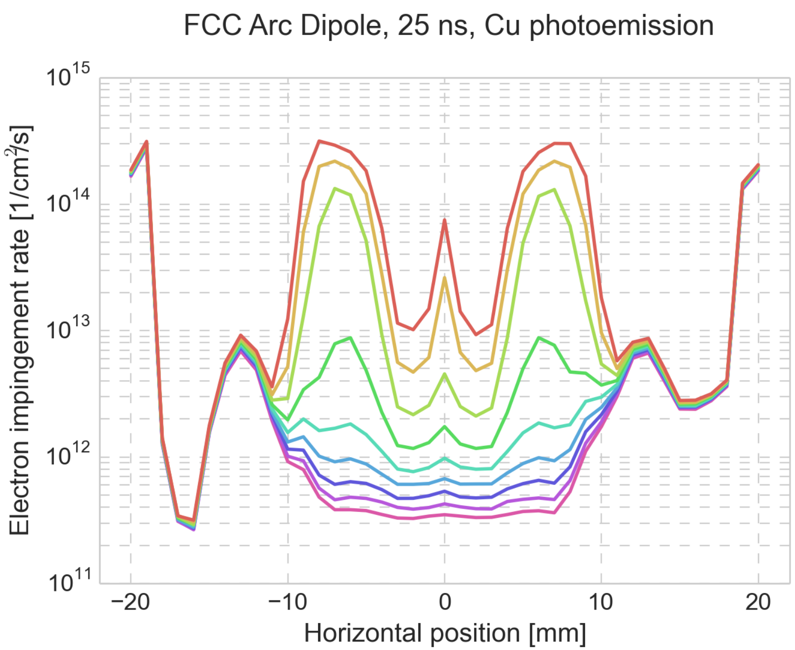


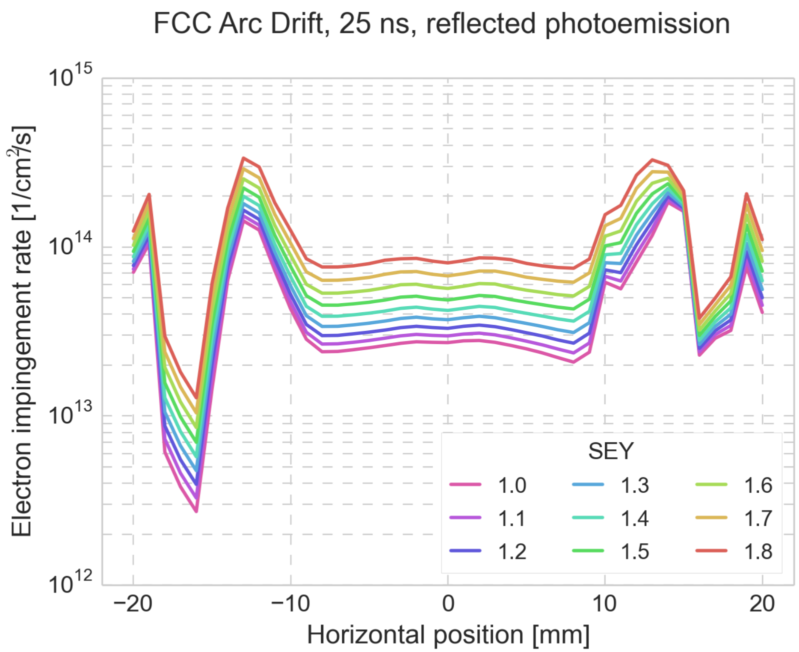


Electron impingement rates

The simulations with photoelectrons have also been used to estimate electron impingement rates and the average energies of impinging electrons

→ Used for studying the effect of electron stimulated desorption on the vacuum (WP4)

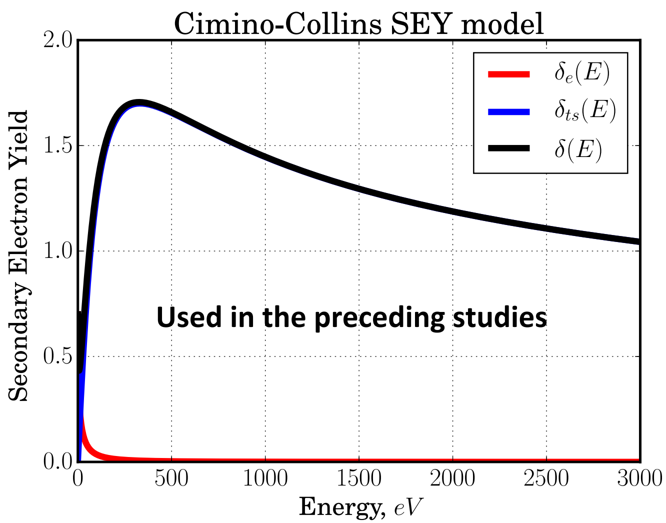


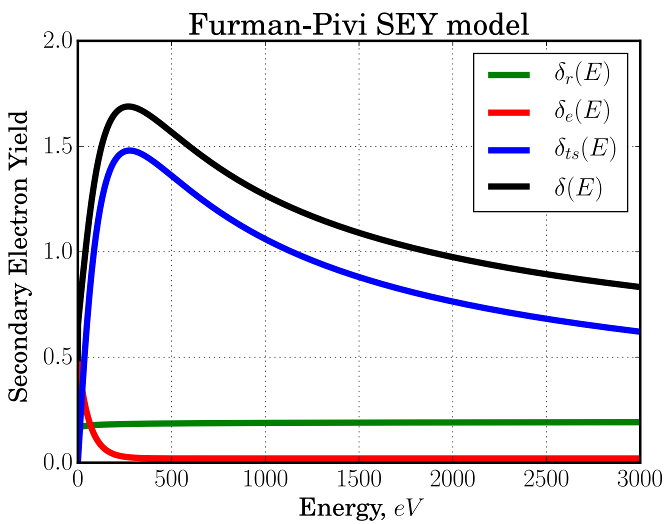


The electron impingement rate in the drifts is high, even for low SEY
The effect of residual magnetic fields (not considered here) may alleviate the problem

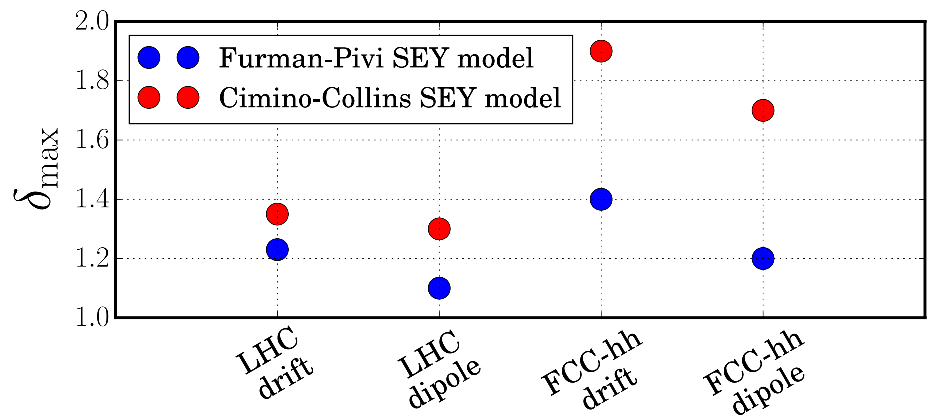
Secondary emission yield model

A comparison of two different SEY models for Cu surfaces was presented in Amsterdam





Work by D. Astapovych, using openECLOUD code



Significant differences in the multipacting thresholds with the two models were found

Possible causes:

- Shape of total SEY curve for given δ_{max}

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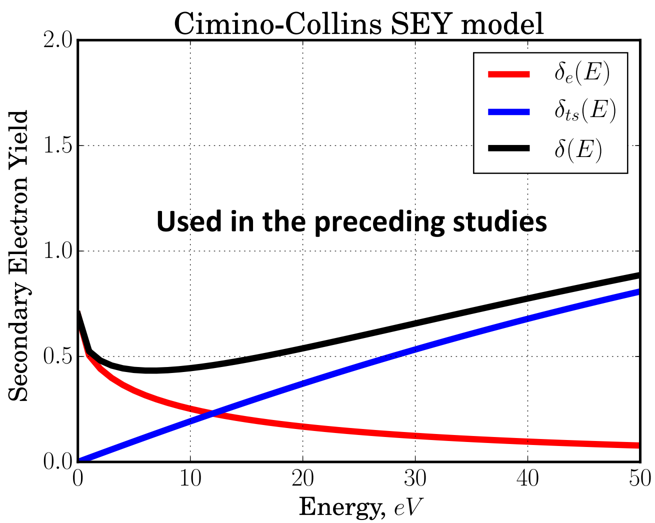

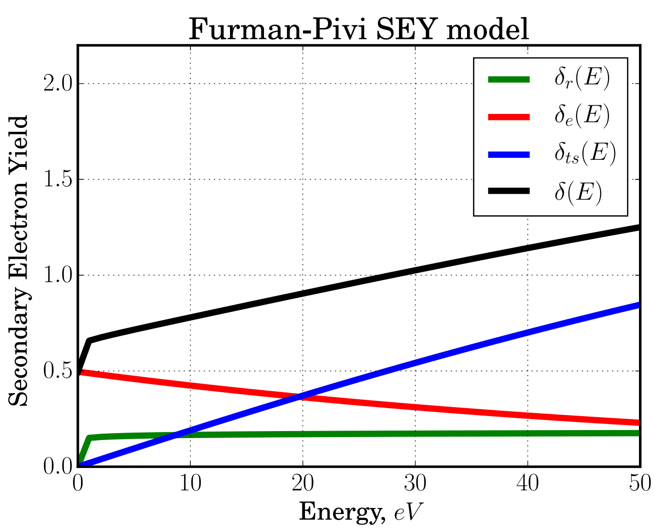

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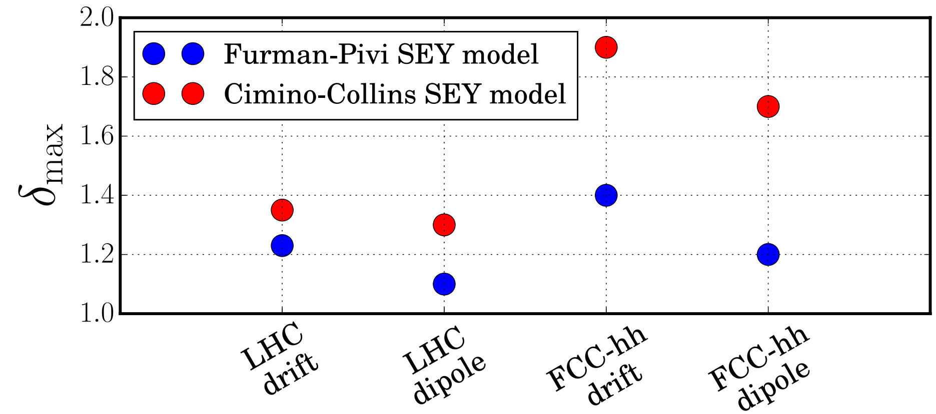

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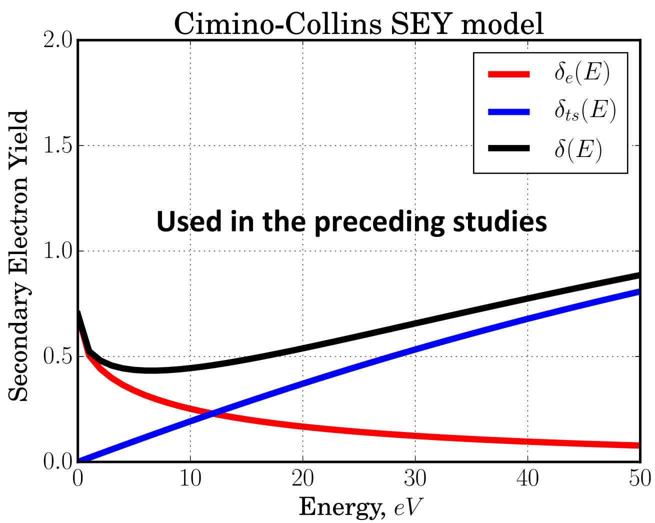

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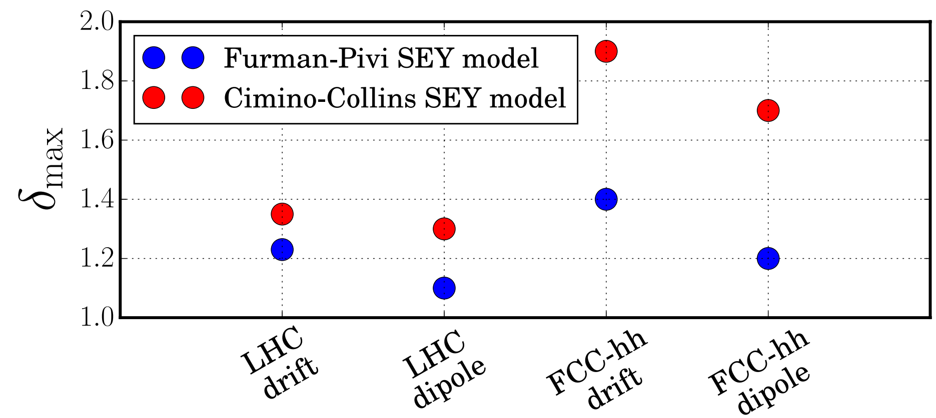
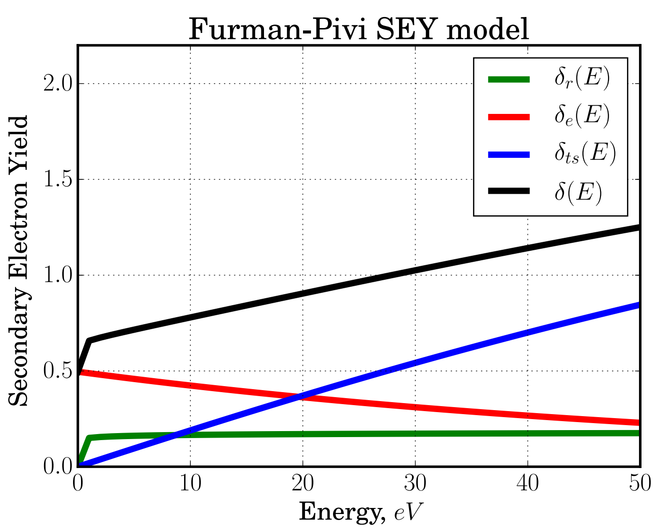




Significant differences in the multipacting thresholds with the two models were found

Possible causes:

- Shape of total SEY curve for given δ_{max}
- Energy spectrum of emitted electrons for rediffused component
- Numerical details e.g. representation of emitted electrons

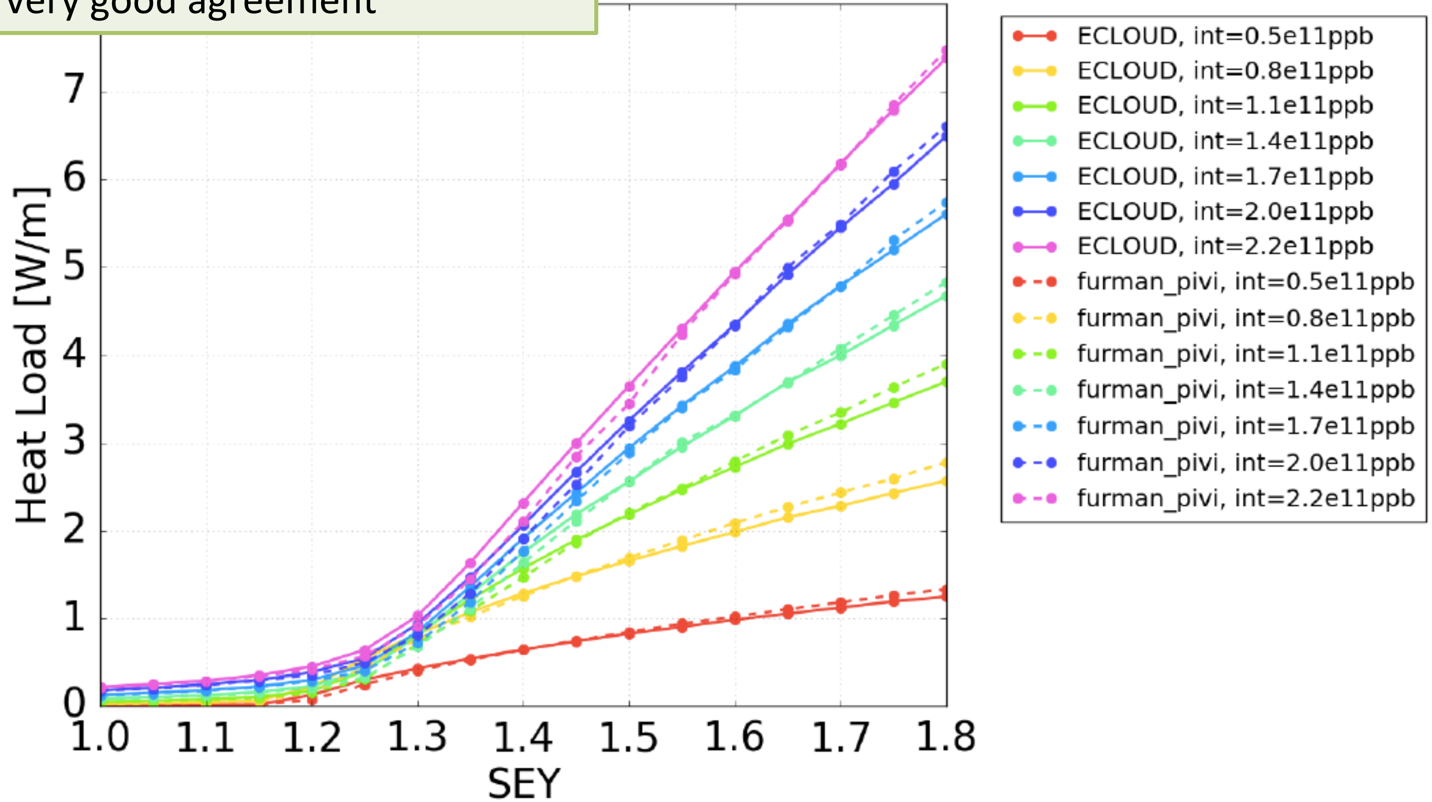
Secondary emission yield model

The Furman-Pivi model has recently been implemented also in the PyECLOUD code

Identified parameters for the F-P model that reproduce as well as possible both the SEY curve and the emission energy spectra of the C-C model (no rediffused electrons)

Work by E. Wulff, G. Iadarola

Simulation results with the two models are in very good agreement



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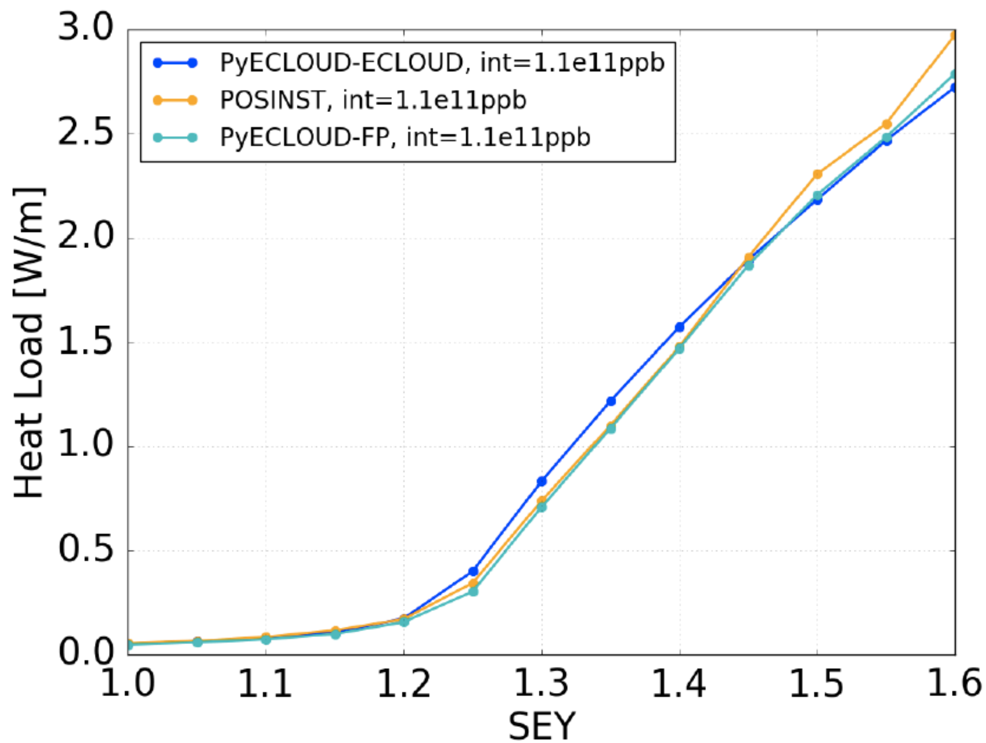

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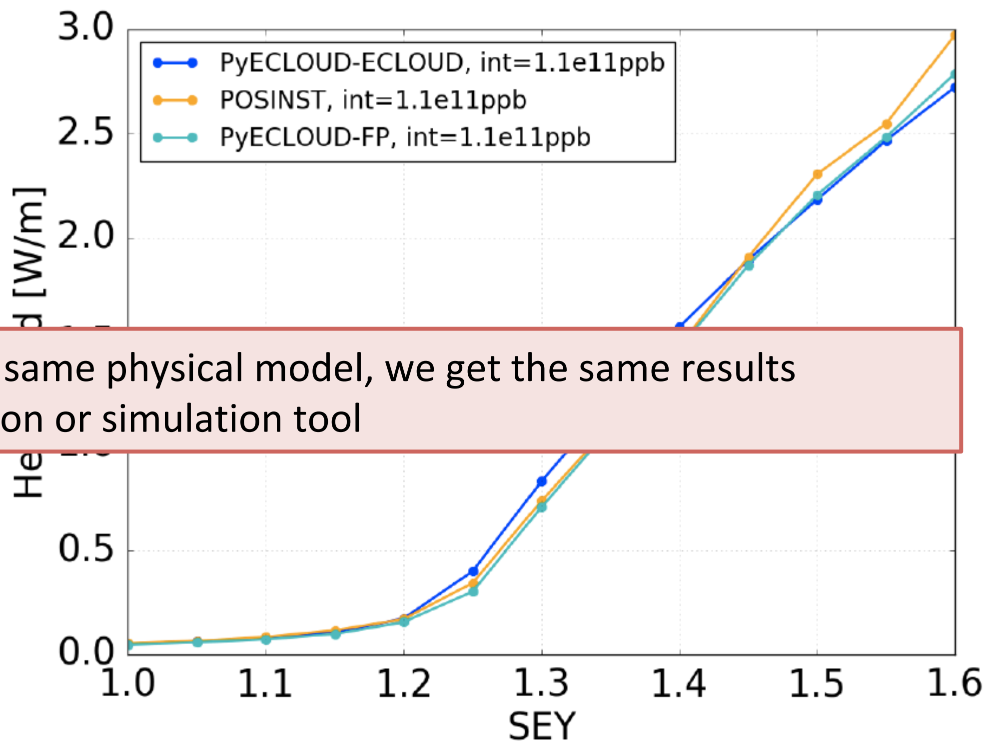

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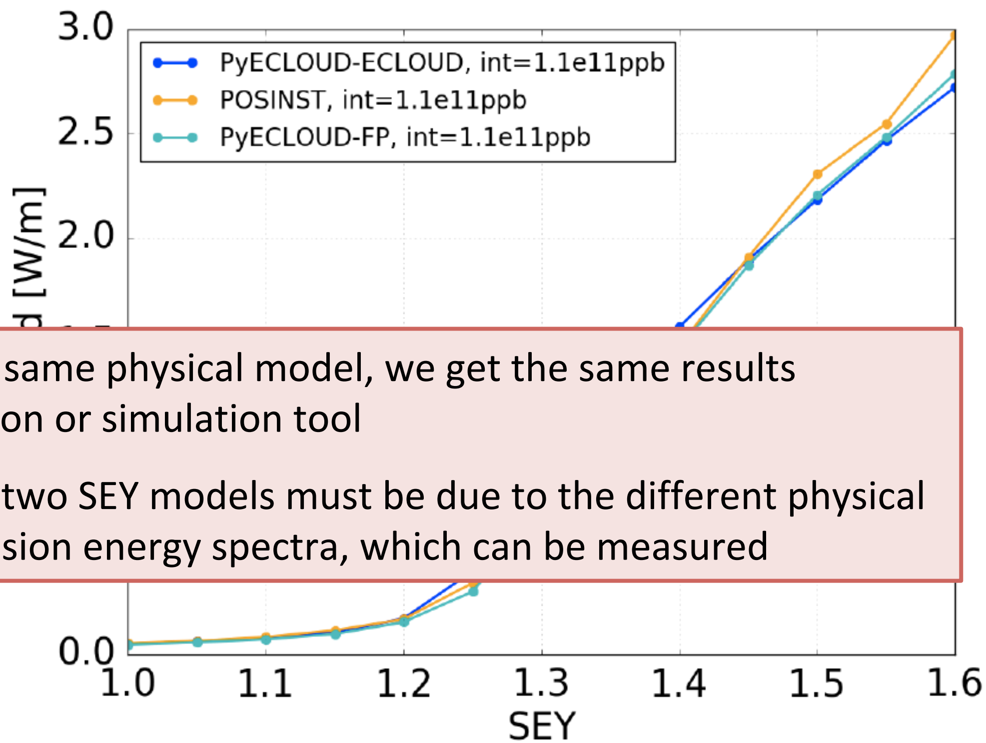

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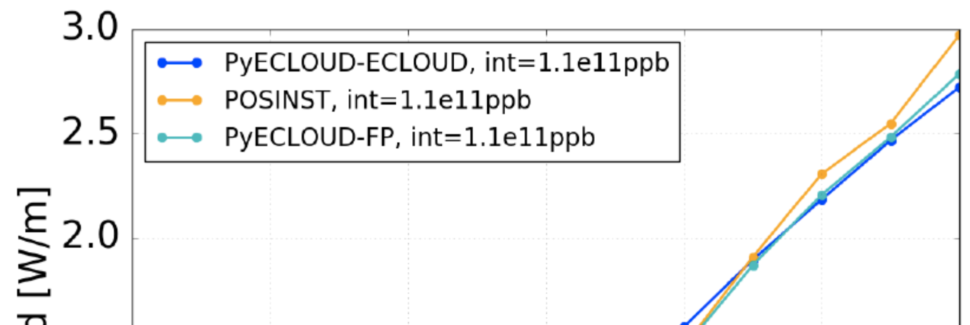

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→ The F-P parameters used in the original comparison are based on measurements of a Cu surface for a single δ_{max}, the amount of rediffused electrons is kept fixed when δ_{max} is changed − not clear if this is supported by measurements

Conclusions

- A baseline scenario for electron cloud mitigation has been identified
  - » Amorphous carbon coating in dipoles and quadrupoles for the 25 ns beam
  - » LASE coating in quadrupoles (and dipoles) and mitigation in drifts may be needed for the alternative beams → impedance reduction of LASE still to be studied
- The effect of photoelectrons has been carefully considered
  - » Saw-tooth at synchrotron radiation impact point provides sufficient mitigation
  - » High electron densities are predicted in the region of the radiation absorbers
    → Potentially an issue for vacuum quality and for the 5 ns beam also stability
    → More detailed studies considering e.g. residual magnetic fields may improve prospects
- Different physical SEY models give significantly different predictions
  - » Need to take care to base our simulation models on extensive and relevant measurements
    → Concerns also e.g. for Cu vs LASE

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