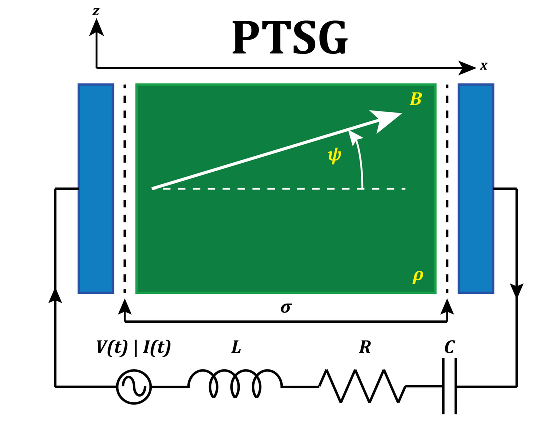

Simulation of Multipactor Initiation in FRIB Halfwave Cavities

Scott Rice and John Verboncoeur

Plasma Theory and Simulation Group

Michigan State University

Introduction

Multipactor [1, 2] is a resonant phenomenon in which an electromagnetic field causes a free electron to impact a surface, resulting in the surface emitting one or more secondary electrons. If the surface geometry and electromagnetic fields are appropriately arranged, the secondary electrons can then be accelerated and again impact a surface in the bounding geometry. If the net number of secondary electrons participating in multipactor is non-decreasing, then the process can repeat indefinitely. This phenomenon is of considerable practical interest in the design and operation of radio frequency (RF) resonant structures, windows, and supporting structures.

The Facility for Rare Isotope Beams (FRIB) is a particle accelerator that is currently being constructed at Michigan State University. A portion of the beam line will employ coaxial half wave cavities to generate the fields to accelerate the charged beam. One of the cavity design considerations is the susceptibility to multipactor within these accelerating cavities; the presence of multipactor could hinder the cavities from realizing their intended field strength.

This research presents simulated results for multipactor initiation within the FRIB halfwave resonant cavities, for the case of both single- and multi-mode excitation. This work builds upon previous work [3][4] done to assess multipactor initiation in idealized coaxial cavities, but the present simulations use the actual FRIB cavity geometry. Comparisons to preliminary measured FRIB cavity data is also discussed.

The formation of multipactor is strongly dependent upon the secondary electron yield (SEY) of a surface, and the emission velocities of the emitted electrons. A typical SEY curve is shown in Figure 1 below, illustrating a low SEY at low and high impact energies, and a high SEY at an intermediate impact energy. The medianized version of Furman's SEY model [3][4] for copper is used for electron impact events in this study.

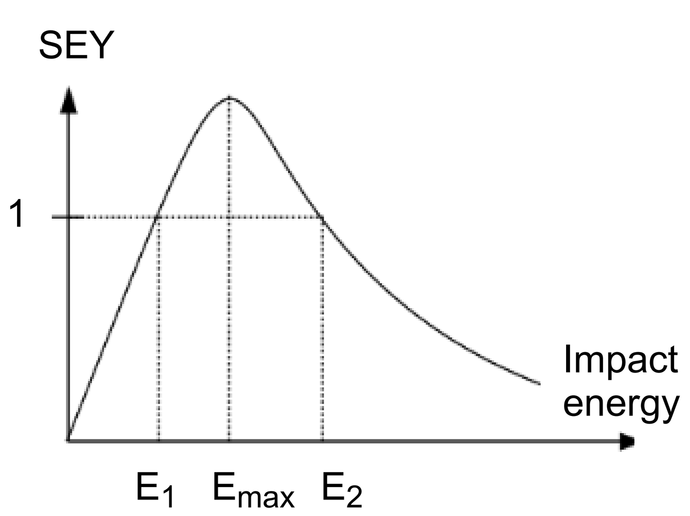

Figure 1: Typical SEY curve.

Numerical Multipactor Simulations

The FRIB halfwave resonant cavity is an approximately coaxial cavity shorted at both ends, with various ports and other perturbations to the geometry. Figure 2 shows surface point samples of the cavity from different aspect angles. A numerical electromagnetics solver was used to generate the fields inside the cavity for the fundamental resonant mode which occurs at 322 MHz, as well as the next highest resonant mode which occurs at 800 MHz.

For each maximum field strength and starting phase to be simulated, single-particle simulations were performed for 10 cycles: either a boundary strike a a complete RF period, whichever occurs first:

(1) Allow an electron starts from rest at the outer wall.
(2) Electron is accelerated by the cavity fields until it strikes a boundary.
(3) Record SEY for the impact.
(4) Generate secondary electron from emission energy and angle distributions.
(5) Repeat from step #2.

The net SEY is computed as the product of all the single-impact SEY values.

- Gives a proxy measure of the presence of multipactor.
- Net SEY < 1 would indicate that multipactor is not sustainable.
- At least two boundary impacts over the 10 simulation cycles is required to record a nonzero SEY. Otherwise, net SEY was defined to be 0.

Two longitudinal positions on the cavity outer wall were considered for particles trajectories:

- One point near the end of the cavity (10% of the distance from end towards center).
- One point halfway (50% of the distance) between the end and center of the cavity.

For the multi-mode excitation:

- Both the 322 MHz and 800 MHz modes were present in the cavity.
- Both had the same maximum field magnitude.
- The 800 MHz mode phase is independent of the 322 MHz mode phase in general.
- To characterize this independence, the multimode results were averaged over eight relative phases {0º, 45º, 90º, 135º, 180º, 225º, 270º, 315º} of the 800 MHz mode.

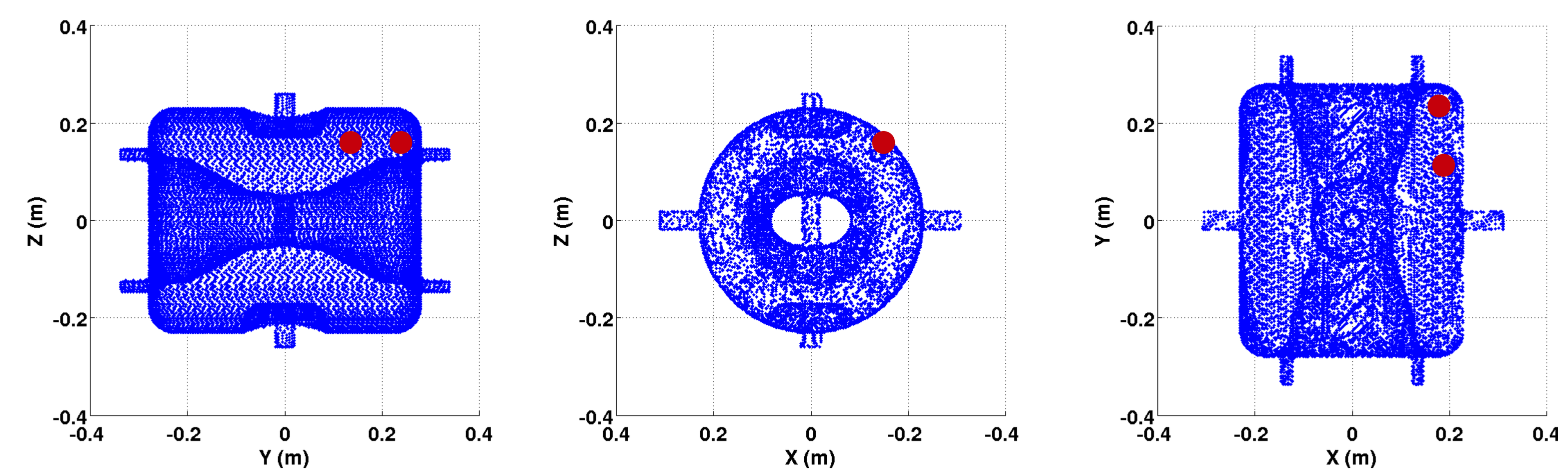

Figure 2: FRIB cavity surface samples from different look angles. The red dots show the starting points of multipactor trajectories being considered. Position 1 is near the end of the cavity, and position 2 is halfway between the end and center of the cavity.

Simulation Results

- The net SEY was recorded for peak field strengths in the baseline (322 MHz) mode ranging from 200 V/m to 20 MV/m, and for particle starting trajectories from -180º to 180º.
- Figure 3 shows the results for both starting positions considered.
- The average over all phase angles (average down each column of Figure 3) gives a measure of multipactor susceptibility vs. field strength, for particles starting from the two location considered.
- These results are shown as the baseline (blue) curves in Figures 4 and 5.
- For each multi-mode simulation (with the 800 MHz mode at one of eight distinct phases relative to the baseline mode), a surface similar to Figure 3 can be constructed.
- For each of these eight surfaces, the column averages can be calculated, and these resulting curves can then further be averaged. This gives a measure of multipactor susceptibility vs. field strength with both modes present.
- These results are shown as the multi-mode (red) curves in Figures 4 and 5.
- The baseline results are in qualitative agreement with the experimental results: The ends of the cavity are prone to multipactor, and the onset of this multipactor tends to occur at peak field strengths around 2 MV/m in the experimental data.

Conclusions and Future Work

- The present multipactor simulation tool and SEY model seem to be capturing the onset of multipactor rather well.
- The presence of the secondary mode observably changed the average SEY per impact, and thus the multipactor susceptibility. For the present cavity, the goal is multipactor suppression, but in other circumstances, increasing multipactor susceptibility may be advantageous.
- Future work will expand the trajectory starting points from two to many scattered over the entire surface of the cavity.
- The field magnitude of the 800 MHz mode was set to be equal to the field magnitude of the 322 MHz mode. The effect of this magnitude ratio will be examined in future work.
- Future work will also address the time dependence of multipactor formation vs. rate of field magnitude change. If a field can grow fast enough, it may "pass through" a multipactor barrier before the multipactor current builds up to an uncontrollable level.
- For this particular FRIB cavity, we ultimately want to address the big question: Can multipactor be reduced by the presence of a second mode in the cavity?

References

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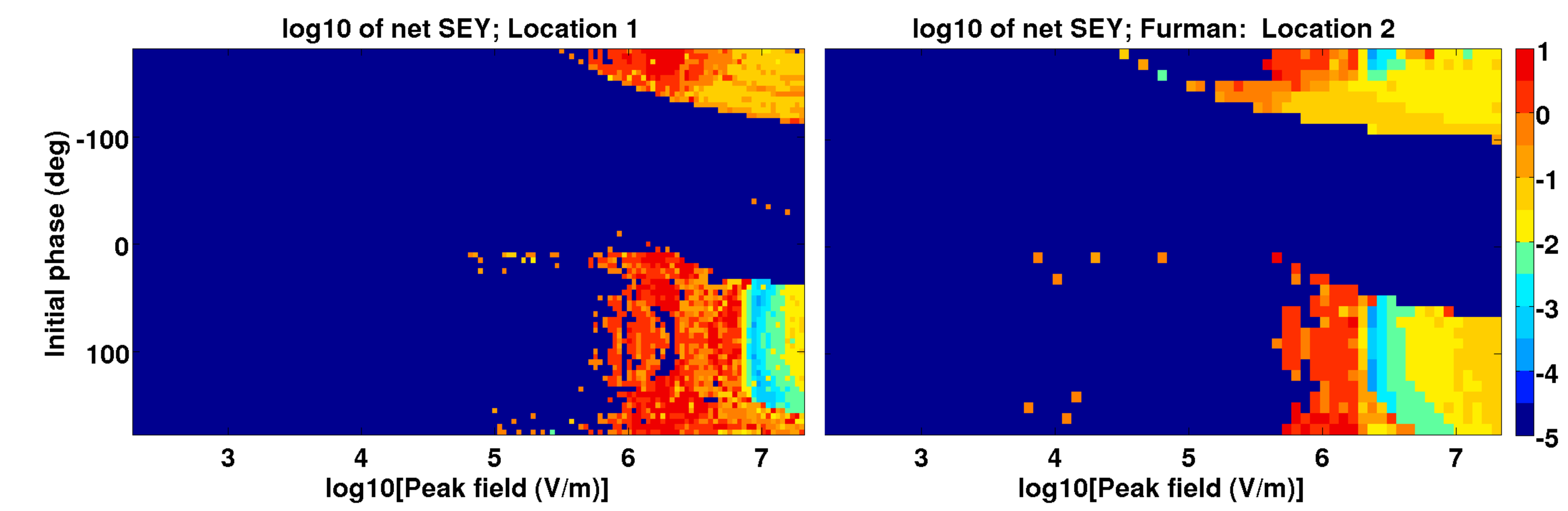

Figure 3: Multipactor sustainability in the FRIB cavity for particles starting at location 1 (left) and location 2 (right).

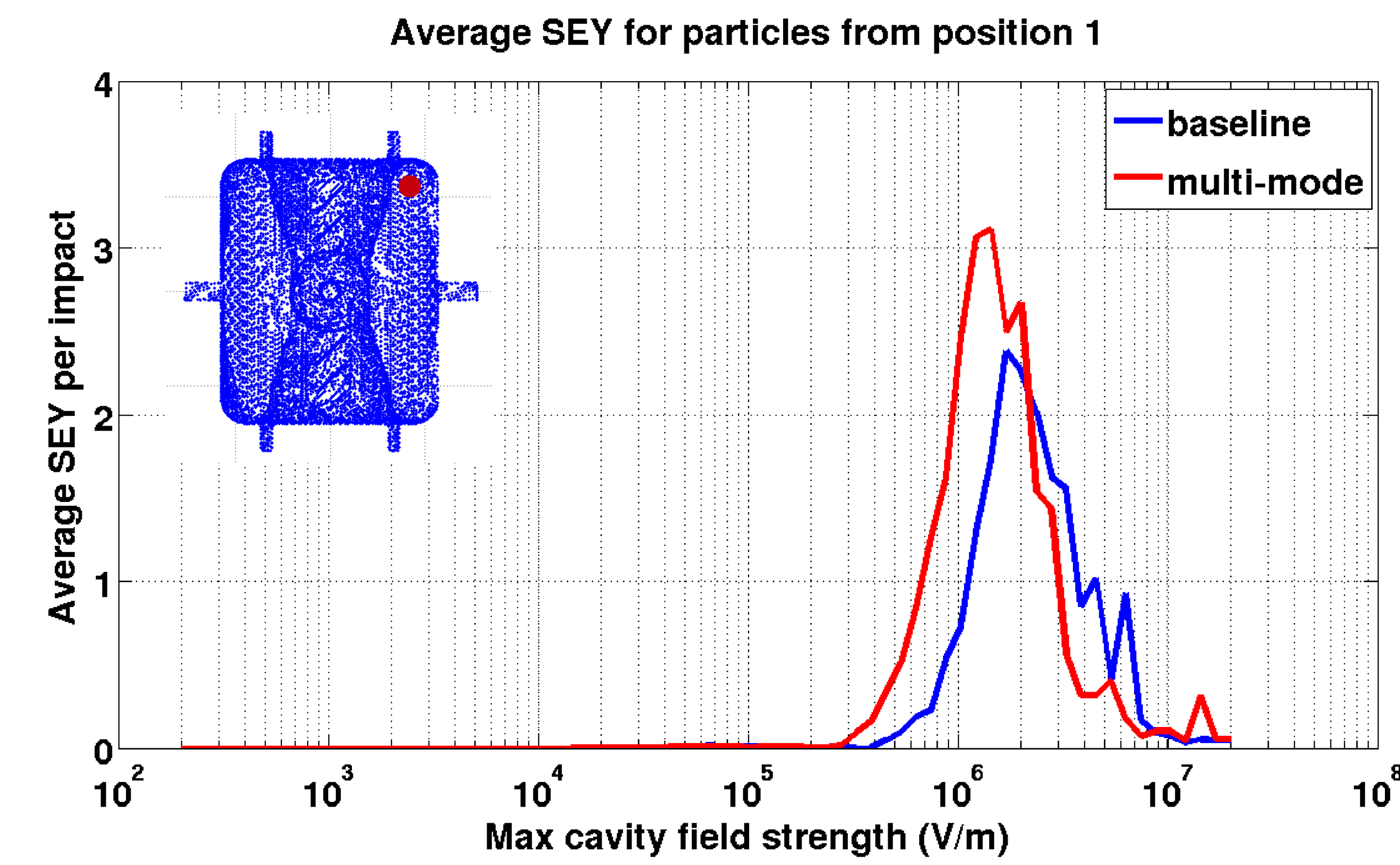

Figure 4: Average SEY vs. cavity field strength for particles starting from positon 1, with and without the 800 MHz mode present. The maximum cavity field strength on the x-axis is the field strength of the 322 MHz mode.

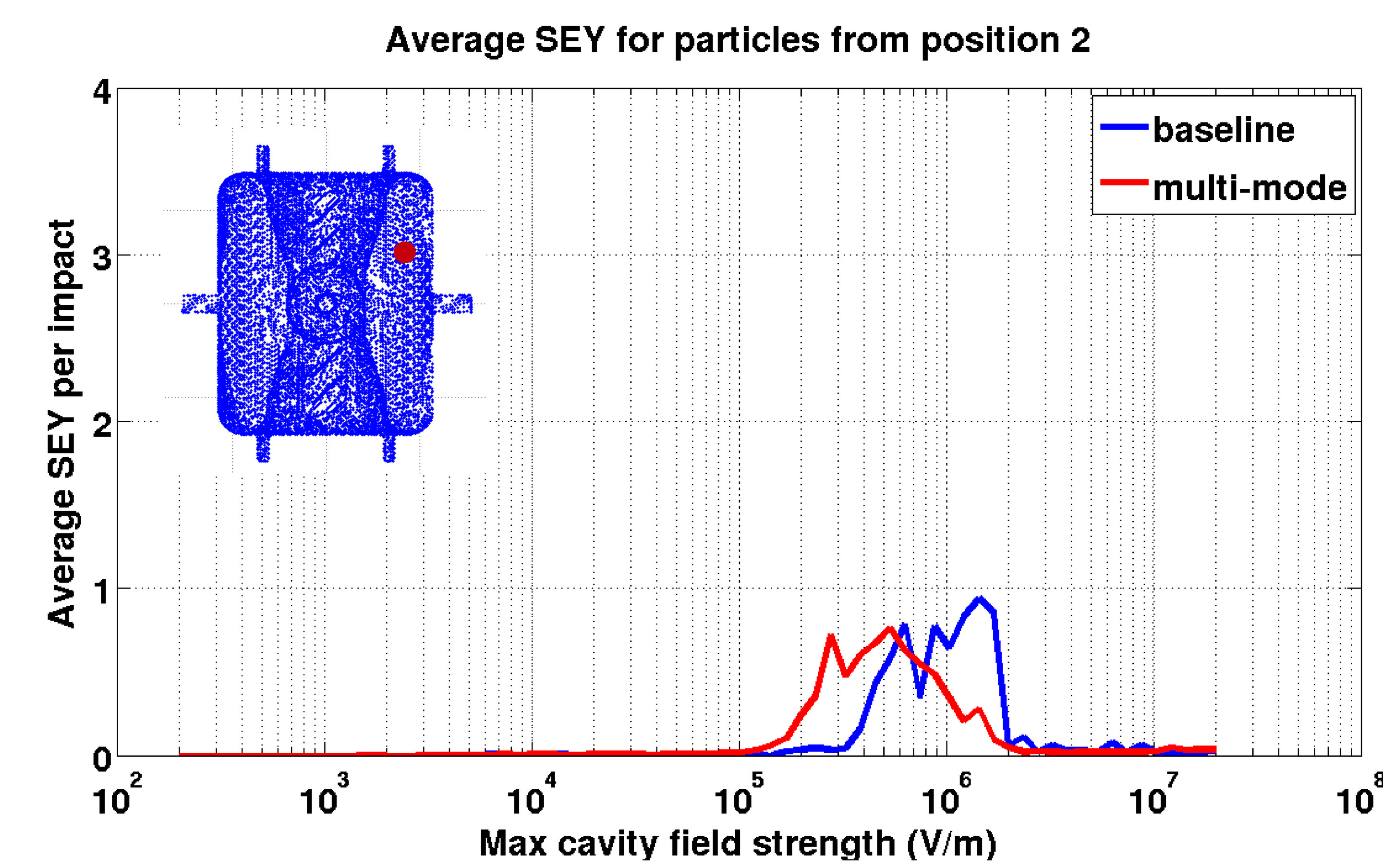

Figure 5: Average SEY vs. cavity field strength for particles starting from positon 2, with and without the 800 MHz mode present. The maximum cavity field strength on the x-axis is the field strength of the 322 MHz mode.

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