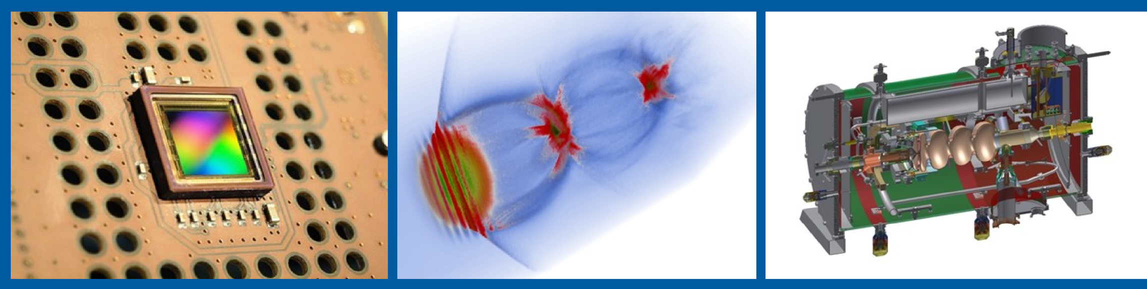
Programme Matter and Technologies

A Multipacting Electron Gun



ARD-ST3: Picosecond and Femtosecond Electron Beams

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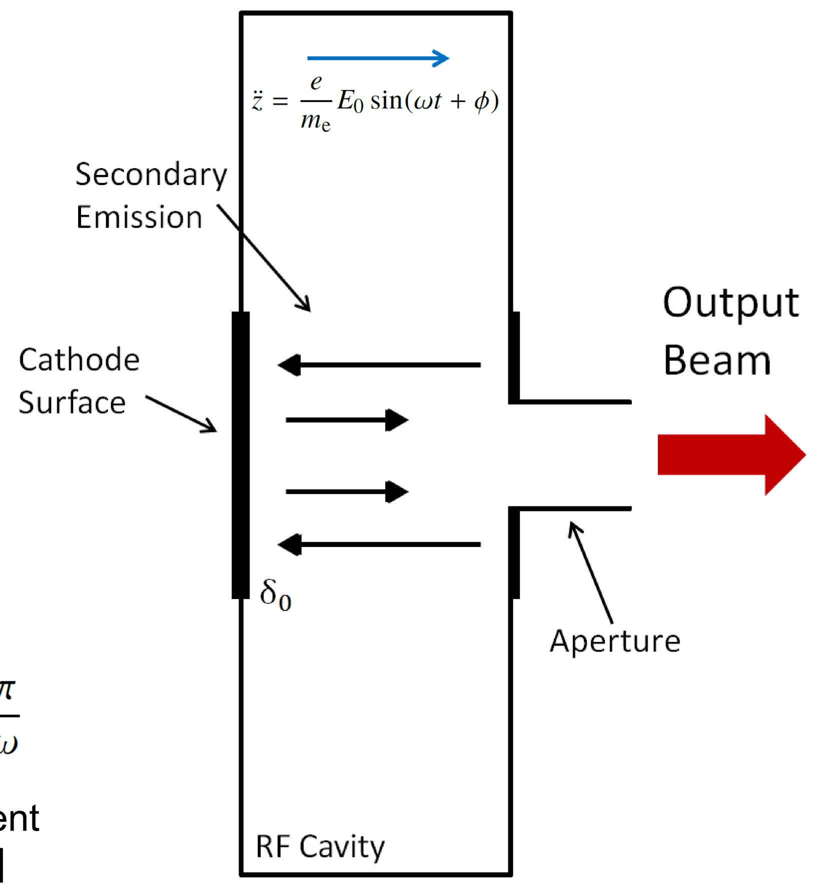
K. Floettmann (DESY)

Abstract A multipacting electron gun (MEG) is a micro-pulse electron source, based on secondary electron emission in a resonant microwave cavity structure, for the generation of bunched low-emittance electron beams in continuous wave operation. Based on numerical simulations, an experimental test setup for low-energy electron bunches at the frequency of 2.998 GHz has been established. Here, the mechanical design of the experimental configuration as well as the power transmission into the gun cavity plays an important role for stable MEG operation. In the early stage of the experiment we use the output beam current as the measurable quantity for optimization studies of the modifiable parameter space with respect to electron emission. This denotes the first step in the development of an MEG setup for higher energetic electron beams and subsequent investigation of essential beam characteristics like emittance and energy distribution for further optimization with regard to best possible beam quality and future fields of application.

MEG Principle

Electron Emission Processes

- Thermionic Emission
- Field Emission
- Photoemission
- **Secondary Electron Emission (SE)**



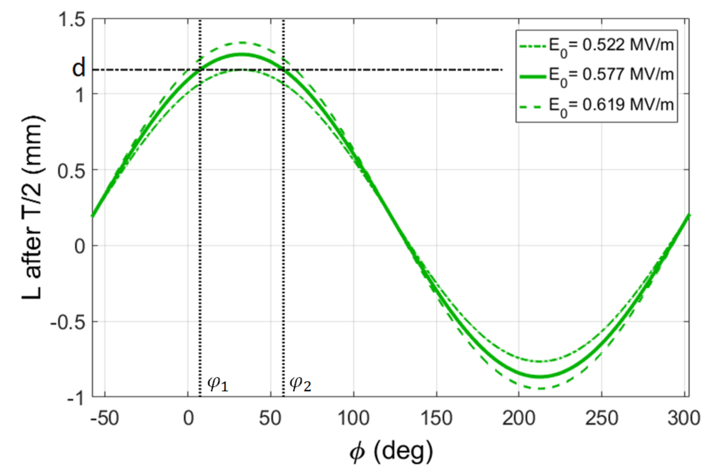
SE based on Multipacting
in a resonant microwave cavity, initially mentioned by Gallagher in 1969 [1]

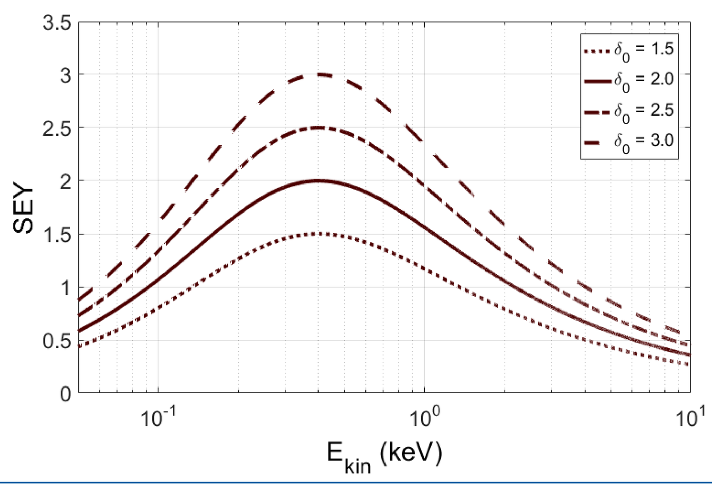
Self Bunching

- Particles of resonant phase hit the cathode surfaces alternatively

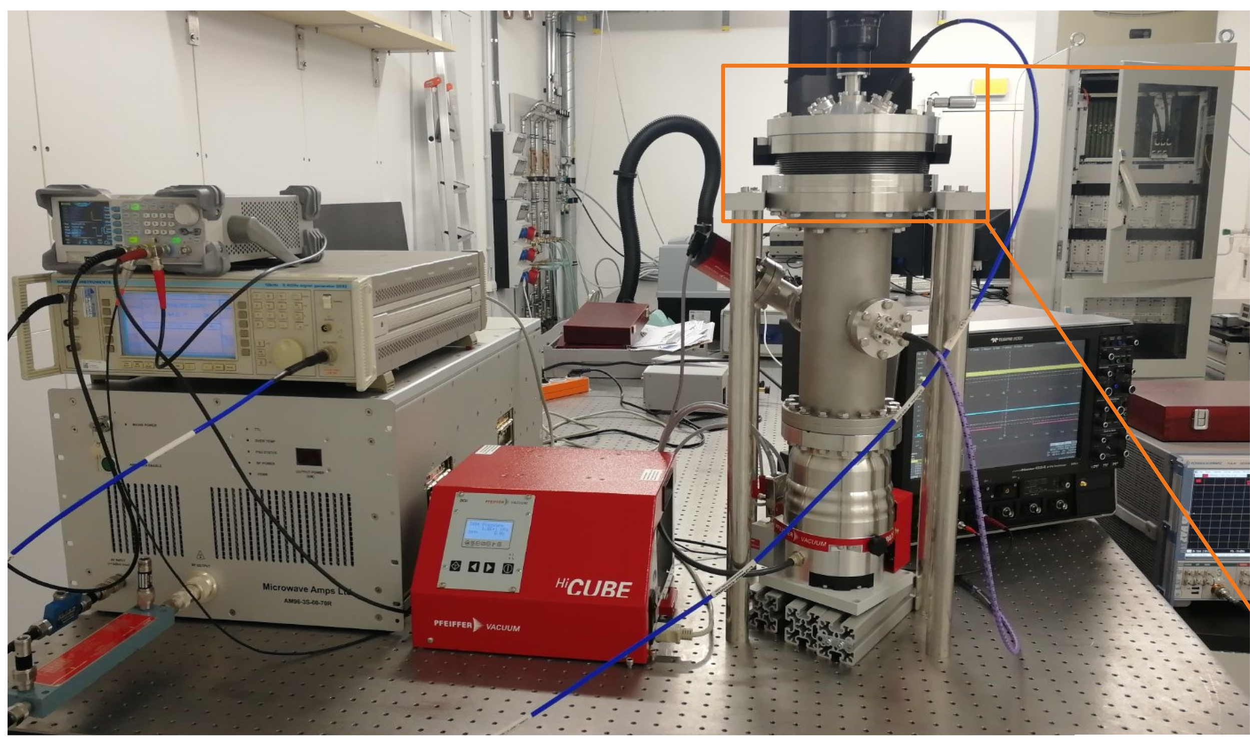
$$L = z(T/2) = \frac{eE_0}{m_e\omega^2}\left[2\sin(\phi) + \pi\cos(\phi)\right] + v_0\frac{\pi}{\omega}$$

- Bunching due to different energy gain at different phases around the synchronous phase φ_1 [2,3]
- Resonant charge amplification process due to secondary electron generation at incident electron energies in the order of 100 eV – 1 keV. SEY curves in accordance to [4] for aluminum.

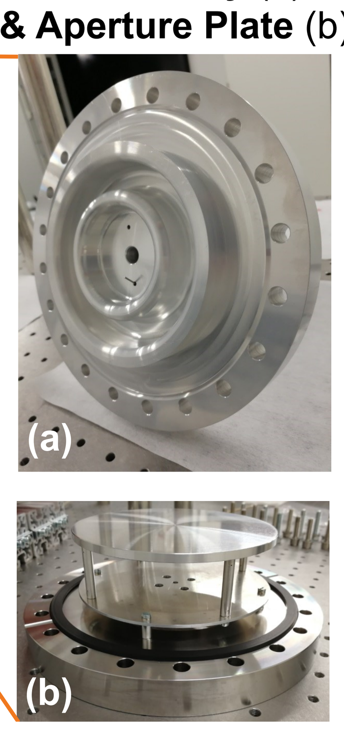




Test Stand

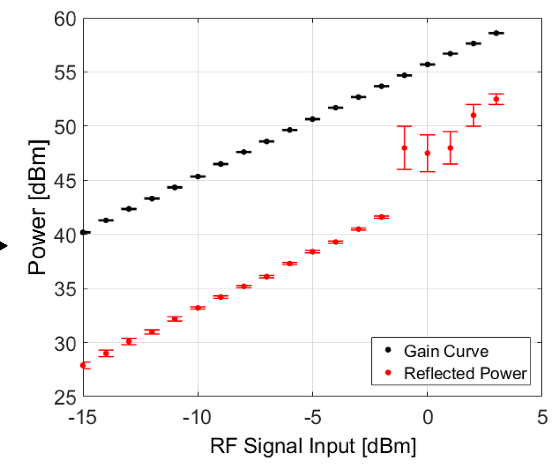


Gun Cavity (a) & **Aperture Plate** (b)

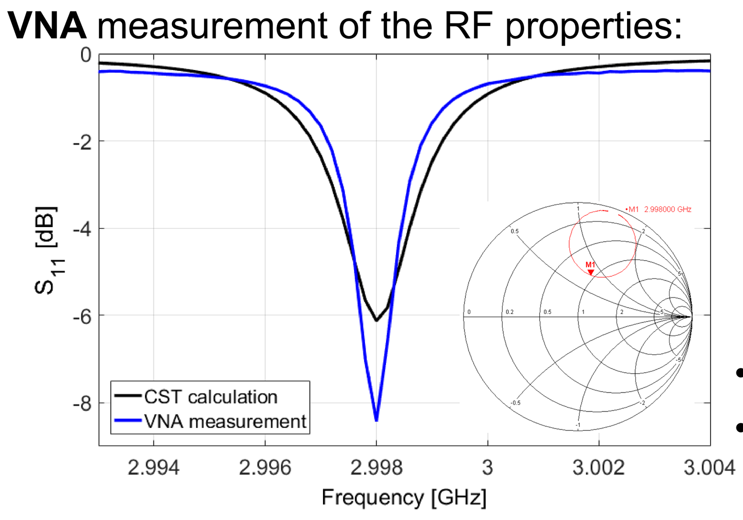


RF System using a 70 dBm amplifier from Microwave Amps

- 4 – 10 µs pulse width, 10 – 100 Hz pulse rep. frequency
- Gain of 55.5 ± 0.2 dBm for the test stand application

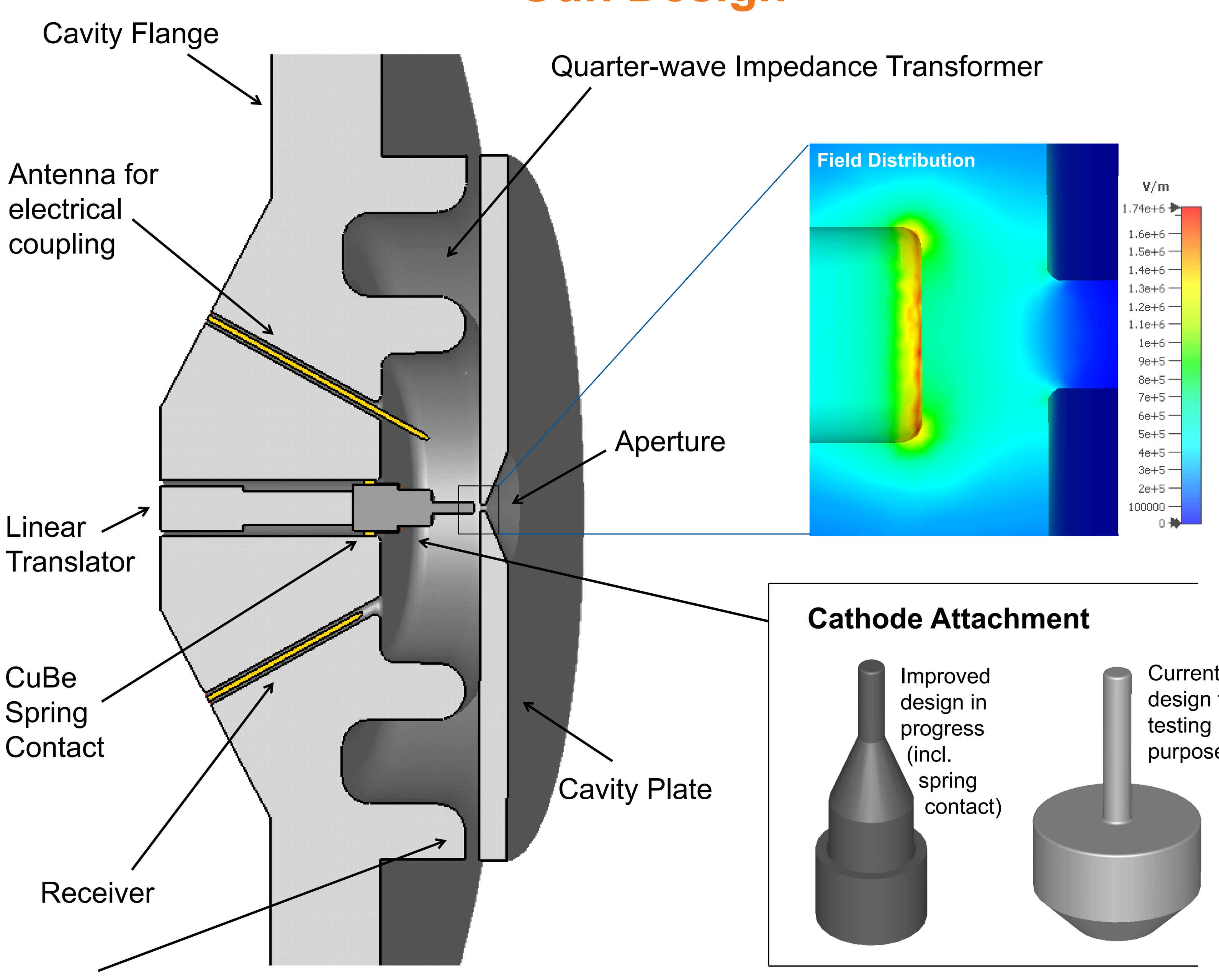


VNA measurement of the RF properties:



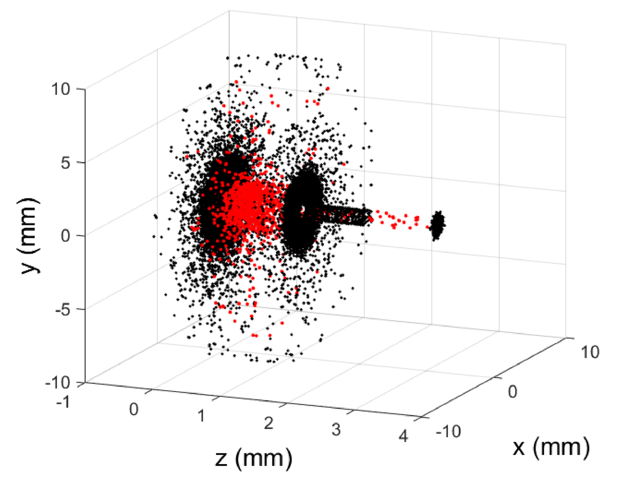
- Measured loaded Q: 2140 ± 90
- Measured coupling constant: 0.5

Gun Design



Tune: Affects the resonance frequency while maintaining the distance between the cathodes.

Tracking Simulation



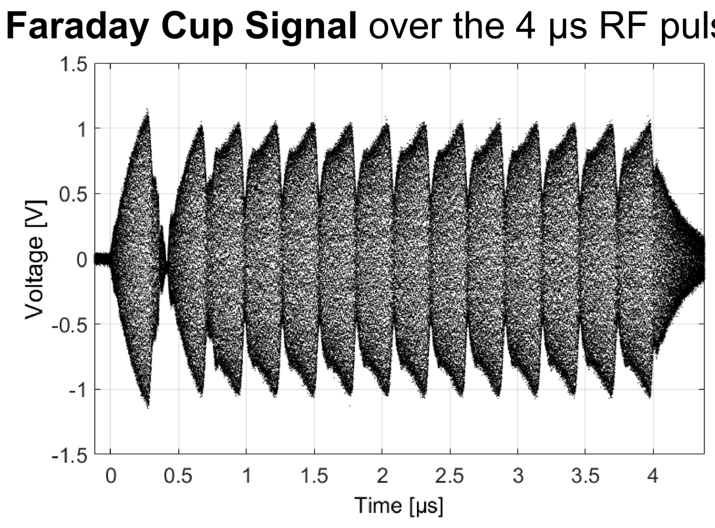
Typical MEG charge distribution obtained numerically by ASTRA [5]. Active electrons in red.

Charge Tracking Results using ASTRA

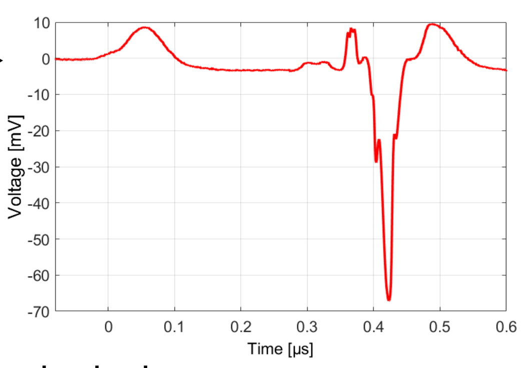
- Simulation of first 10–15 ns of operation
- Consideration of space charge forces and beam loading with same initial input power for all calculations
- Predicted average current of **>1 mA**
- Higher input power would increase the current due to more SE emission in the equilibrium state
- Current heavily influenced by the emitter geometry
- $\varepsilon_{rms} = (0.65 \pm 0.10)$mm mrad

First Experimental Data

Faraday Cup Signal over the 4 µs RF pulse



- Large 2.998 GHz noise floor, proportional to RF input
- Most probably due to field leakage into the cup
- Bandwidth limited signal shows a drop in signal
- Noise minima due to beam loading



- Resonant multipacting condition possible with improved cathode design

Conclusion

- A high repetition rate MEG has been designed, supported by numerical calculations
- The experimental test setup, where the radio frequency meets the TM_{010} mode resonantly for coupling at 2.998 GHz, is set to work – Measurement sensibility needs to be increased
- Gap size variation between cavity flange and opposing plate for resonance frequency fine tuning
- An average output current of a few mA is predicted by ASTRA simulations
- The current would also be increased by application of higher input power leading to a stronger cavity field and thus more SE in the equilibrium state of gun operation
- First measurements indicate strong coupling of generated electrons to the internal RF field

References

[1] W. J. Gallagher, "The multipactor electron gun", *Proc. IEEE*, vol. 57, pp. 94–95, 1969.
[2] L. K. Len and F. M. Mako, "Self-bunching electron guns", in *Proc. Particle Accelerator Conference '99*, New York, USA, April 1999, vol. 1, pp. 70–74.
[3] D. Yang *et al.*, "Study on the maximum stable output of a novel s-band micro-pulse electron gun", *AIP Advances*, vol. 8, pp. 075313, 2018
[4] Y. Lin and D. C. Joy, "A new examination of secondary electron yield data", *Surf. Interface Anal.*, vol. 37, pp. 895–900, 2005.
[5] K. Floettmann, *A Space Charge Tracking Algorithm*, Hamburg, Germany, Mar. 2017, Version 3.2

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES