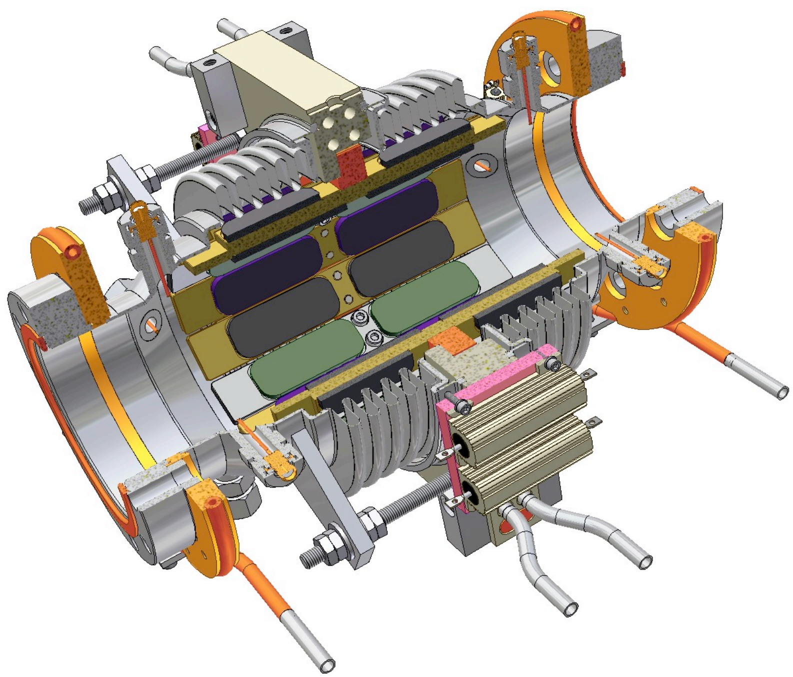
Higher-Order-Mode Damping in SRF Cavities



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Matthias Liepe, Cornell University
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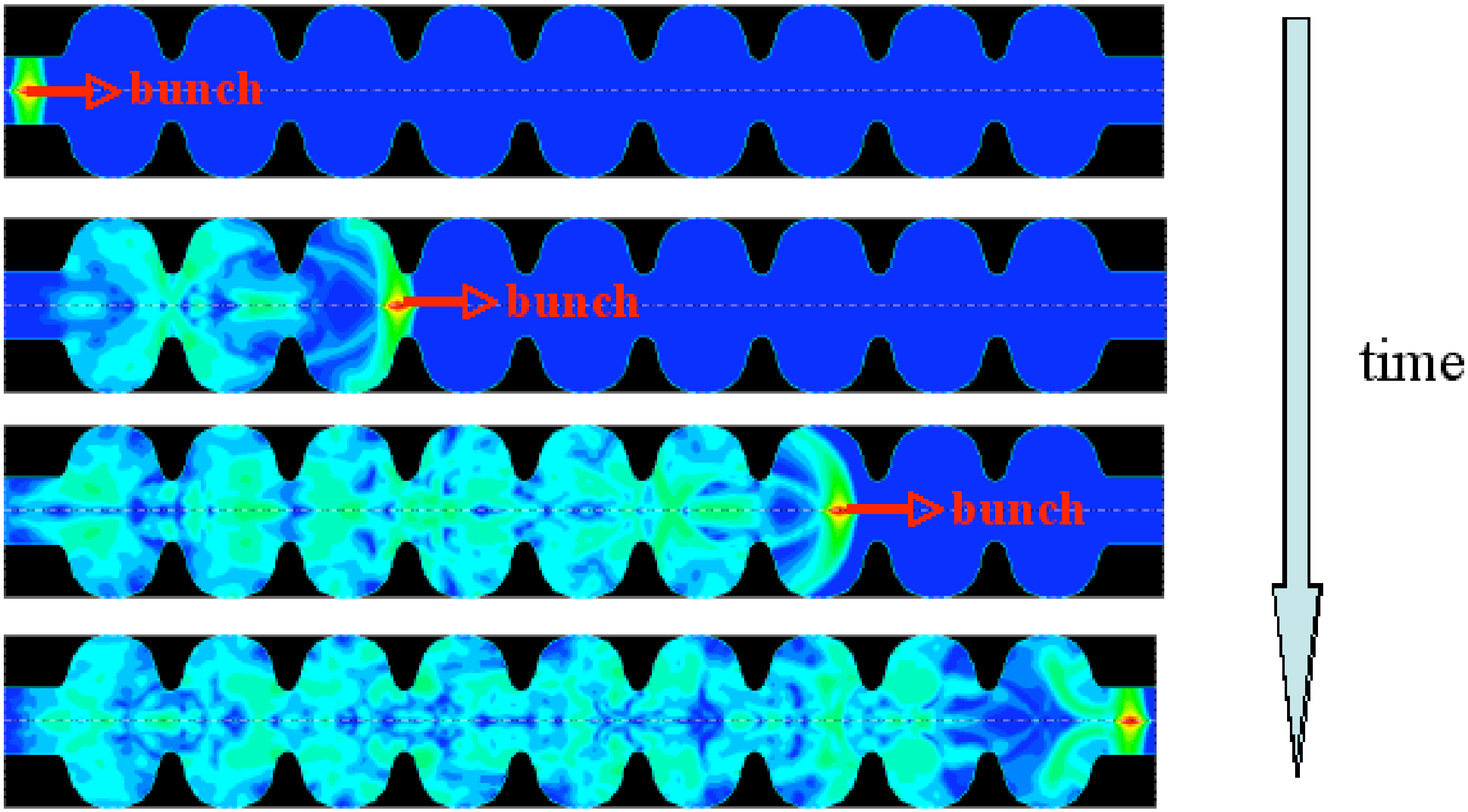
New York State Section of the APS
Spring Joint Topical Symposium on
Accelerator-Based Sciences

Cornell University, April 18, 2008

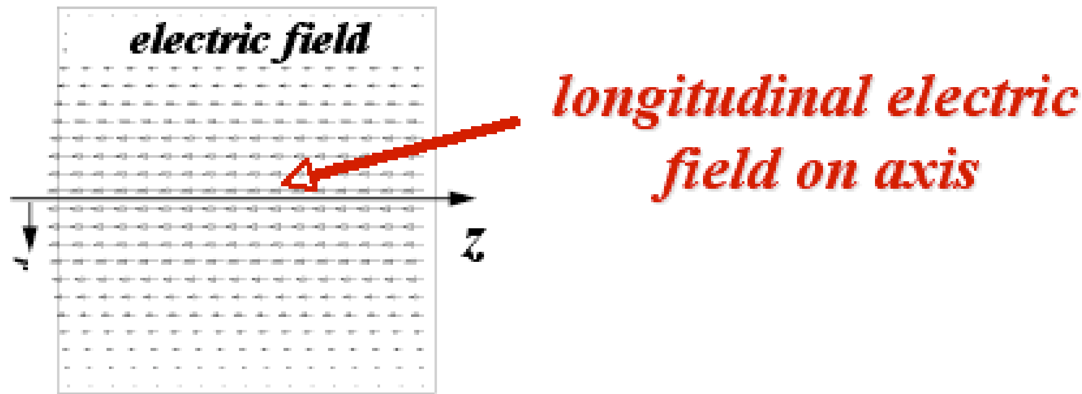
What is an HOM?



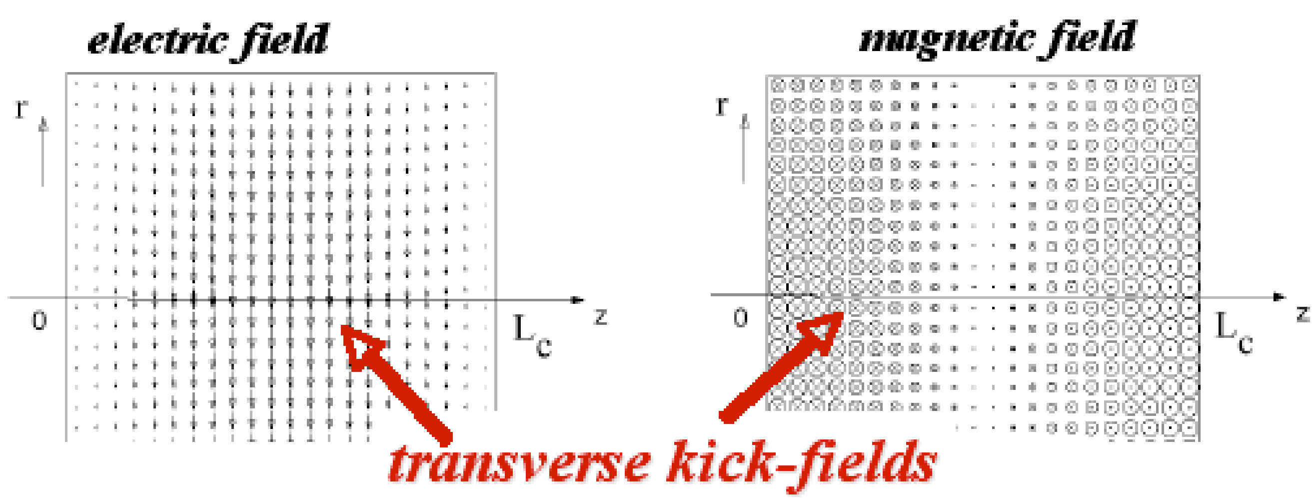
Electromagnetic fields (wakefields) are created by the electron beam.

What is an HOM?

Monopole modes



Dipole modes, quadrupole modes, …

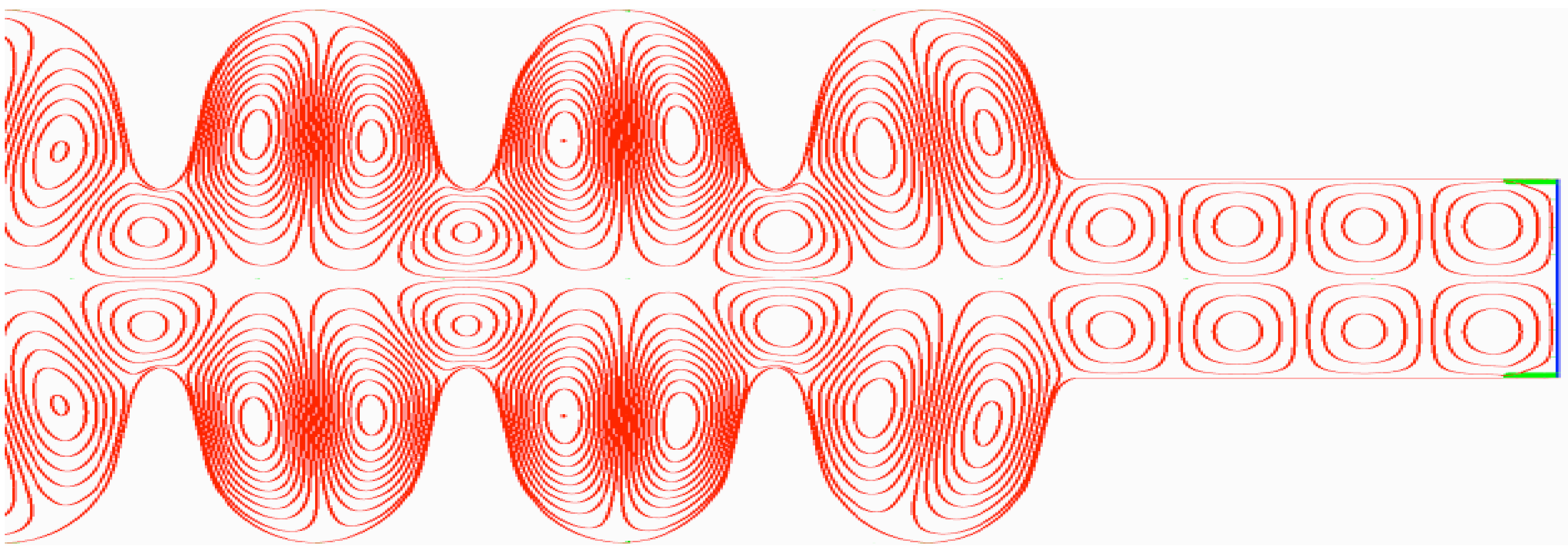


HOMs are bad

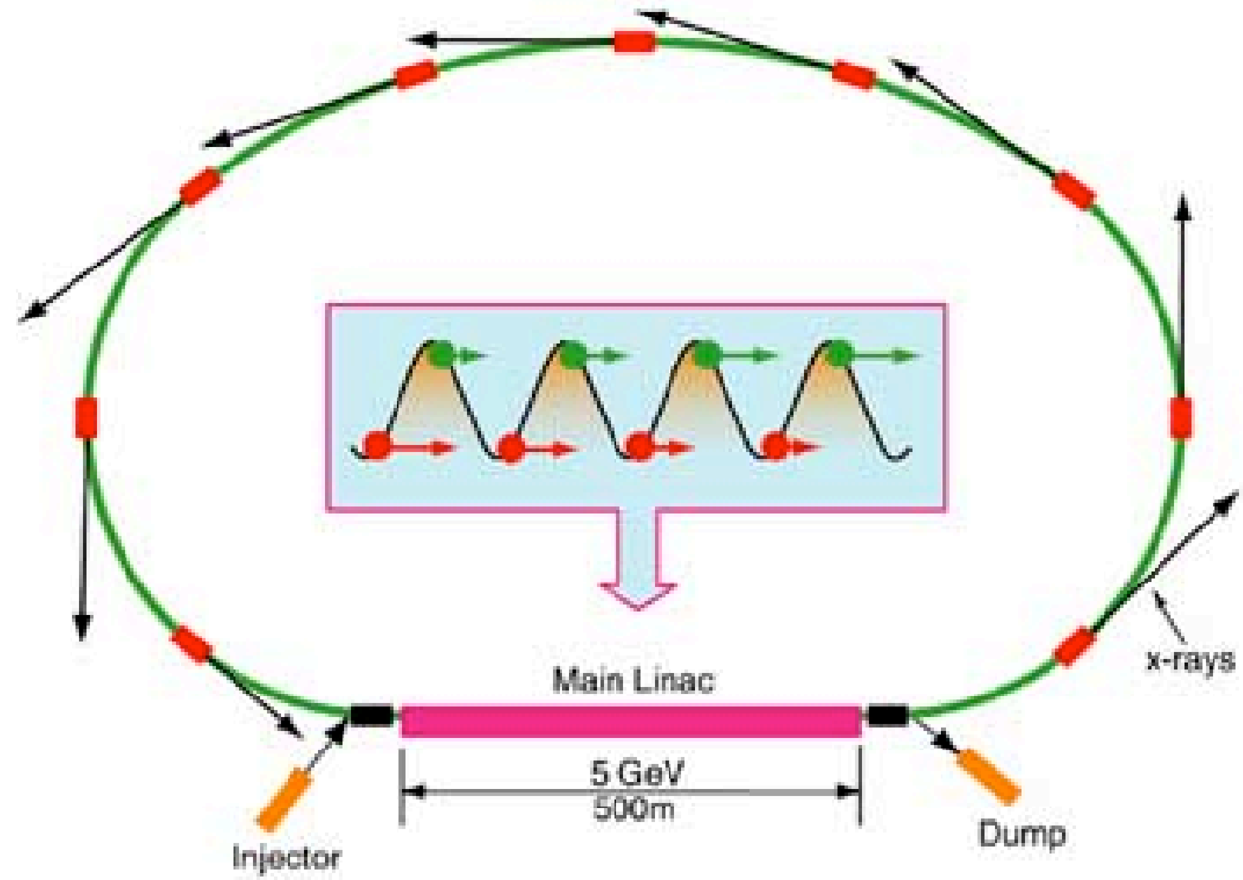
Higher-Order Modes cause problems because:

- They give beam transverse kicks, causing it to widen

- Power from HOMs causes heating, which raises refrigeration costs- at 2 K, 1 W of HOM power needs 1 kW in refrigeration power

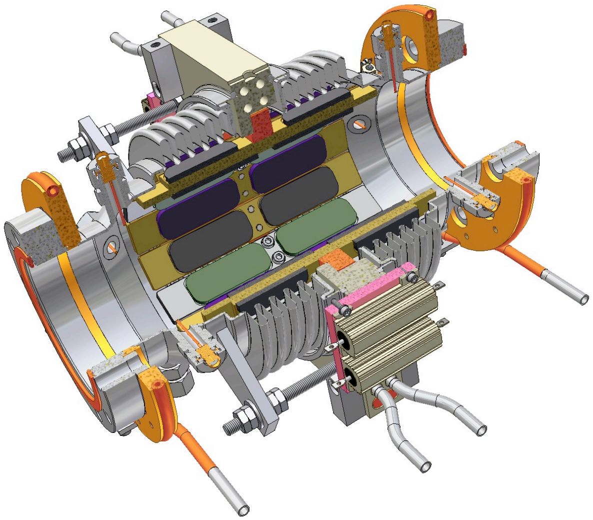


Energy Recovery Linac

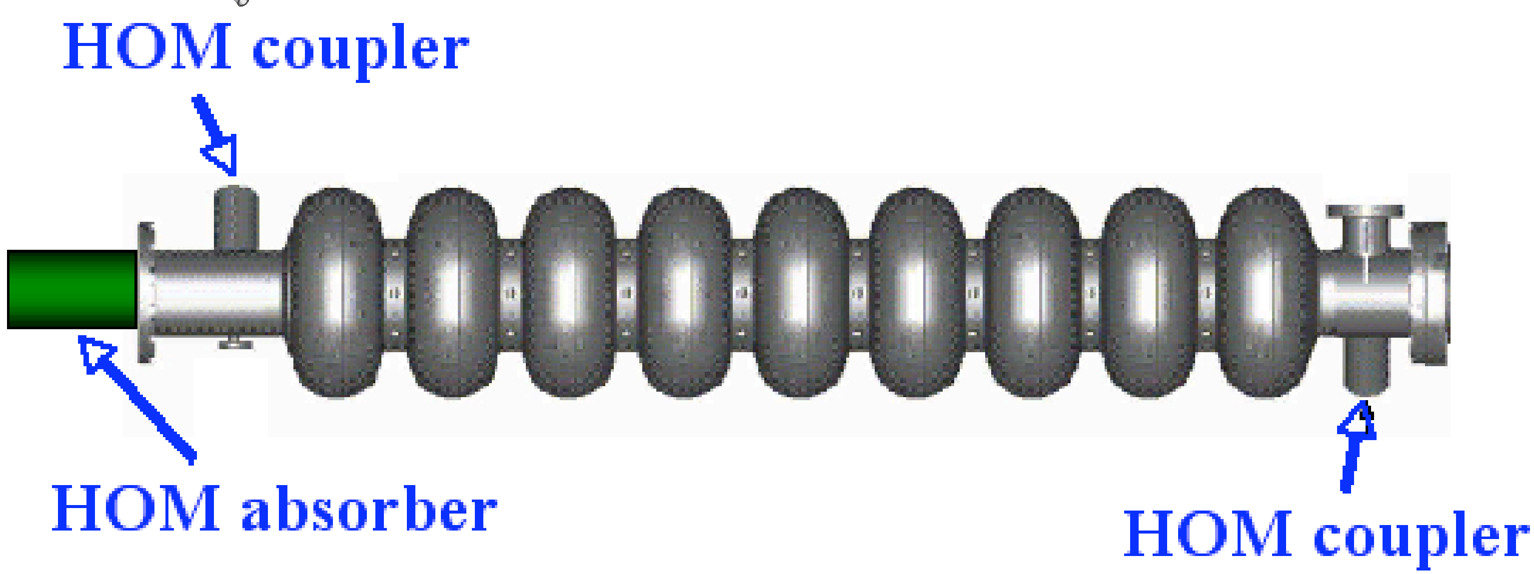


$P_{HOM} \sim Q_{HOM} I^2_{beam}$ for resonant modes,, and ERL current is on the order of 100 times anything currently used in linear accelerators

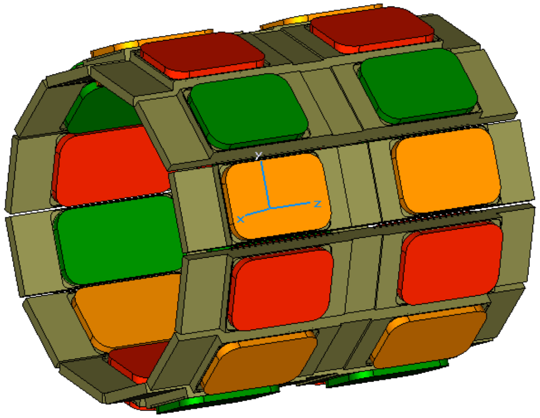
HOM damping in the ERL



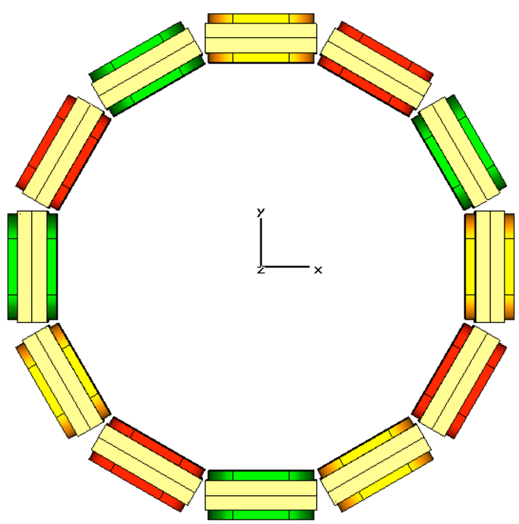
HOM absorber: Materials that absorb E and M fields are placed in parts of the beamline that the fundamental (accelerating) modes can't reach, and that are not kept as cold as the SRF cavities.

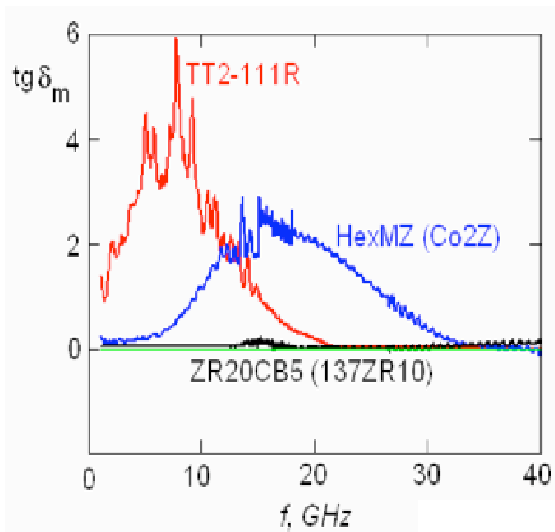


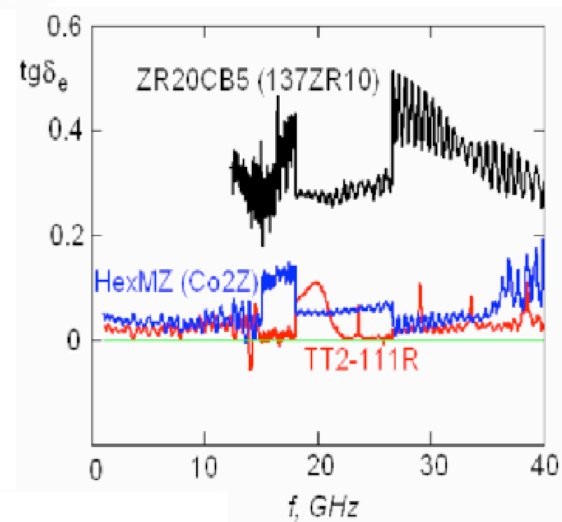
HOM Load- Tile Details



- 12 tiles- 3 materials, 4 of each material
- 2 types of ferrites (TT2-111R and Co2Z) to damp magnetic fields
- 1 type of ceramic (ZR20CB5) to damp electric fields
- Arranged so that most orientations of waves will encounter multiple materials



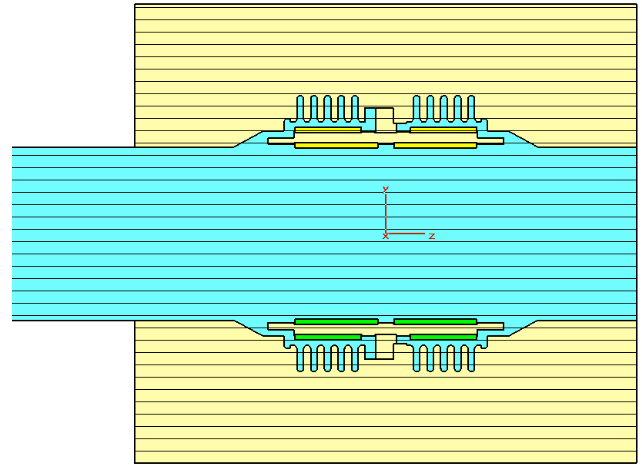


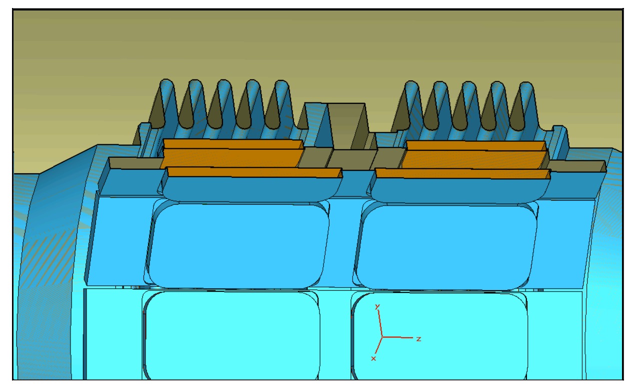


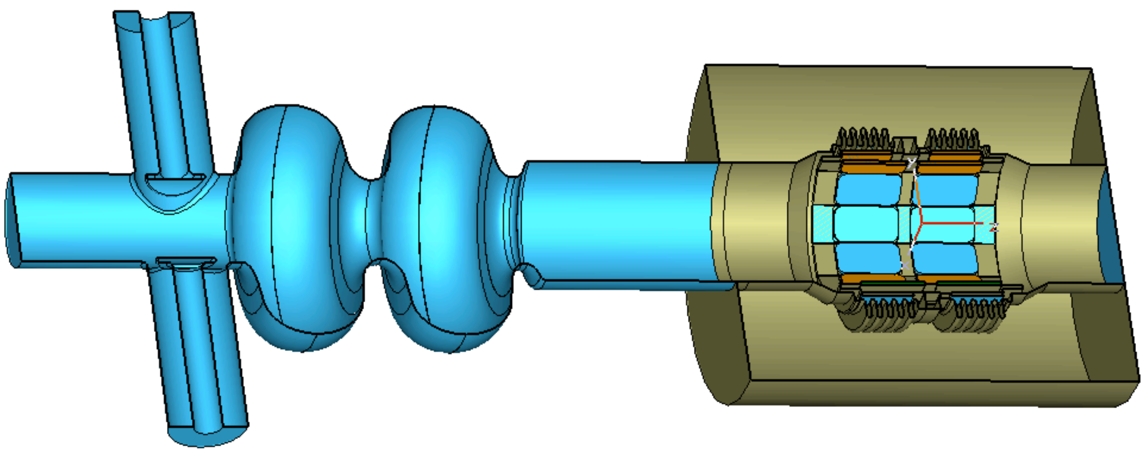
Magnetic and electric tgds of materials (courtesy V. Shemelin)

3-D Computer Modeling

- Models were created in CST Microwave Studio
- Eigenmodes were calculated numerically in CST MWS
- Calculations were time-consuming

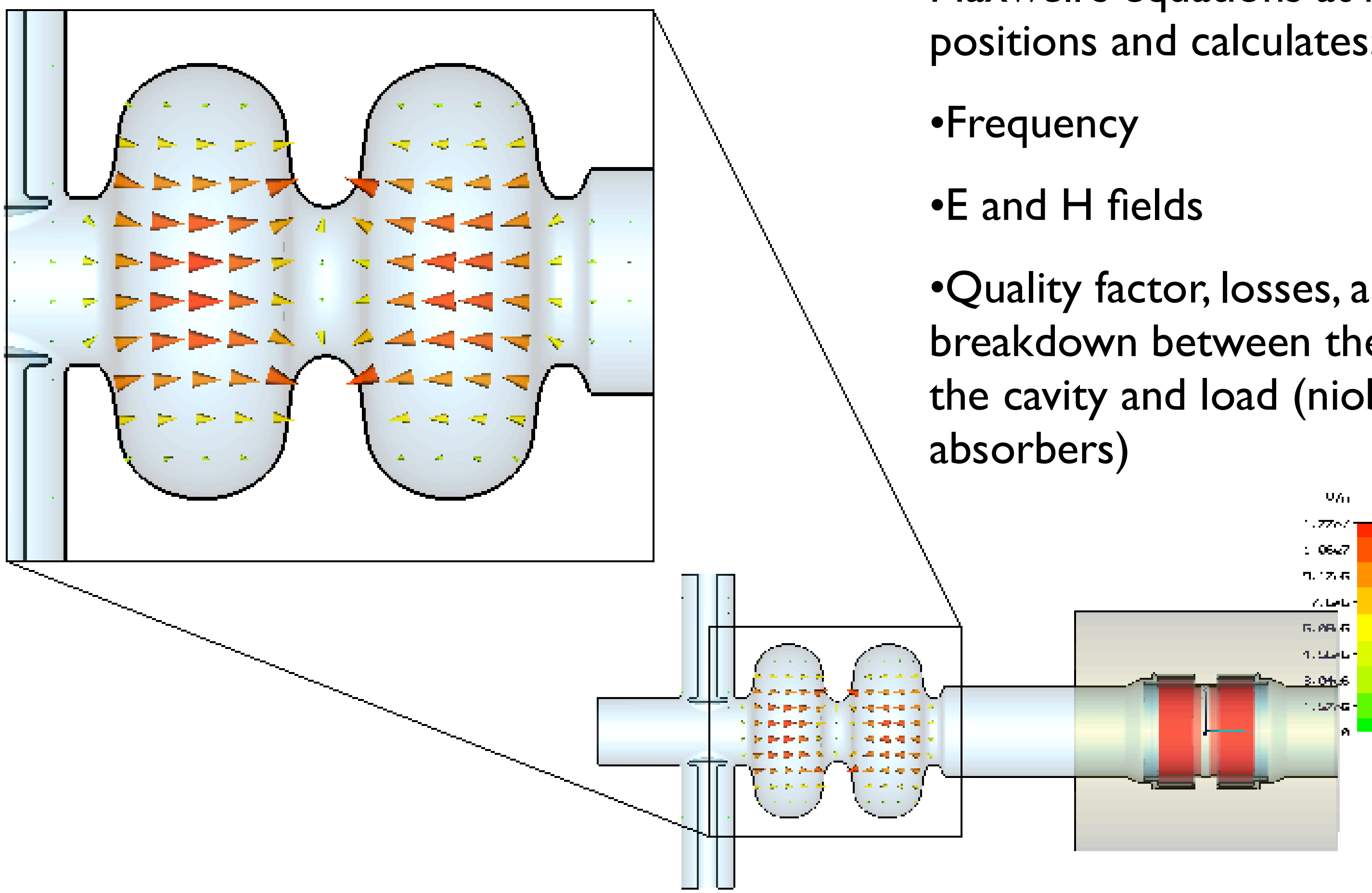






Microwave Studio Output

E Field of Fundamental Mode

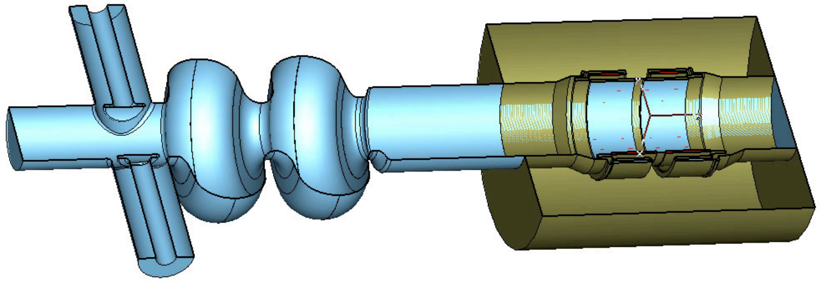


For each mode, MWS solves Maxwell's equations at many positions and calculates:

- Frequency
- E and H fields
- Quality factor, losses, and their breakdown between the elements of the cavity and load (niobium, copper, absorbers)

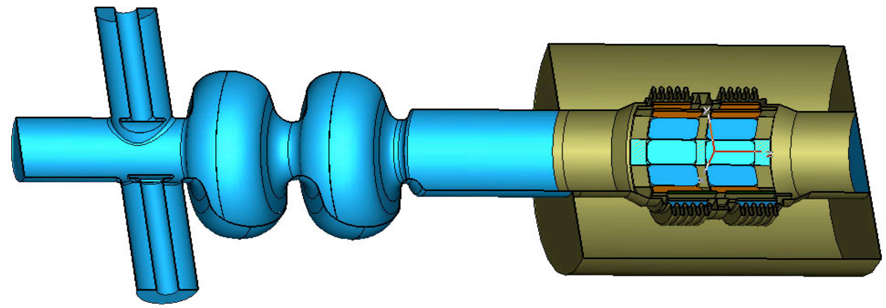
Seriously, it's Time-Consuming

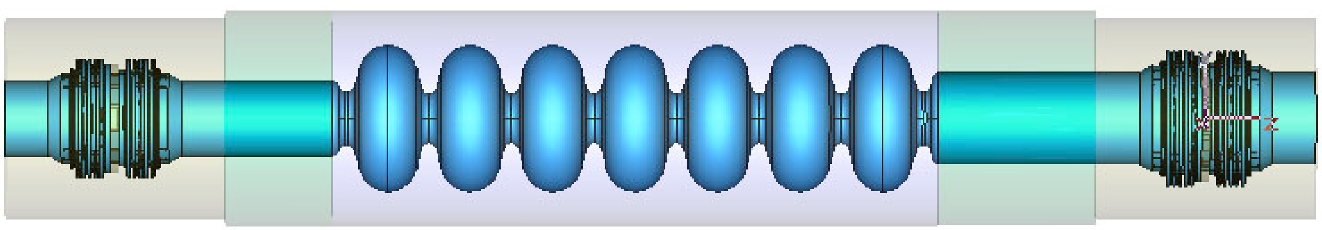
To calculate 25 modes with reasonable accuracy it takes:



2-cell model with ferrite plates: 2 weeks

2-cell model with 4 ferrite cylinders: 2 days



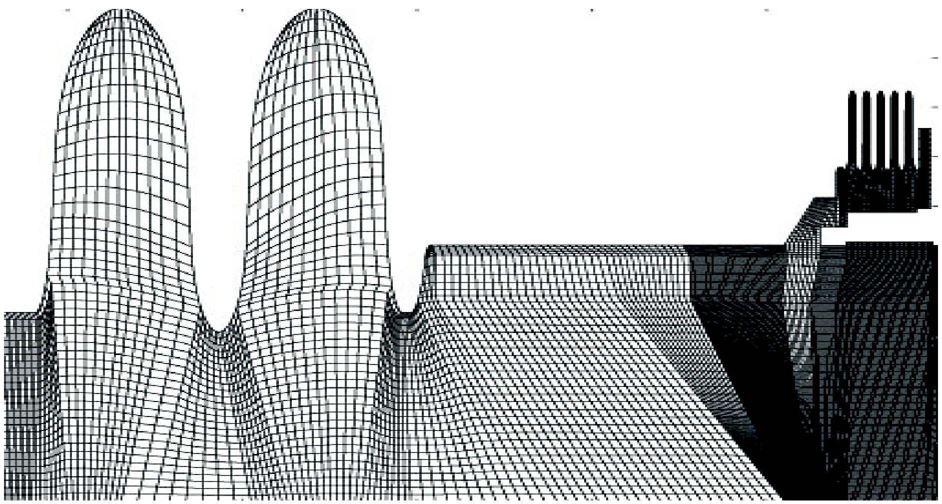


7-cell model with 2 loads: ?

To calculate even the 2-cell model with ferrite plates, I had to have a new computer ordered with 12 GB of RAM and dual 3.40 GHz processors!

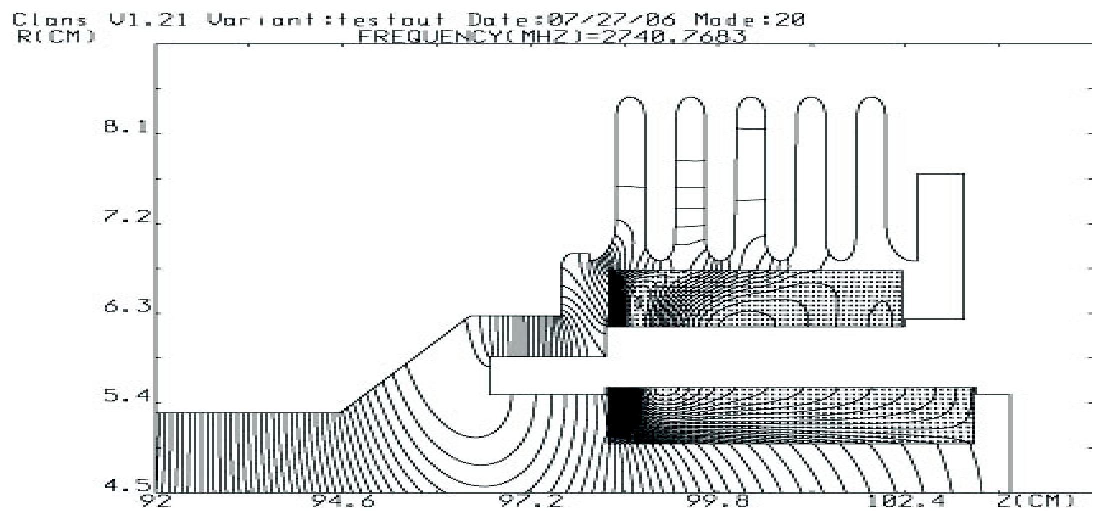
2-D Computer Modeling

- CLANS is a 2-D code for axially symmetric cavities
- Used axially-symmetric approximation in model: rings of TT2 ferrite
- 2-cell cavity and half-load



Mesh of the cavity and half-load

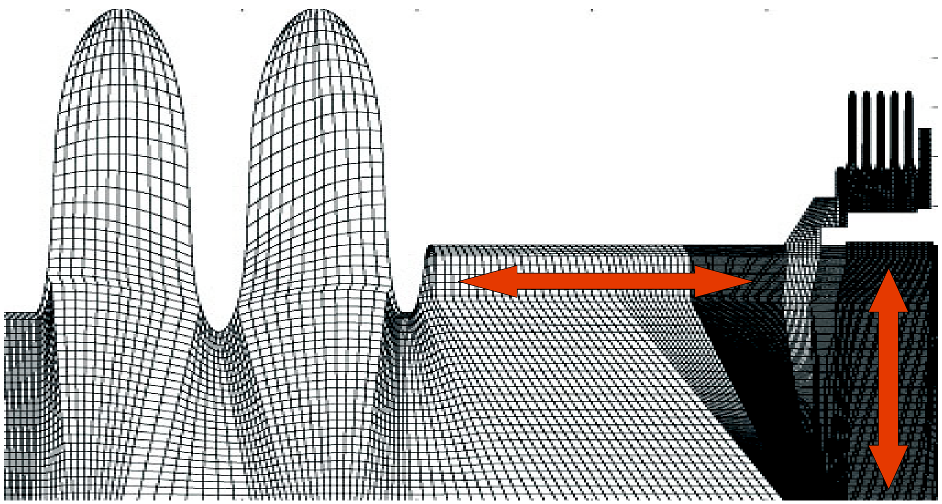
force lines of an HOM in the ferrites



- Used Matlab code to vary characteristics of cavity
- Output: Q, R/Q, E and H fields of modes

Optimization

- Matlab programs were written to vary four parameters:

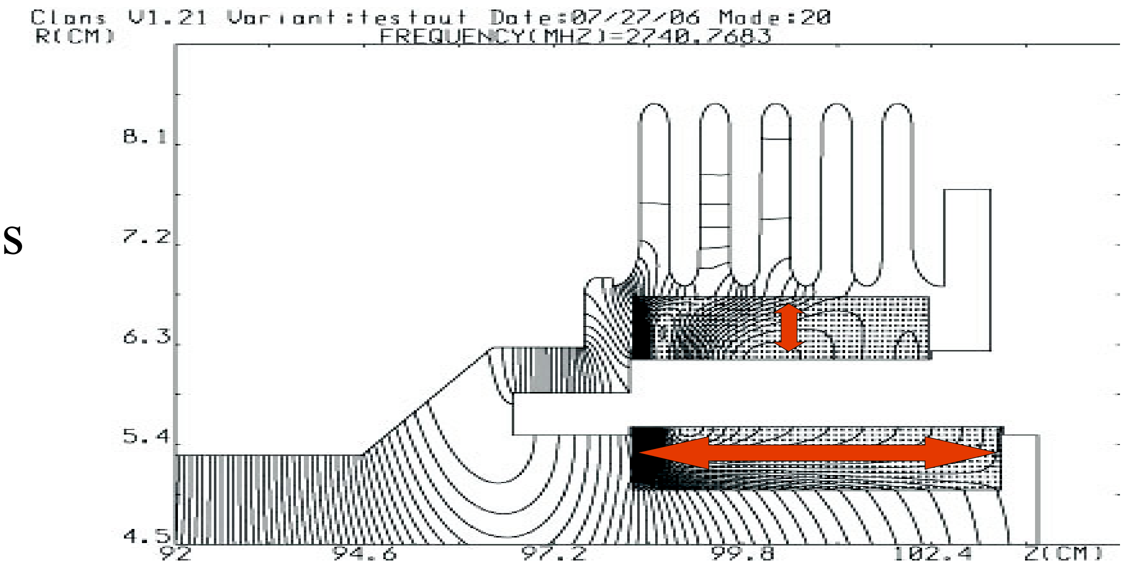


Length of tube between cavity and load

Radial position of ferrites

Thickness of ferrites

Length of ferrites



In *average* the total HOM losses per cavity are given by the single bunch losses (77 pC bunch charge, 2.6 GHz bunch repetition rate, $\sigma_b = 600\ \mu m$):

$$P_{||} = k_{||} Q_{bunch} I_{beam} = 10.4\,\mathrm{V/pC} \cdot 77\,\mathrm{pC} \cdot 0.2\ \mathrm{A} = 160\ \mathrm{W}$$

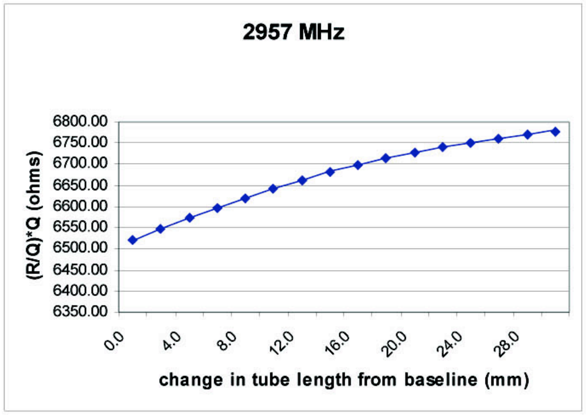
But: If a monopole mode is excited on resonance, the loss for this mode can be much higher:

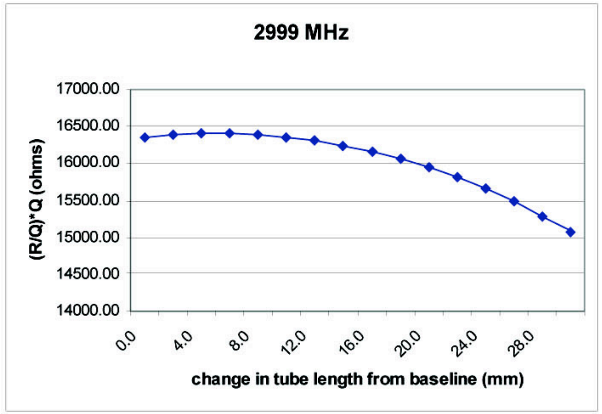
$$P = \left(\frac{R}{Q}\right) Q I_{beam}^2$$

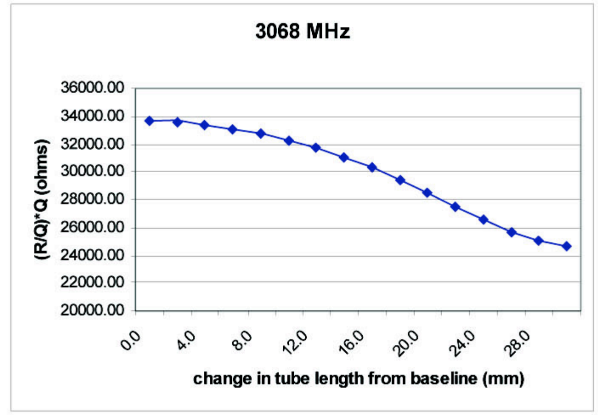
$\Rightarrow$ To stay below 200 W:

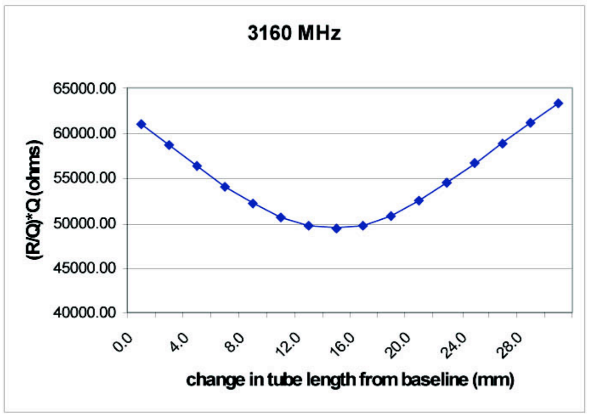
- achieve $(R/Q)Q < 5000$,
- or avoid resonant excitation of the mode.

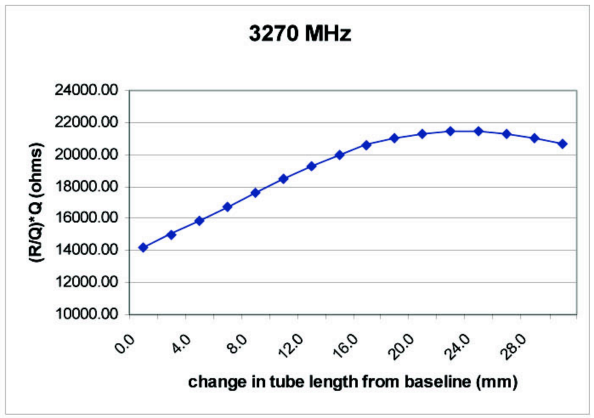
1) Tube Length









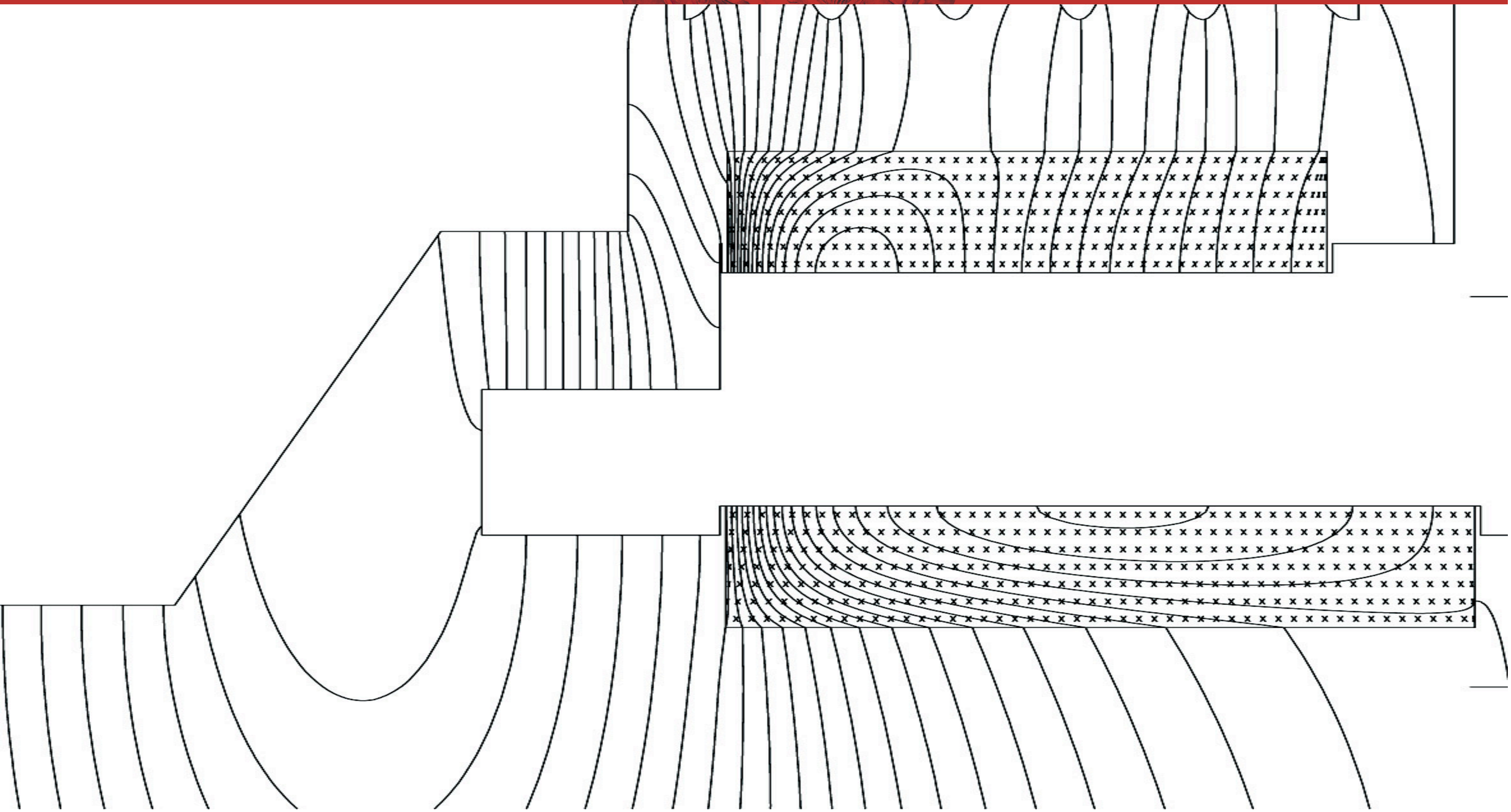


(R/Q)*Q of some strongly-coupled HOMs:

- Wavelength ~ 90-100 mm
- Length change: about 1/3 wavelength
- (R/Q)*Q change: about 25%

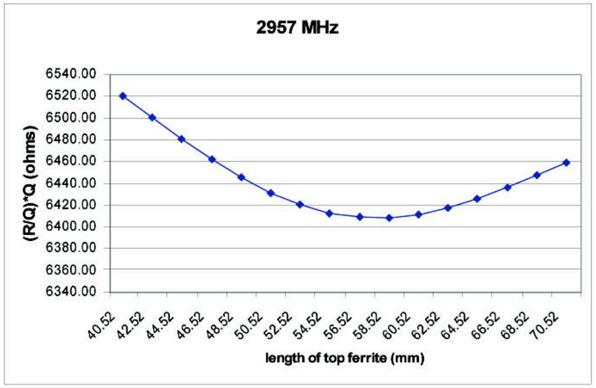
- Each HOM is affected very differently- can only optimize for the worst
- Dependence is semi-periodic
- Cavity/tube coupling and amplitude of H at location of ferrite

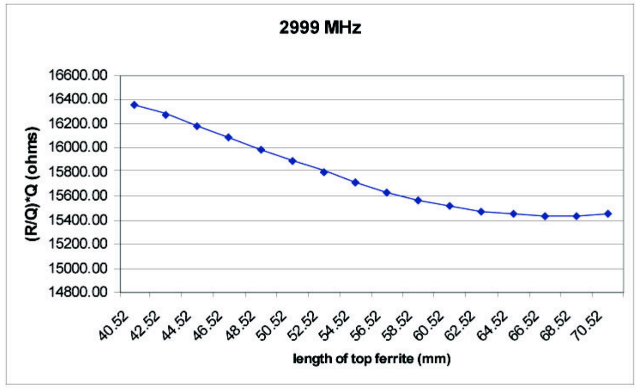
Distribution of Losses

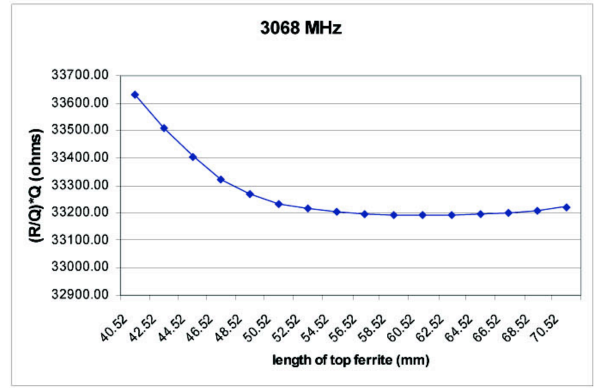


- 61% of ferrite losses in left half of inner ferrite, 25% in left half of outer ferrite
- Ferrite losses depend mostly on strength of H in this small area

2) Ferrite Length







- Ferrite length was varied from baseline to baseline + 30 mm
- Metal plate length and dimensions of outer walls of load model also adjusted to accomodate ferrites

- (R/Q)*Q changes by less than 10% with these variations
- Dependence appears to be damped-sinusoidal
- Increasing ferrite length damps HOMs, but position is still very important, possibly because the losses are so concentrated in part of ferrites

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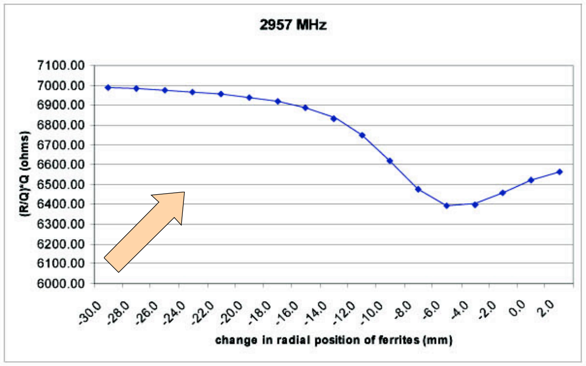
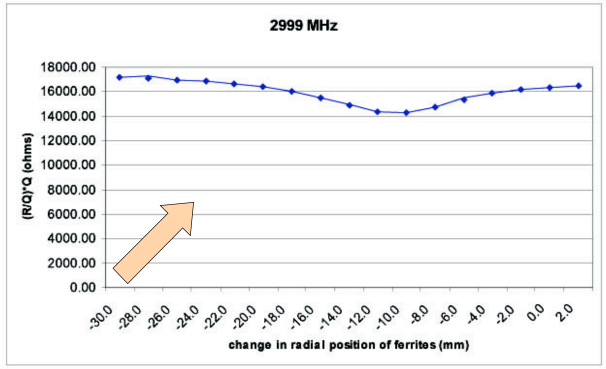
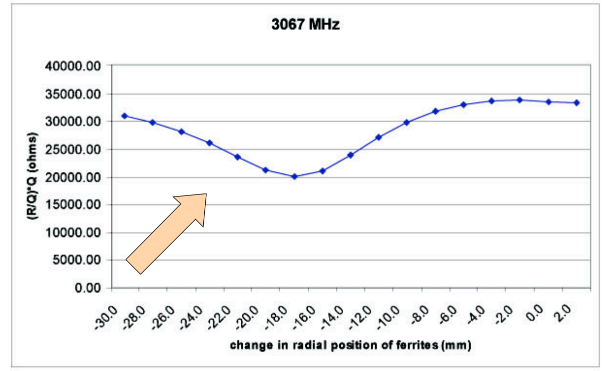
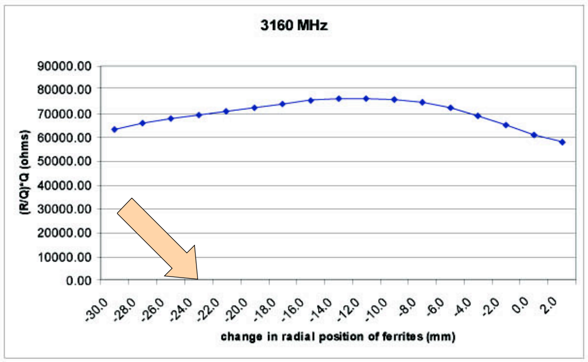
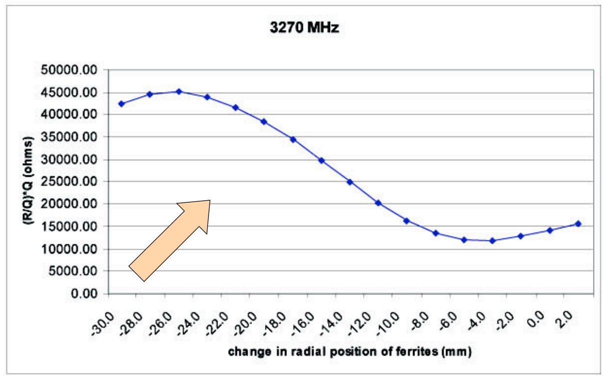
3) Radial Position of Ferrite

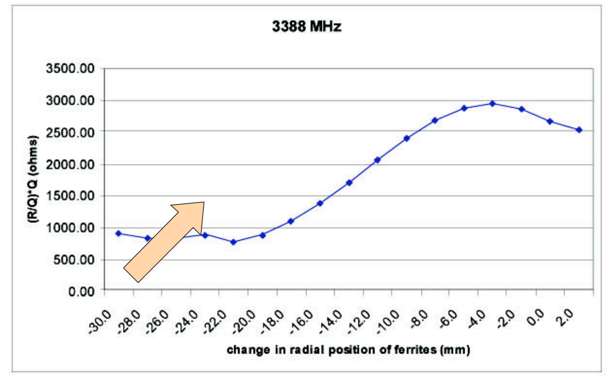






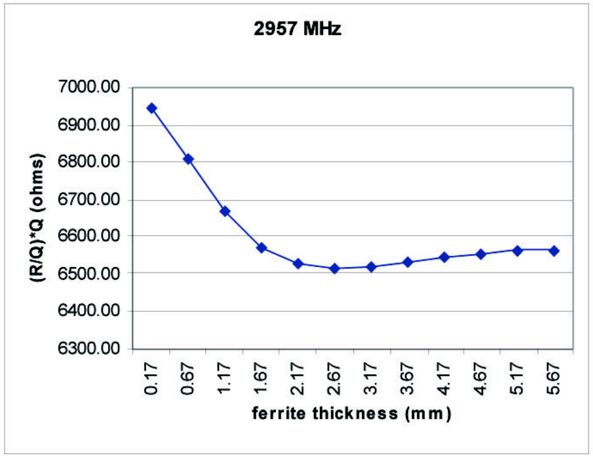


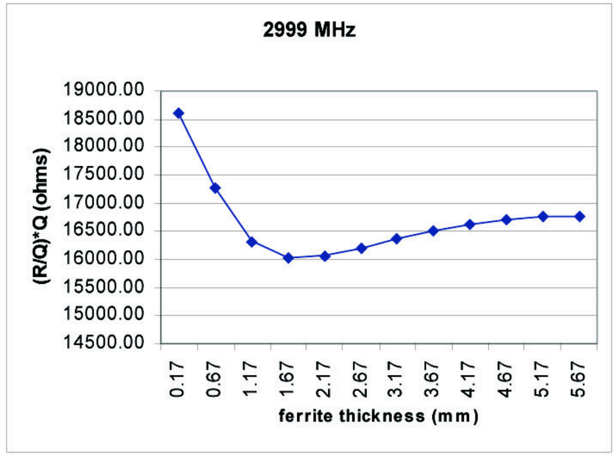


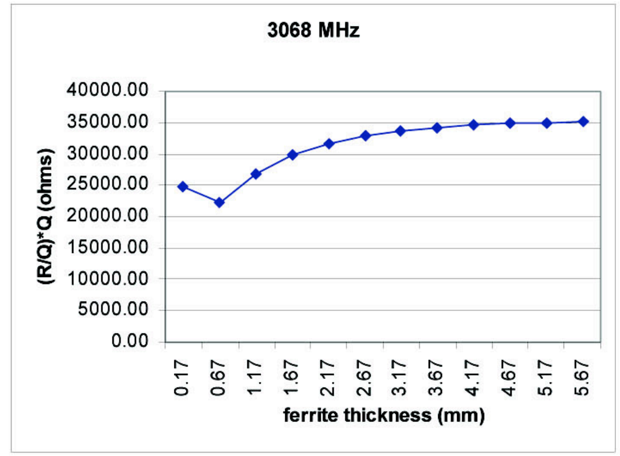


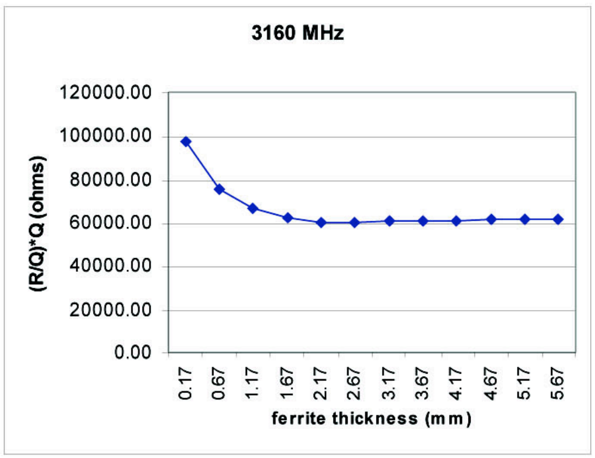
- Change in radius varies from -30 mm to +2 mm (about 1/3 wavelength)
- (R/Q)*Q changes by 10% - 300%, greater than in first two optimizations
- Affects each mode differently, but may be useful for optimization of worst modes because of large change of (R/Q)*Q
- Arrows indicate sign of derivative of |Re(H)| upon entering ferrite; varies w/ concavity- could indicate resonance in the ferrite for these modes

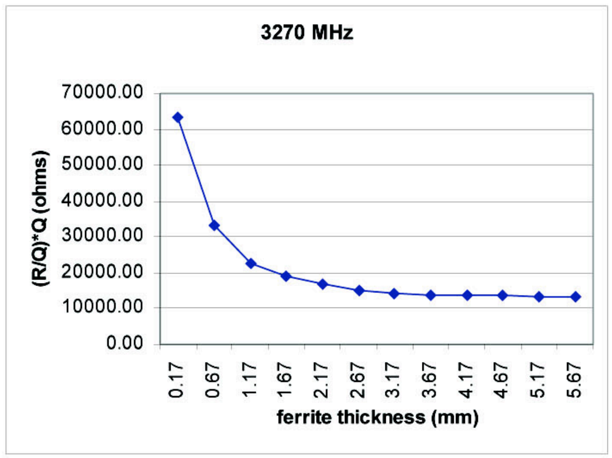
4) Ferrite Thickness

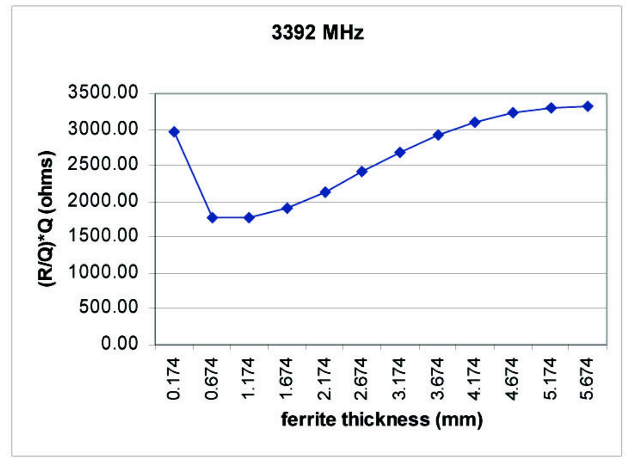












- Each mode affected differently- caused by some kind of resonance, but cannot be explained simply, and is not well understood
- (R/Q)*Q changes are large (up to 600%) and can be used for optimization
- Thin ferrite doesn't work well, but benefit of increased thickness drops off

Summary of Findings

- Changing length of the ferrites or tube between cavity and load has a small effect on HOMs, and might best only be adjusted as fine-tuning

- Changing ferrite thickness and/or radial position of ferrites affect HOMs significantly and should be parameters in an optimization

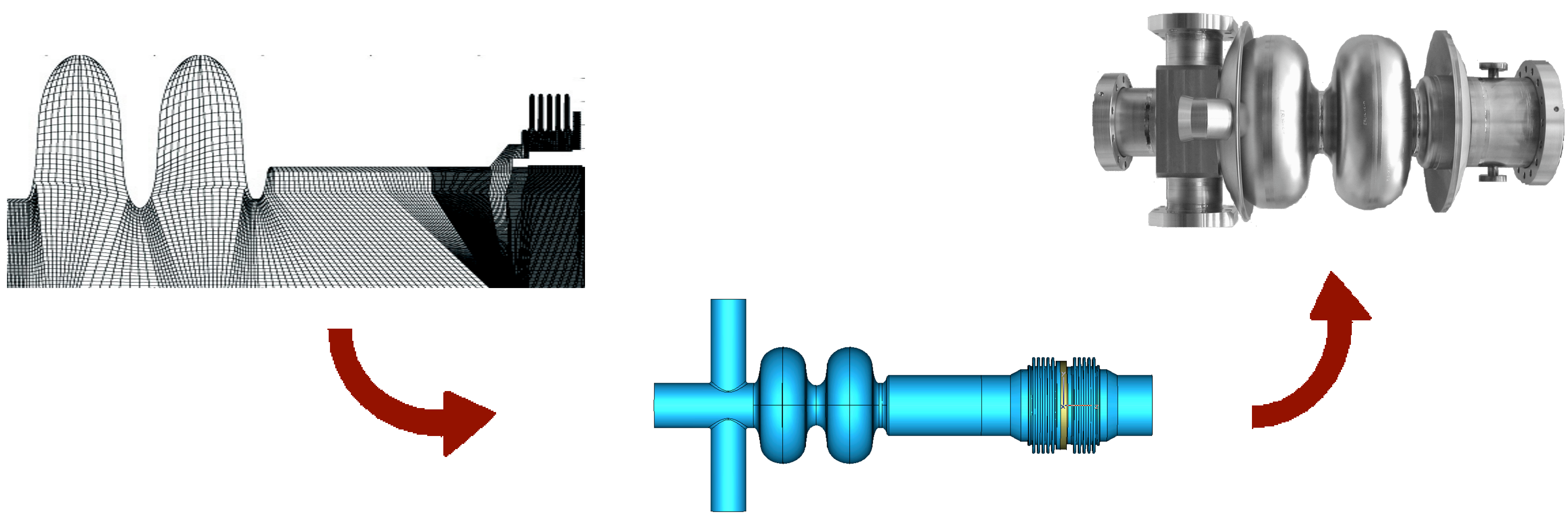
- A group of split ferrites behave like a single ferrite with similar geometry, and losses are highest in the 2nd lower ferrite in this model

- In general, each mode is affected differently, so can only optimize for a few modes in any given parameter

- Calculations are extremely time-consuming even for simplified models, so brute-force testing of the whole parameter space is infeasible, and future tests must be designed cleverly

The Future

- Test model with baseline 7-cell cavity and optimized 7-cell cavity
- Calculate many modes to find worst HOMs and optimize wrt them
- Explore effects of parameter changes on each other
- Look beyond monopole modes
- Optimization with Co2Z ferrite, ceramic, and combinations
- Do 3-D calculations of optimized model in Microwave Studio
- Major barrier: computing time



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