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Multipactor Modeling in 2D for Open Insight into the EM Behavior of Metalic Microwave Components

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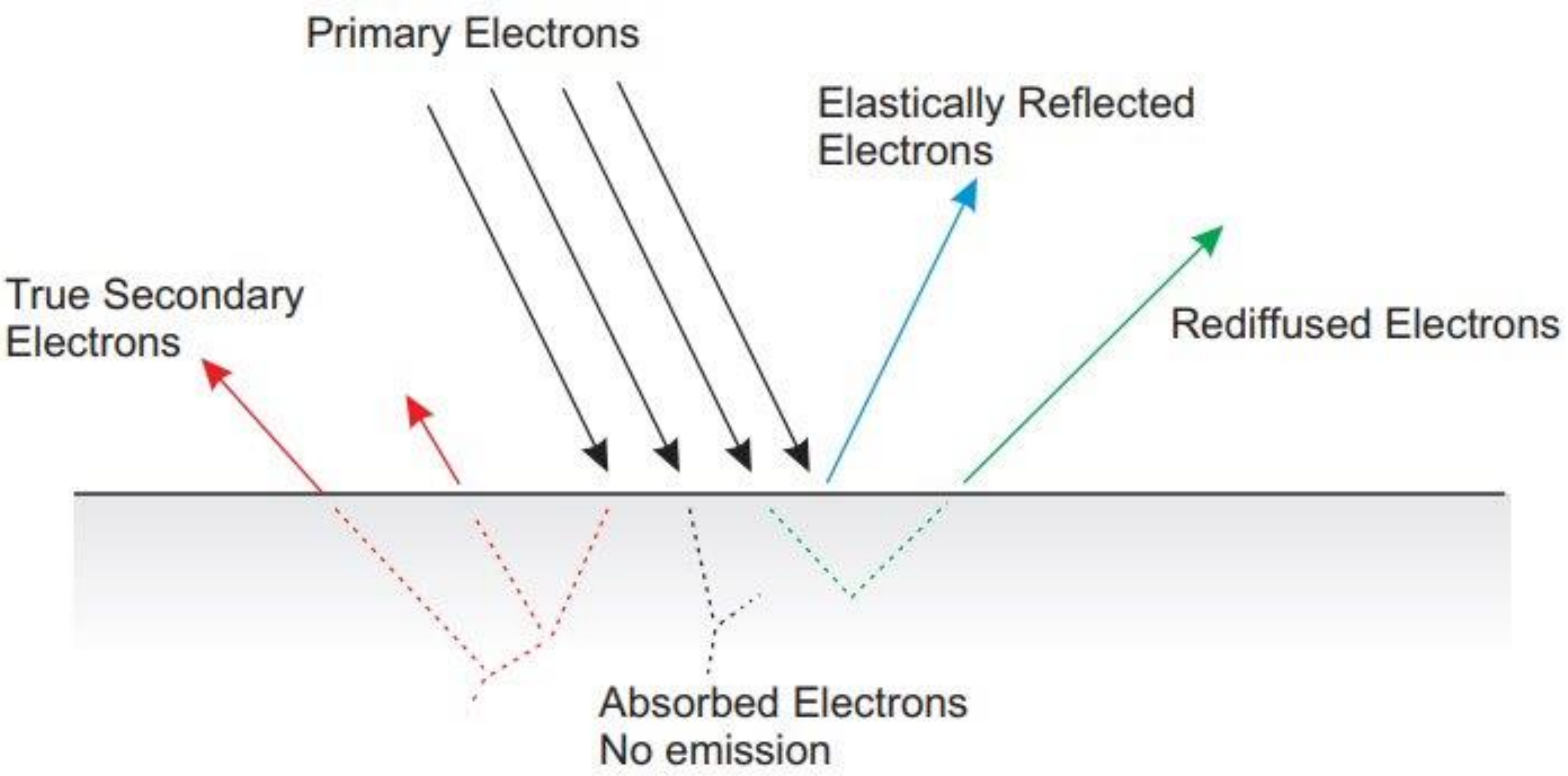
Outline

1. Theory.
2. Motivation.
3. Model Design.
4. Results.
5. Conclusions.
6. Future Works.

Theory

Secondary Electron Emission (SEE)

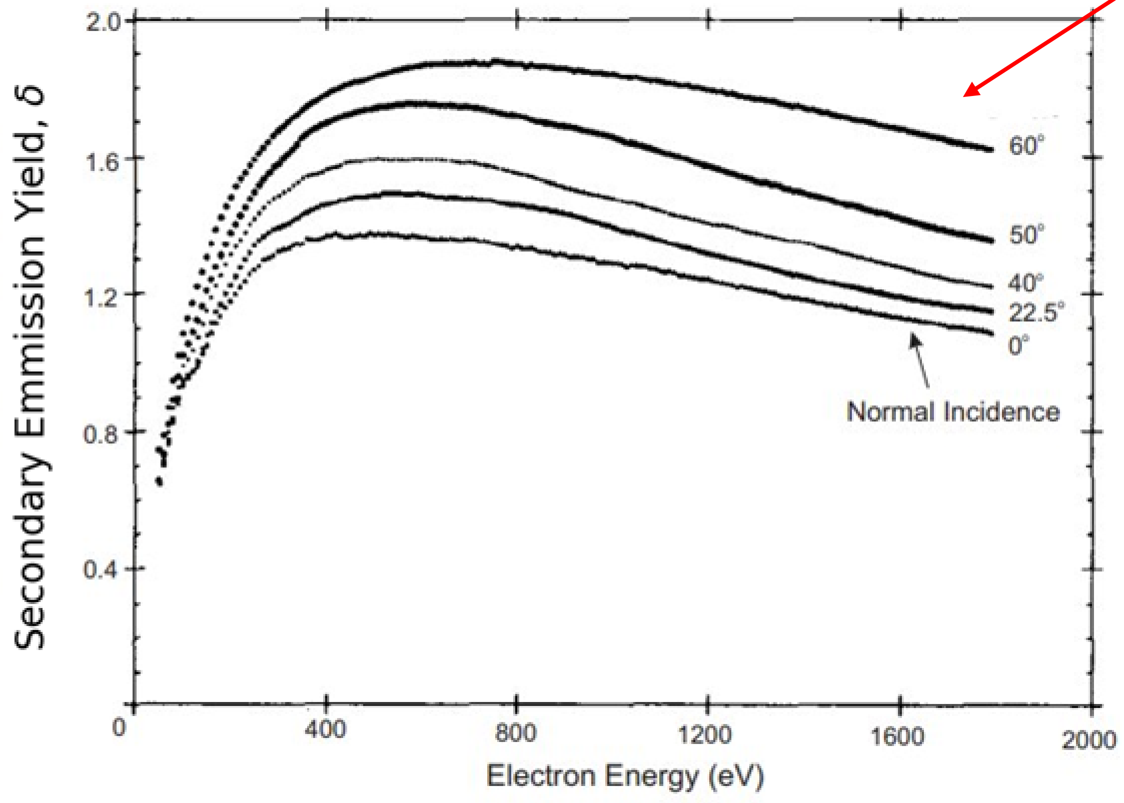


Soulas A., *Modeling of Long-Term Multipactor Evolution in Microwave Components*

4 different possible outcoumes

Theory

Secondary Emission Yield (SEY)



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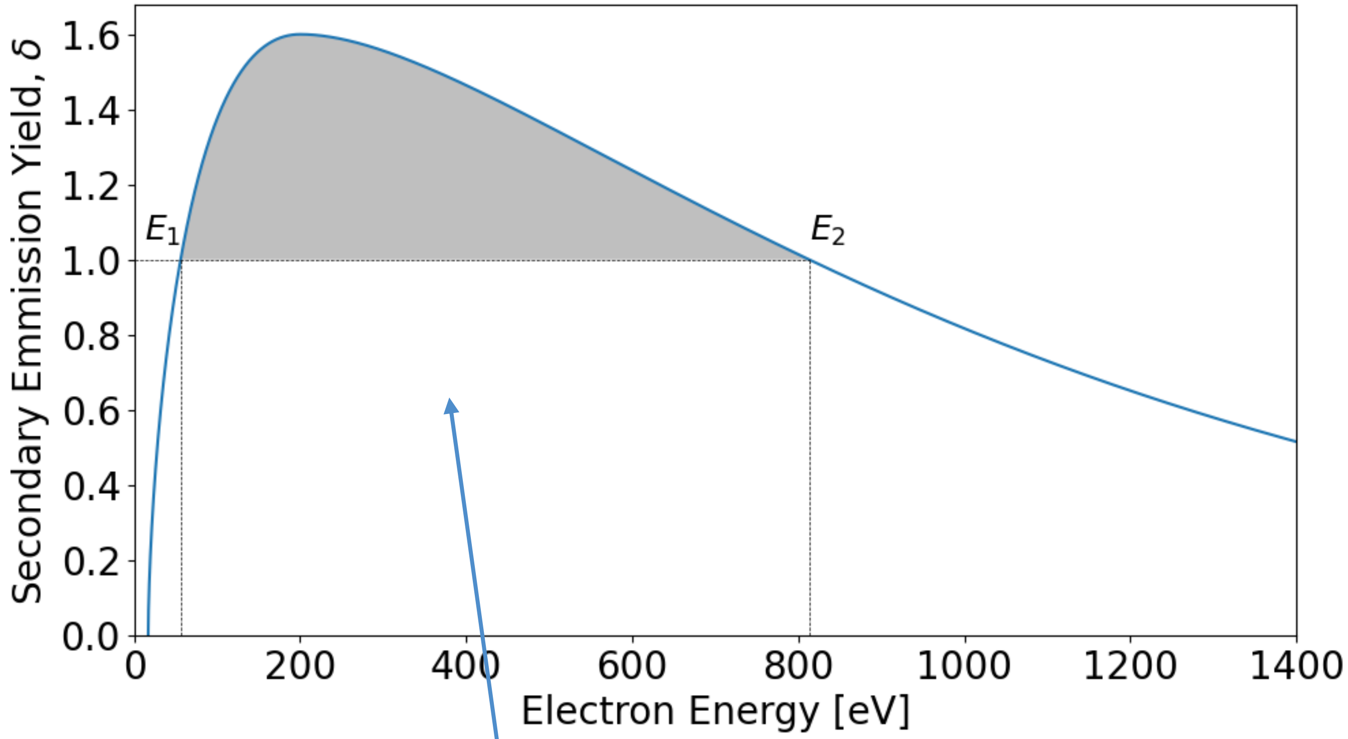
Measurements



Empirical model (Vaughan)

Theory

What is multipactor?

- **Multipactor** is phenomenon where secondary electron emission (SEE) in resonance with electromagnetic field leads to exponential electron multiplication.
- It may detune a microwave signal and heat the surface, thus increasing noise level and causing damage.
- **Multipactor threshold** is the device power value at which there is a risk of a multipactor event.

Motivation

Multipactor Simulations:

- Multipactor is typically undesirable effect, it is crucial to mitigate the risk of its occurence.
- Simulations are much less expensive than multipactor experimental tests.

2D Multipactor:

- Easy to use tool for predicting multipactor treshold.
- Demo for a full 3D model.

Model Design

- Rectangular waveguide AxB – TE10 mode.
- Particle-in-cell (PIC) approach.
- Tracking particle-EM field interactions through the Lorentz Force*.
- Tracking macroparticles (MP) instead of each electron.
- Random particles starting positions and kinetic energies (0 eV – 4 eV).

$$* \frac{v^{n+1}-v^{n}}{\Delta \mathrm{t}} = \frac{q}{m}\left(E^{n}+\frac{v^{n+1}+v^{n}}{2}\times B^{n}\right)$$

$$\frac{r^{n+1}-r^{n}}{\Delta t} = v^{n+1}$$

Model Design

SEY model (*modified* Vaughan)

$$\delta(E,\theta) = \delta_{max}(\theta)(V \cdot \exp(1-V))^k \; for \; V \leq 3.6 \quad (8.1)$$

$$\delta(E,\theta) = \delta_{max}(\theta) \cdot 1.125/v^{0.35} \; for \; V > 3.6, (8.2)$$

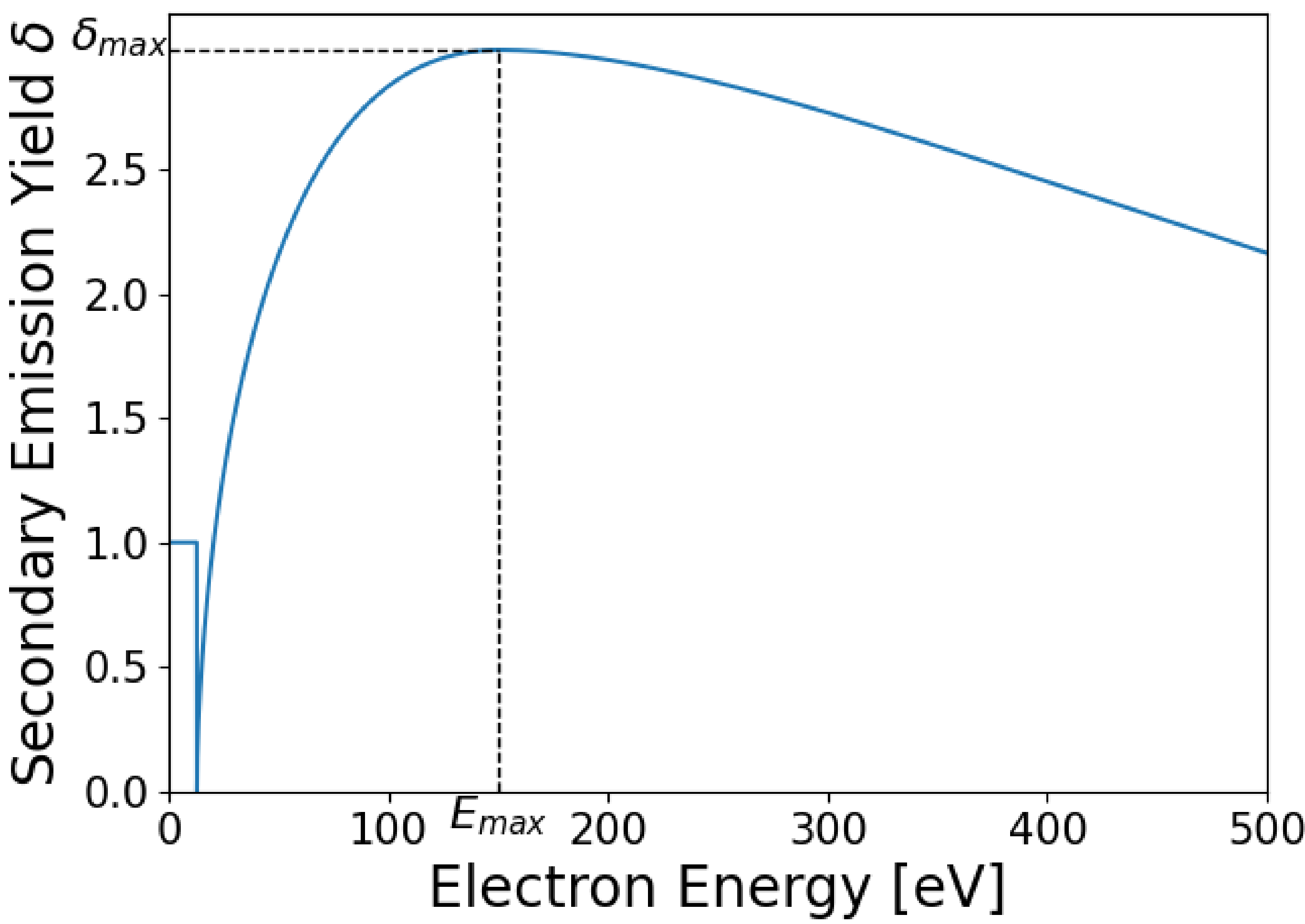
$$V = \frac{E - E_0}{E_{max}(\theta) - E_0},$$

$$k = 0.56 \; for \; V < 1,$$

$$k = 0.25 \; for \; 1 < V \leq 3.6,$$

$$\delta_{\max}(\theta) = \delta_{\max}(1 + k_E\theta^2/2\pi),$$

$$E_{max}(\theta) = E_{max}(1 + k_\theta\theta^2/2\pi),$$



Results

Simulated Problem

- A = 22.86 mm, B = 3 mm, f = 10 GHz
- Number of electrons N = 1000, Macroparticles MP = 20, 100
- SEY parameters: $\delta_{max} = 2.98$, $E_{max} = 150\ eV$, $E_0 = 12.5\ eV$, k_E and k_θ are equal to 1

N – Numbers of electron, MP - Macroparticles

Results

Reference – Ansys HFSS

- Approximating 3D problem to 2D

Length of the section (mm)	Threshold Power (kW)
0.1	8.48
0.5	8.33
1	8.48
3	8.02
5	8.33
10	8.02

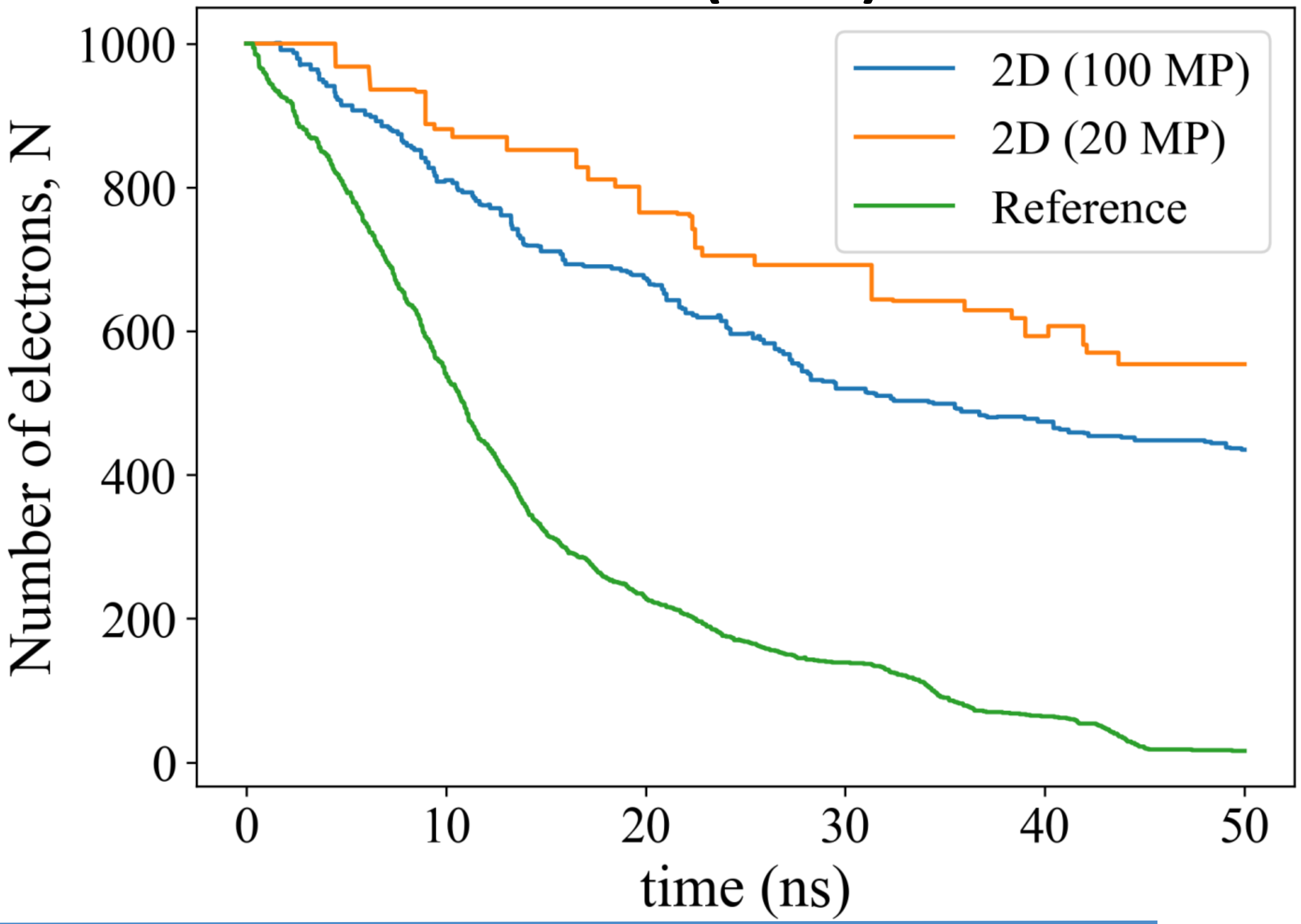
The differences in the threshold power estimated by software remain within $\pm 3\%$, with the average value of **8.28 kW**.

While the 2D Simulations estimated the threshold to be between **7.5 and 8.5 kW.**

Simulations are not exactly repeatable due to random initial values and the nature of the SEE phenomenon!

Results

Below the Threshold (2kW)



Number of electrons systematically decreases over time in both models.

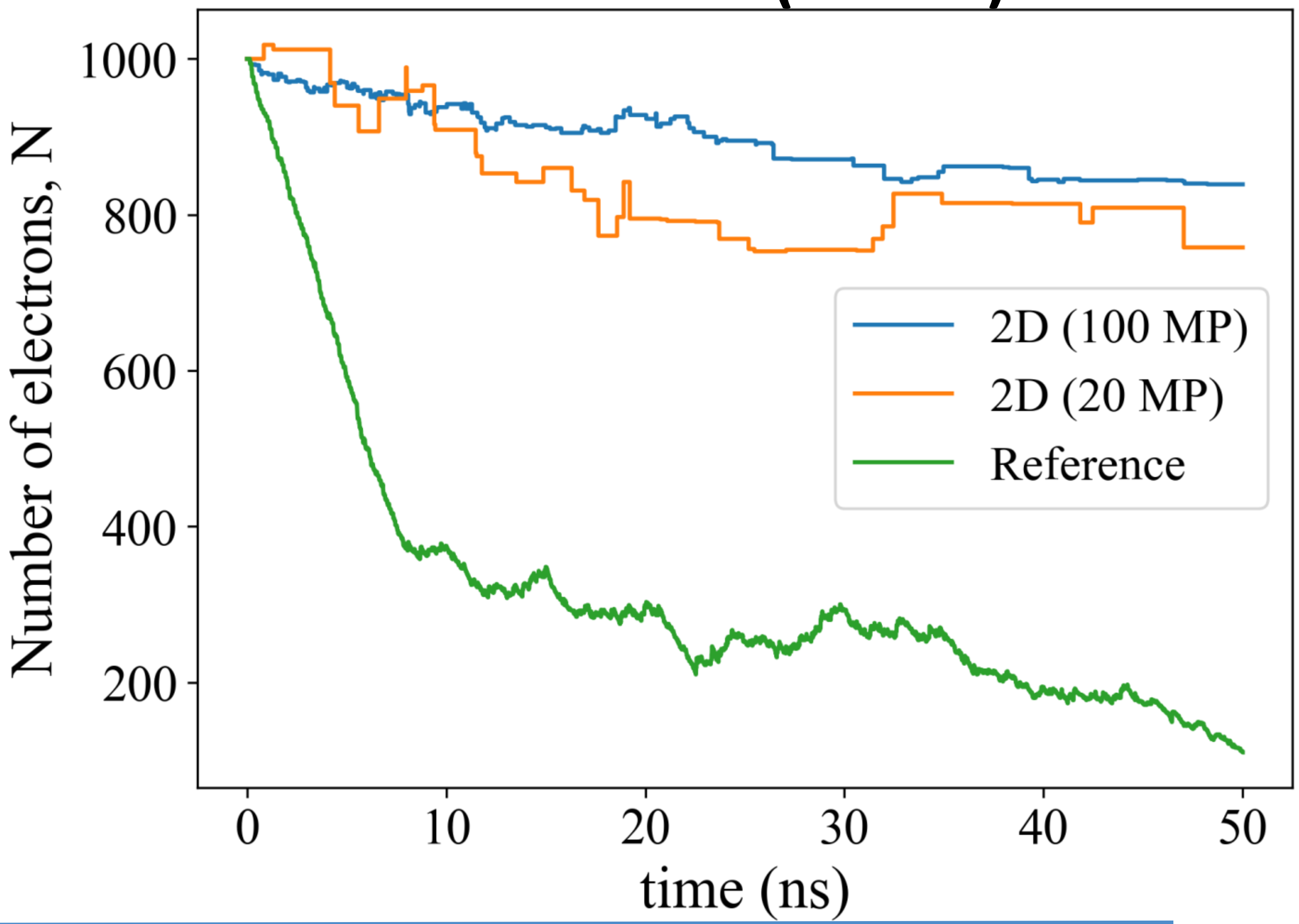
In both models we can observe similar dynamics of the number of electrons.

The number of electrons itself is not important!!!

-> the faster decrease of the number of electrons in the ref. model can be explained by different longitudinal boudary condictions (electrons escaping in the longitudinal direction)

Results

Close to the Threshold (8.5kW)



Cyclical increases in the number of electrons can be seen in both models.

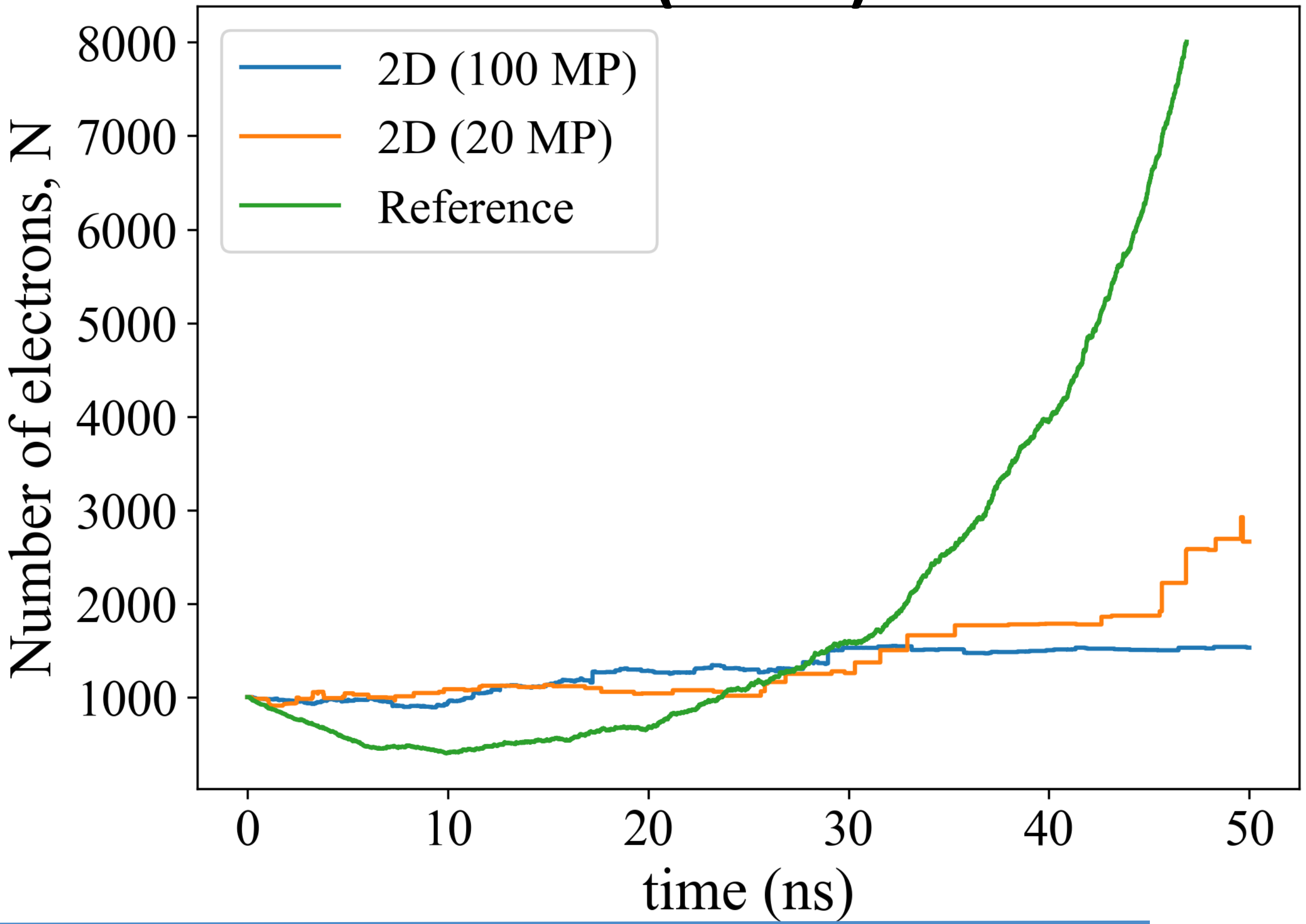
In both models we can observe similar dynamics of the number of electrons.

The number of electrons itself is not important!!!

-> the faster decrease of the number of electrons in the ref. model can be explained by different longitudinal boudary condictions (electrons escaping in the longitudinal direction)

Results

Over the Threshold (12kW)



The number of electrons tends to increase exponentially in both models.

In both models we can observe similar dynamics of the number of electrons.

The number of electrons itself is not important!!!

-> the faster decrease of the number of electrons in the ref. model can be explained by different longitudinal boudary conditions (electrons escaping in the longitudinal direction)

Conlusion

- Comparing to reference commercial software it is fair to say that this 2D model adequately reflects the SEE and multipactor phenomenon.
- There are differences in terms of the number of electrons over time. It can be attributed to the different coniditions in the longitudinal direction.

Future Works

- 3D Multipactor is close to be finished and will soon be available for use with QuickWave and InventSim softwares.
- We are open to all collaborations.

Acknowledgment

This work was partially performed within the EUREKA-Eurostars 5G_Foil project, which receives funding from the Polish National Centre for Research and Development under contracts DWM/InnovativeSMEs/176/2023 and InnovativeSMEs/4/90/5G_Foil/2023 and by the Luxembourg Ministry of Economy under contract 2023-A127-X187. Tomasz Nalecz thanks the Industrial Development Agency JSC (ARP S. A.) for supporting the first stage of his work under the Polish Space Fellowship Internship Program 2023

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