Multipaction Analysis in Traveling Wave Tubes

P. Birtel, W. Dürr, J. Wegener, Thales Deutschland GmbH

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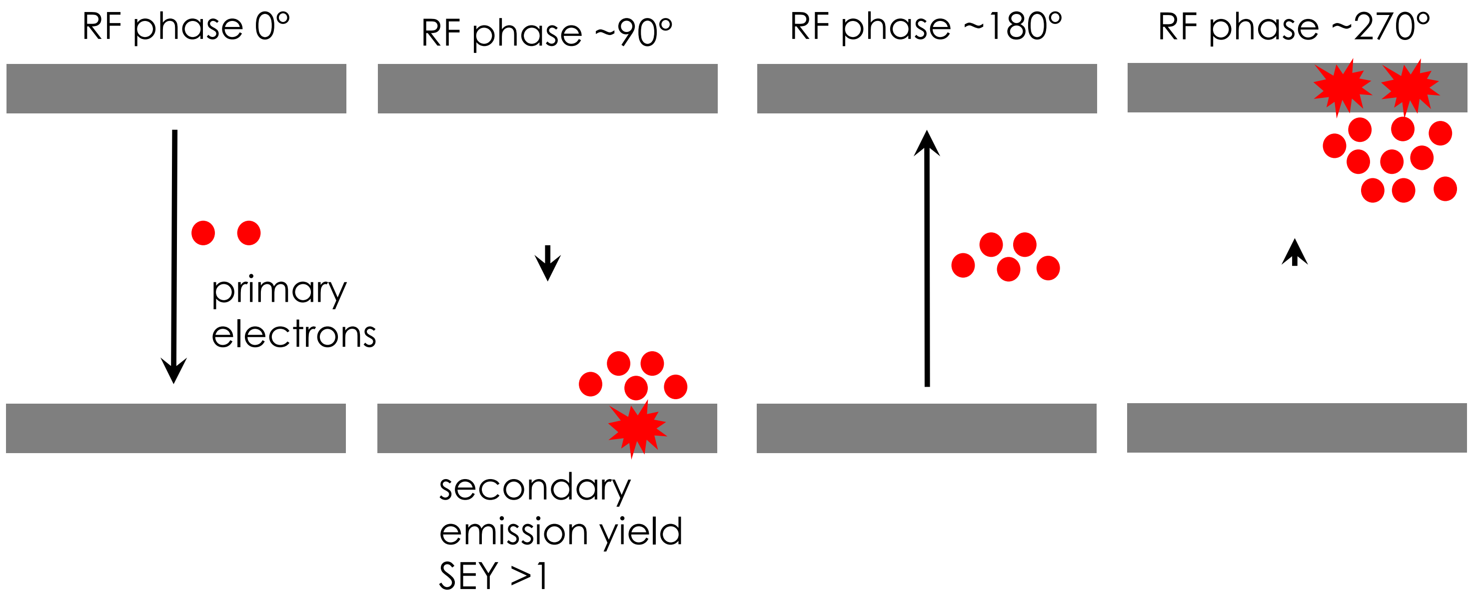
What is Multipaction?

- Multipaction: Electron avalanche effect
- Prerequisites: High-power RF fields, material with SEY > 1, timing, vacuum



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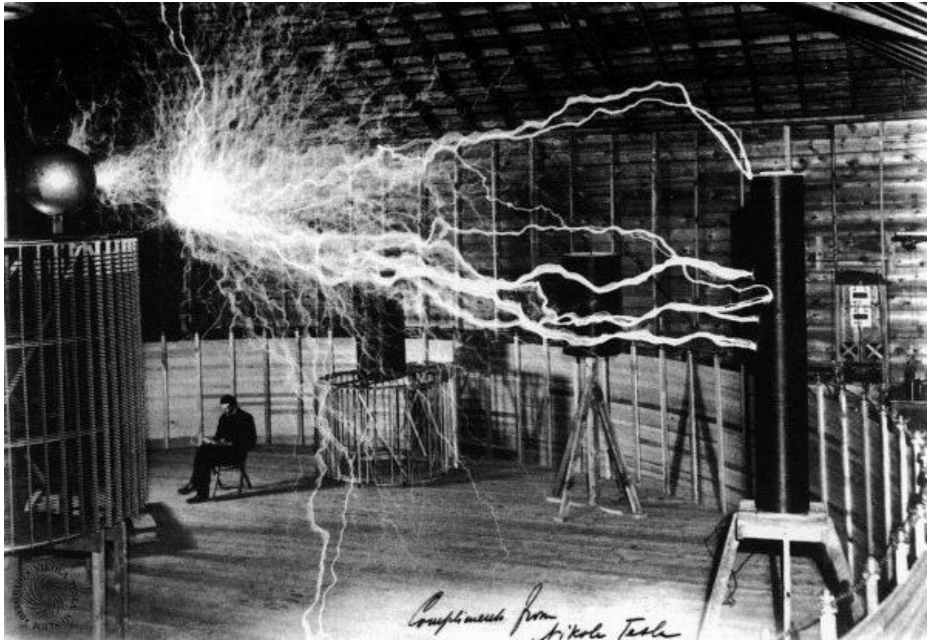
Problems of Multipaction

- Device damage through thermal effects
- Signal distortion
- Consequence: Device has to be multipaction-free!
- Analysis or testing required
  - Here: focus on analysis
  - (testing notoriously difficult)



NOT Multipaction

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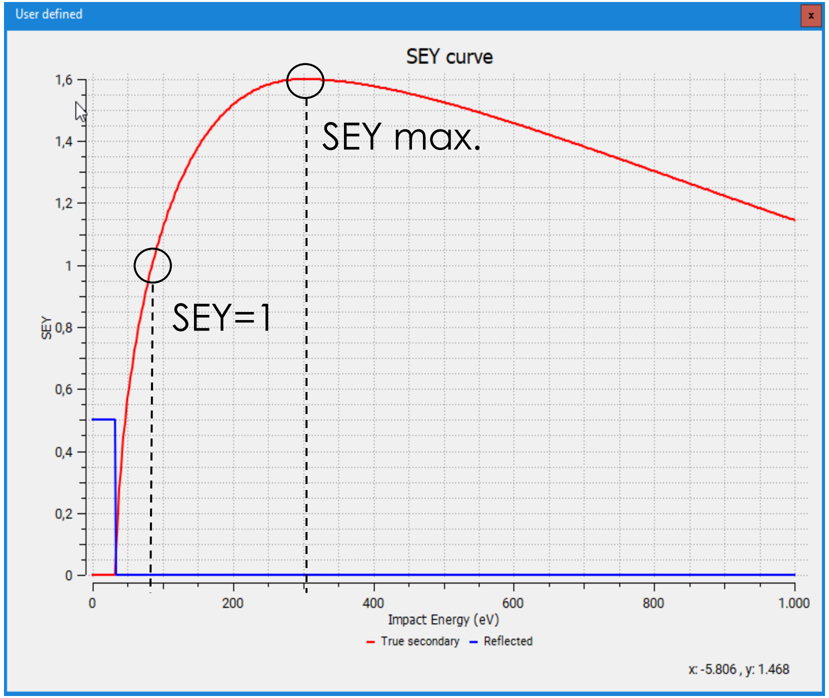
Material Parameter: Secondary Electron Yield

- „How many secondary electrons are emitted upon impact of primary electron?“
- SEY < 1: no multipaction possible
  - Minimum power for multipaction
- Also dependent on angle of impact
- Great variation between materials



SEY: Secondary Electron Yield
from SPARK3D

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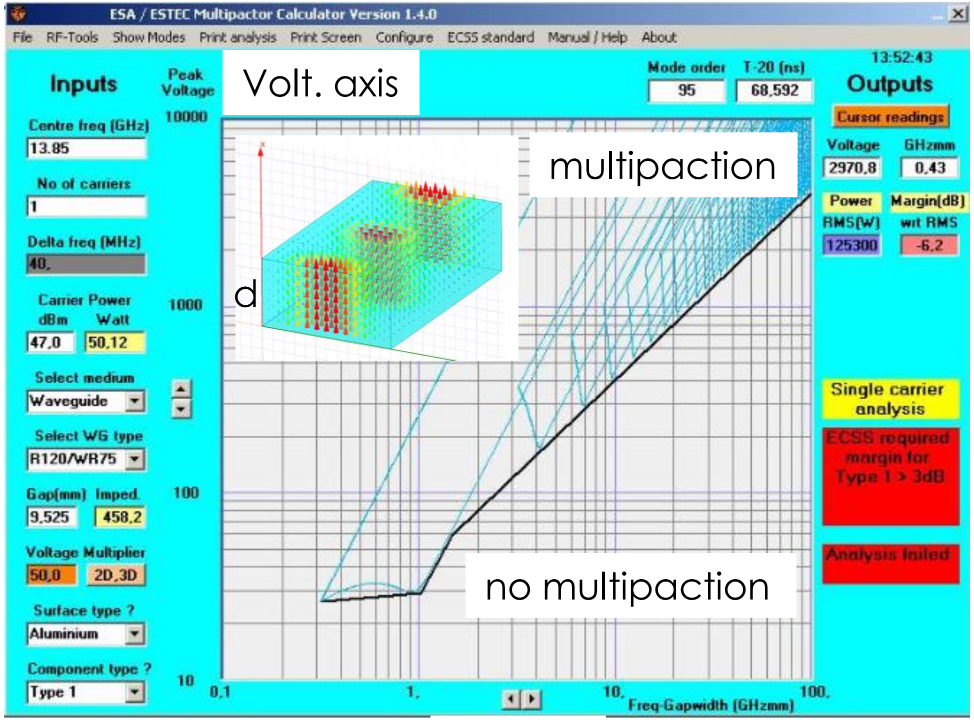
Device Geometry and Analytical Solution (Level-1 Analysis)

- **Analytical solution for homogeneous RF fields**
  - Expample: Rectangular waveguide
- **Gap-Frequency product f*d crucial (in GHz * mm)**
- **f*d close to unity: Device especially critical**
- **Lower cut-off for f*d**



f*d axis

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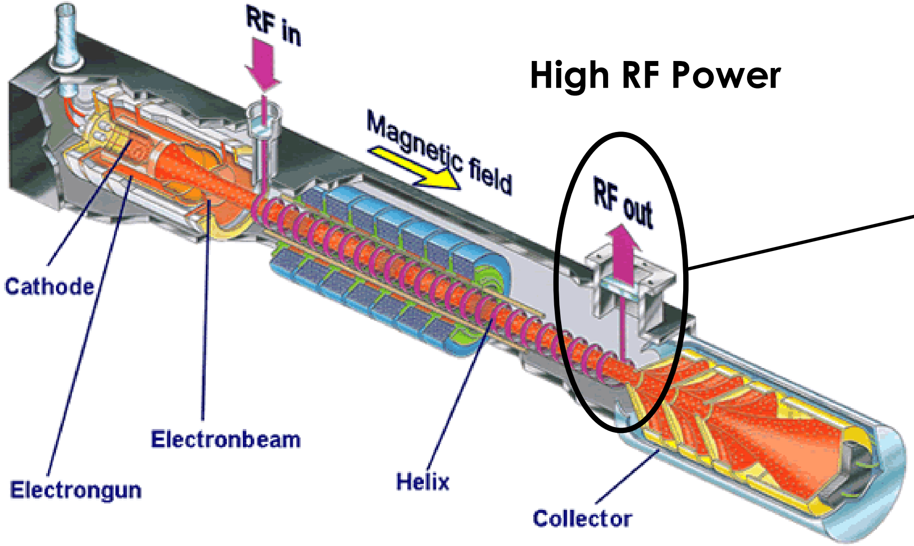
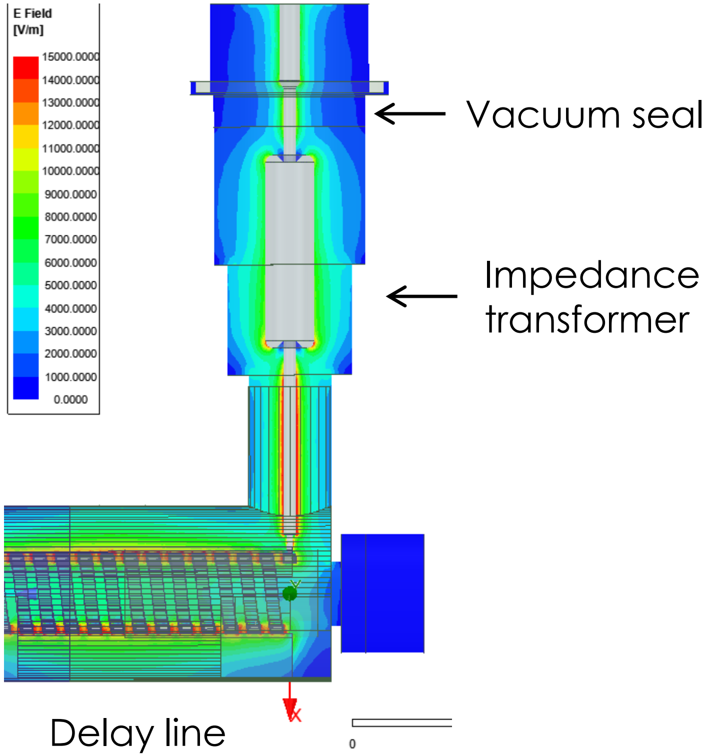
Multipaction in TWTs

- **Multipaction: High power, small gaps, low frequency**
- **TWT: End of delay line, output coupler**

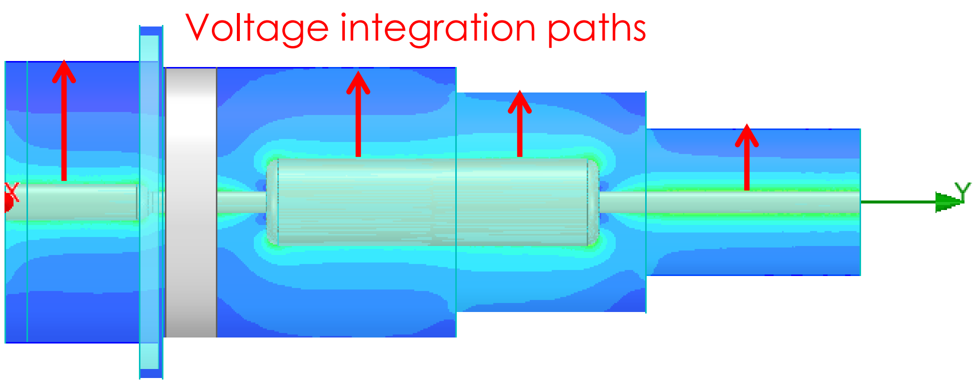


High RF Power



Non-Uniform Structures (Level-2 Analysis)

- Impedance transformers, filters etc.: Standing-wave patterns
- RF analysis with numerical solver (e.g. HFSS, CST)
- Integration of peak E-field to obtain peak voltage
- Continue as in Level-1 analysis



When is a Level-2 Analysis not good enough?

Non-homogeneous RF fields

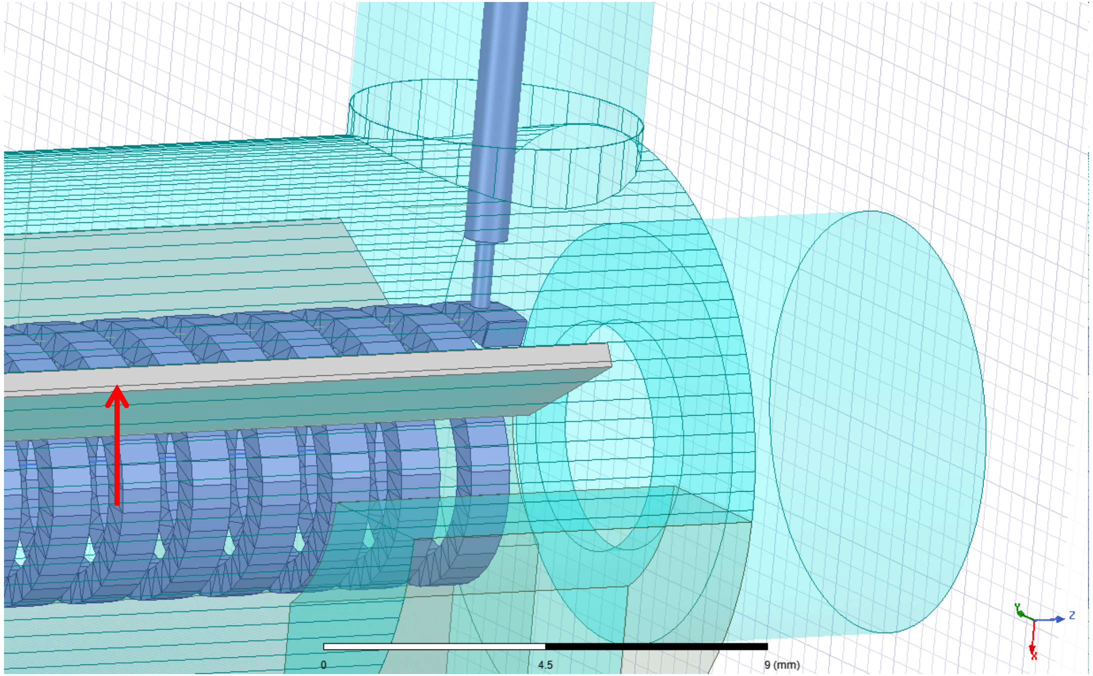
- High-impedance coax
- Any complicated geometry

Static electric fields

- TWT: no issue

Static magnetic fields

- TWT: PPM focusing field (several 0.1 T)



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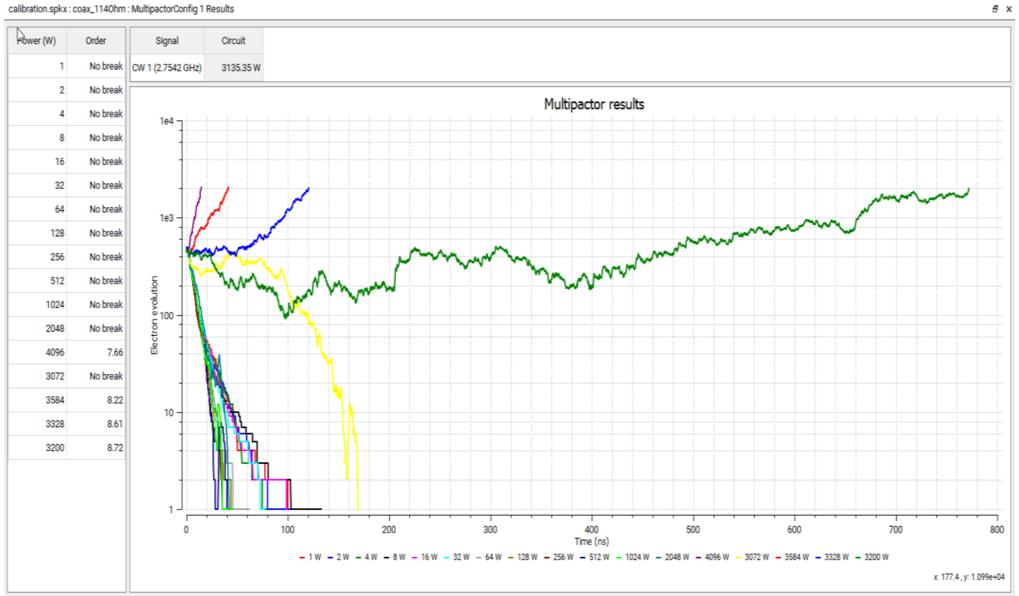
Level-3 Analysis: Time-Domain Tracking of Electrons

Commercial code: SPARK3D

- Part of the CST Suite

Workflow:

- Import RF fields from HFSS, CST, or FEST
- Define material
- Define static fields (E and/or B)
- Seed electrons
- Track electrons including secondary emission
- Growing number of electrons: multipaction



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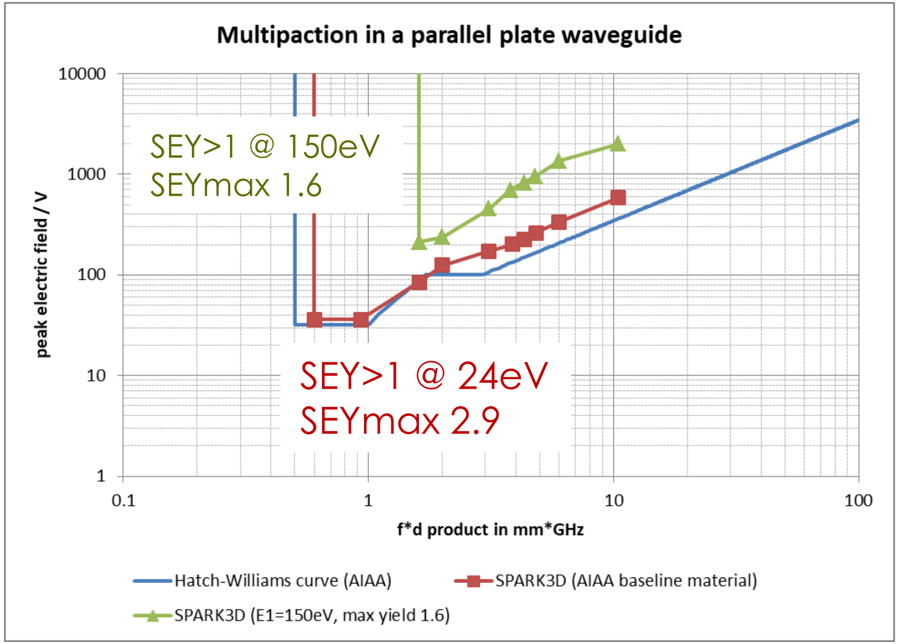
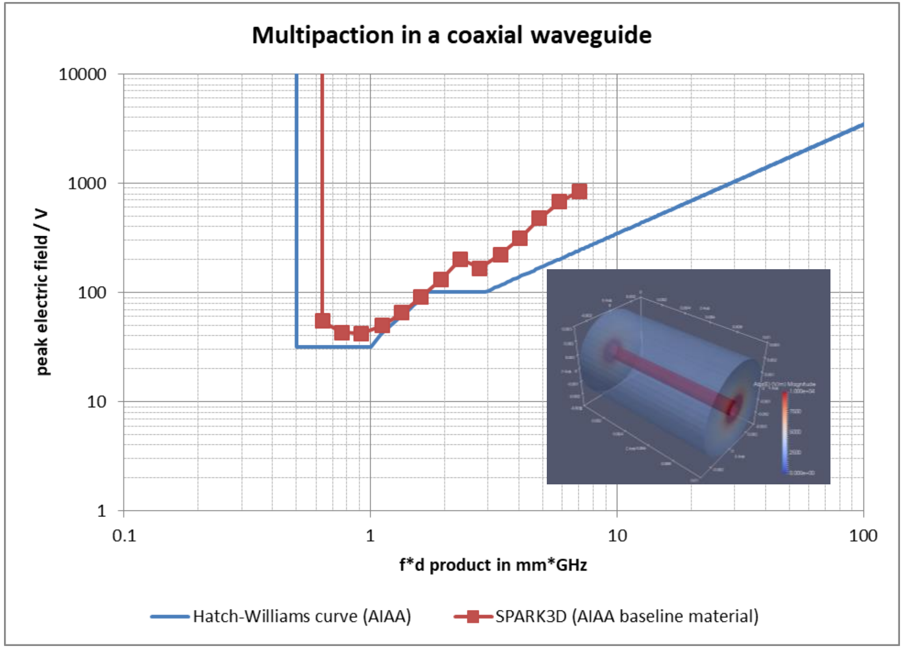
Analytical Solution vs. SPARK3D





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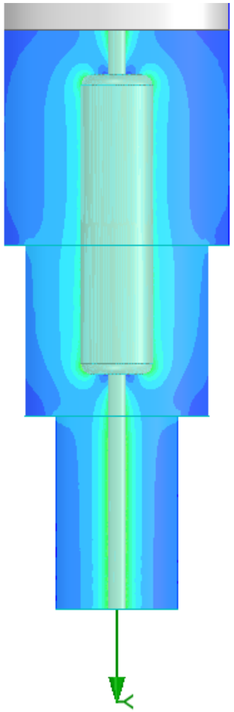
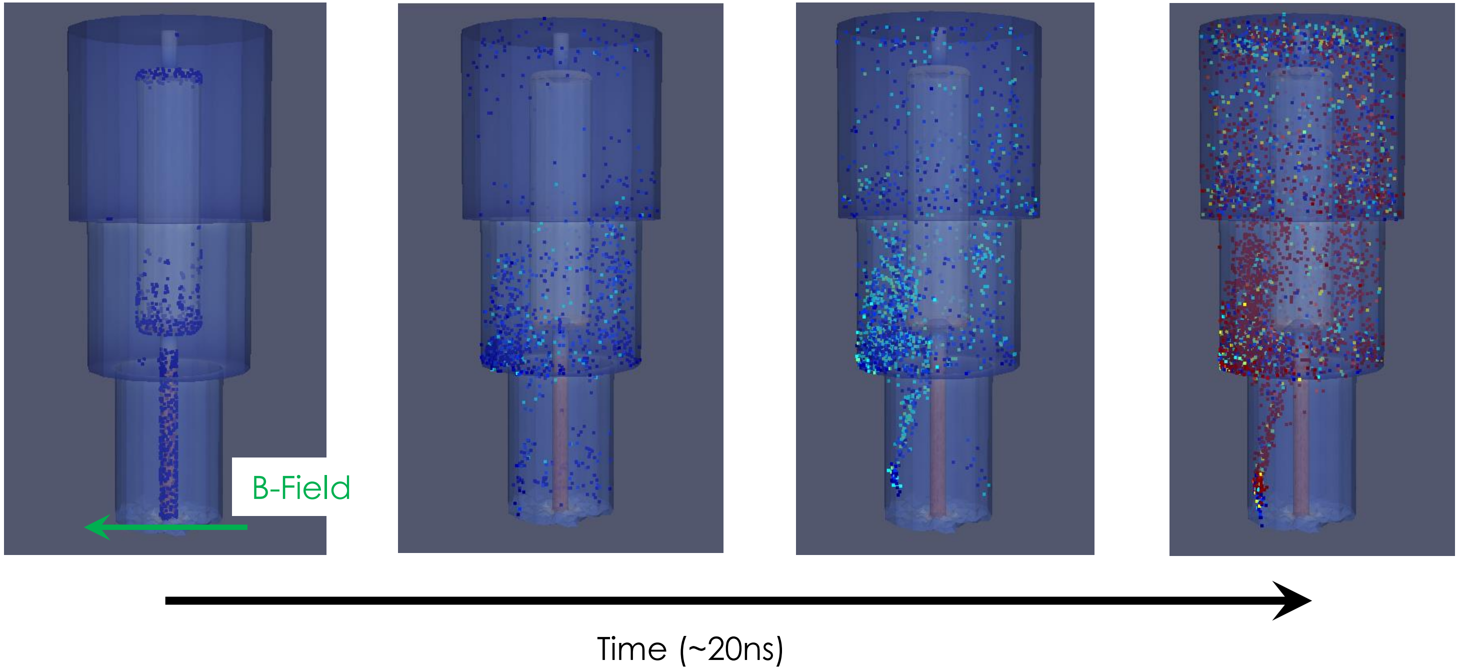
Multipaction in the output coupler (vacuum envelope) 1/2





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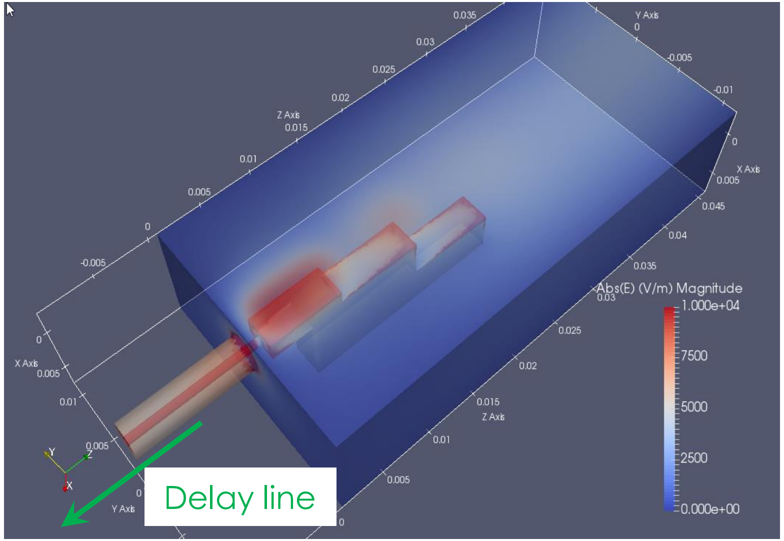
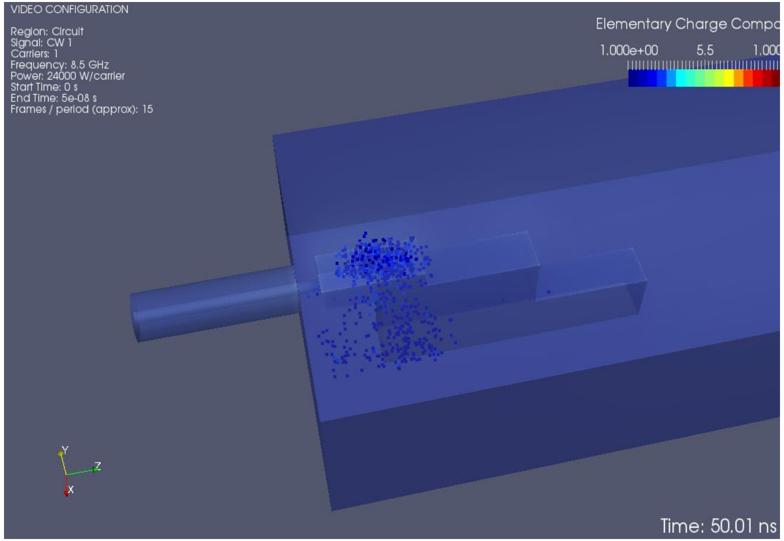
Multipaction in the output coupler (vacuum envelope) 2/2



E-Field as imported from HFSS



Multipaction electron cloud

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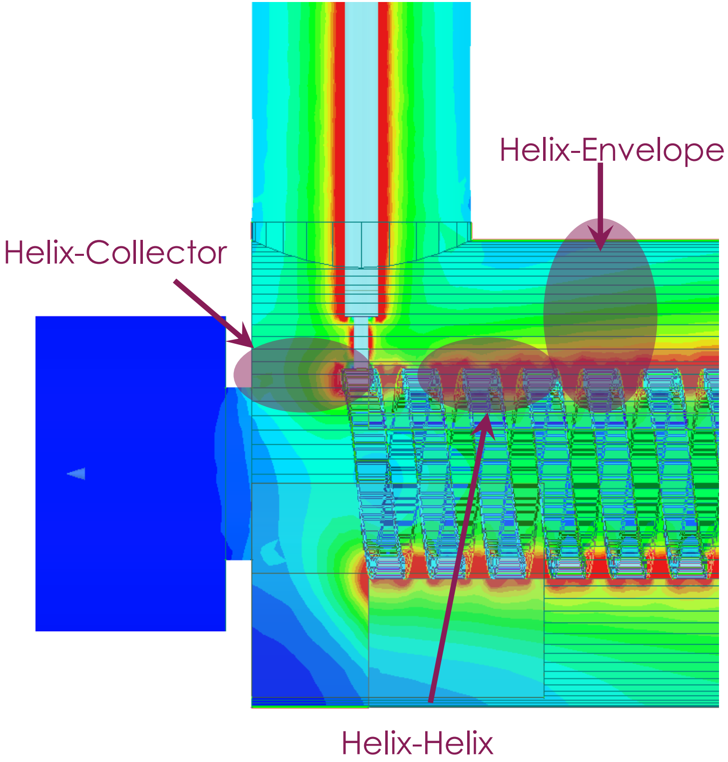
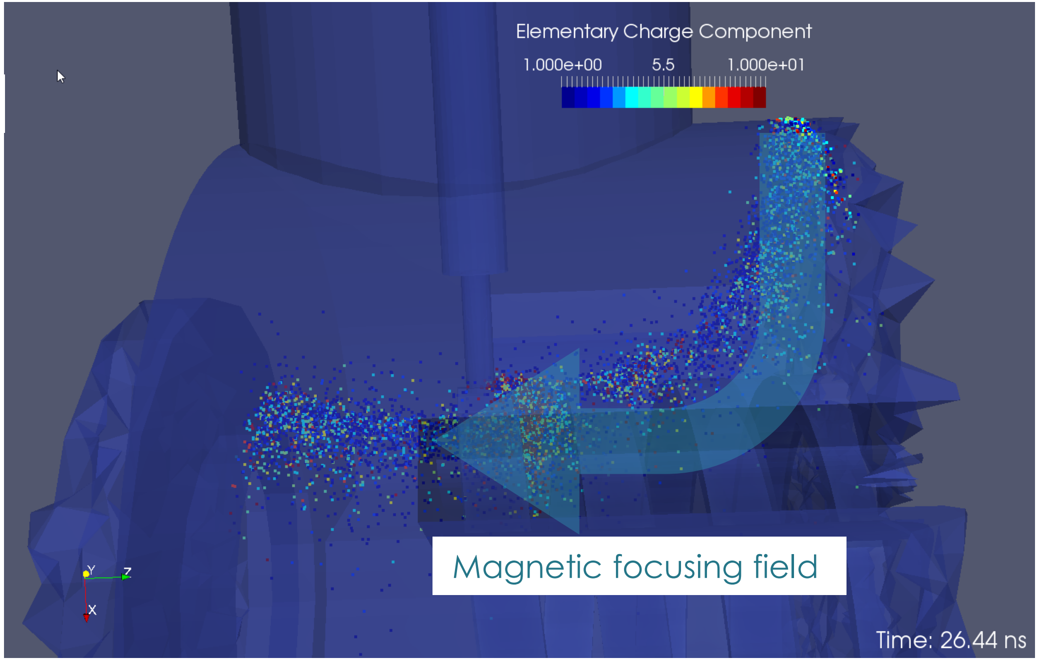
Multipaction in the delay line





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What can we do against multipaction?

Geometry: Keep the gaps far away from f*d=1

Baking [1]: SEY is reduced by evacuation and heating

- TWTs are evacuated at >450°C

Electron/Ion bombardment [2]

- Fortunately there are a lot of scattered electrons in a TWT

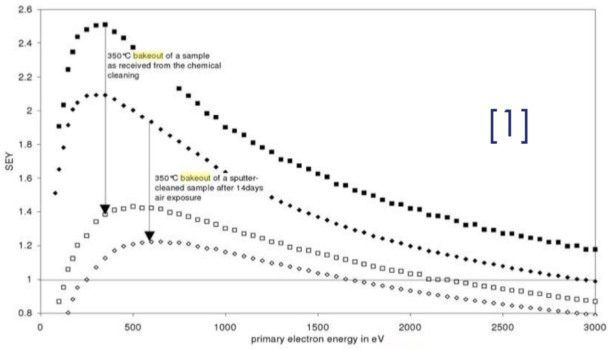
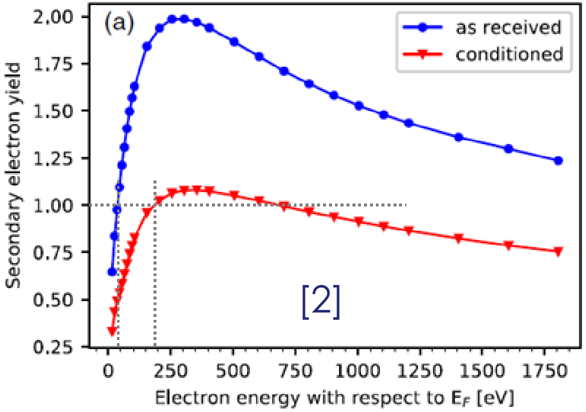


Figure 20: Difference of the secondary electron emission after a 350°C bakeout of a sample as received and after a 350°C bakeout of a sample which had been sputtercleaned and then exposed to air for 14 days



[1] Christian Scheuerlein "The Influence of an Air Exposure on the Secondary Electron Yield of Copper", CERN, Master Thesis, ISBN 9783832454326
[2] Role of the different chemical components in the conditioning process of air exposer copper surfaces, Physical review accelerators and beams 22, CERN & ONERA, 08/2019

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Summary

- **TWTs are required to be multipaction-free**
- **Level-1 analysis (purely analytical): Fast, but strictly limited scope**
- **Level-2 analysis (numerical/analytical): More precise, but still limited**
  - Relatively simple geometry, no static fields
- **Level-3 analysis (numerical): Most reliable, but time-consuming**
- **Sensitivity greatly dependent on material parameters**
- **So far, no final TWT design has exhibited multipaction effects**