PARASITIC RESONANCES IN HIGH POWER PROTON LINACS

Rob Ainsworth

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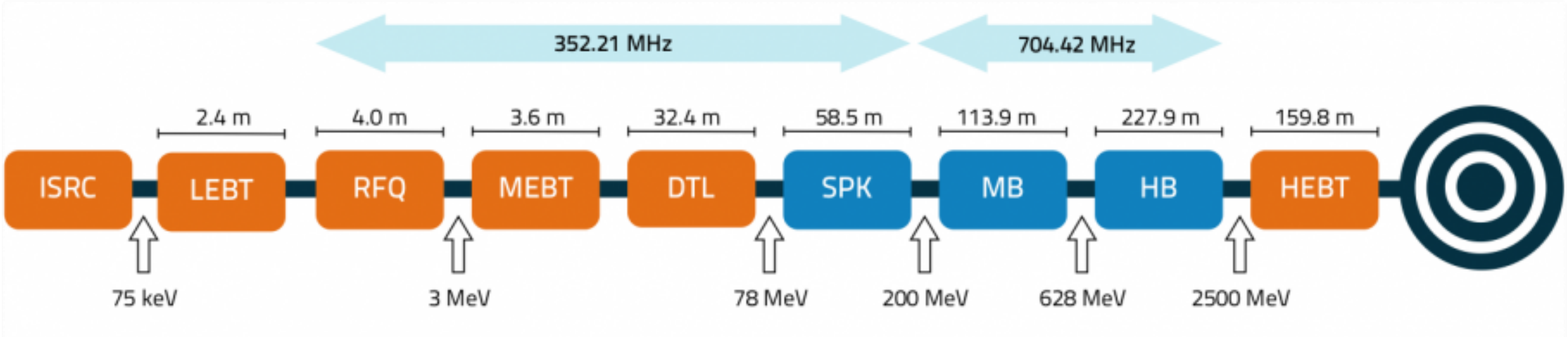
OUTLINE

- European Spallation Source
- Cavity Modes
  - Spoke Cavities
  - Elliptical Cavities
- Influence of Parasitic Modes
  - Same Order Modes (SOMs)
  - Higher Order Modes (HOMs)
- HOM coupler designs
  - Multipacting

EUROPEAN SPALLATION SOURCE



	Value	Unit
Final kinetic energy	2.5	GeV
Current	50	mA
Pulse repetition rate	14	Hz
Bunch frequency	352.21	MHz
Average power	5	MW
Peak power	125	MW

CAVITY MODES

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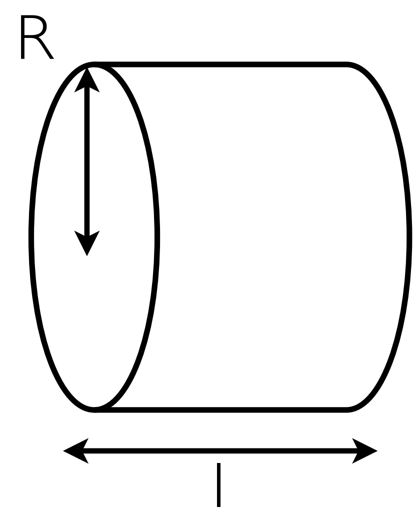
PILLBOX CAVITY



Try simple azimuthally symmetric trial solution $E_z(r, z, t) = R(r)e^{iwt}$

Wave Equation $$\frac{\partial^2 E_z}{\partial z^2} + \frac{1}{r}\frac{\partial E_z}{\partial r} + \frac{\partial^2 E_z}{\partial r^2} - \frac{1}{c^2}\frac{\partial^2 E_z}{\partial t^2} = 0$$

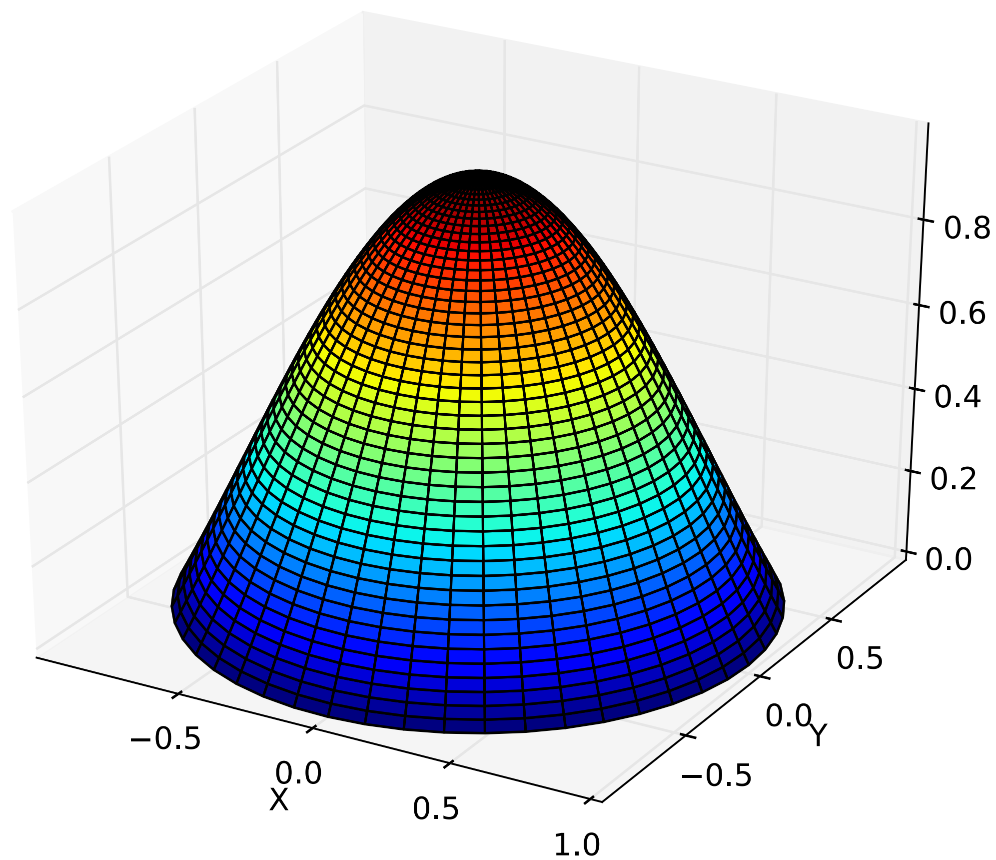
Boundary Condition: No tangential E field

No normal B field

ACCELERATING MODE

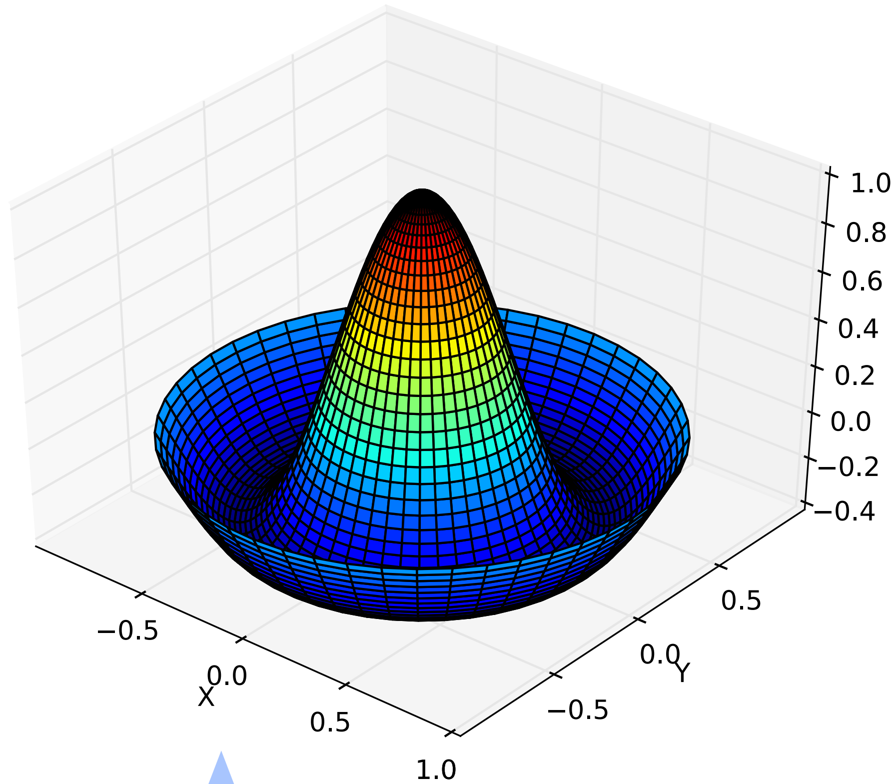
Transverse Magnetic Mode (TM)

$$E_z = E_0 J_0(k_r r)\cos\omega t \qquad B_\theta = -\frac{E_0}{c} J_1(k_r r)\sin\omega t$$



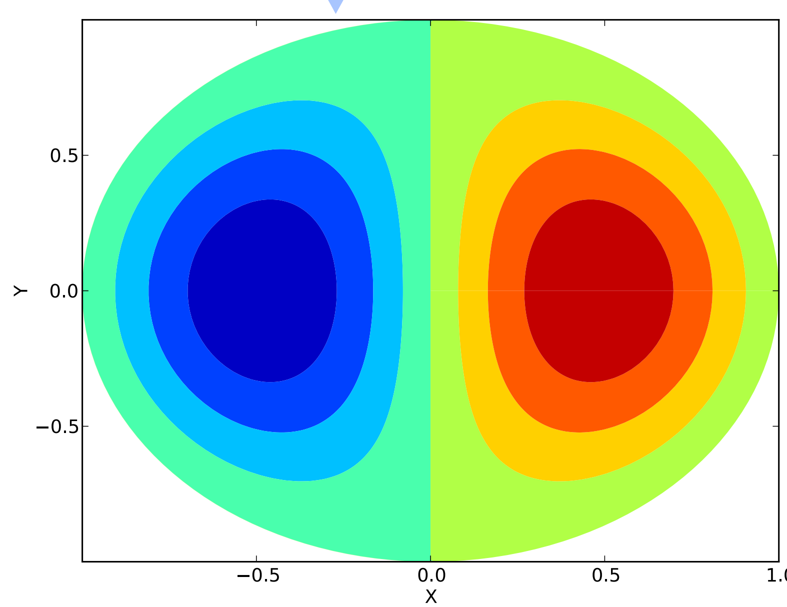
However, not the only mode . ..

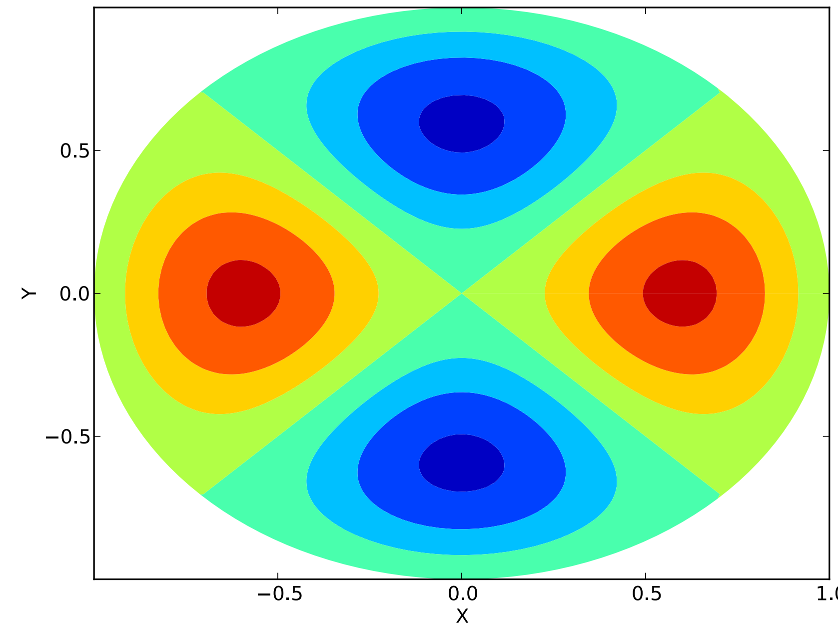
HIGHER ORDER MODES



Higher order monopole

Dipole





Quadrupole

And many more...

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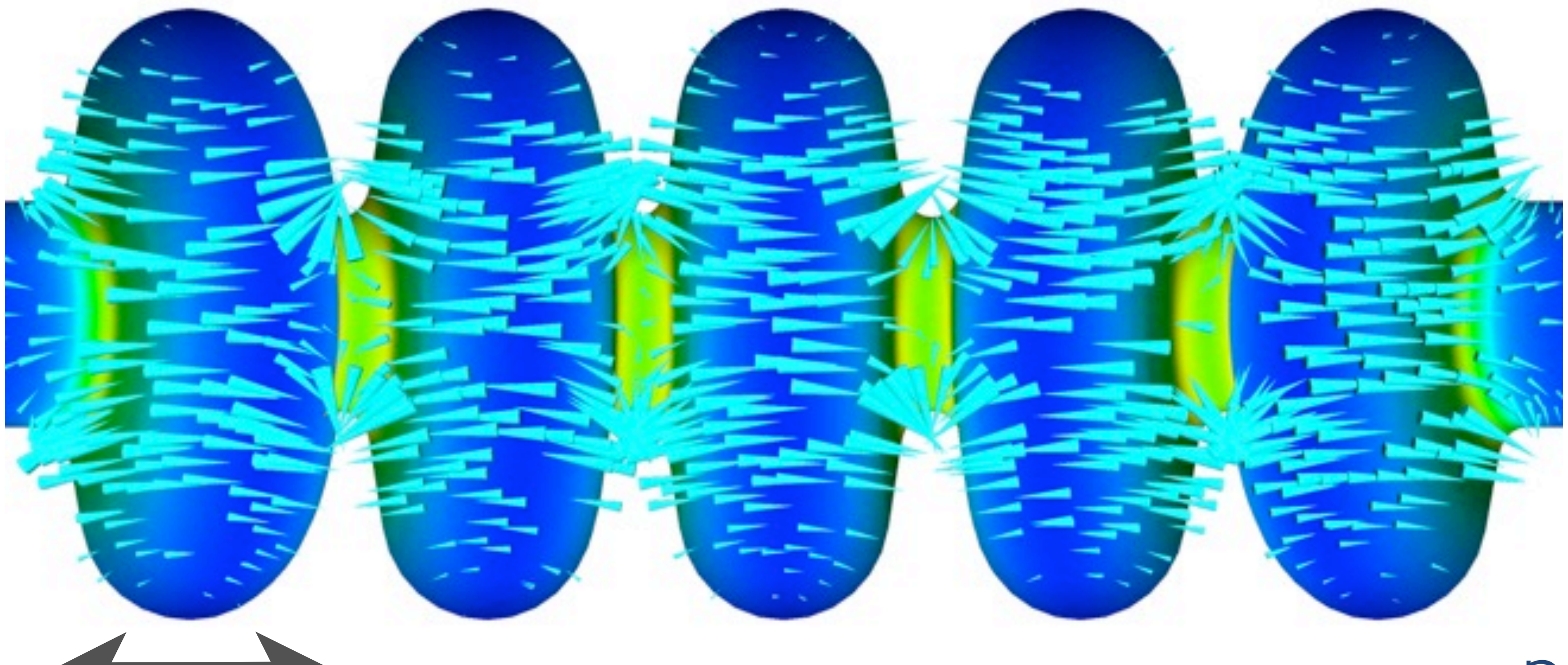
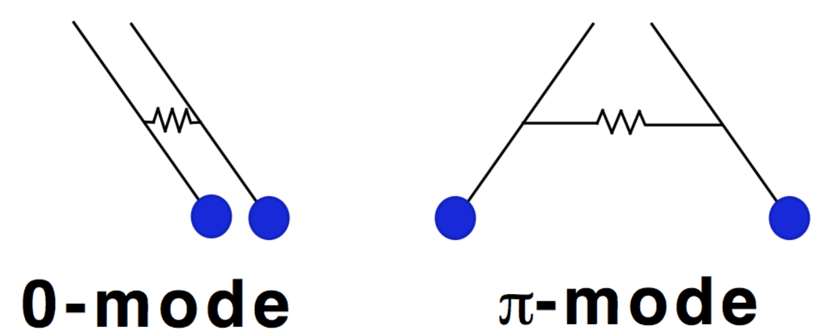
ELLIPTICAL CAVITIES



$\beta_g\lambda/2$

N coupled pillbox cavities

Modes split into passbands with differing phase advance per cell



Two families of ellipticals operating in π - mode @ 704.42 MHz

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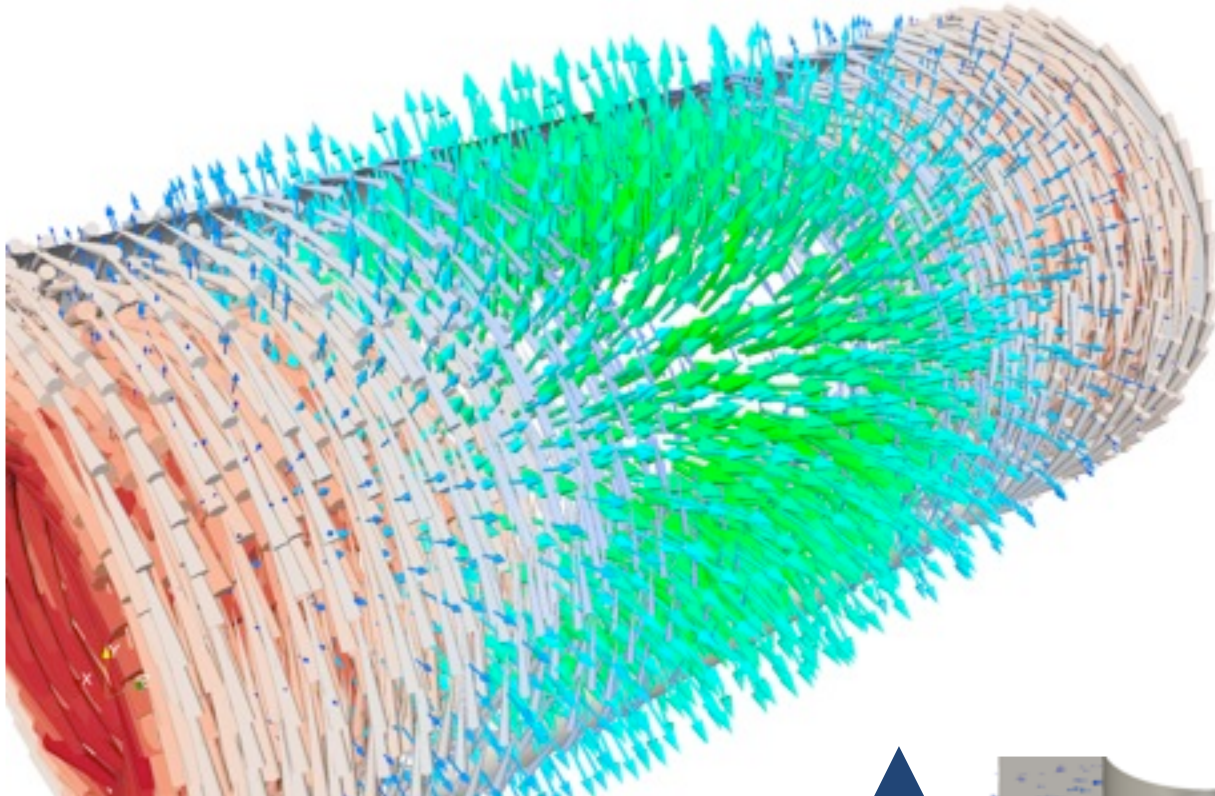
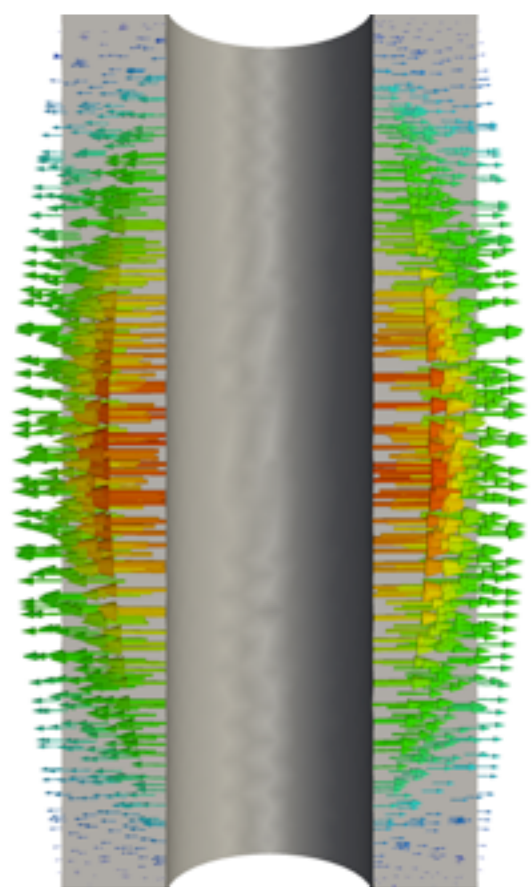
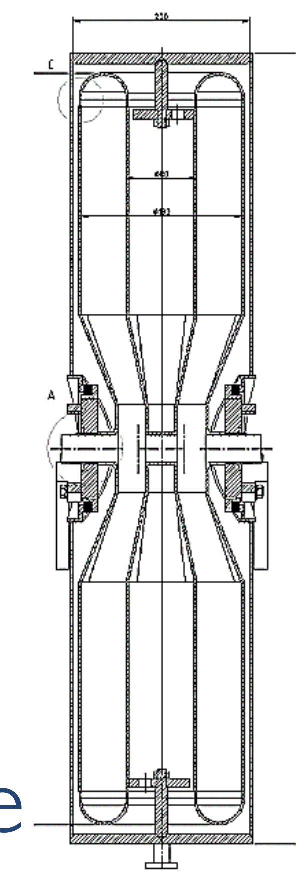
TEM RESONATOR



Traverse ElectroMagnetic Mode

$\lambda/2$





Half-wave resonator

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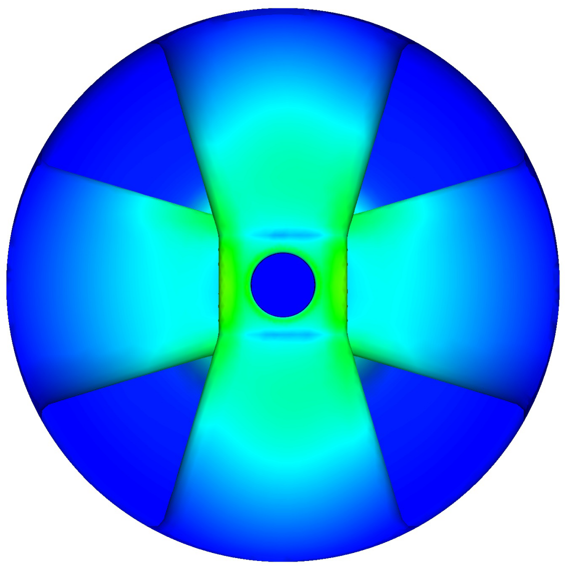
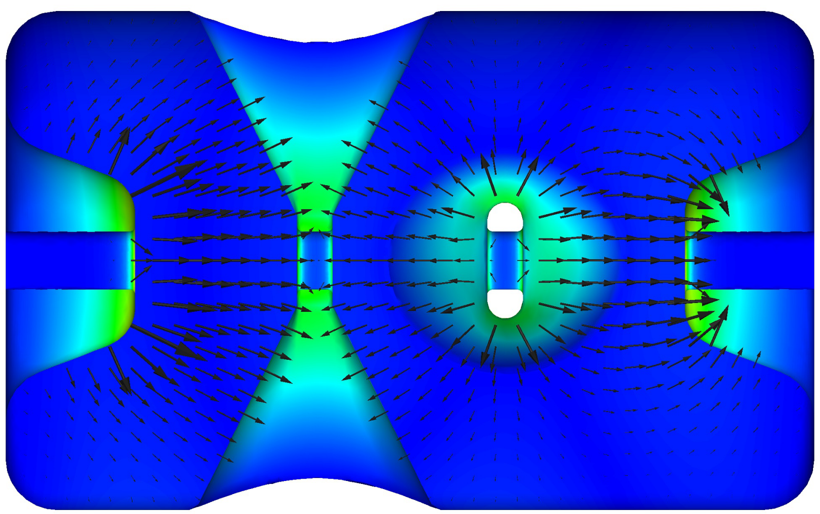
SPOKE RESONATORS



Each spoke rotated by 90°



Variant of TEM cavity

n stacked HWRs

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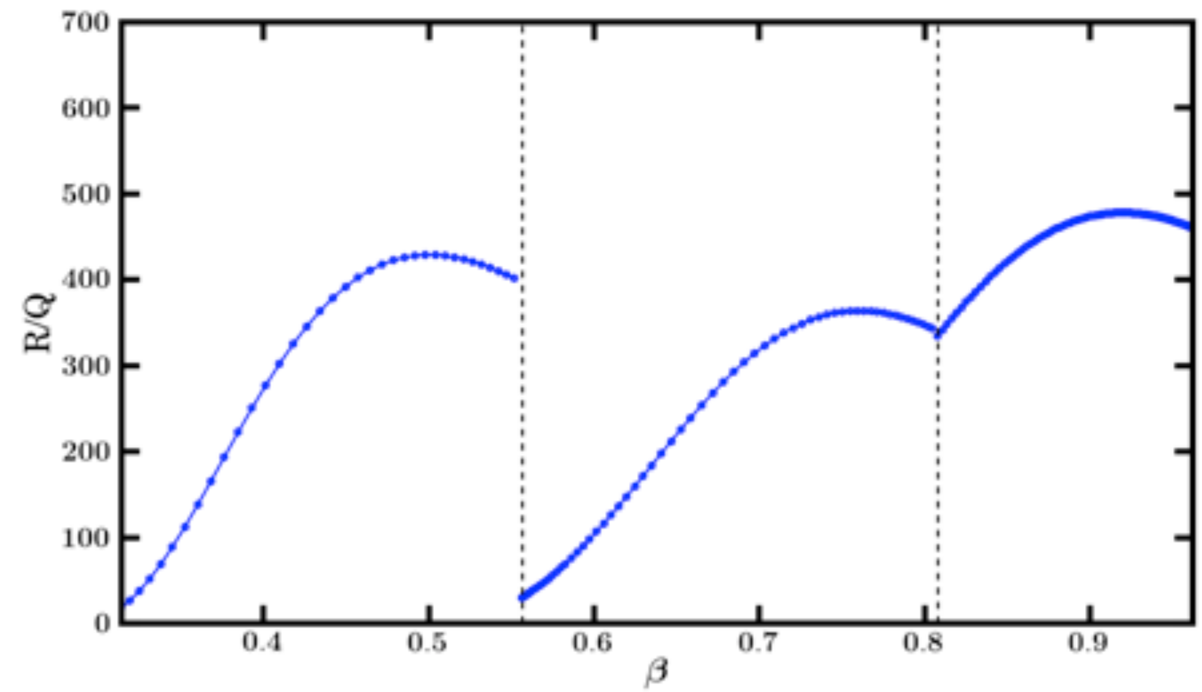
THE NEED FOR 3 FAMILIES

$$(R/Q)_n(\beta) = \frac{\left|\int_{-\infty}^{\infty} E_{z,n}(r=0,z) e^{i\omega_n \frac{z}{\beta c}} dz\right|^2}{\omega_n U_n}$$



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THE NEED FOR 3 FAMILIES

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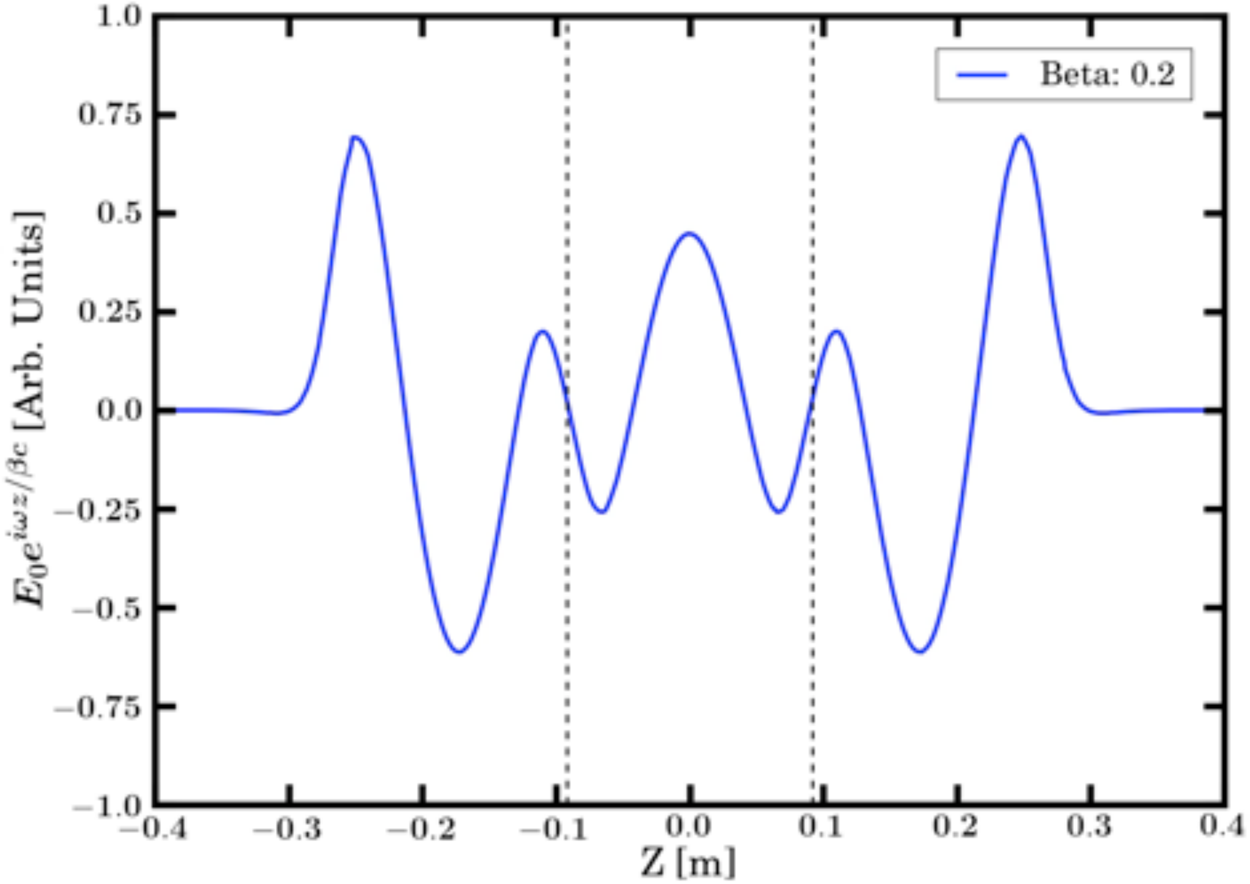

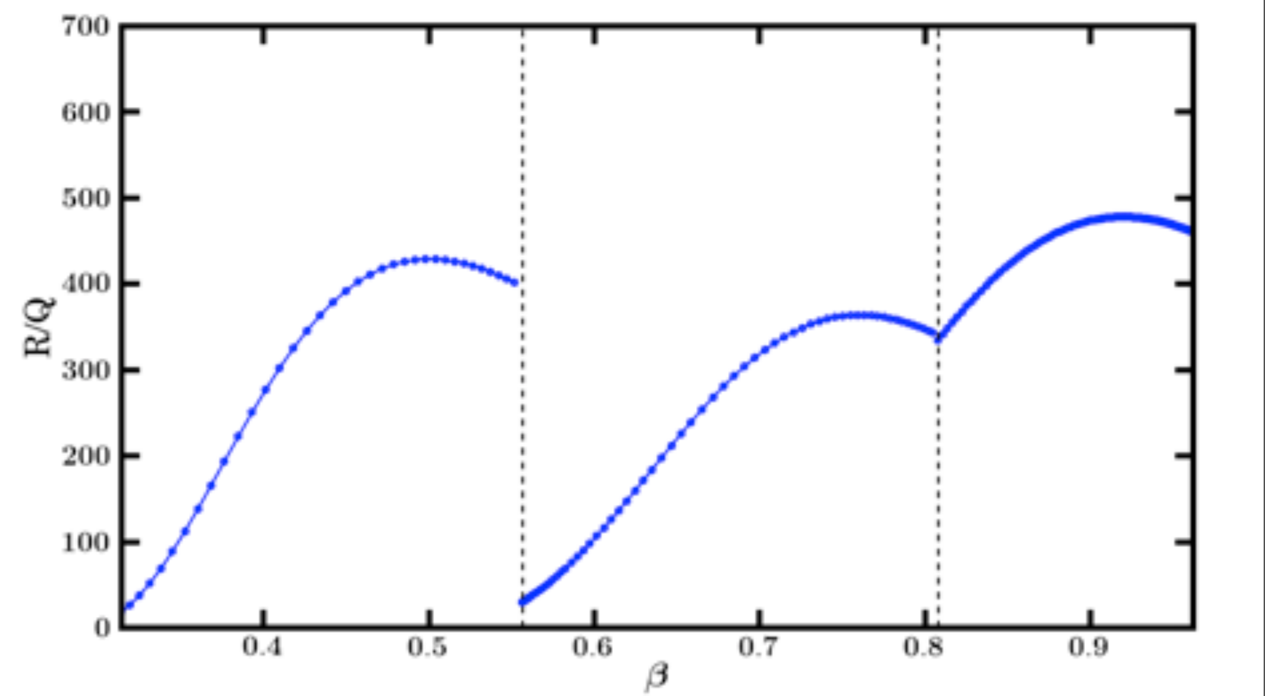

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PARASITIC MODES

MOTIVATION

Beam induced modes in SCRF cavities may drive the **beam unstable** and **increase the cryogenic load**, therefore **HOM couplers** are usually installed to provide sufficient damping.

.....However, recent experience at SNS has shown **couplers may be unnecessary** and have **degraded performance** of the machine.

Questions:
Will SOMs mean the cavity design needs to be changed?
Does ESS need HOM couplers?

- **Beam dynamics** → Simulations performed by myself
- **Power** → Simulations performed at CEA Saclay

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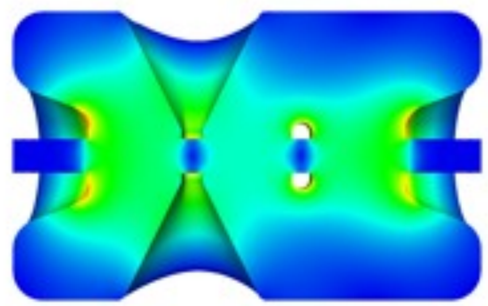
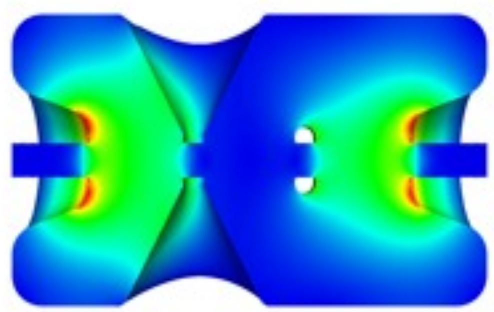
SAME ORDER MODES

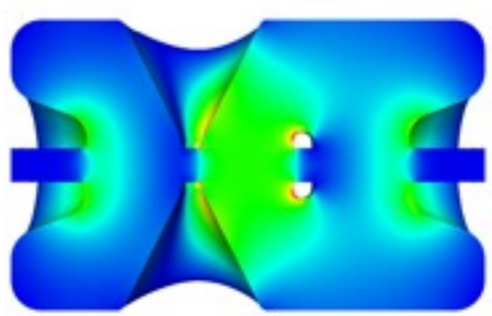
π-mode
352.21 MHz



0-mode
362.69 MHz

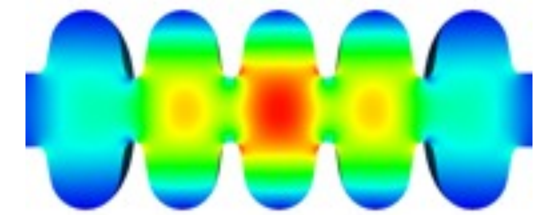


396.96 MHz

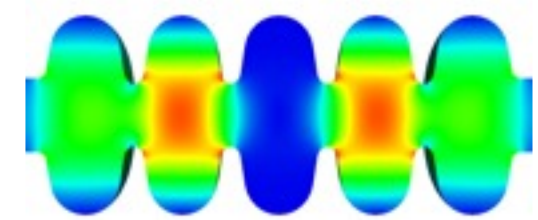


Part of
same passband as
fundamental

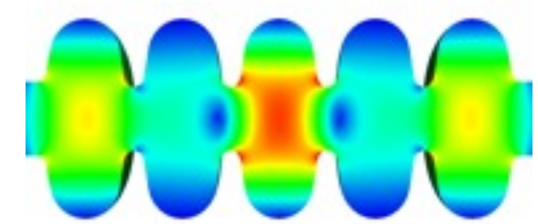
Same order, just
different phase
advance



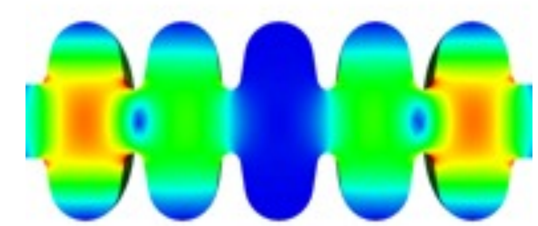
π/5 - mode
693.19 MHz



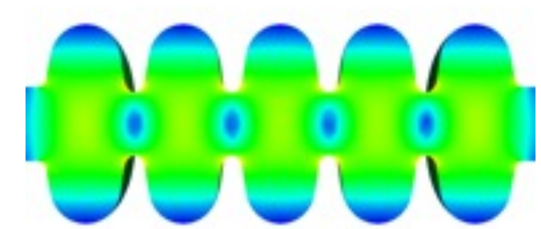
2π/5 - mode
696.30 MHz



3π/5 - mode
700.14 MHz



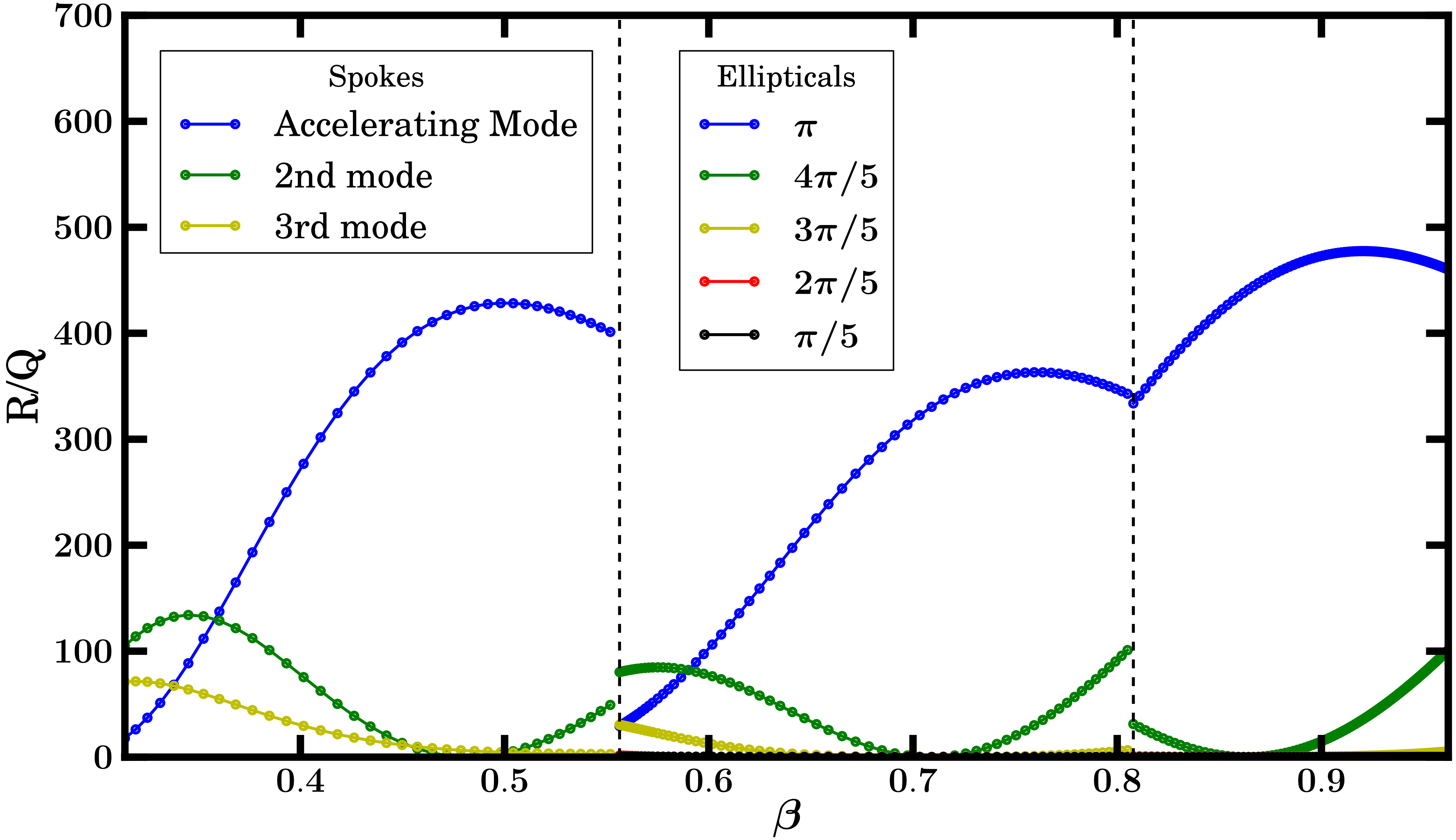
4π/5 - mode
703.2 MHz



π - mode
704.42 MHz

Close in frequency to accelerating mode
➡Cannot damp using couplers

SAME ORDER MODES



High R/Q with respect to accelerating mode

- ➡Modify geometric beta
- ➡Alter velocity partitioning

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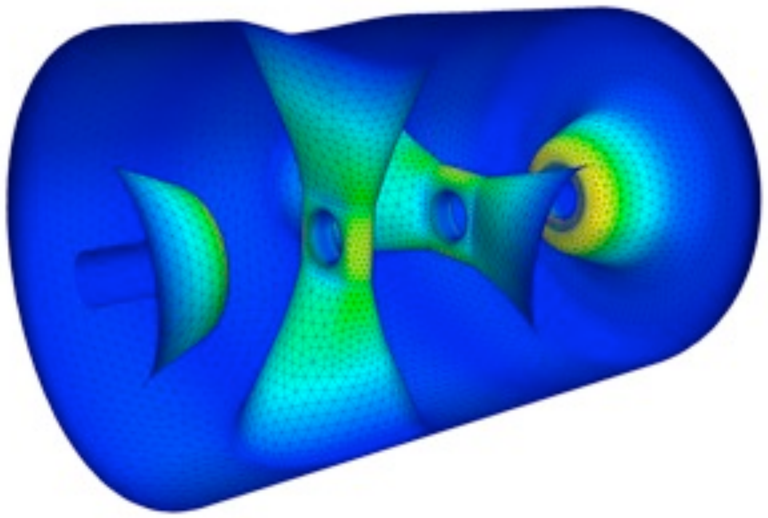
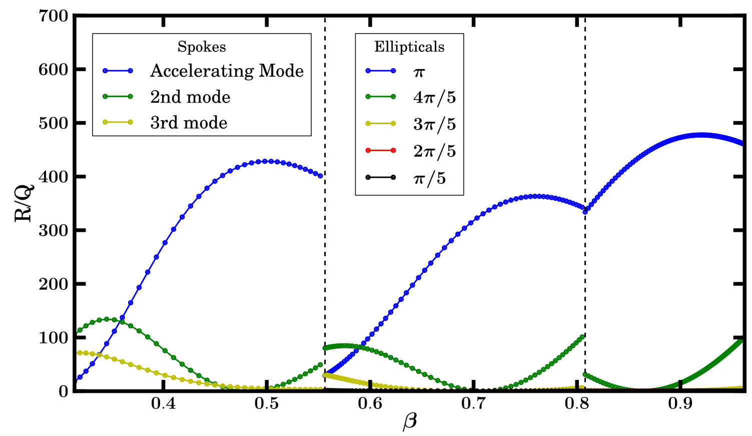
SIMULATION INFO

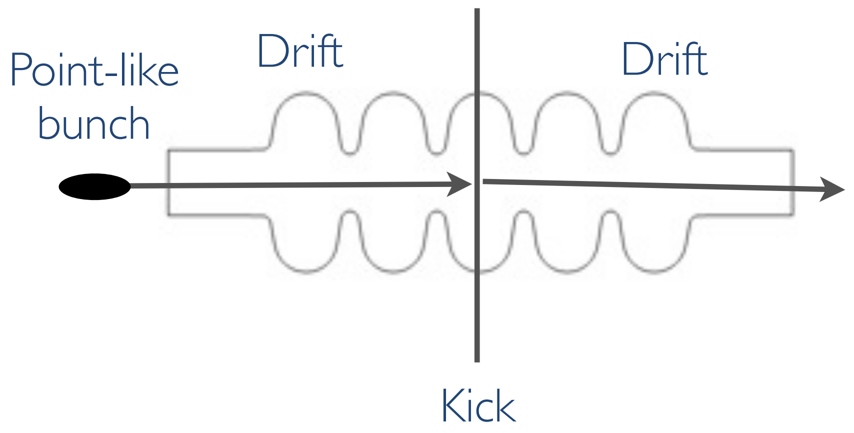
Simulate cavity geometries to extract field-maps

Determine R/Q, frequencies of modes below cutoff

Calculate the influence of modes of beam quality







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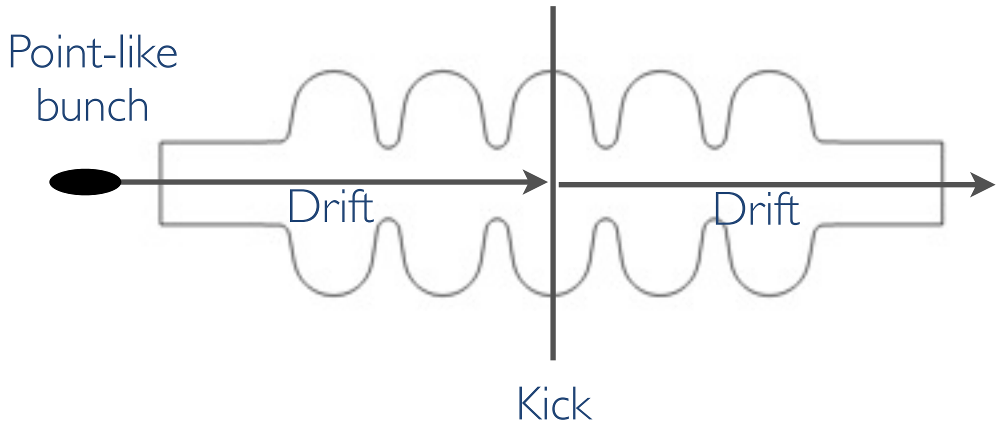
SIMULATION INFO



Energy and time error calculated at each cavity with respect to synchronous bunch

$$\Delta E^{(m+1)} = \Delta E^{(m)} + \Delta U_{RF}^{(m)} + \Delta U_n^{(m)}$$

$$\Delta t^{(m+1)} = \Delta t^{(m)} + (dt/dE)_E^{(m)} \cdot \Delta E^{(m)}$$

- 1 million point-like bunches tracked per linac
- SOM/HOM frequencies distributed with a gaussian spread
- $\sigma = 1.09 \times 10^{-3}.|f_0 - f_{hom}|$

$$\Delta U_n = q(\Re(V_n)\cos(\omega_n dt) - \Im(V_n)\sin(\omega_n dt)) - \frac{1}{2}\Delta V_{q,n}$$

$$\Delta V_{q,n} = -q\frac{\omega_n}{2}(R/Q)_n(\beta)$$

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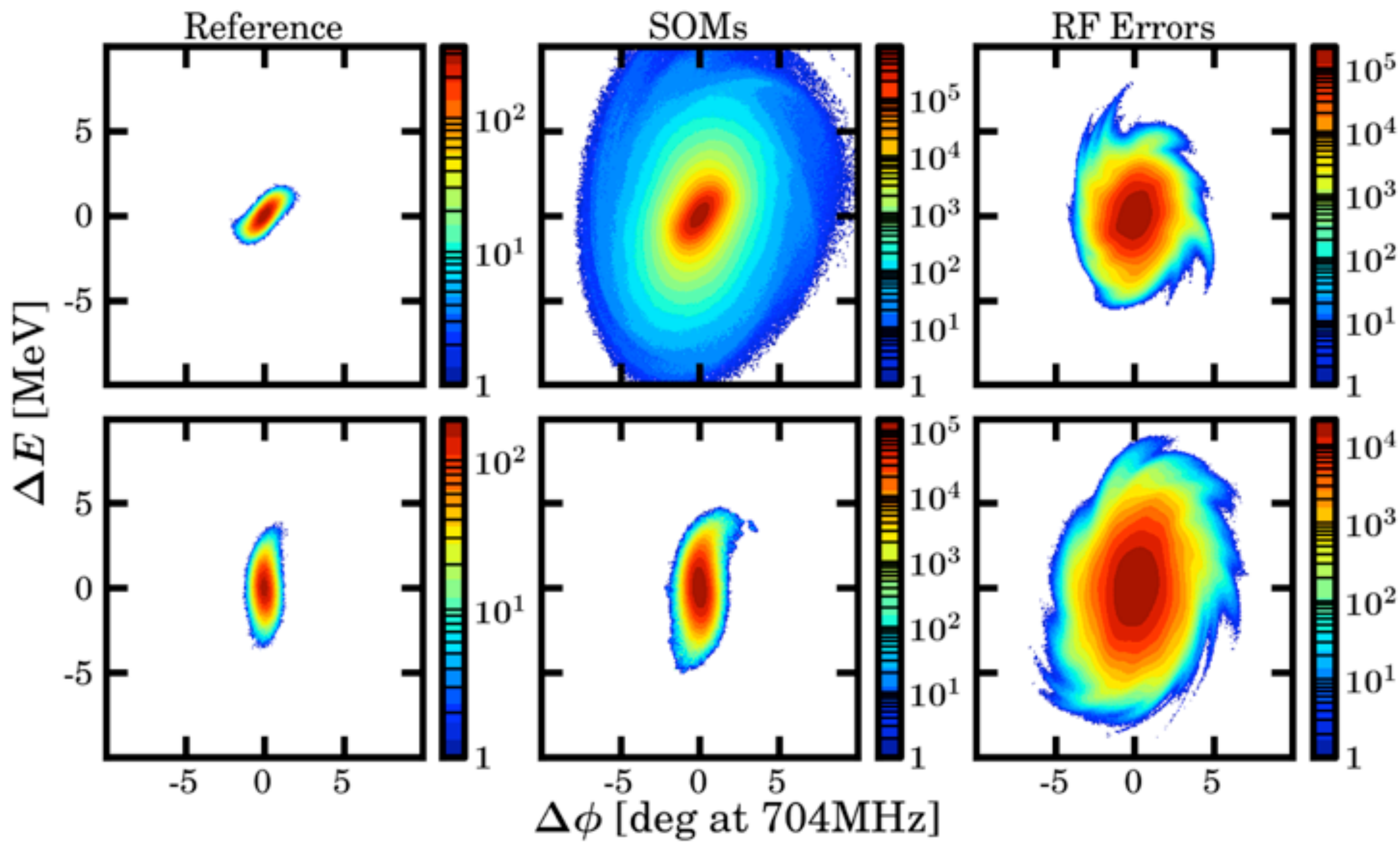
COMPARISON OF LINACS



It is possible to design a linac susceptible to SOMs however the latest baseline shows no adverse effects

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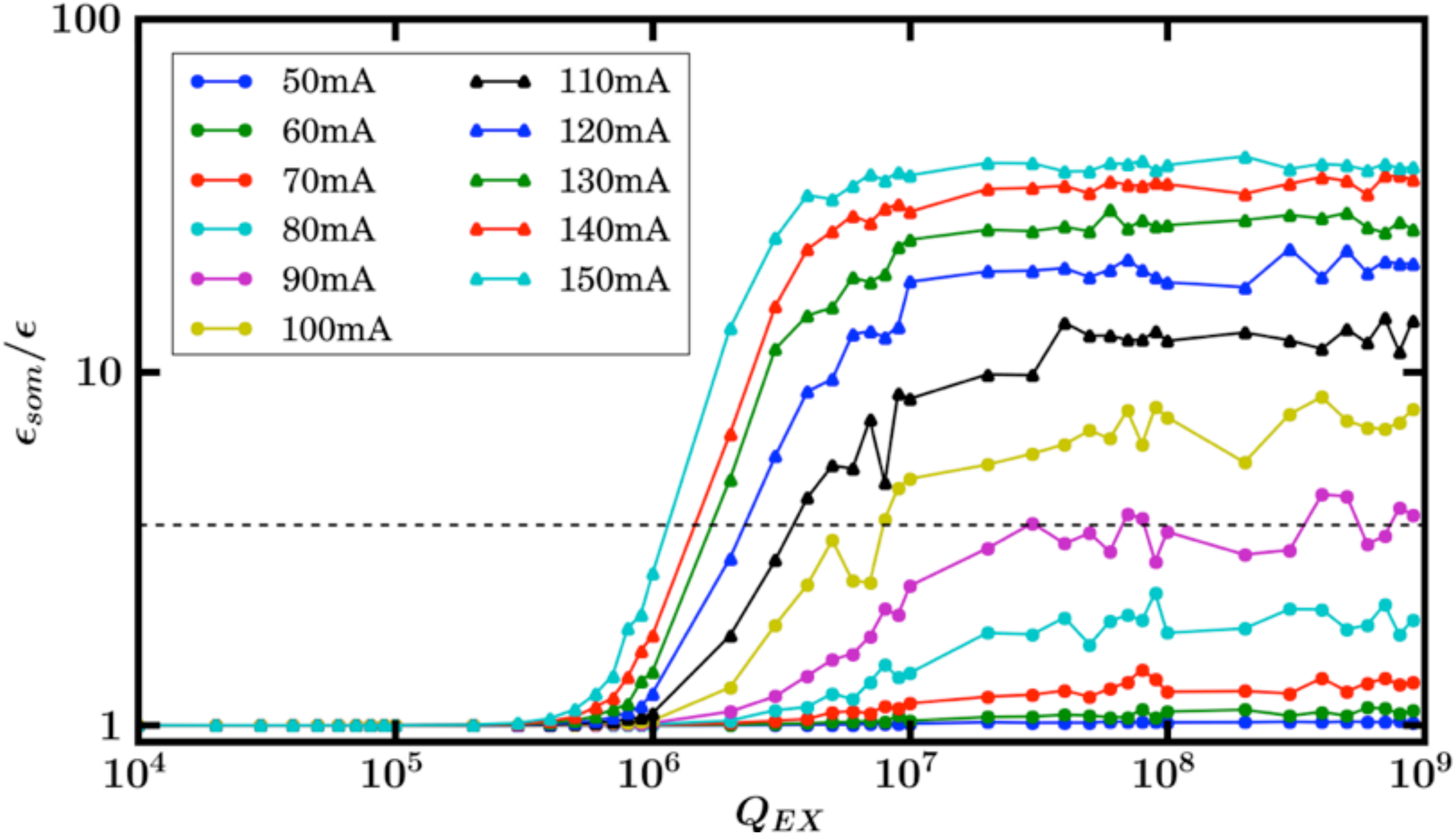
CURRENT & DAMPING SCAN

$$T_{d,n} = 2Q_{L,n}/\omega_n \approx 2Q_{EX,n}/\omega_n$$



SOMs start to become problematic at ~90 mA

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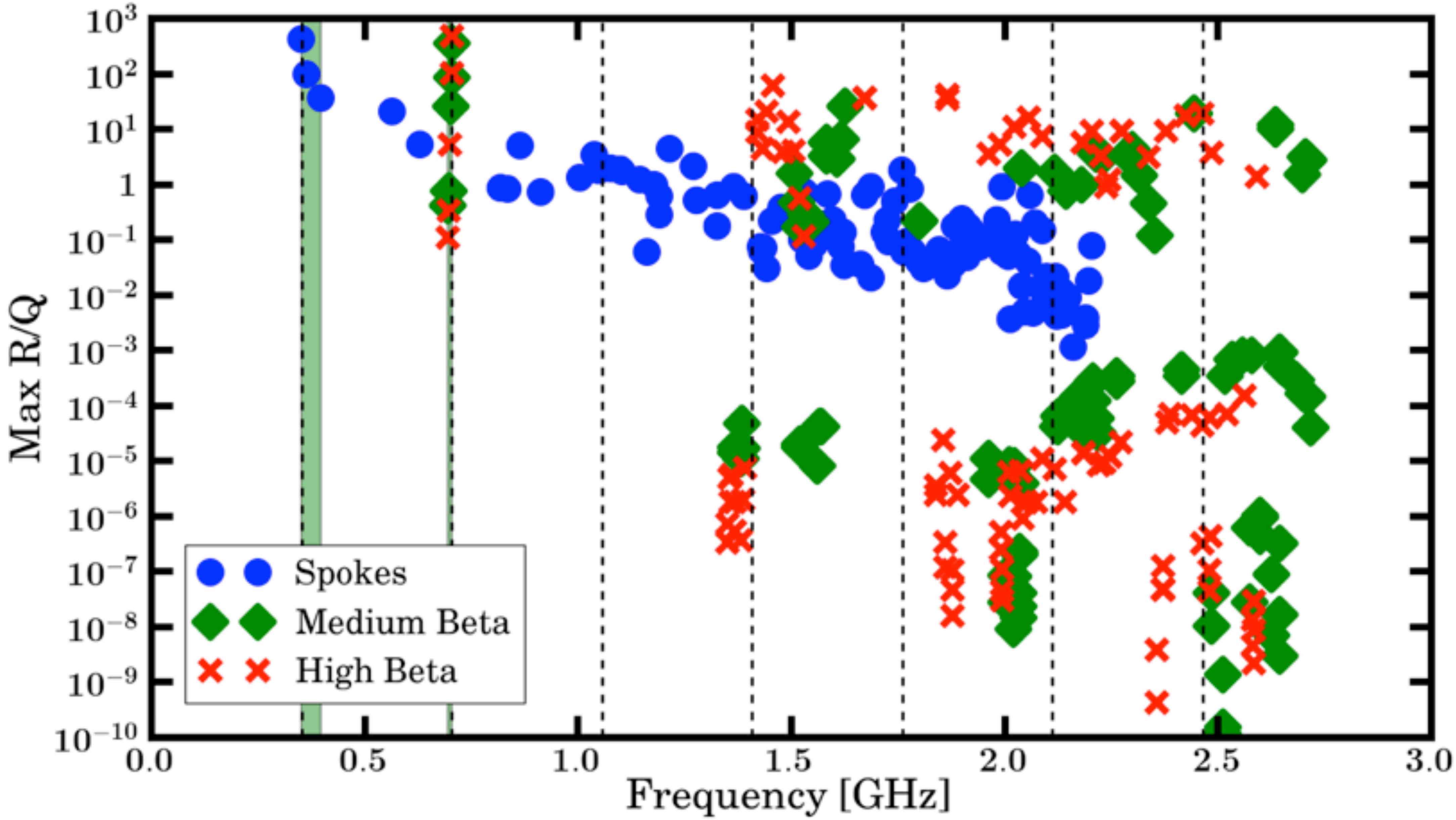
HIGHER ORDER MODES



Need to determine if HOMs are a problem

Are HOM couplers needed?

$$f_{ML} = n \cdot 352.21\text{MHz}$$

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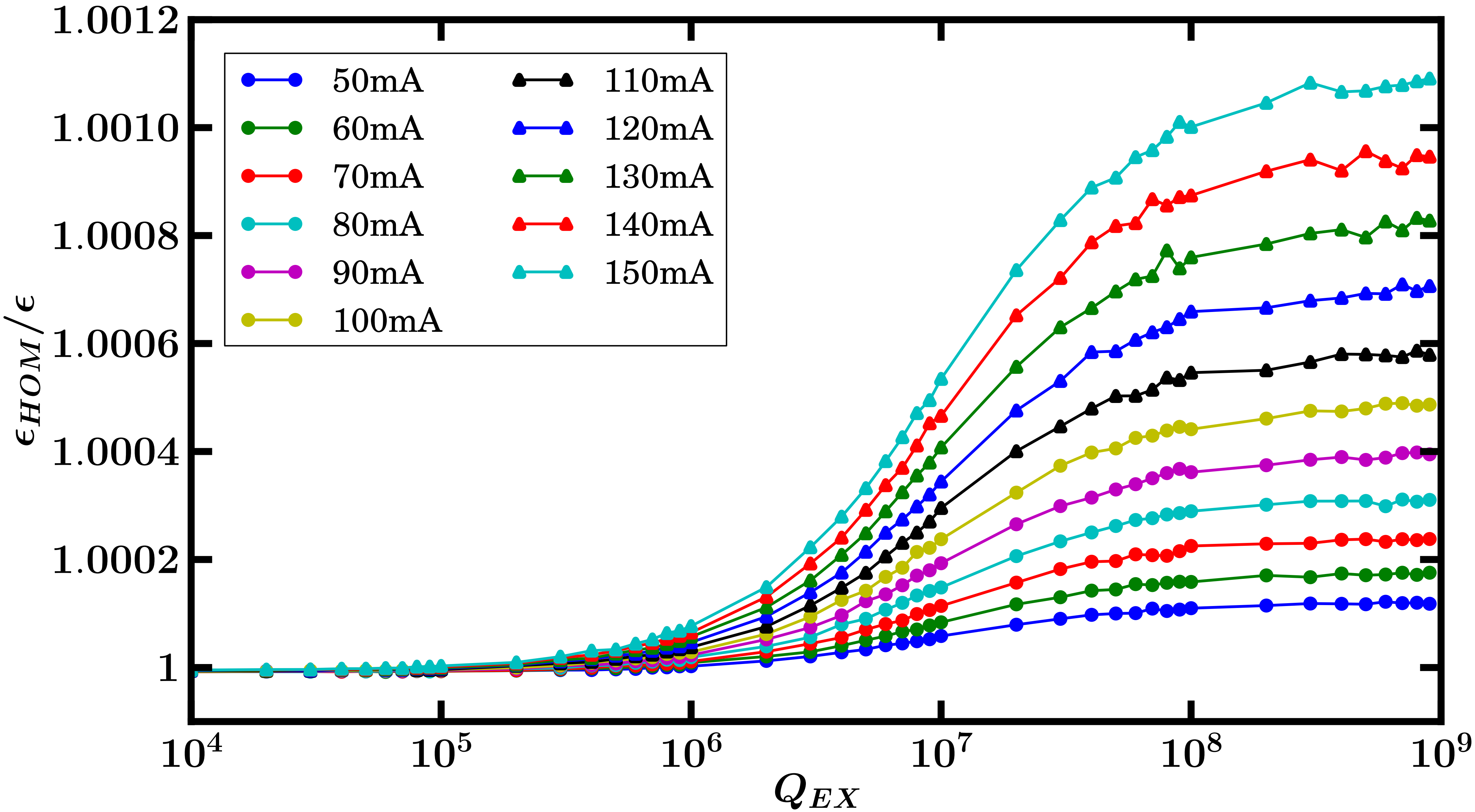
CURRENT & DAMPING SCAN



Away from a machine line, HOMs are of no concern

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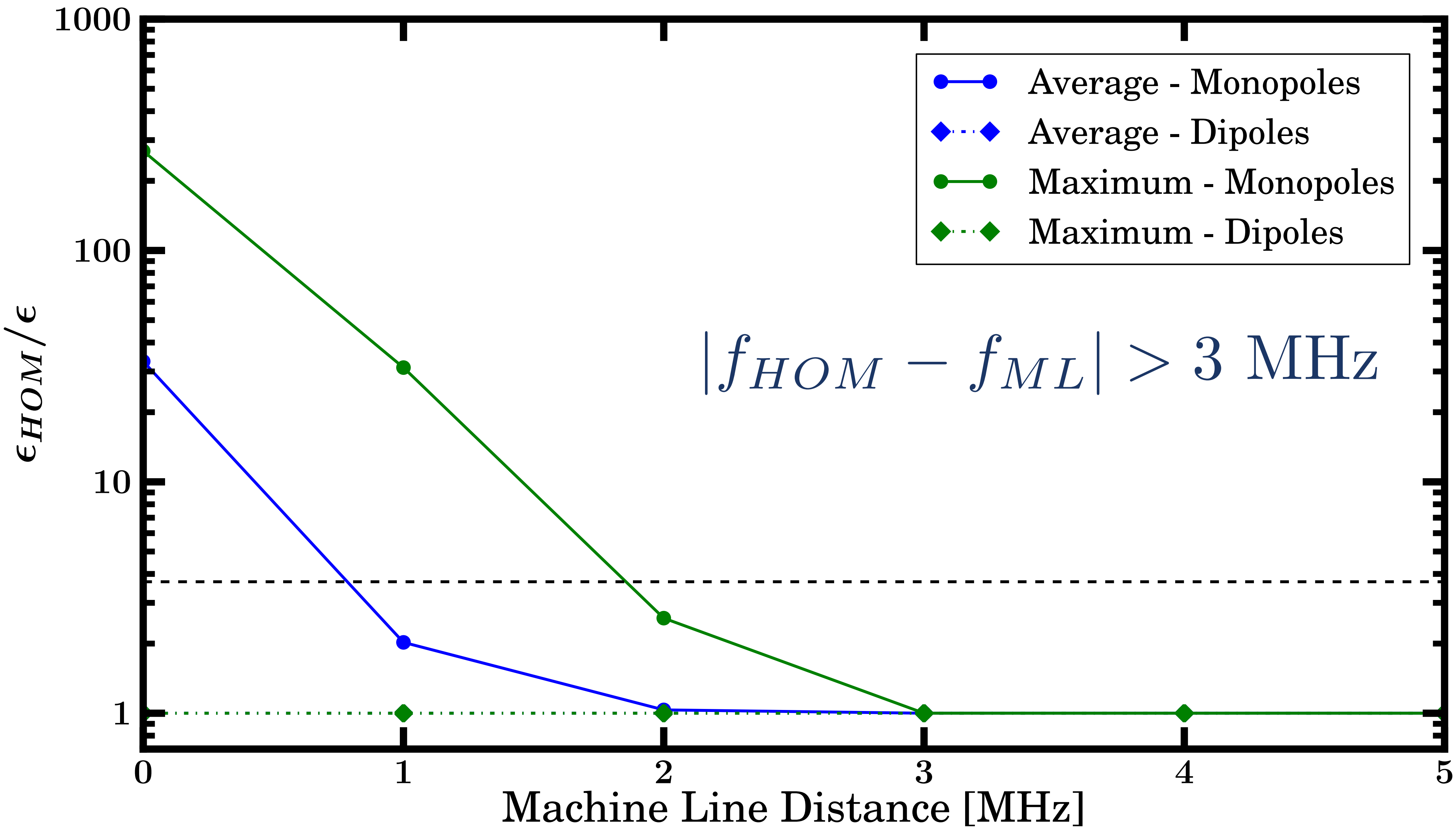
SAFE DISTANCE



HOMs should be at least 3 MHz away from a machine line in cavity design

$$f_{ML} = n \cdot 352.21\text{MHz}$$

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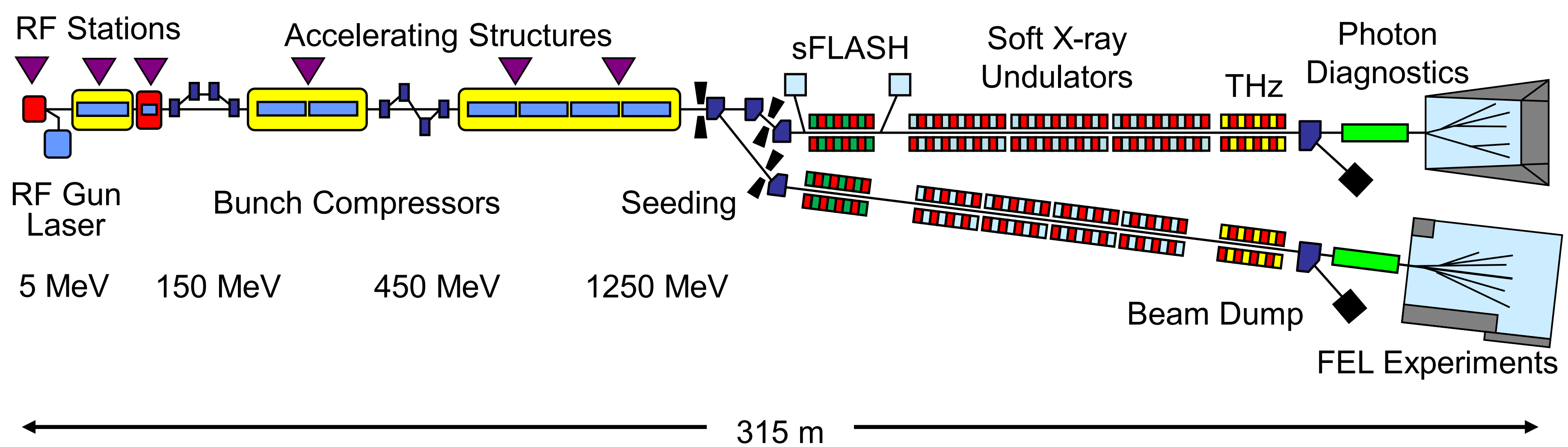
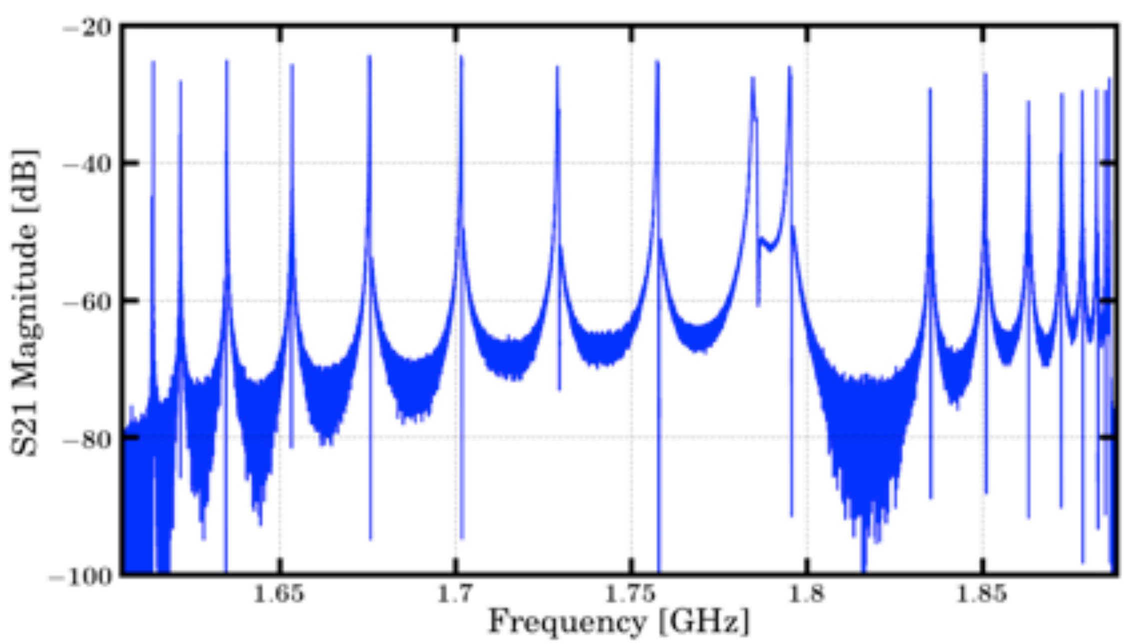
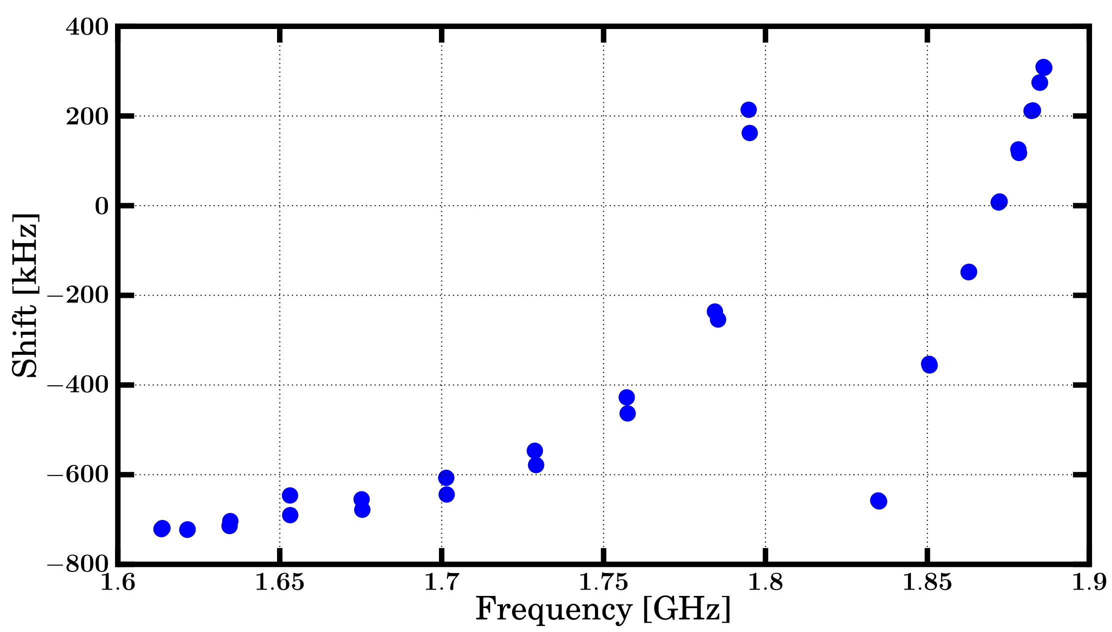
DETUNING STUDIES







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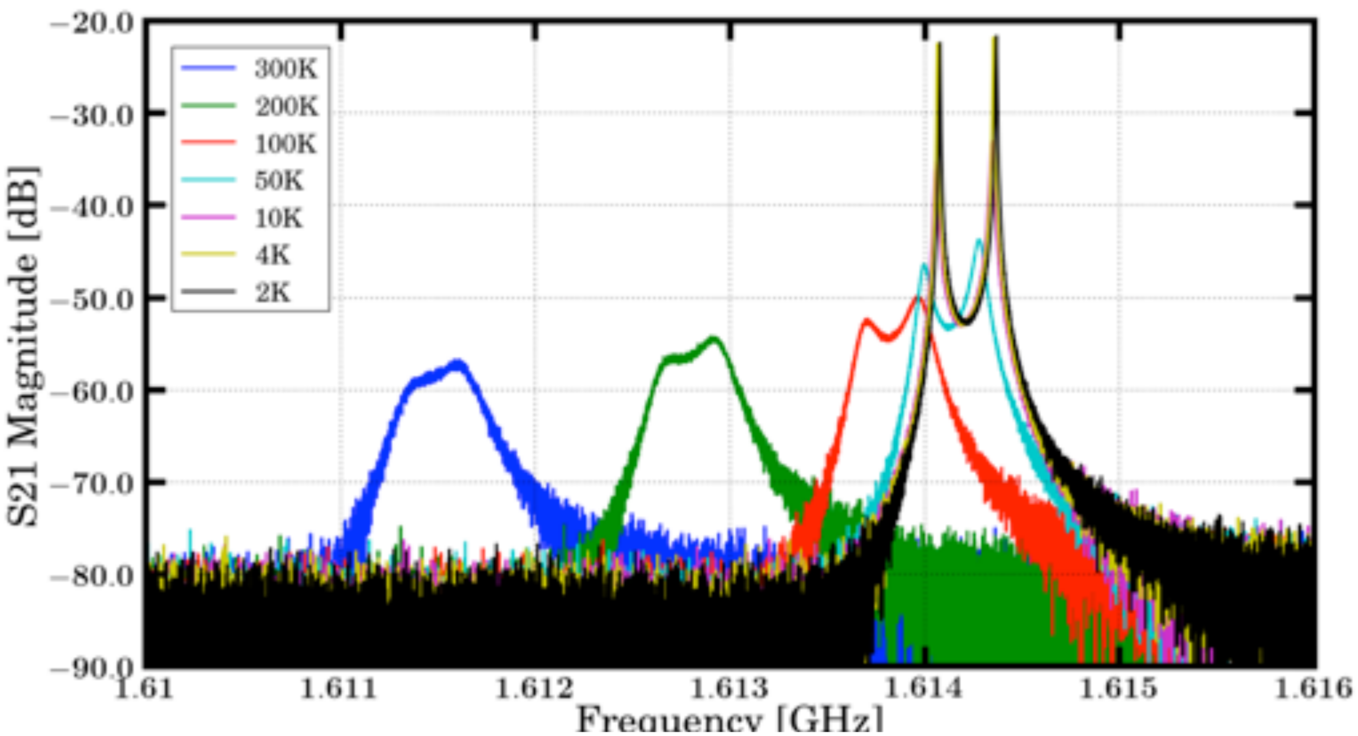
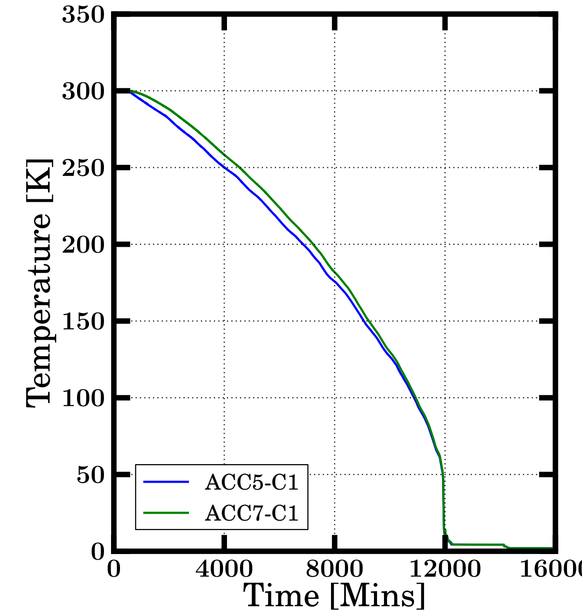
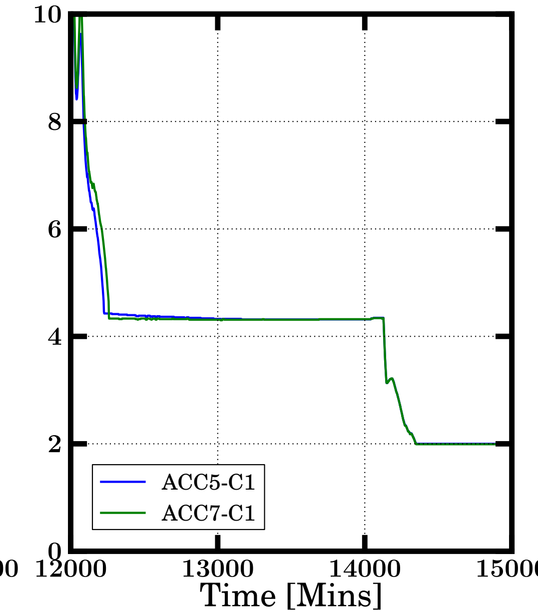
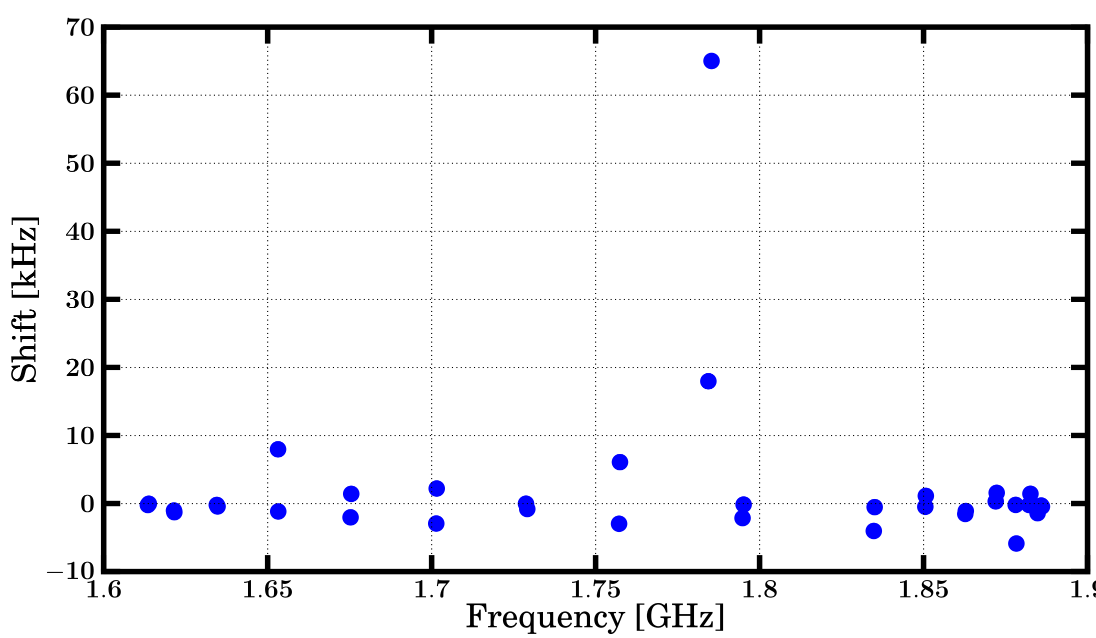
WARMUP, COOLDOWN AND RETUNED









Total shift after all procedures on the order of a few kHz

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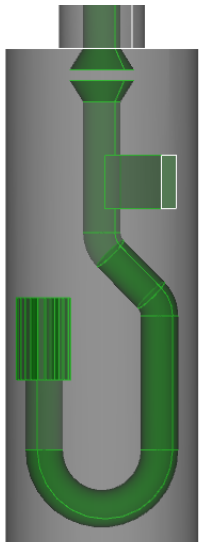
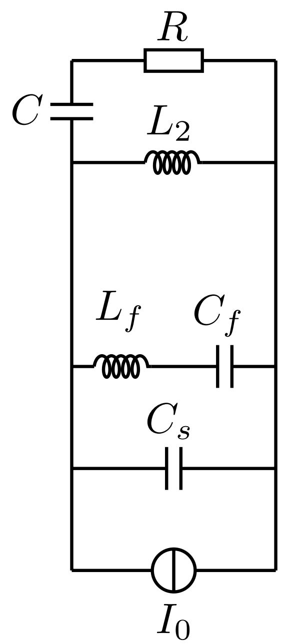
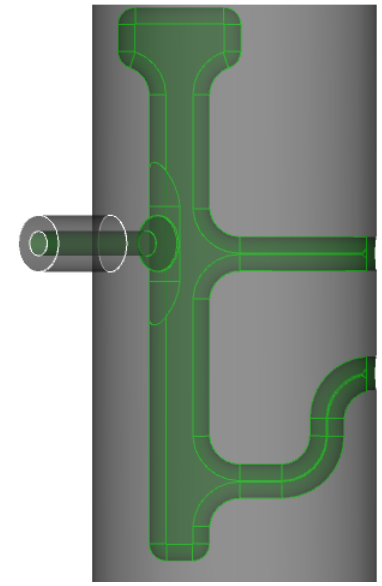
HOM COUPLER STUDIES

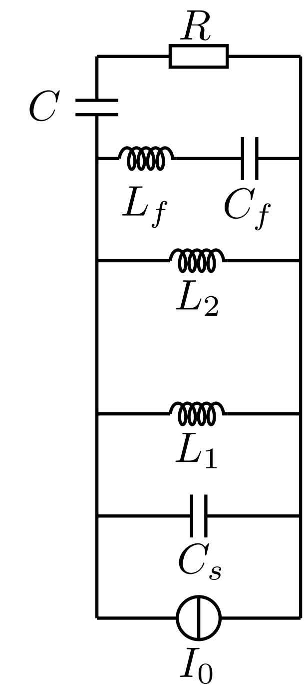
INITIAL DESIGNS



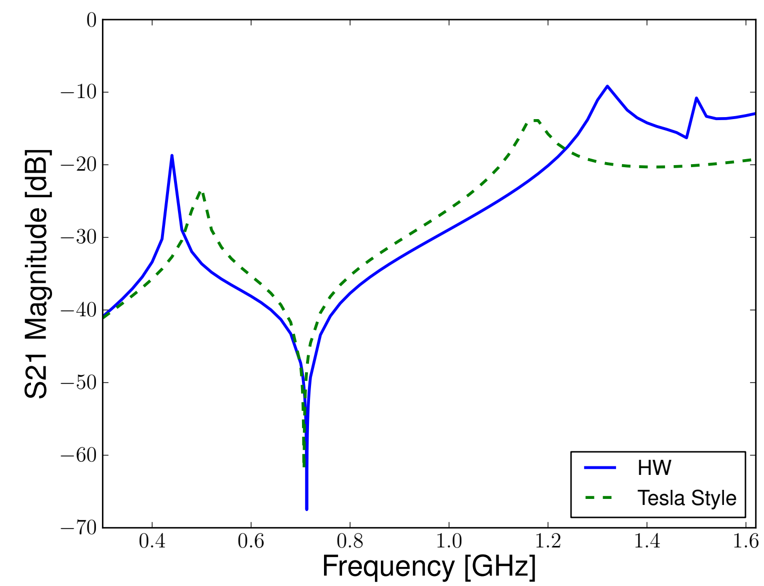


Designed by Rostock University (C. Potratz, H.W. Glock)





Rescaled SNS coupler (R. Calaga)



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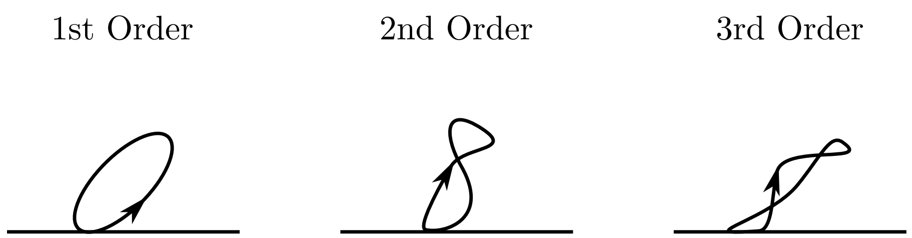
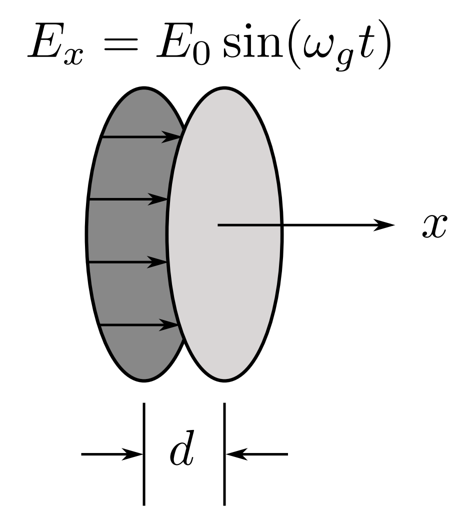
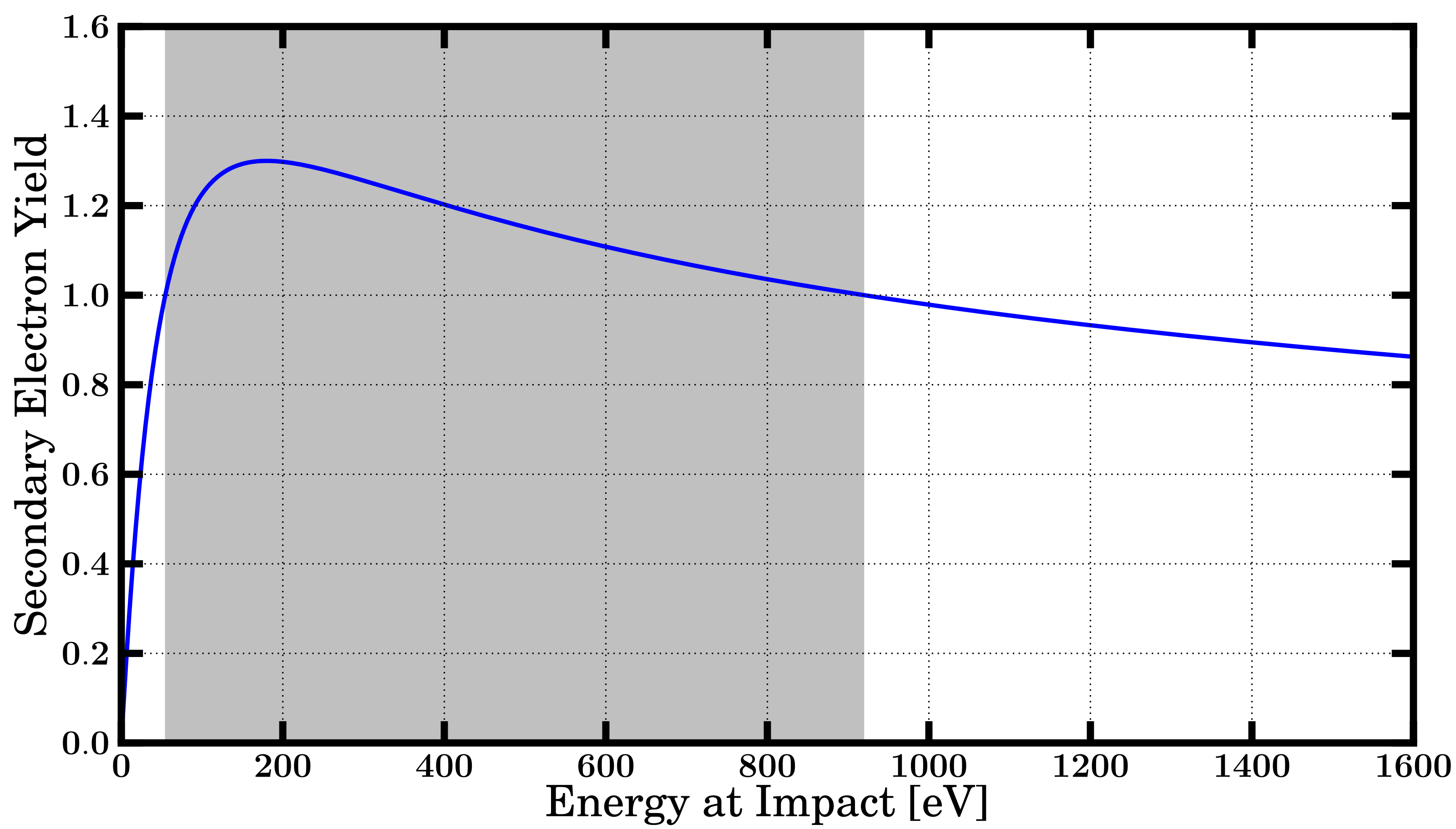
MULTIPACTING

One point



Two point





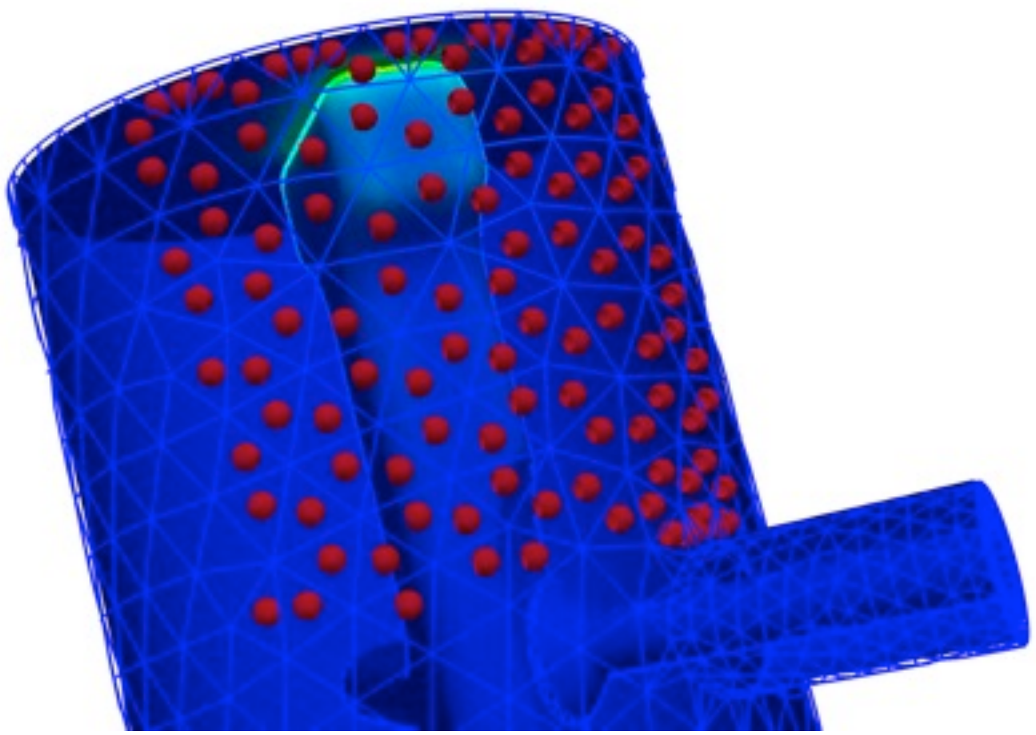
TRACK3P

Define bounding box for emission

Particles emitted from centre of mesh elements within box

Occurs every 3.6° for 1 RF cycle

Particles tracked for a further 19 RF cycles



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TRACK3P

Upon impact with a surface

If phase conditions correct

Particle re-emitted normal to surface at 2eV

Particle survives more than 4 impacts

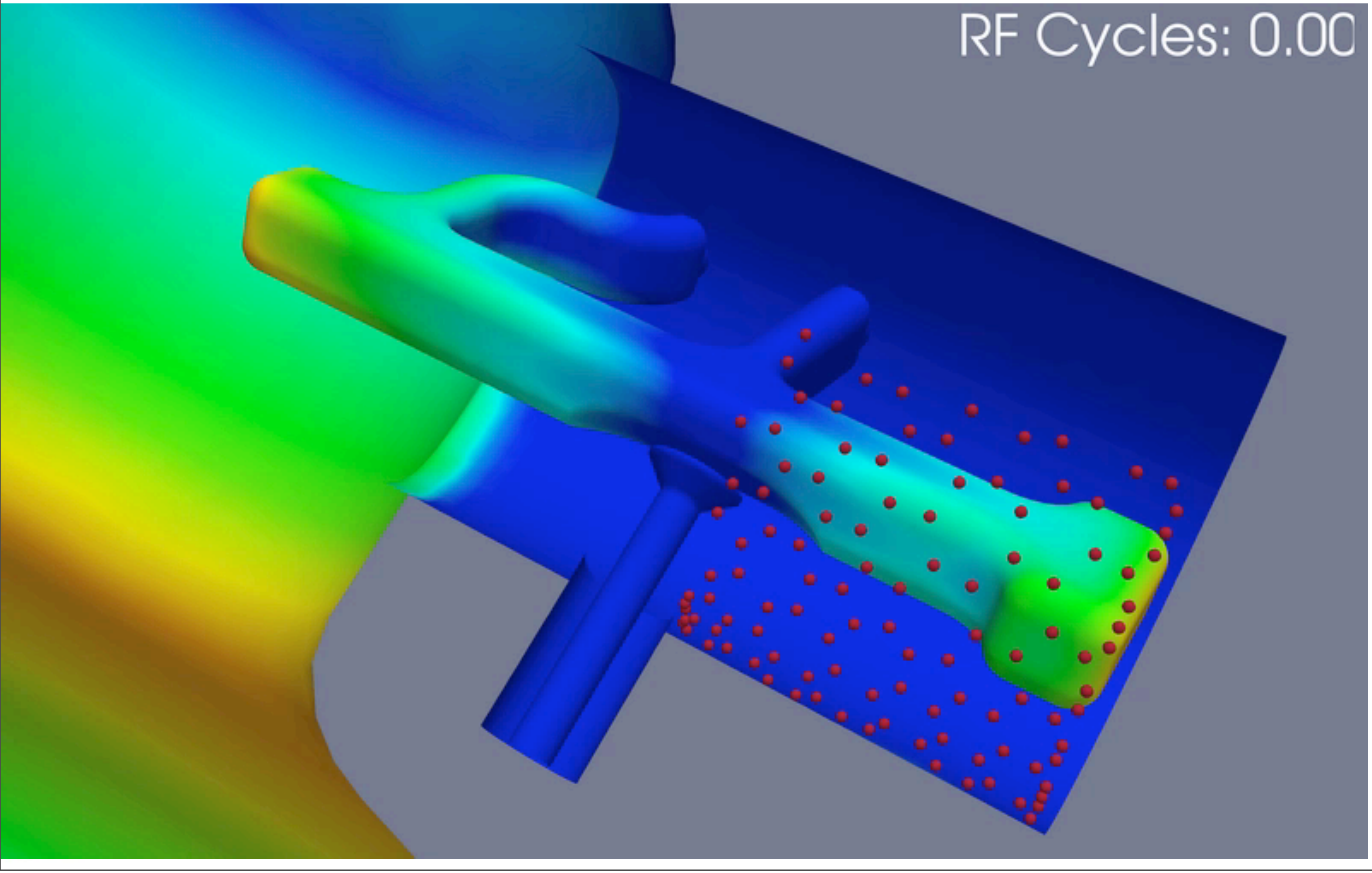
↓

RESONANT

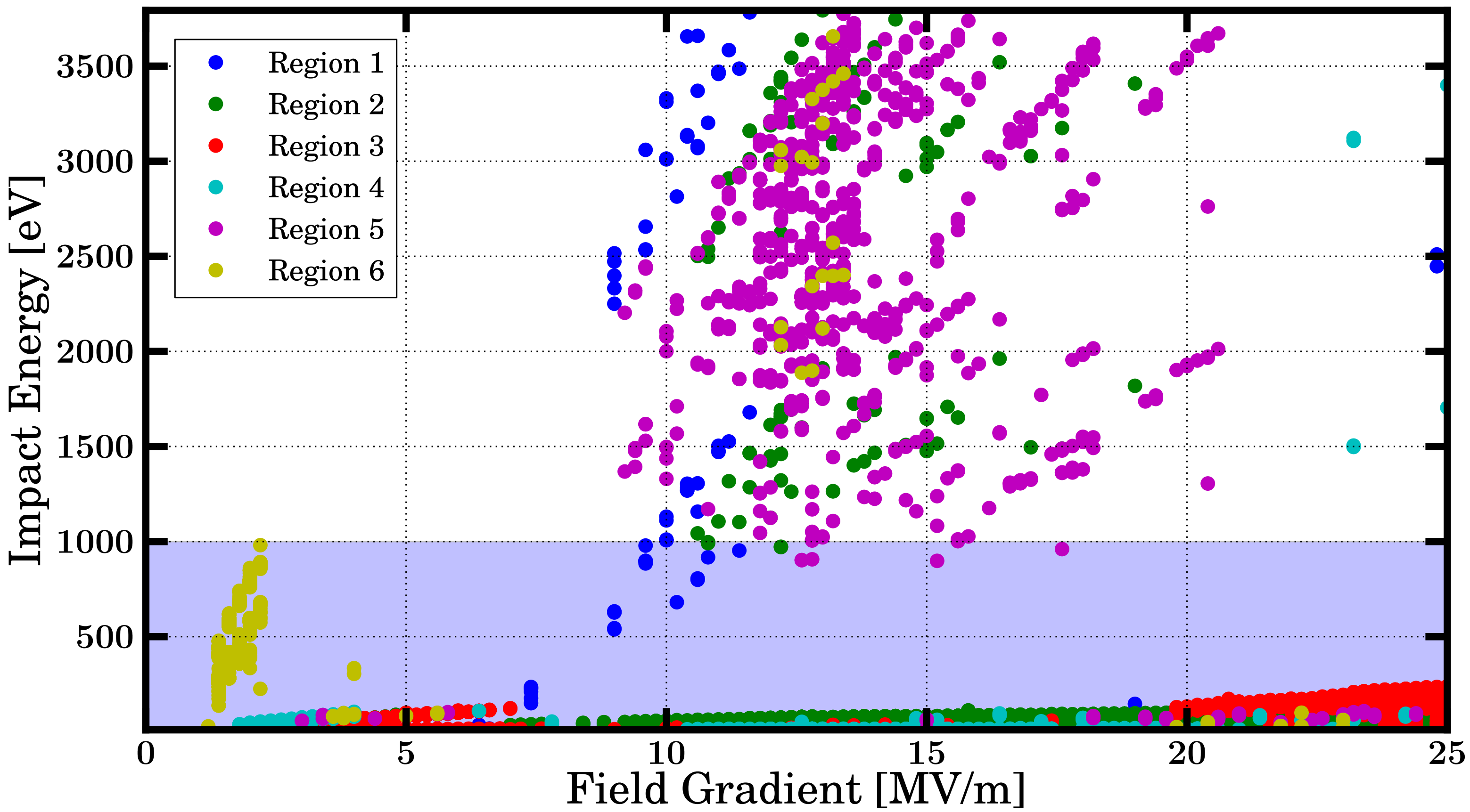
Note: 20RF cycles means cannot resolve trajectories higher than 5th order

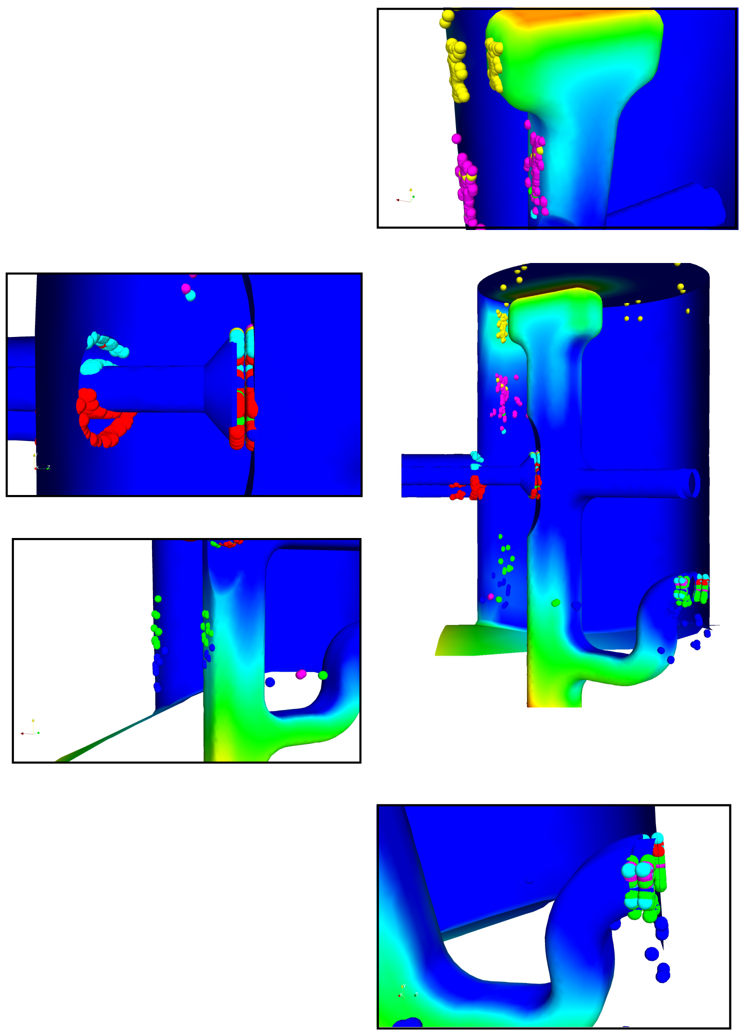
MULTIPACTING

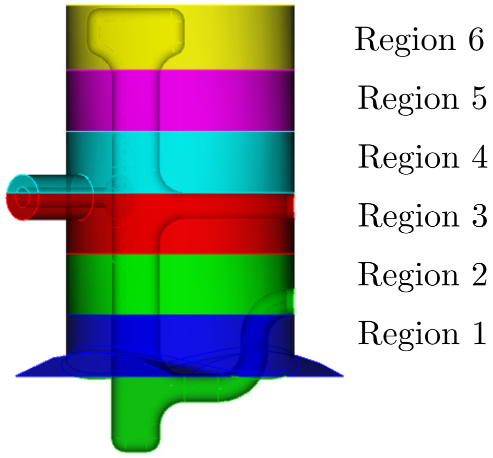
http://twiki.ph.rhul.ac.uk/twiki/pub/PP/Public/RobAinsworthRCDesign704/RC-Coupler-highQuality.mov



MP IN TESLA STYLE







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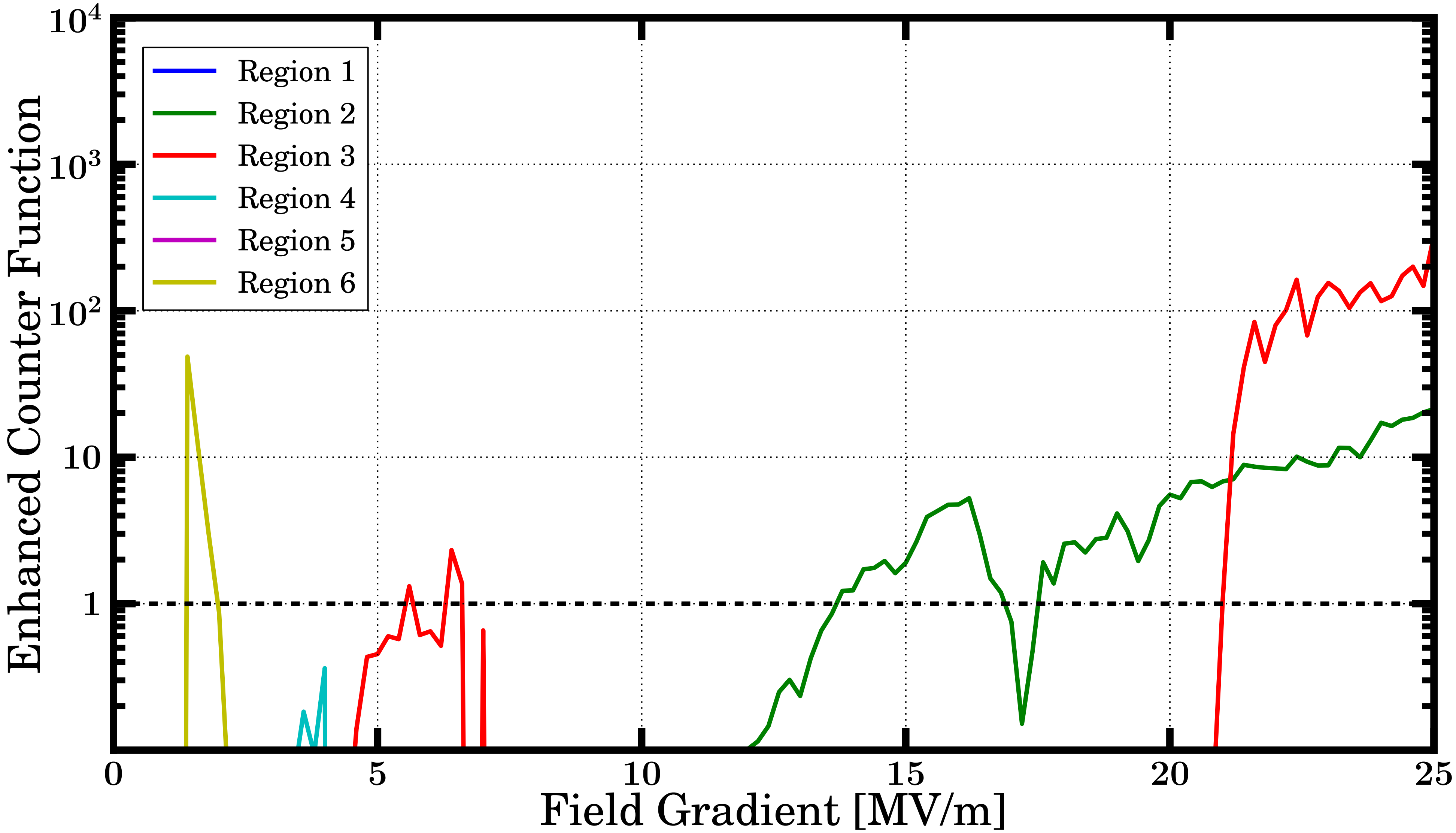
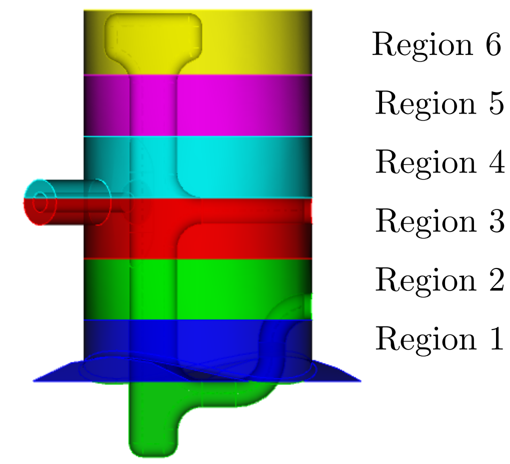
MP IN TESLA STYLE





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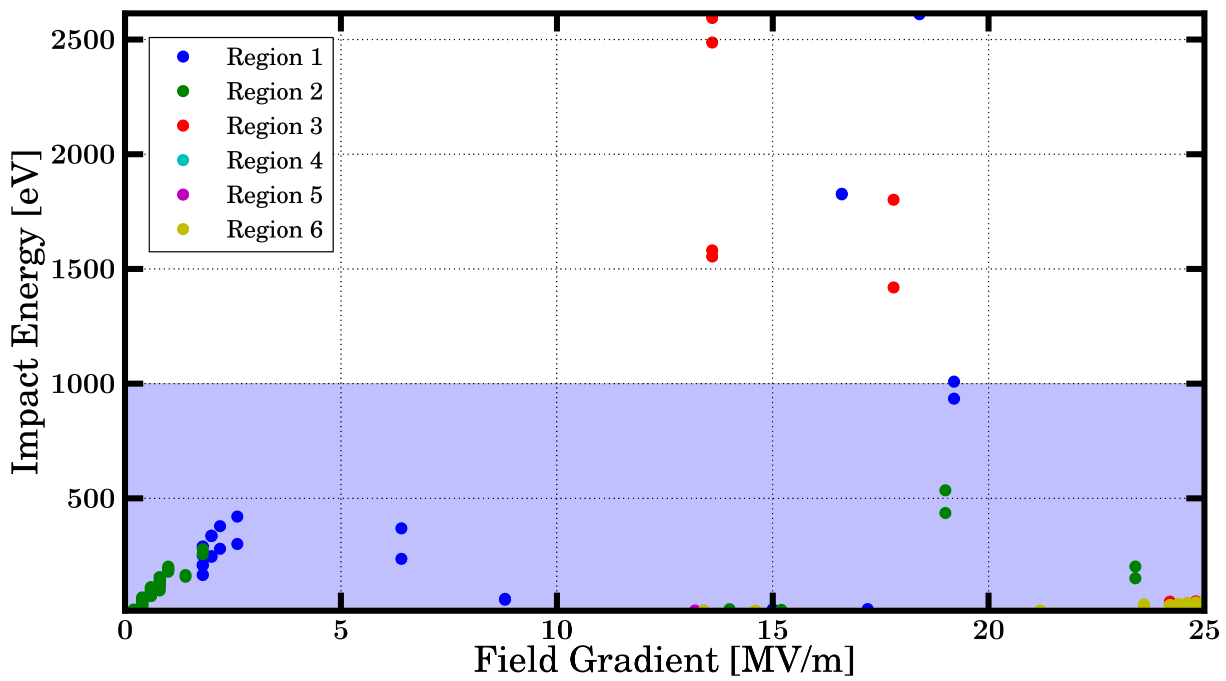
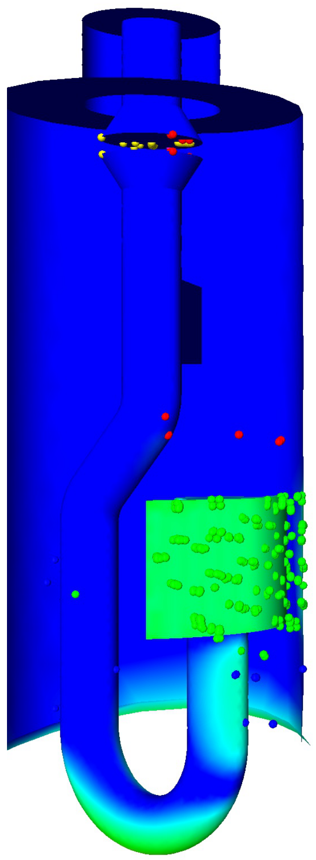
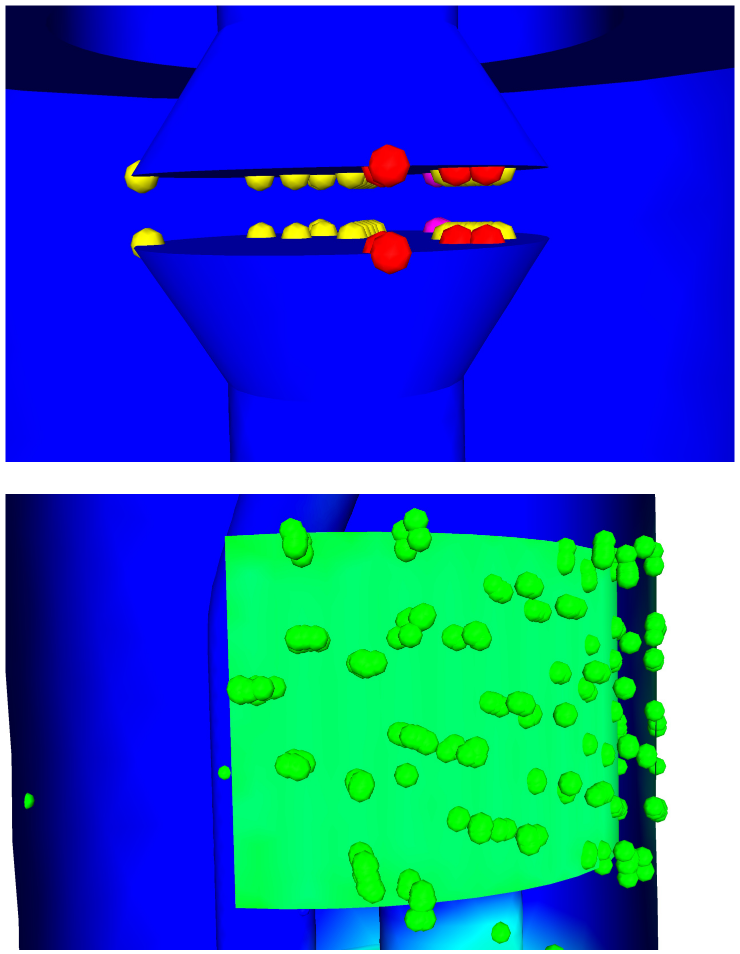
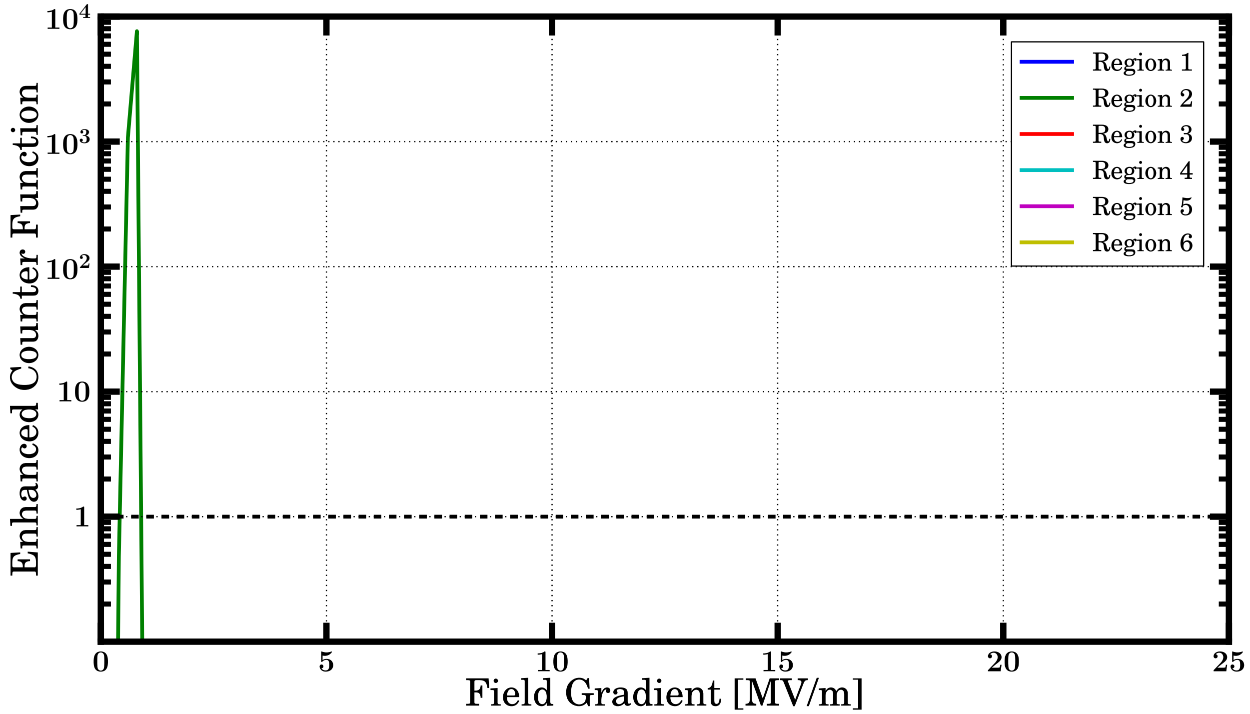
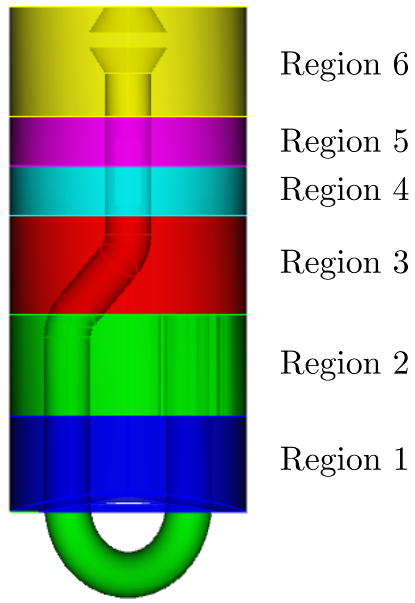
MP IN ROSTOCK DESIGN





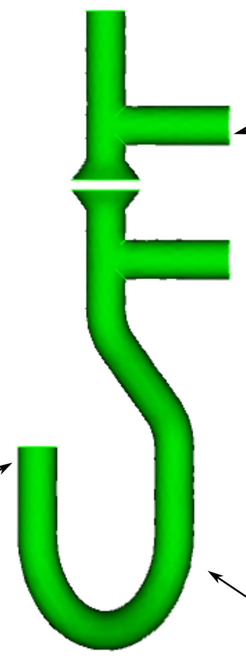


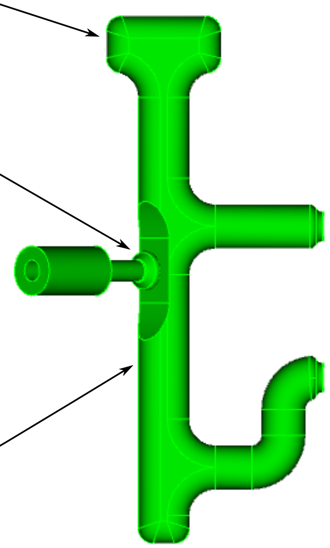


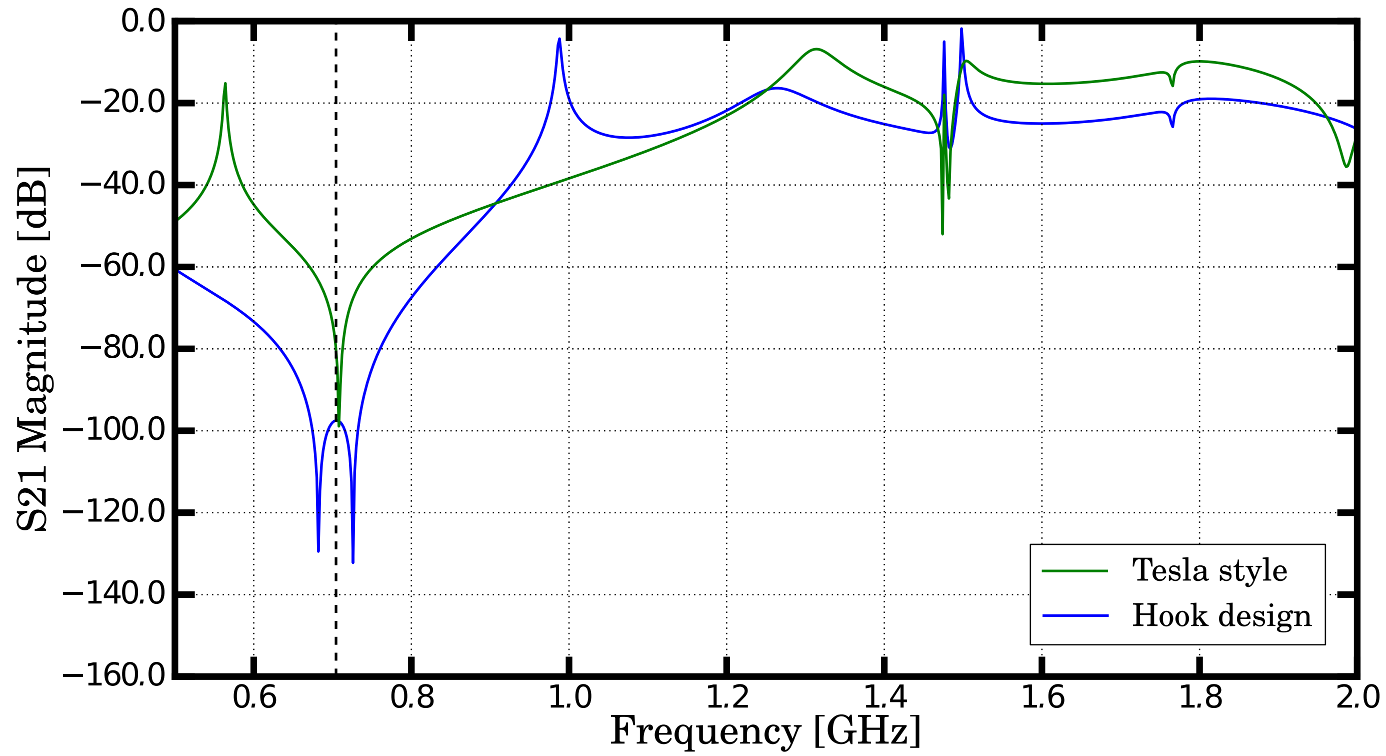


Thursday, 15 May 2014

MODIFICATIONS







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SUMMARY

- SOMs
  - It is possible to design a linac susceptible to SOMs
  - May baseline shows no problems up ~90 mA
- HOMs
  - High R/Q modes are not a concern far from ML
  - $|f_{hom} - f_{ml}| > 3$ MHz
  - HOM Couplers are not required!
    - ➡Limits future flexibility (chopping schemes > 100kHz)
- Modified HOM couplers to reduce multipacting

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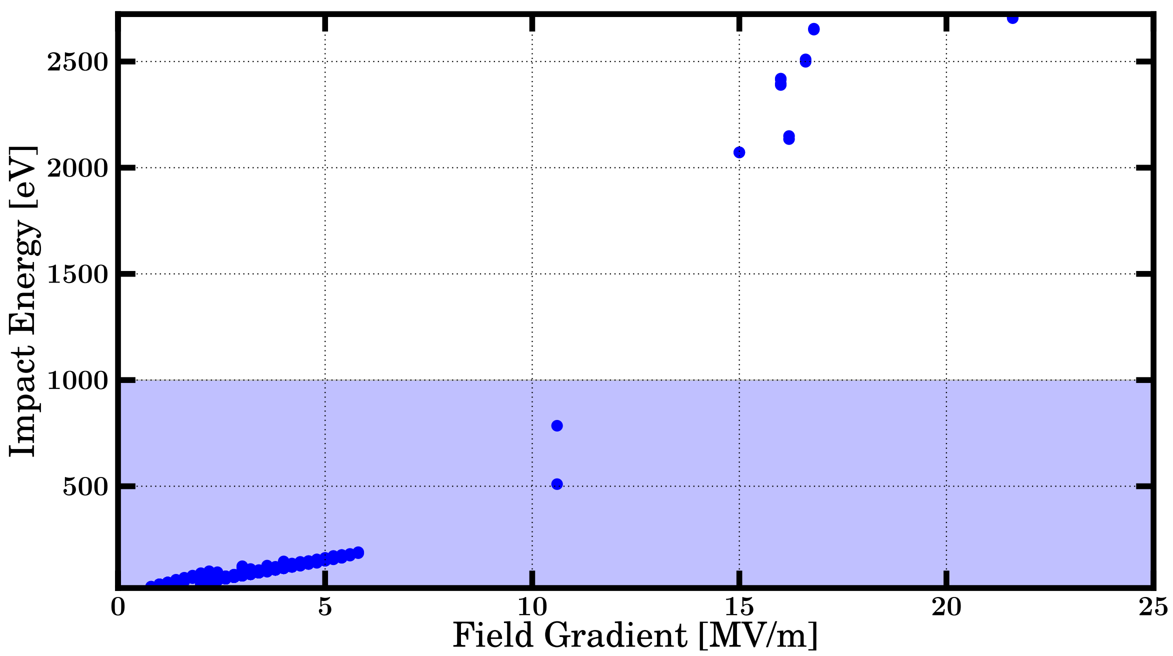
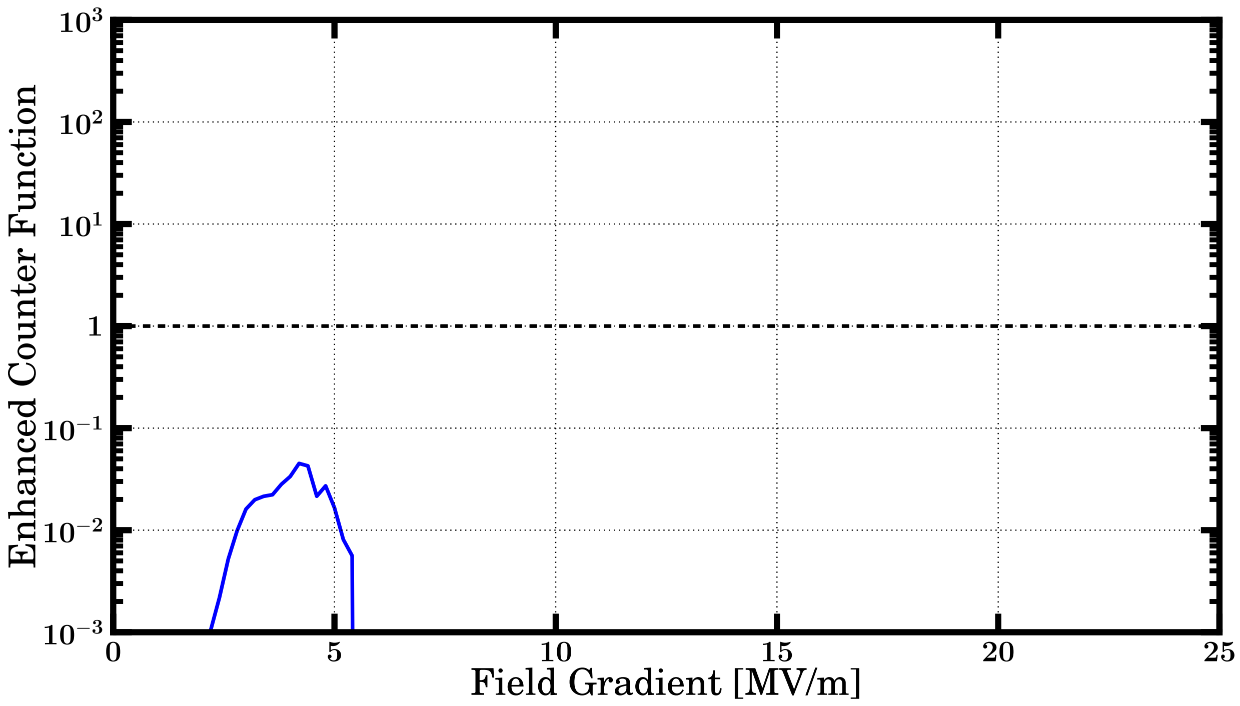
MODIFIED HOOK





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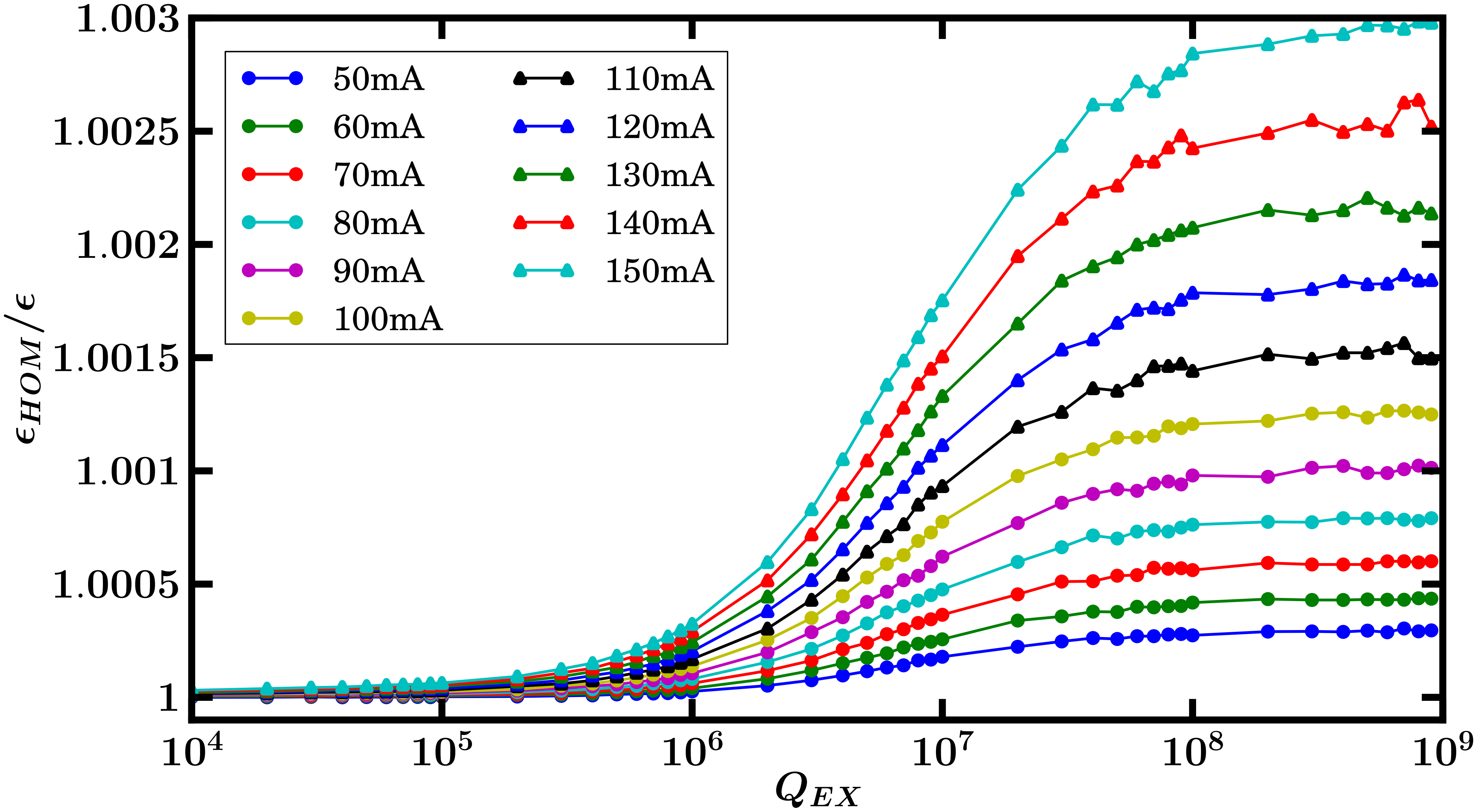
TRANSVERSE



1.003
1.0025
1.002
1.0015
1.001
1.0005
1
ϵ_{HOM}/ϵ
10^4
10^5
10^6
10^7
10^8
10^9
Q_{EX}
50mA
60mA
70mA
80mA
90mA
100mA
110mA
120mA
130mA
140mA
150mA