Multipactor and Dark Current Studies of a 17GHz Standing Wave Accelerator Structure

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Outline

- Motivation and introduction
- Multipactor simulations
- Multipactor experiments
- Discussion and conclusion
- Future plans

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- Multipactor experiments
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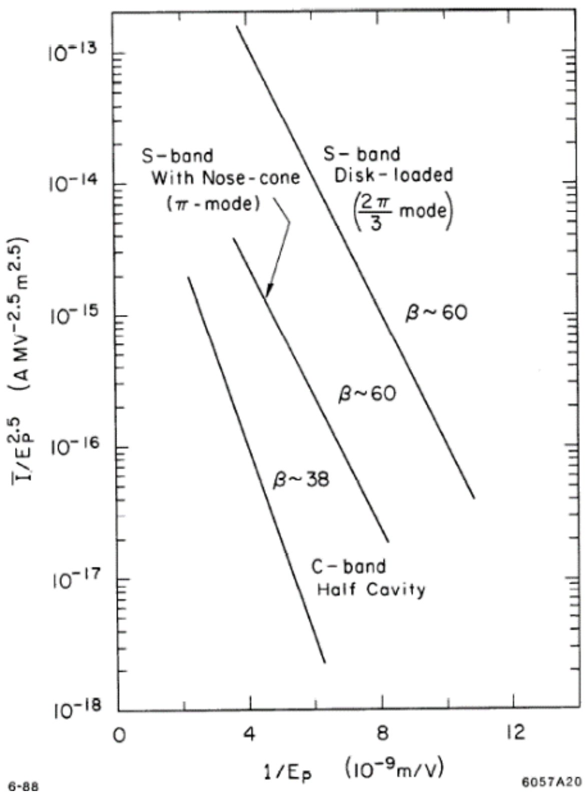
- Future plans

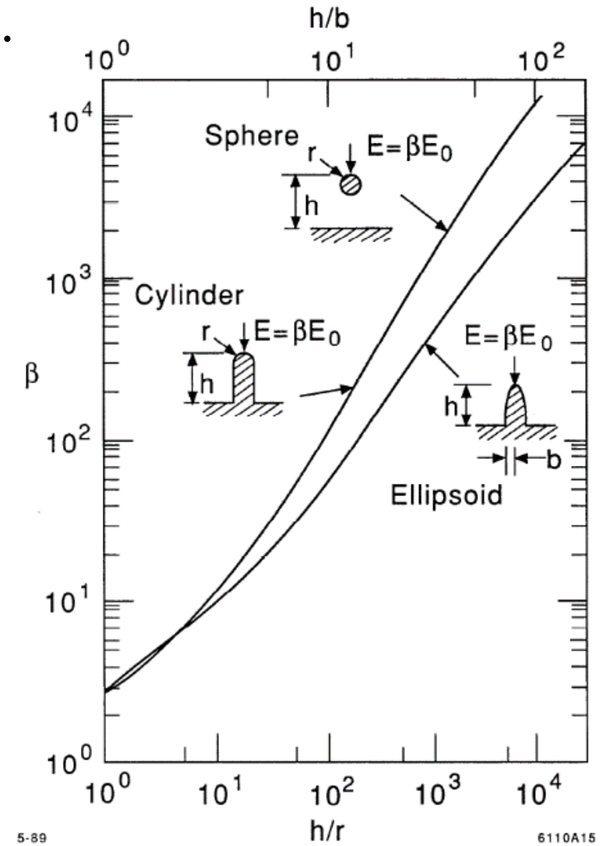
Motivation and Introduction

- Dark current is studied in high gradient accelerator research using Faraday cups at the ends of the structures.
- Internal dark current is observed in accelerator cavity conditioning, but is not usually directly measured.
- This study is about the calculation and the measurement of the internal dark current.
  - Dark current generation by multipactor
  - Comparison with theories

Prior Studies

- Dark current measurement
  - Dark current is usually measured at the ends of the structure.
  - Field enhancement factor calculated from fitting using Fowler-Nordheim field emission formula is always much bigger than the estimation from geometric observation*.

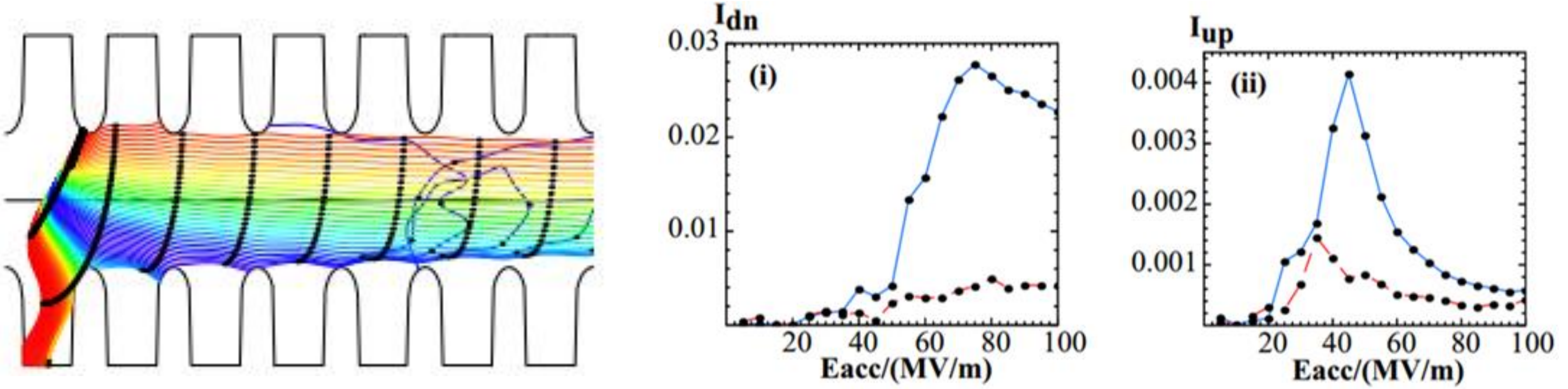




* Wang, J. W. (1989). Rf Properties of Periodic Accelerating Structures for Linear Colliders* r--m.

Prior Studies

- Internal dark current simulation
  - Only a fraction of the dark current can reach the current monitors at the ends of the structure*.

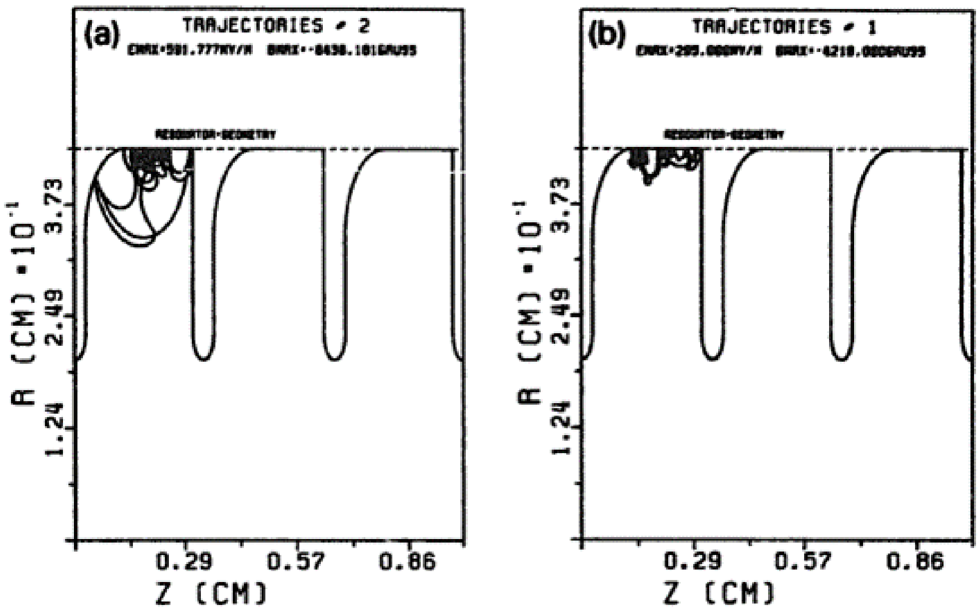


Particle trajectories for 11.4 GHz, 65 MV/m gradient (left) and gradient dependence of the fraction of the field emission current that reaches the detectors (right)

* Bane, K. L., Dolgashev, V. A., & Stupakov, G. V. (2004, June). Simulation of dark currents in X-band accelerator structures. In EPAC (Vol. 4, pp. 5-9).

Prior Studies

- Internal dark current simulation
  - Multipactor barriers in disk-loaded waveguide structures*



The first and the second multipactor barrier due to the magnetic field, simulation for 30 GHz structures

* Bienvenu, G., Fernandes, P., & Parodi, R. (1992). An investigation on the field emitted electrons in travelling wave accelerating structures. Nucl. Instr. Meth. Phys. Res. Sec. A: Accelerators, Spectrometers, Detectors and Associated Equipment, 320(1-2), 1-8.

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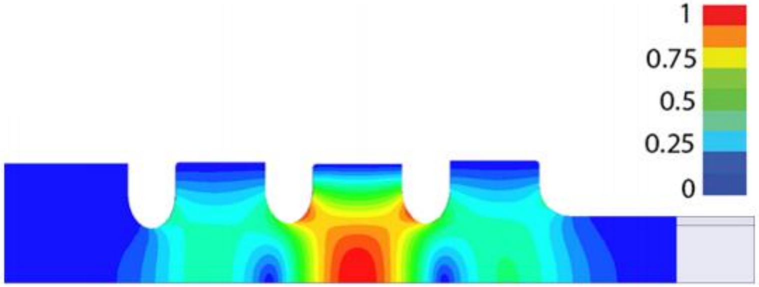
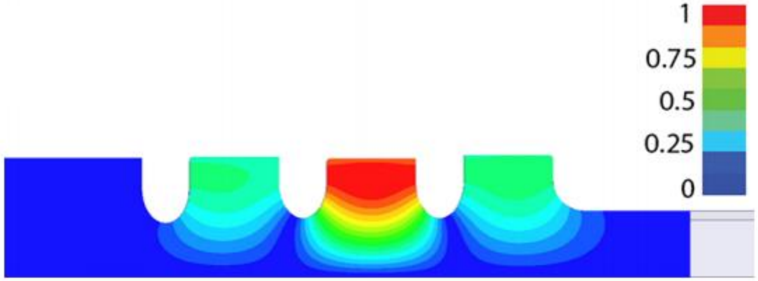
- Motivation and introduction
- **Multipactor simulations**
  - **Modes of multipactor**
  - **Particle-in-cell (PIC) simulations**
- Multipactor experiments
- Discussion and conclusion
- Future plans

MIT-DLWG Structure

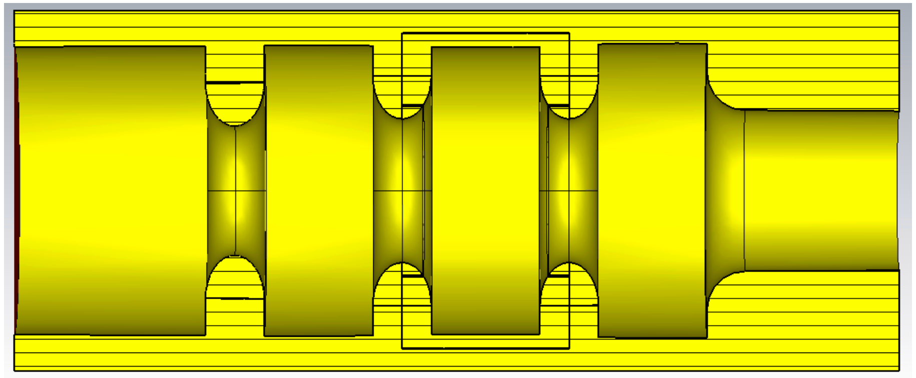
- 17 GHz standing wave single cell disk loaded waveguide (DLWG) structure



Electric field distribution



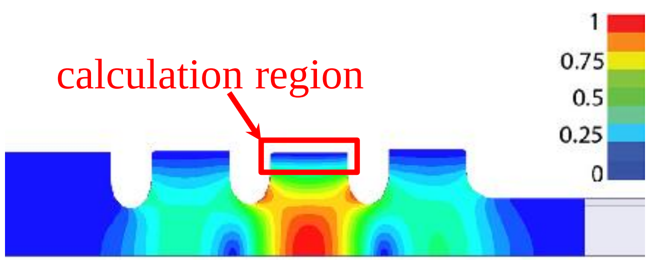
Magnetic field distribution

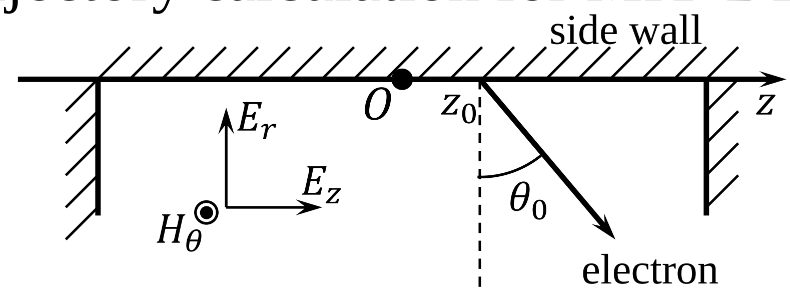


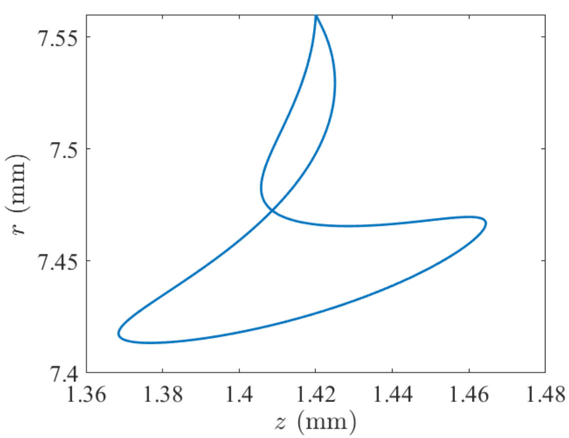
MIT-DLWG structure design

Multipactor Simulation - Modes

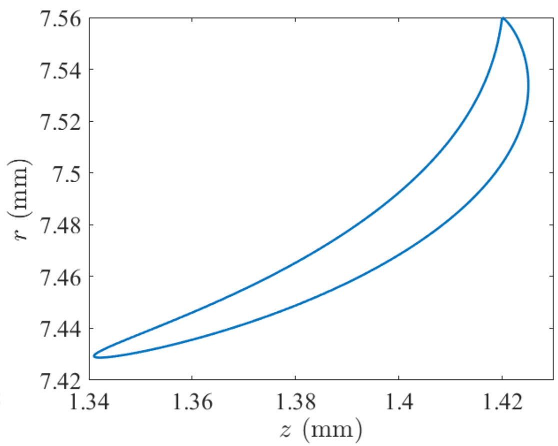
- Multipactor
  - Electrons collide with the structure surface with a time interval of an integer number of (half) RF periods
  - Average secondary electron yield (SEY) larger than unity
- Multipactor mode / electron trajectory calculation for MIT-DLWG



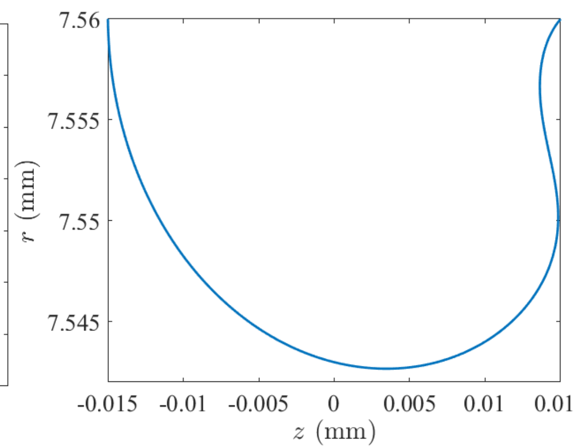




$H = 2$, $E_g = 45$ MV/m



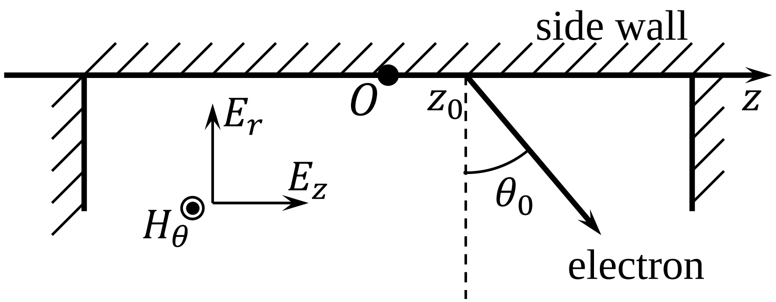
$H = 1$, $E_g = 72$ MV/m

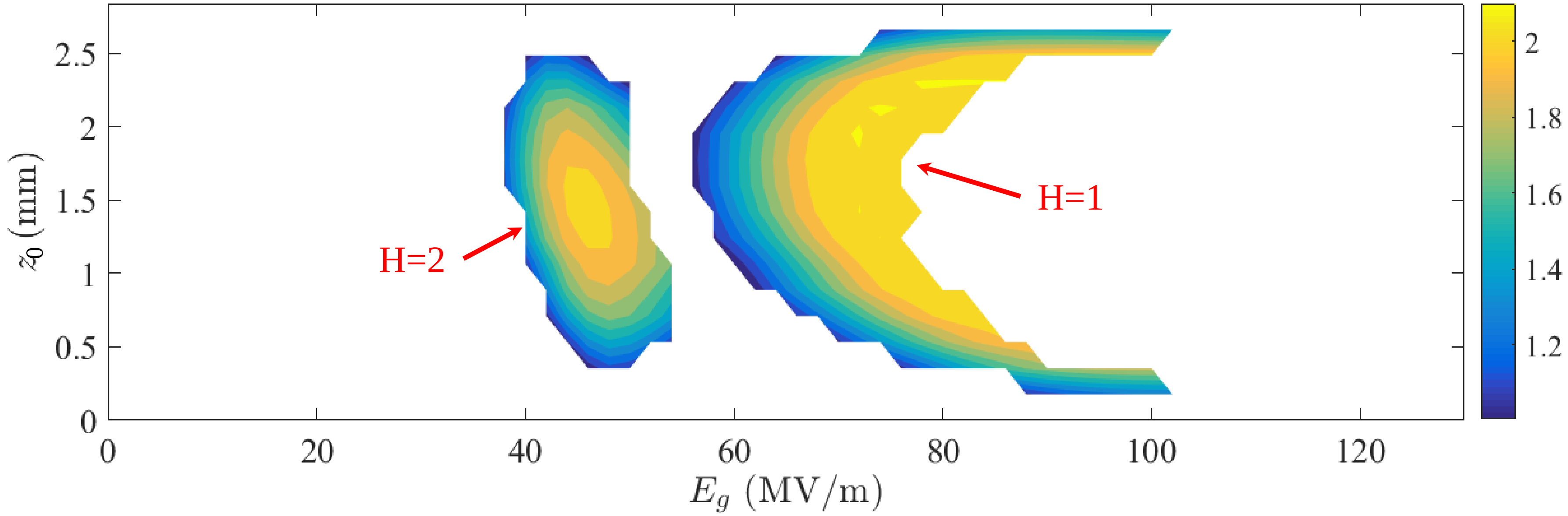


$H = 0.5$, $E_g = 250$ MV/m

Multipactor Simulation - Modes

- Multipactor susceptibility diagrams
  - 1-point multipactor modes

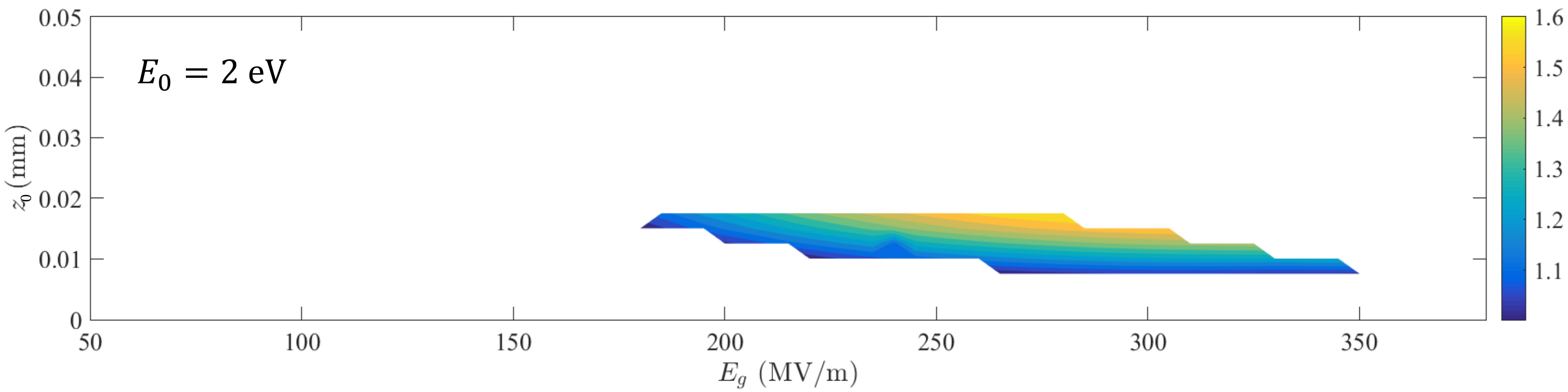


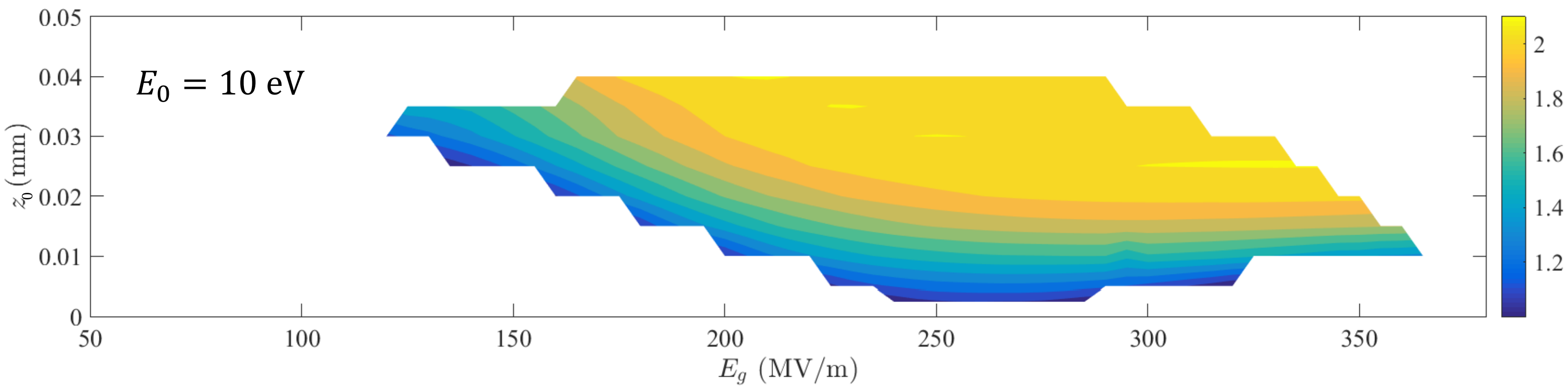


Contour color indicates the value of the secondary electron yield, calculated for $E_0 = 2$ eV.

Multipactor Simulation - Modes

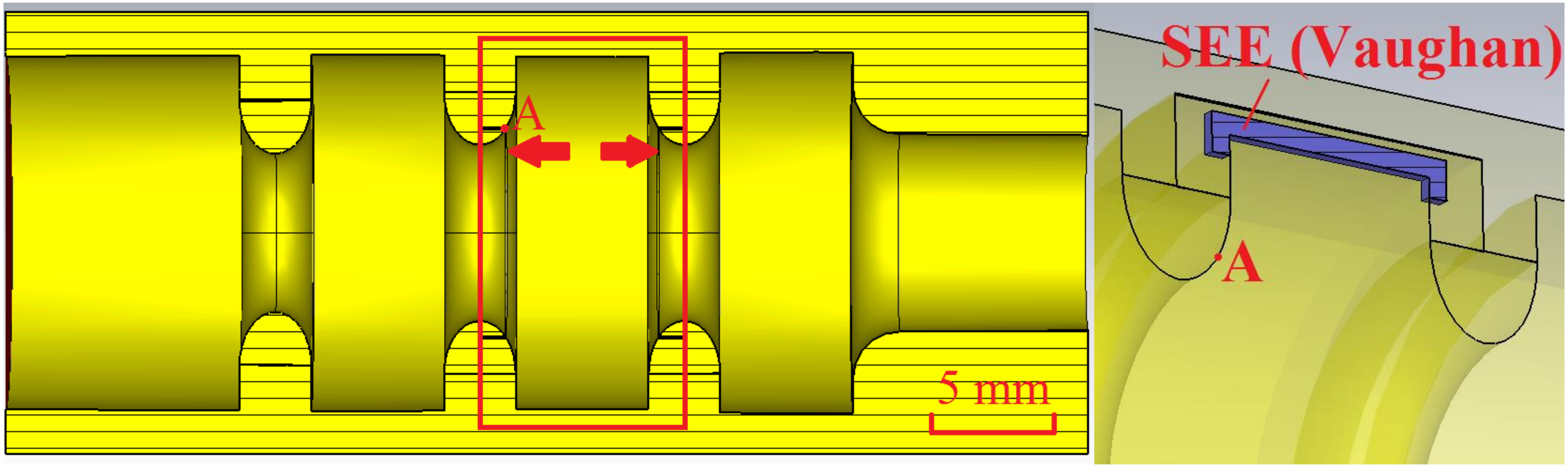
- Multipactor susceptibility diagrams
  - 2-point multipactor mode (H = 0.5)





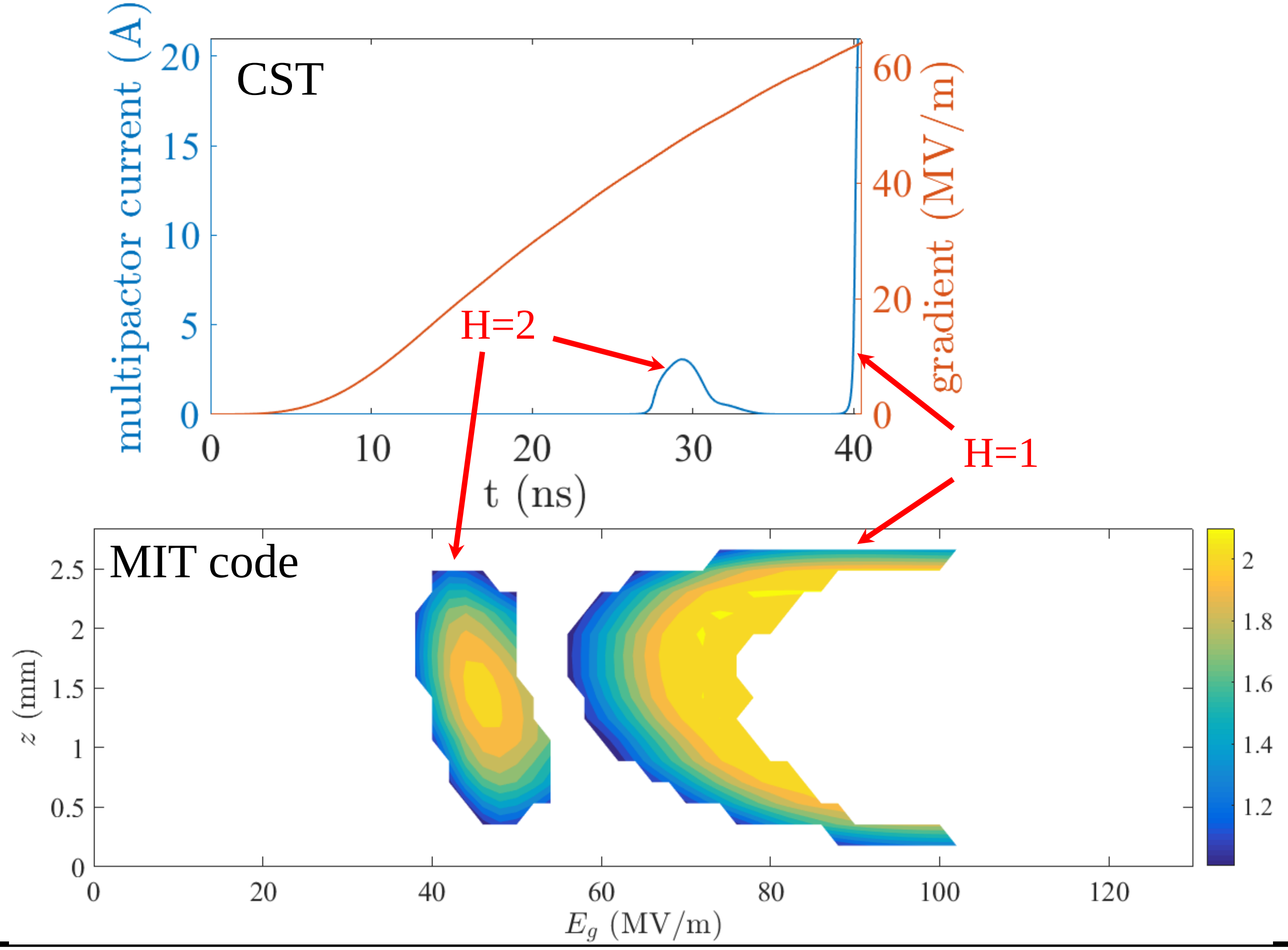
Multipactor Simulation - PIC

- Multipactor PIC simulation for MIT-DLWG structure in CST
  - 1 mm wide strip on the side wall assigned with secondary emission property (Vaughan's model)
  - Single point source, gaussian profile for emission current, constant current amplitude



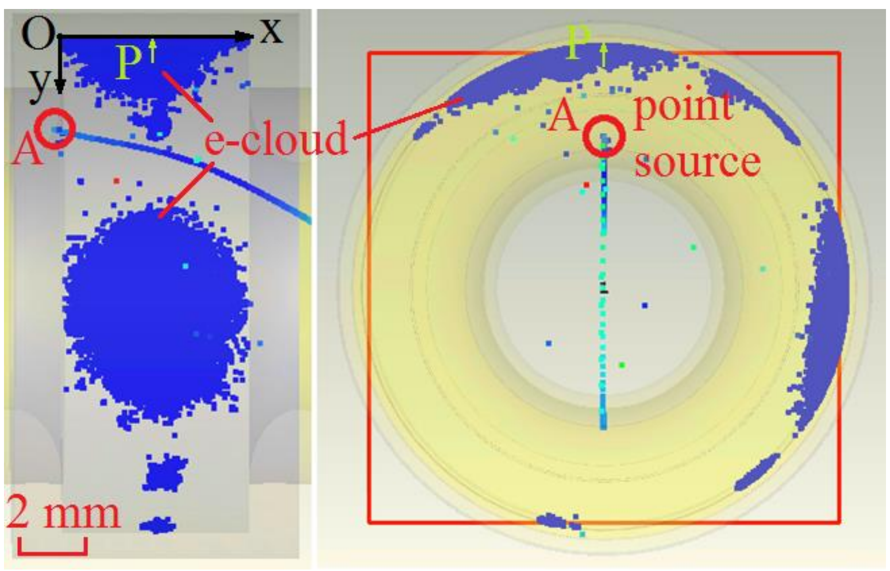
Multipactor Simulation - PIC

- Multipactor PIC simulation result
  - Multipactor current profile shows features conforming to the susceptibility diagram

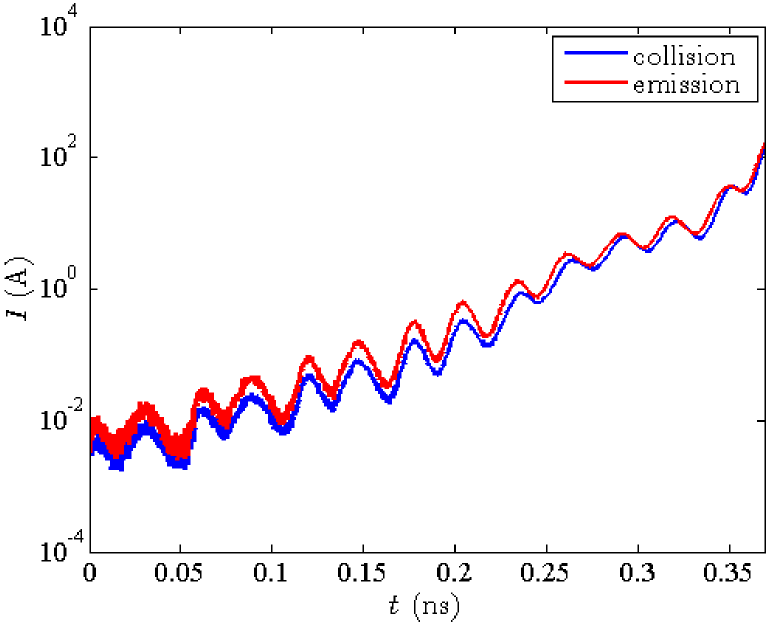


Multipactor Simulation - PIC

- Multipactor PIC simulation for MIT-DLWG structure in CST
  - Entire side wall is assigned with secondary emission property (Vaughan's model)
  - Simulation at 80 MV/m gradient
  - Multipactor current exceeds 100 A



Electron cloud formation at the side wall surface



Multipactor current

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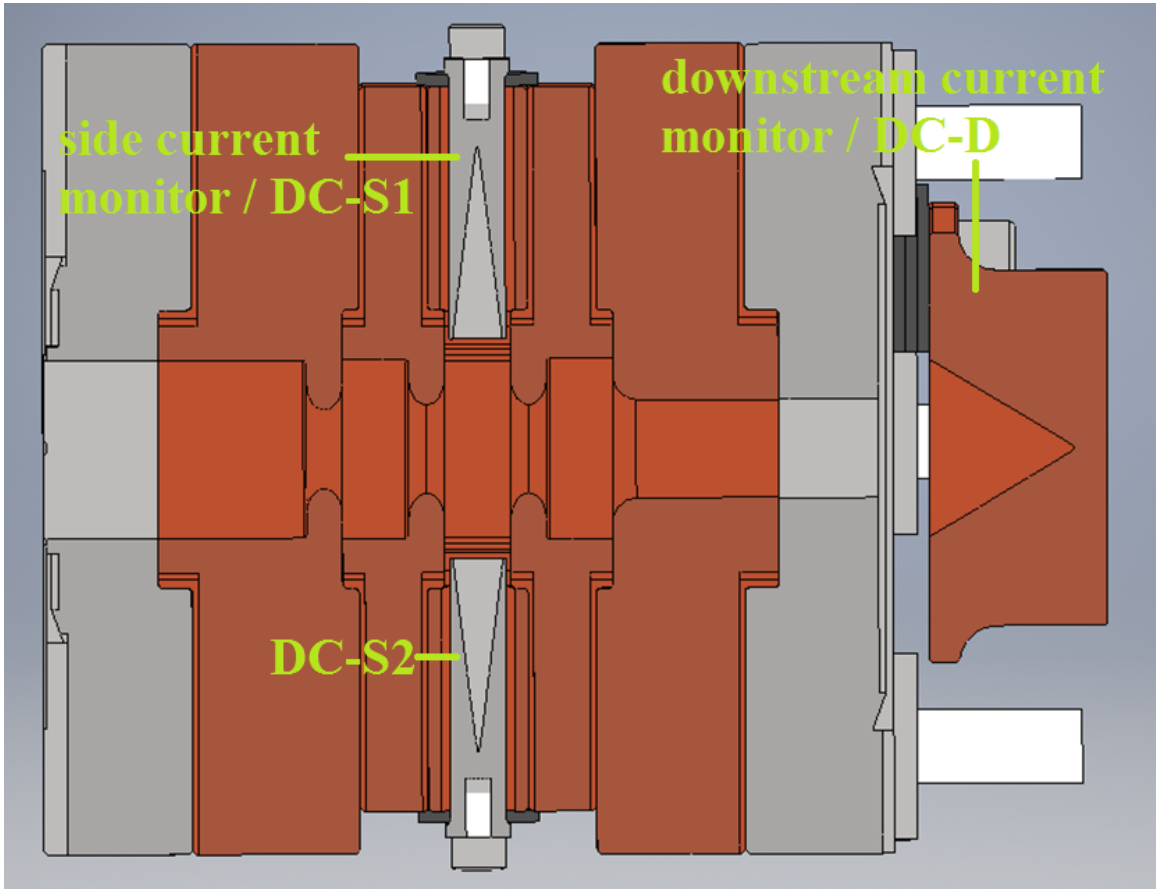
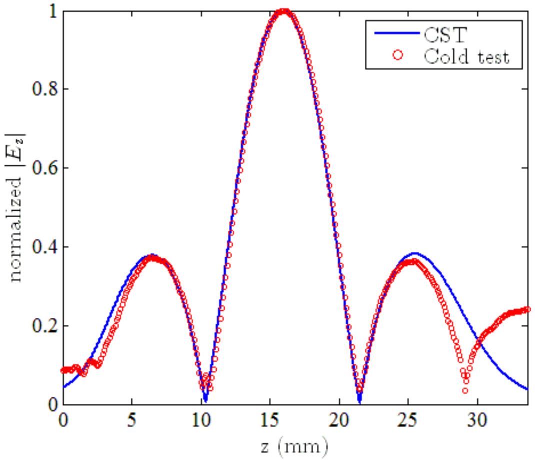
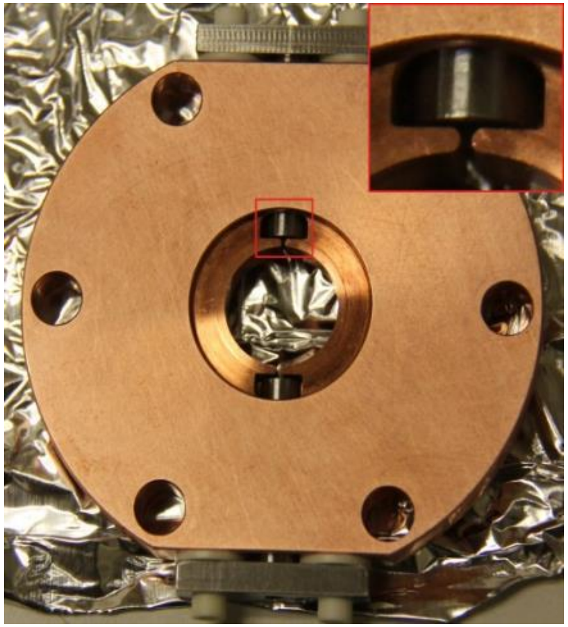
- **Multipactor experiments**
  - **Structure design**
  - **High power test**
  - **Comparison with simulations**
- Discussion and conclusion
- Future plans

MIT-DLWG-S

- MIT-DLWG-S structure design
  - Side slits designed for dark current extraction

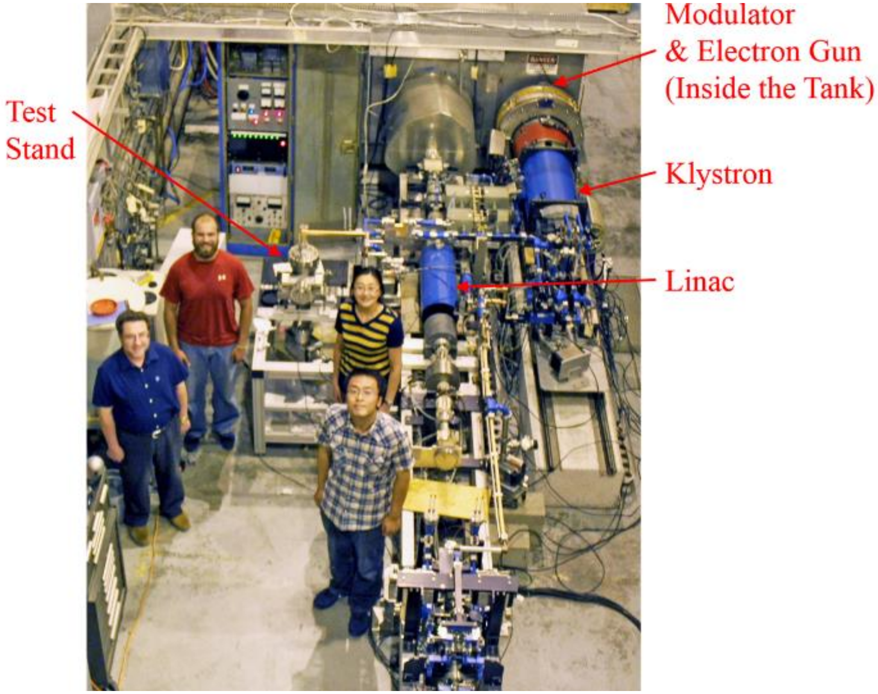




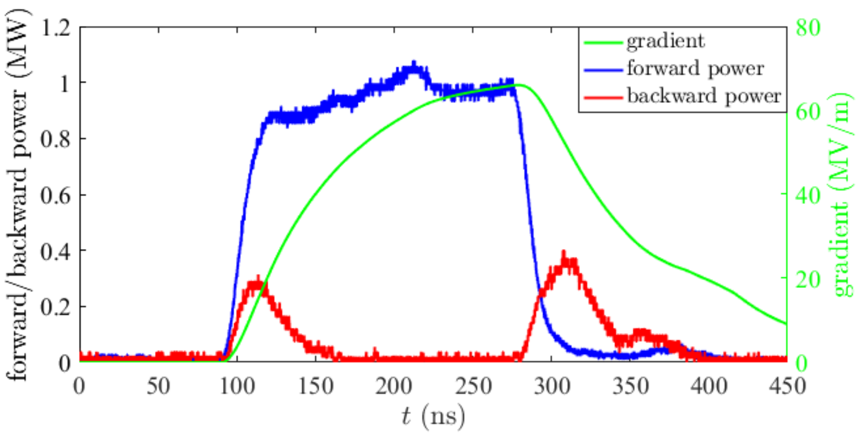


MIT-DLWG-S Testing

- MIT-DLWG-S structure high power test
  - Structure processed with ~1×10^5 pulses
  - Forward / backward power, downstream dark current (DC-D) and the dark currents going through the side slits (DC-S1 and DC-S2) are measured.



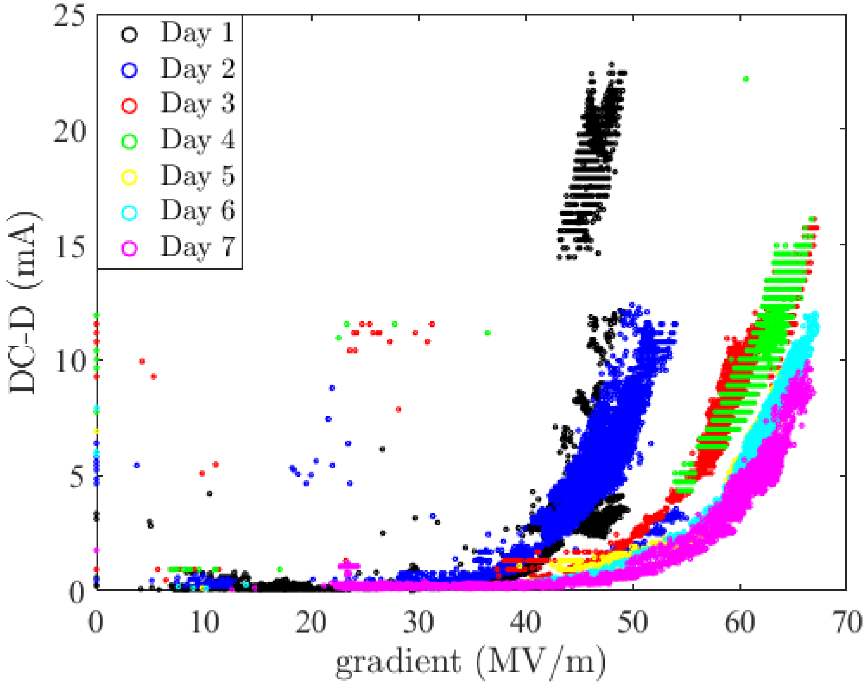
High power testing accelerator laboratory

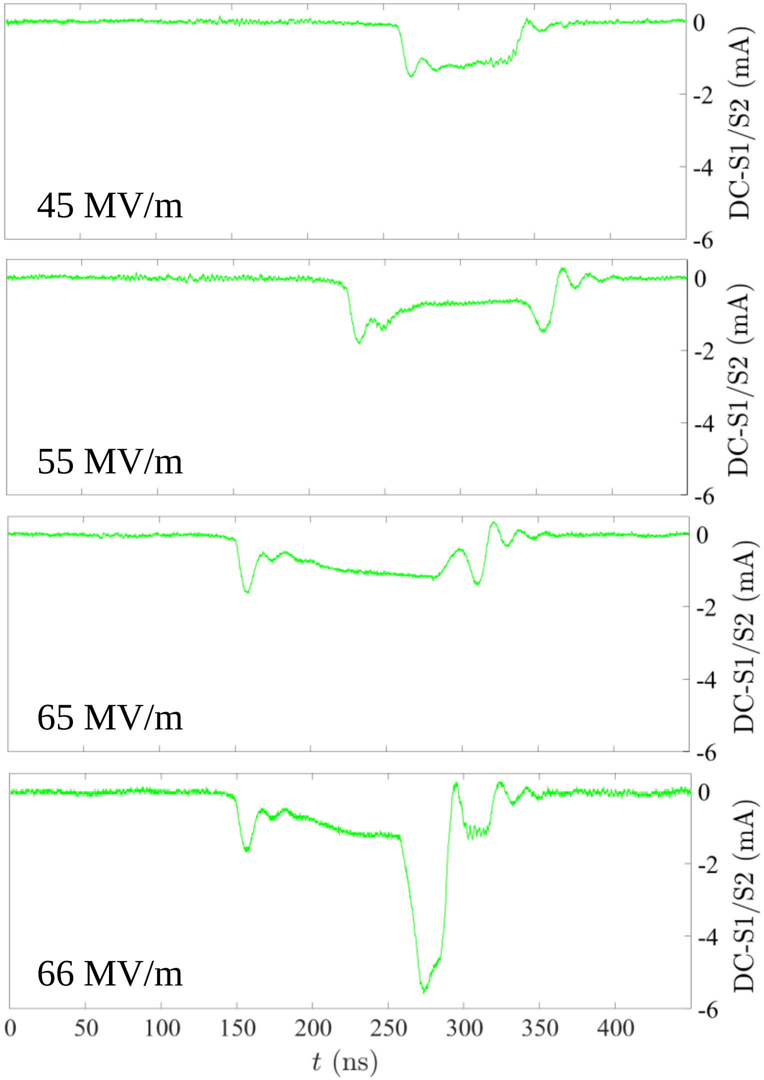


Sample traces of forward / backward power

MIT-DLWG-S Testing

- MIT-DLWG-S dark current measurement result

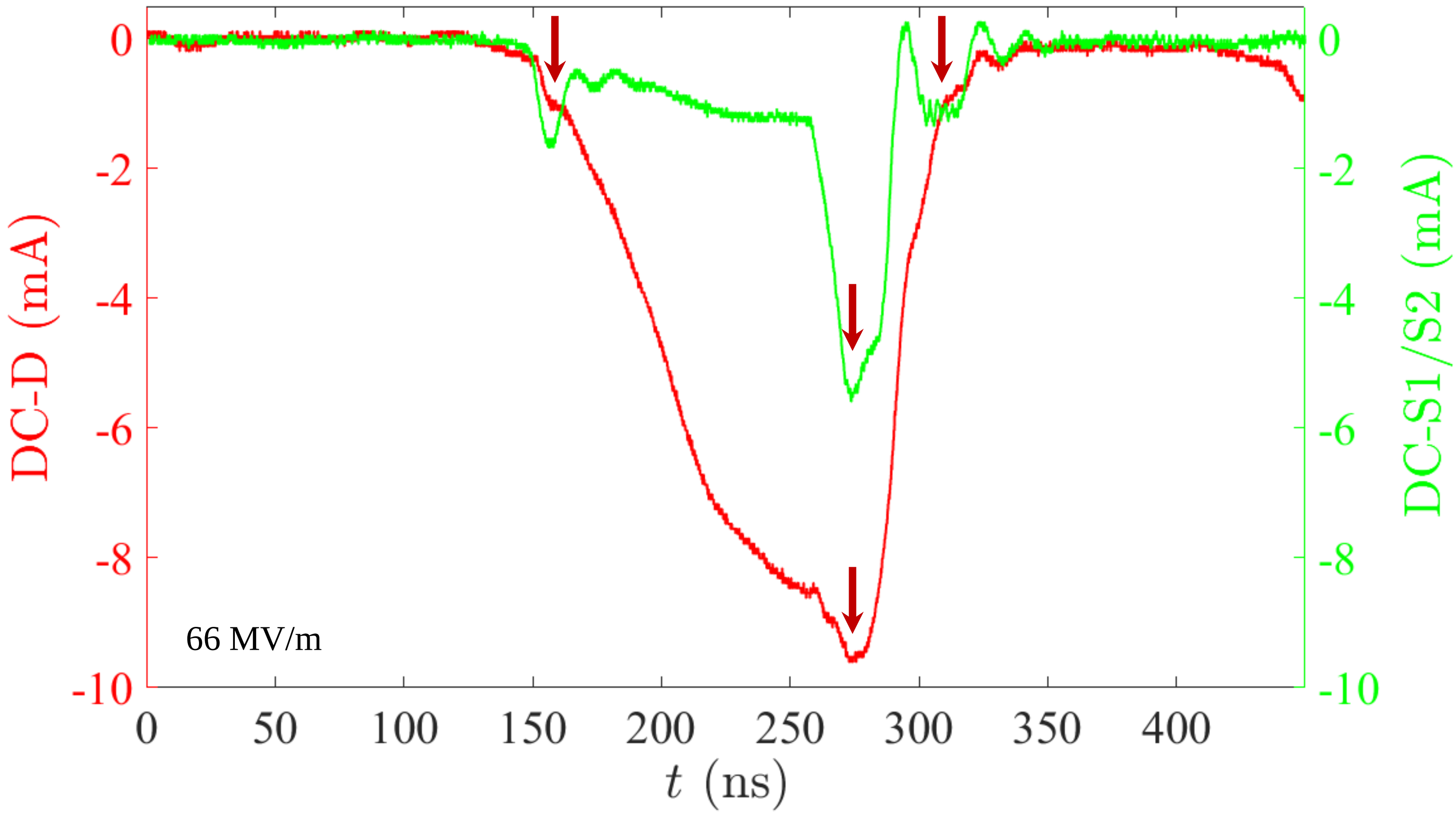




The amplitude of the downstream dark current (DC-D) increases continuously and monotonically with gradient, while the side dark currents (DC-S1/S2) show different features at different gradient levels.

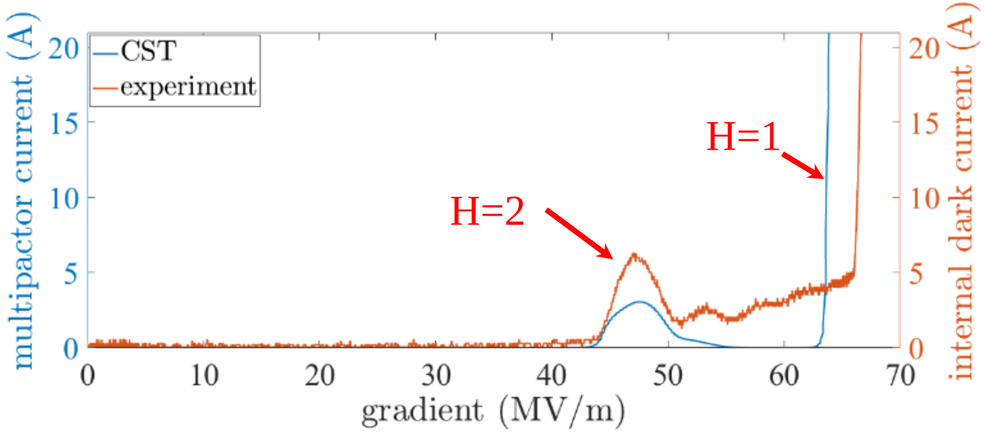
MIT-DLWG-S Testing

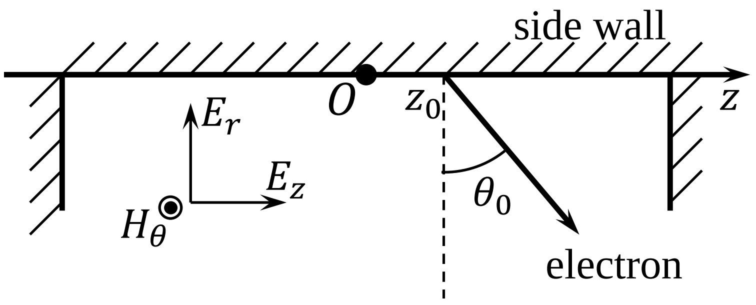
- Side dark current features can also be observed on the downstream dark current profile.

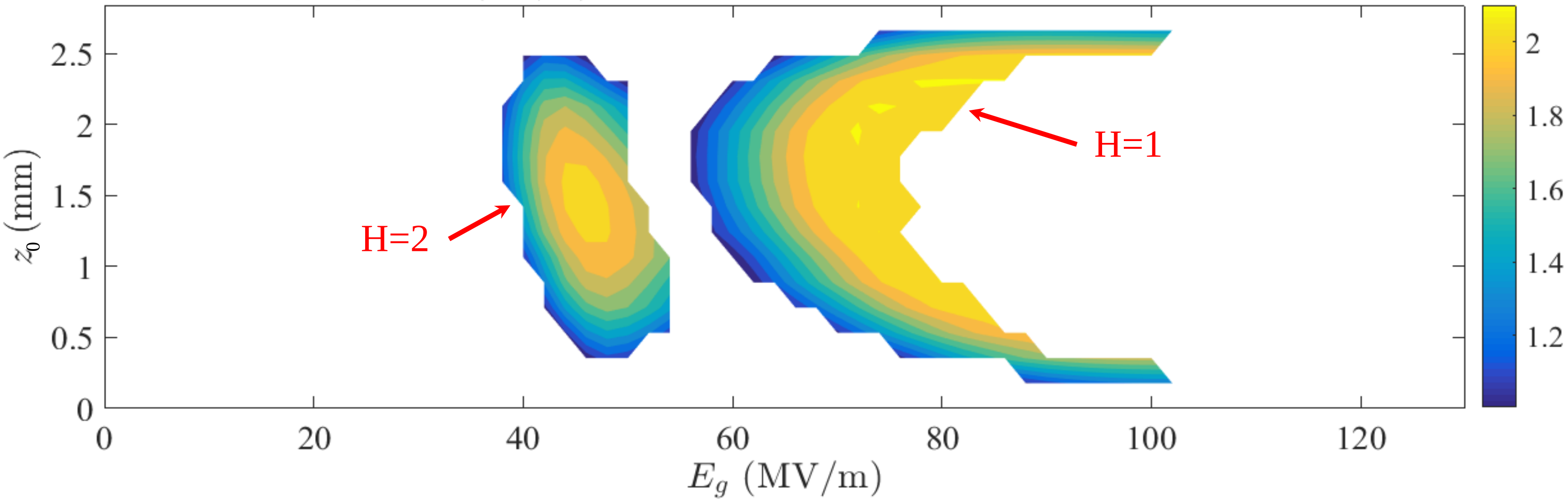


MIT-DLWG-S Testing

- Comparison between MIT-DLWG-S high power testing results and the simulations – good agreement!







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Discussion

- Internal dark current shows spikes at the first and the second order multipactor resonances.
  - These multipactor spikes are also seen in the downstream dark current profile.
- Dark current traces measured from both slits are always identical, implying azimuthally symmetric dark current generation.
- Total internal dark current induced by multipactor on the central cell side wall is estimated to be around 20 A at 70 MV/m gradient.

Conclusion

- An in-house code was developed to study the modes of multipactor seen in CST PIC simulations.
- Multipactor was observed in the MIT-DLWG-S structure, in good agreement with simulations.
- To our knowledge, this is the first detailed study in which the dark current is extracted directly from the side of a high gradient accelerator cell to study multipactor in a normal conducting accelerator structure.

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Future Plans

- High power testing for parts with diamond-like carbon and titanium nitride coatings on the side wall surface.
  - Reduced secondary electron yield
  - Higher breakdown gradient limit expected
- Calculation for outgassing rate and gas densities under multipactor
  - Gas ionization is likely to generate electrons that can travel to the high electric field regions and get captured towards downstream

Acknowledgements

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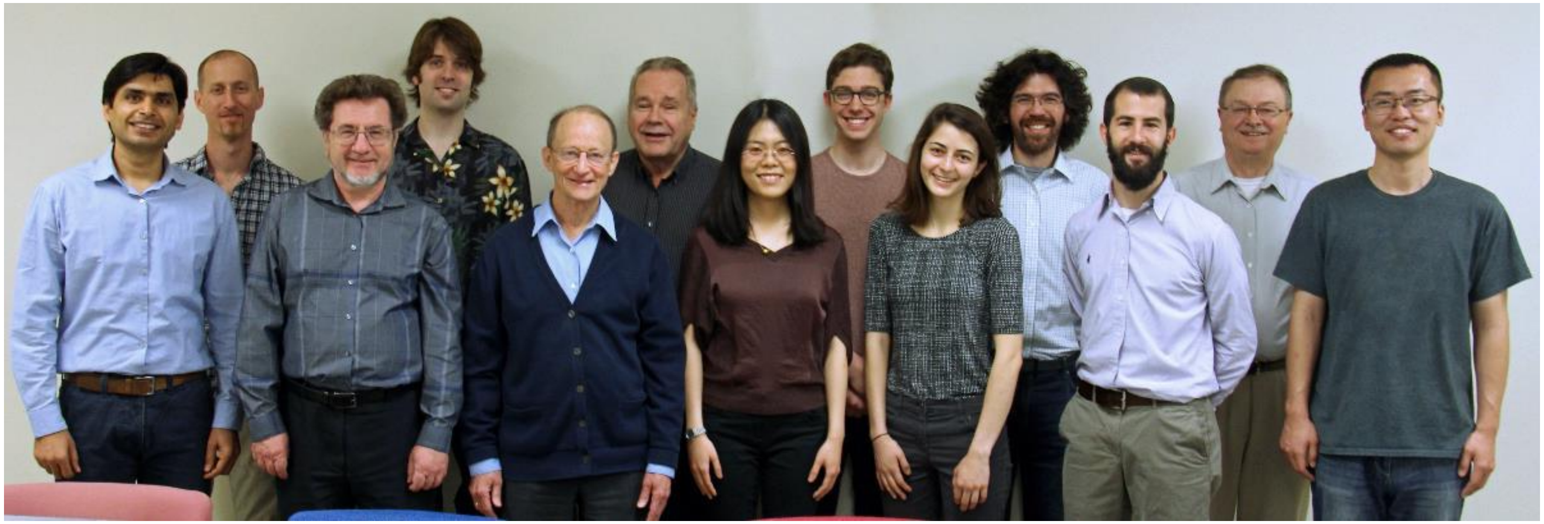

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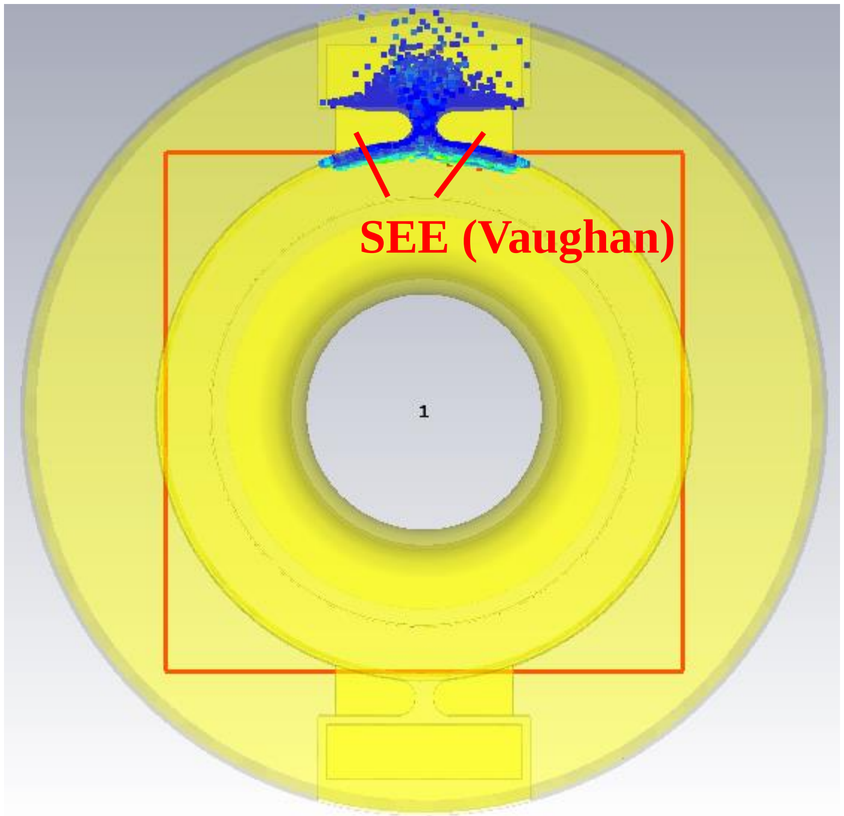
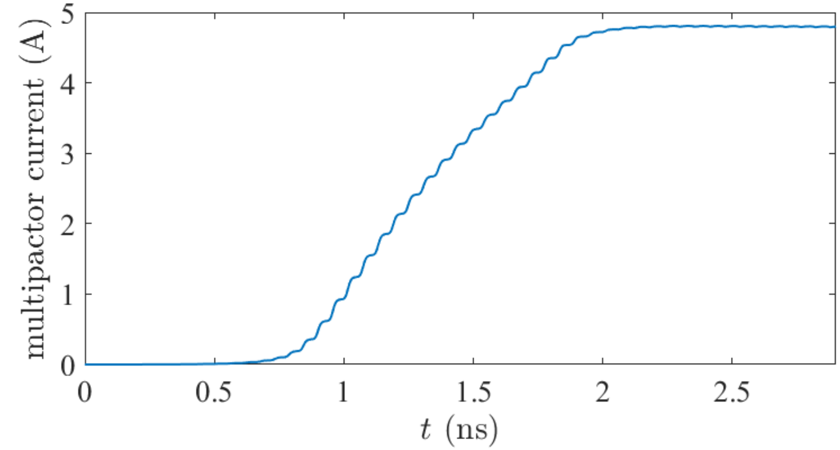
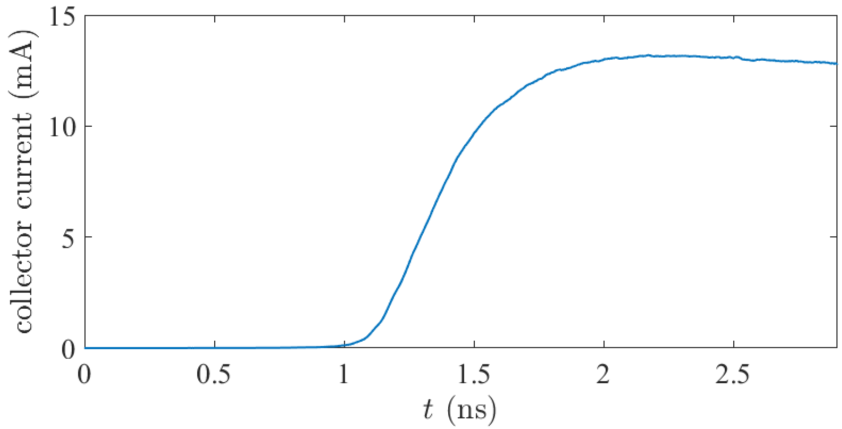
Backup - A

- Estimating the total internal dark current by CST PIC simulation







Backup – B

- X-band 2-point multipactor susceptibility diagrams generated for different iris geometries show good agreement with breakdown probability measurements