Designing a Continuous-Wave RF Cavity for Bunch Rotation in Support of Experiments Mu2e and g-2

ILLINOIS

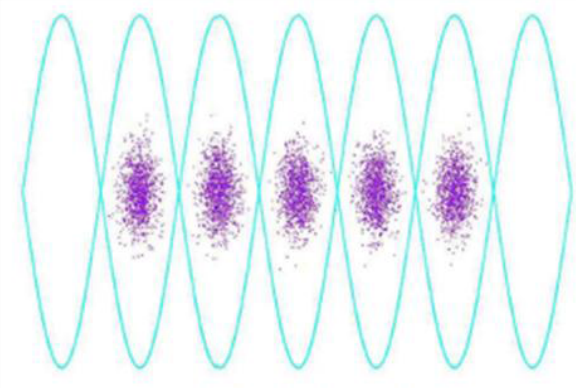
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

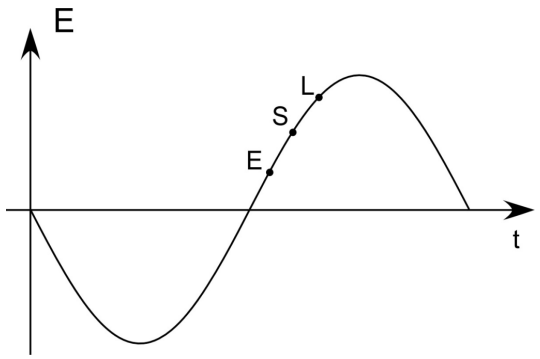
Aaron Smith under the mentorship of Joseph Dey,

Accelerator Division/RF Department

Beam Bunches

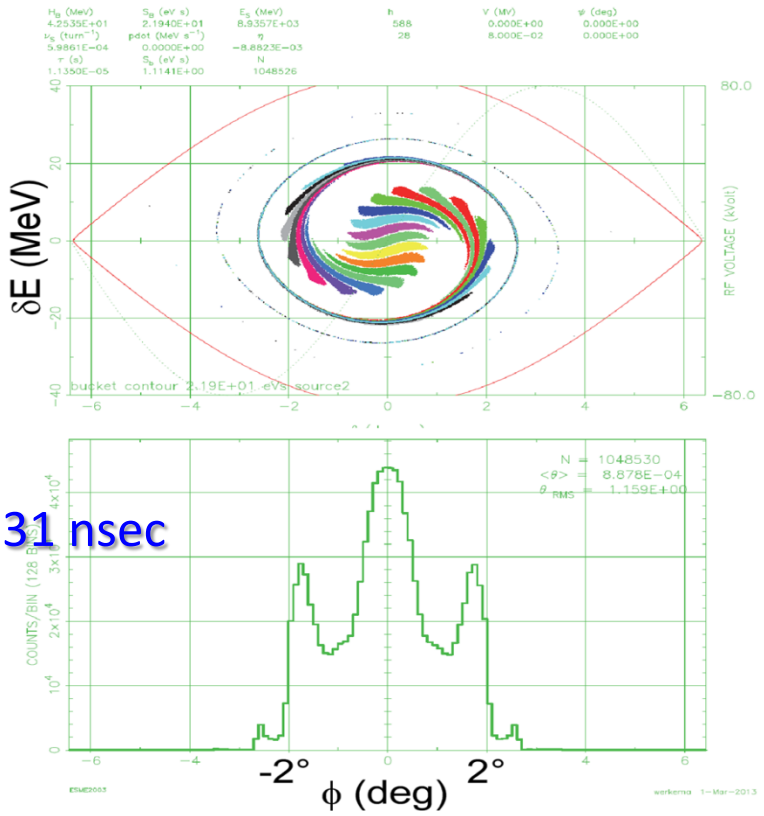
- RF systems cause the beam to form bunches
- The bunch size (width/time) is determined by the frequency of the RF system
- Protons in a bunch rotate from front to back, back to front





Mu2e and g-2 requirements

- The same RF system will be used for both experiments
- g-2 requires a smaller bunch length than Mu2e
- Therefore, RF is being designed to meet g-2
- Cavities also need to be able to run CW (continuous wave)
- Excessive heat necessitates the design of new cavities

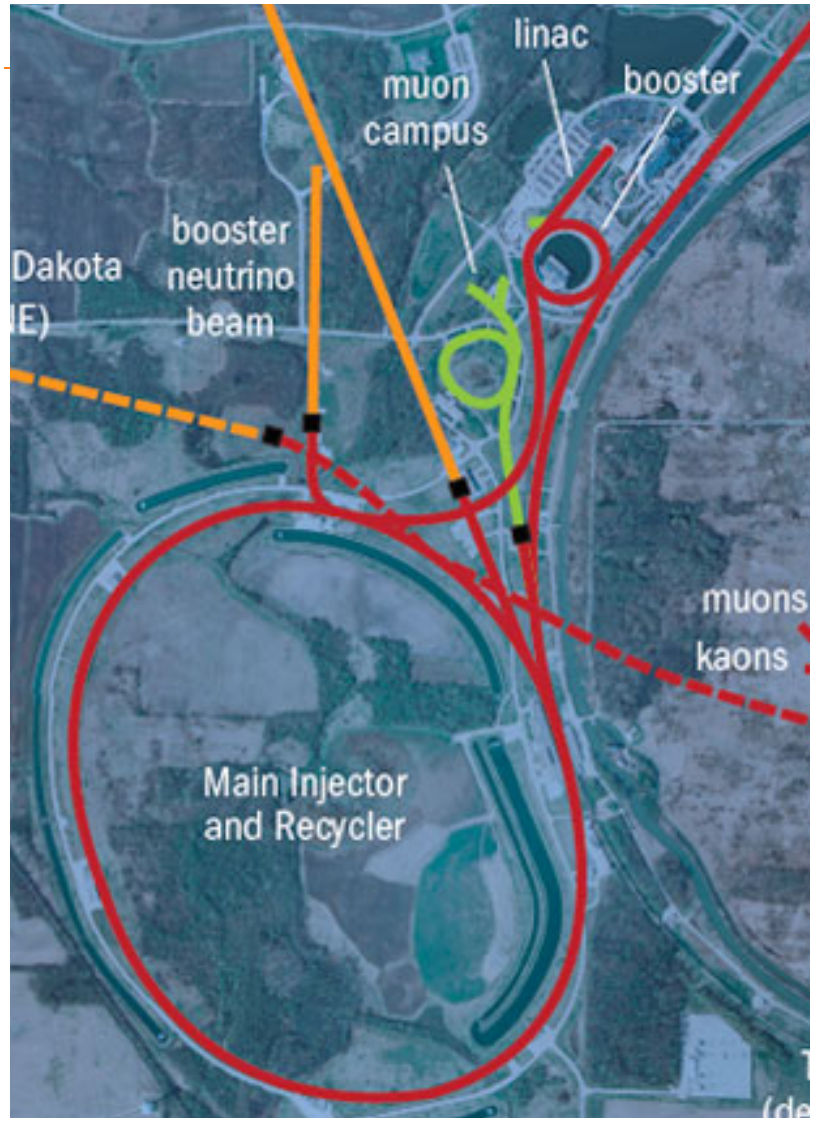


1° = 31 nsec

Bunch Length Requirements Full width	
Mu2e	g-2
250 nsec	149 nsec

Cavity Placement/Use

- Seven new 2.5 MHz cavities for Recycler Ring
- One new 2.4 MHz cavity for Delivery Ring
- Recycler Ring will create four bunches which are extracted one at a time into the Delivery Ring
- Delivery Ring 2.4 MHz cavity will be used to preserve bunch width

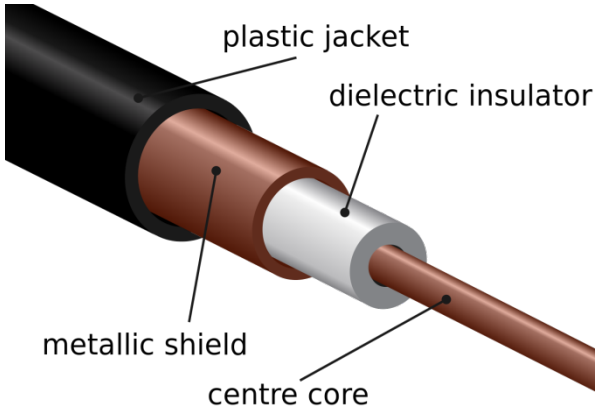


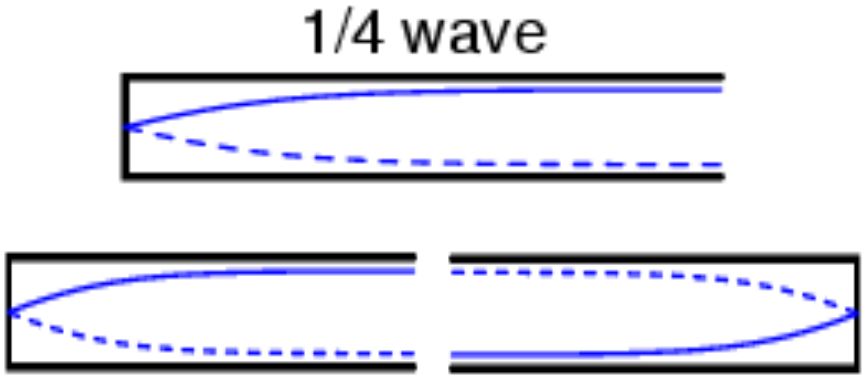
Designing the Cavity

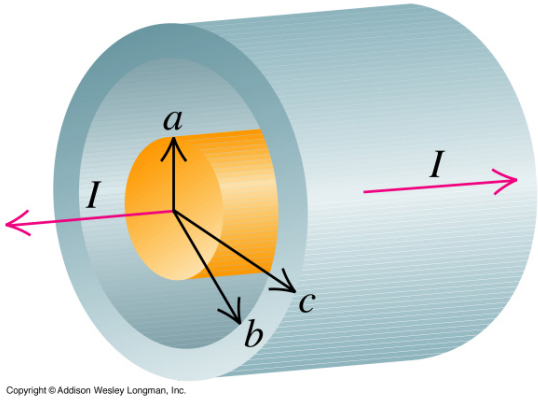
- New cavities require
  - Water cooling system
    - The copper tubing needs to be able to enter/exit the cavity without causing an electrical arc due to potential differences
  - Resonance at 2.4/2.5 MHz
    - This requirement is a condition of the experiments and parameters of the accelerating systems at Fermilab
  - Small footprint due to limited tunnel space
  - Sufficient gap voltage (10kV)
    - Simulations of the beam show that the cavities need 10kV difference across the gap
  - A matched load for power transfer efficiency
    - If our cavity does not appear like a 50 ohm system, power will be reflected back into the amplifiers

Resonant Cavity

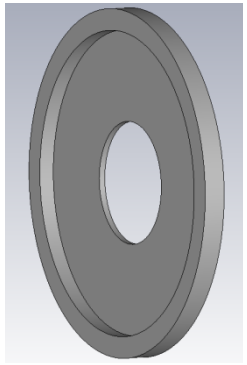
- Significant factors are:
  - Inner/outer conductor radius
  - Dielectric material
  - Length
- The cavity will produce a standing wave similar to the characteristics of a quarter wave resonator



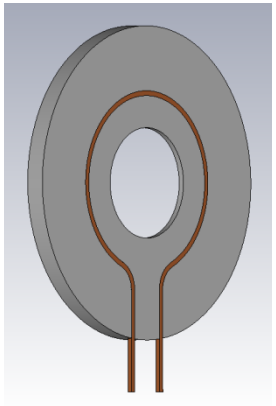




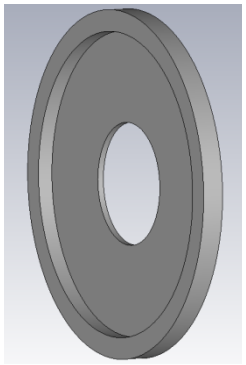
Aluminum/Ferrite Stack

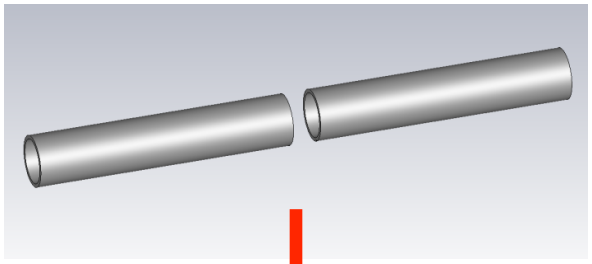


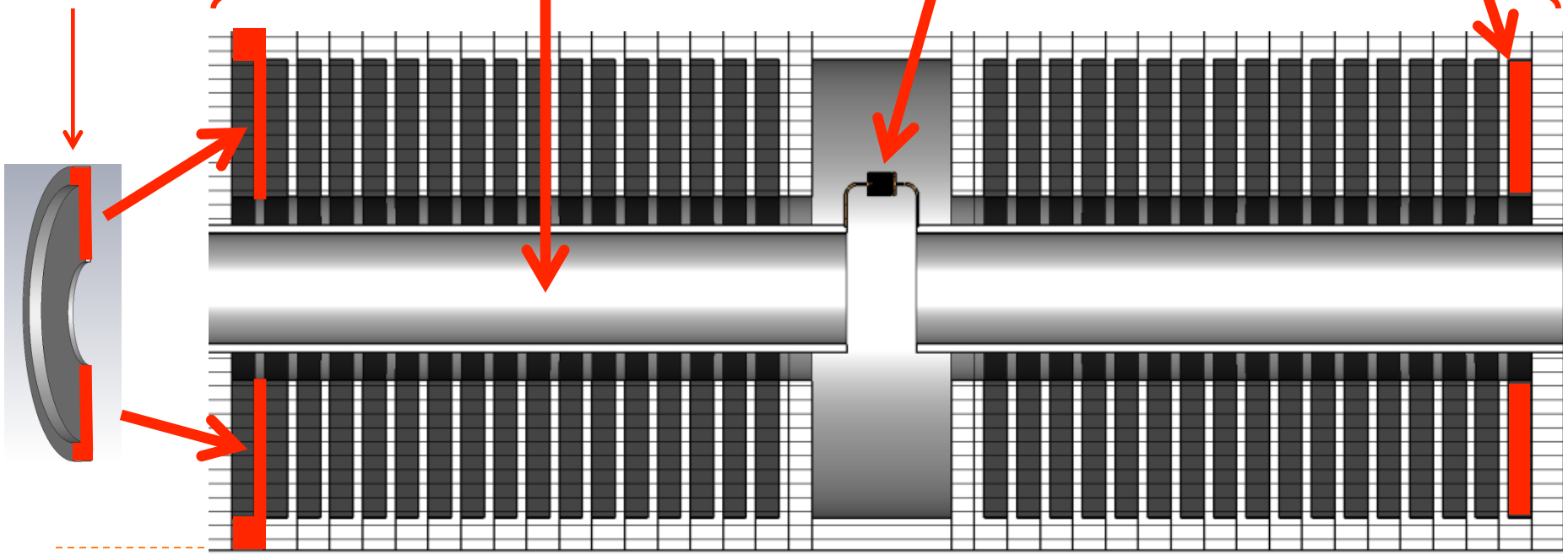
22.5 in.



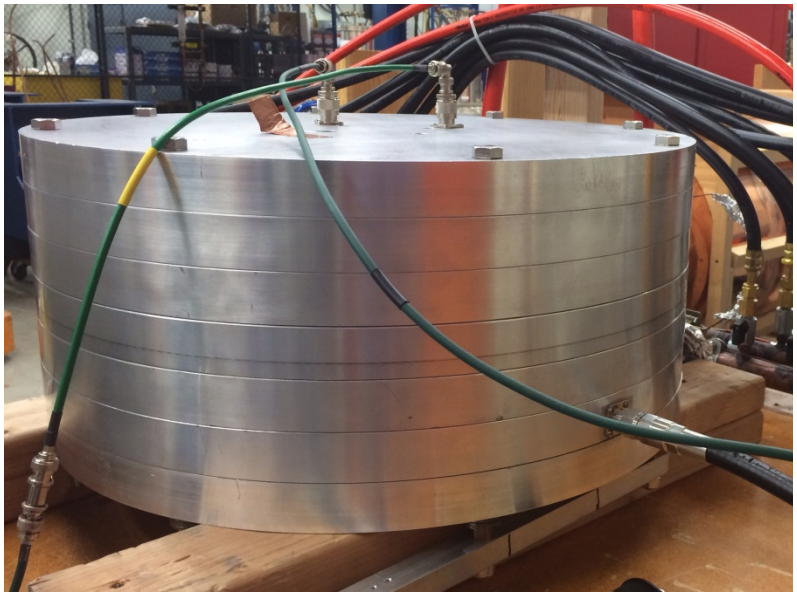
Cavity Cross-section/Components

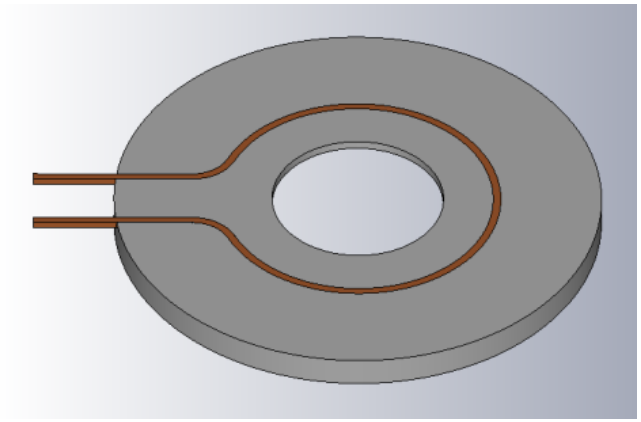






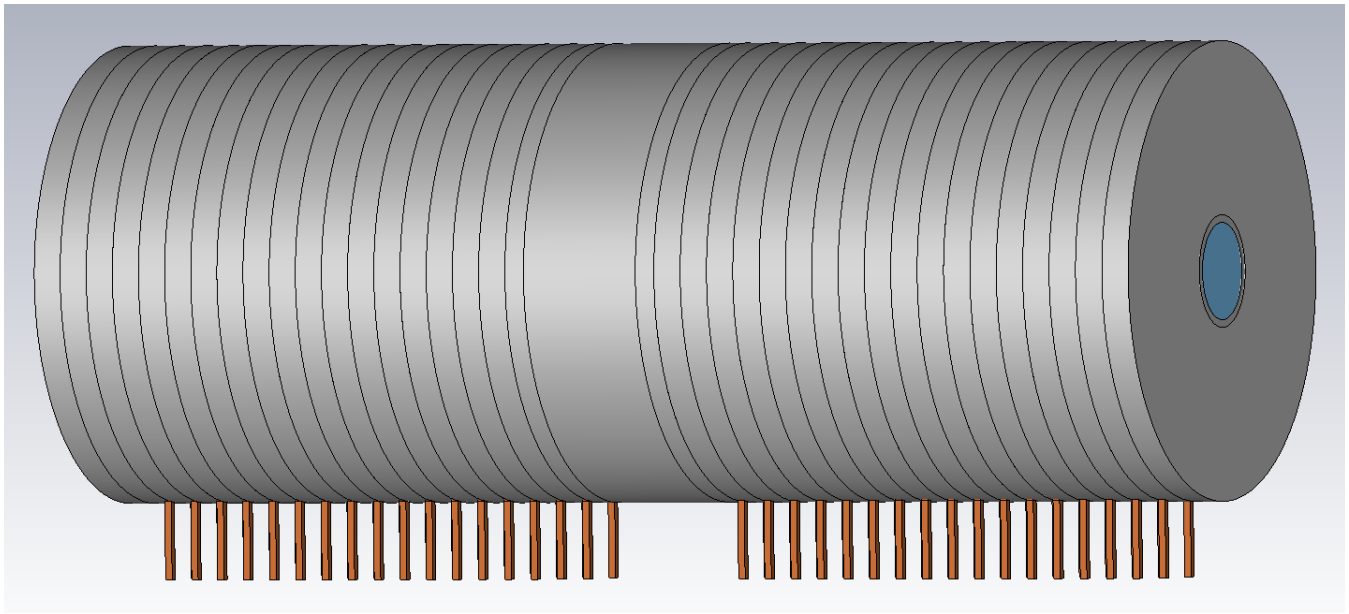
Test Cavity/Water Tubing





Full Cavity

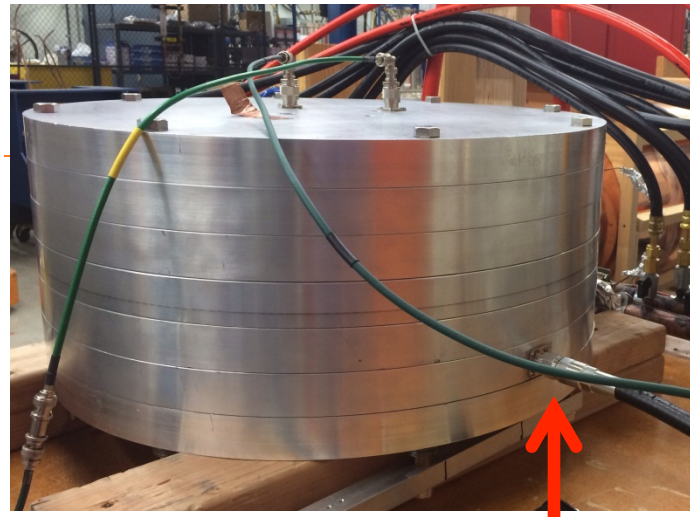
- The cavities for the Recycler Ring and the Delivery Ring will have the same design

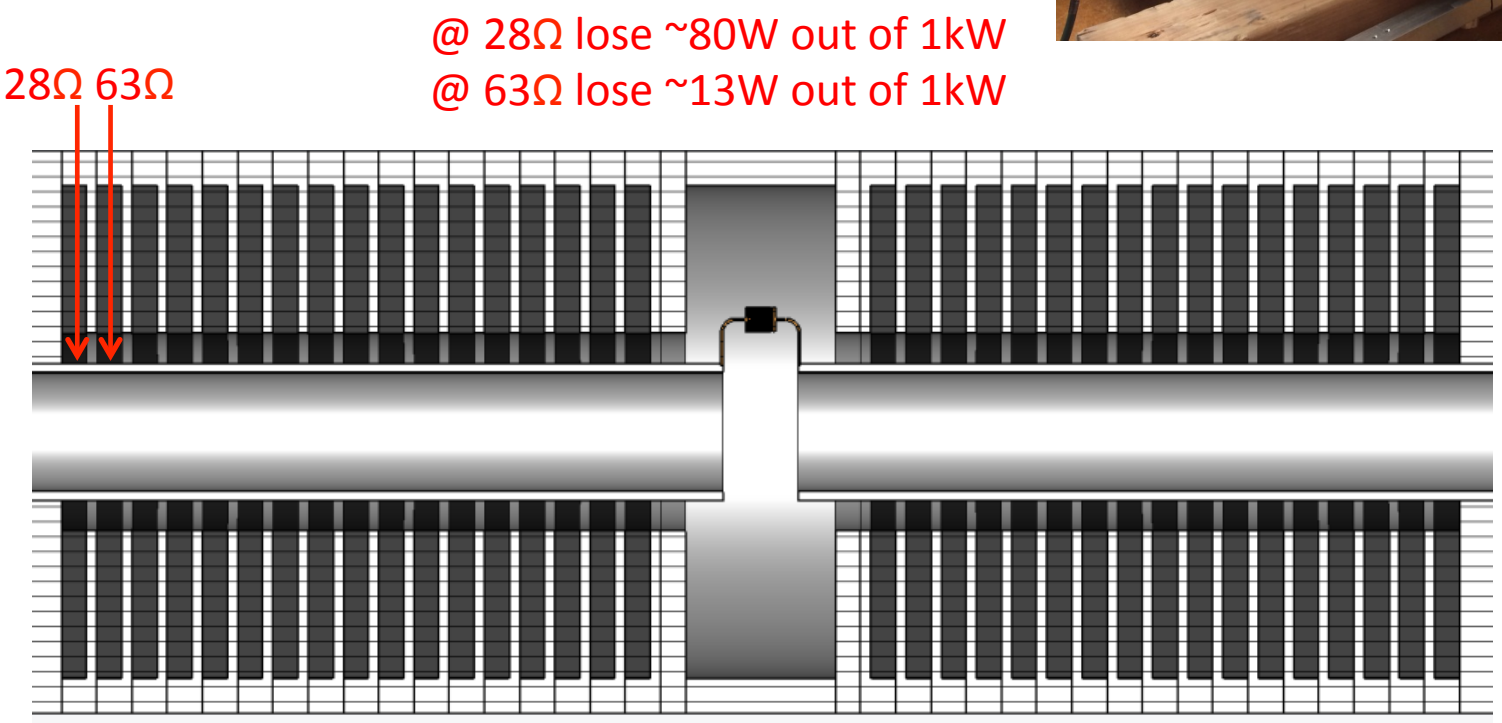


~5 ft.

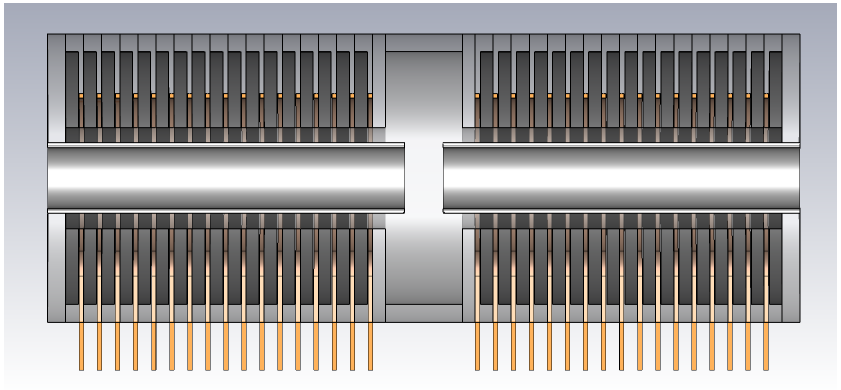
Power Reflection

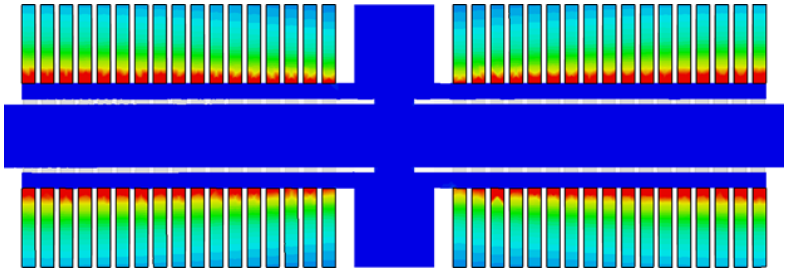
- A mismatched load reflects power back to the amplifier



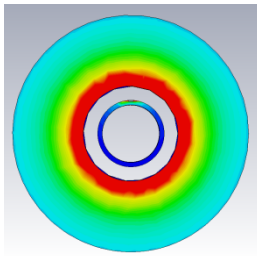


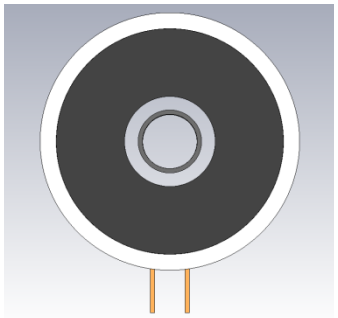
Magnetic Heating/Ferrite

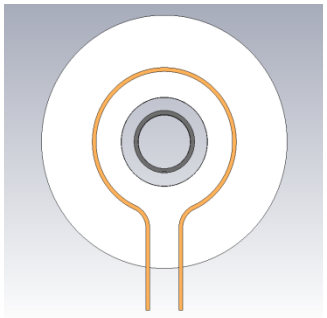




- Main source of heating comes from magnetic flux in ferrite
- Ferrite permeability is a function of temperature
- Over heating will change the Q factor of the cavity and change the resonant frequency
- Heating fairly consistent through all ferrite because wave only rotates 28^{o}

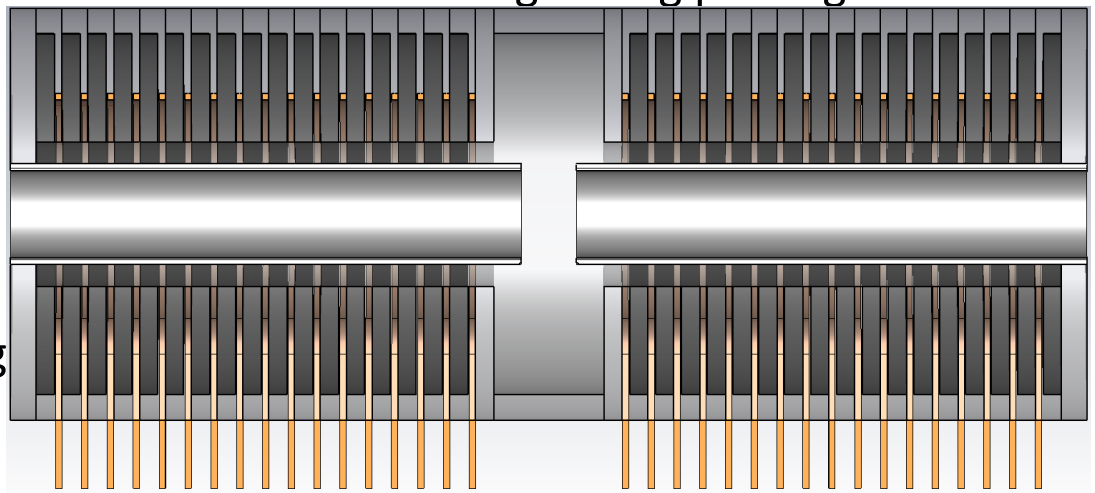


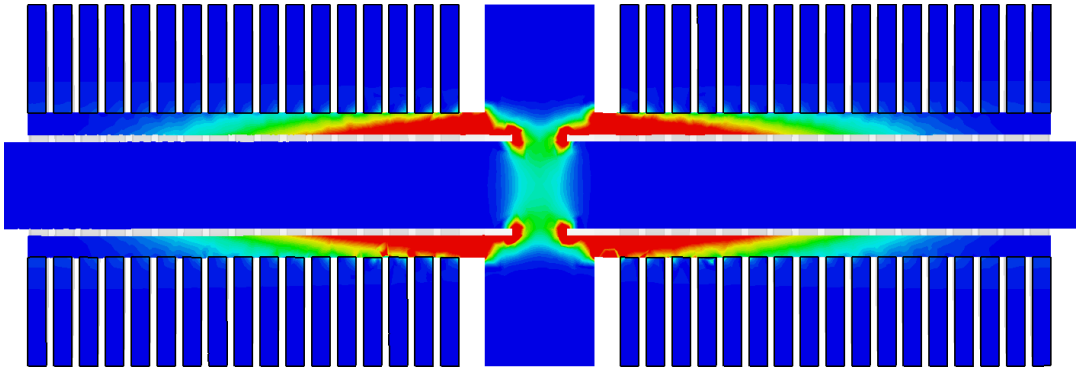




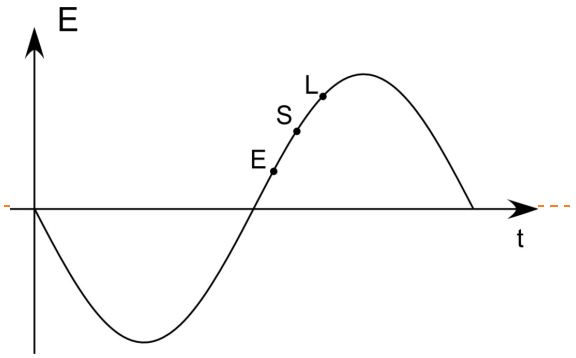
Electrical Arc

- Alters the quality factor of the cavity and changes the resonant frequency
- Previous cavities have had this issue due to water cooling tubing passing through the outer conductor
- The copper tubing exited the cavity through holes in the outer conductor, and were of different potential
- The new cavity design eliminates this issue by keeping the tubing electrically outside the outer conductor
- As the electrical density graph shows, the most likely place for an arc to occur is between the inner conductor, near the gap and the corner of the outer conductor.
- At the voltages required, this should not be an issue

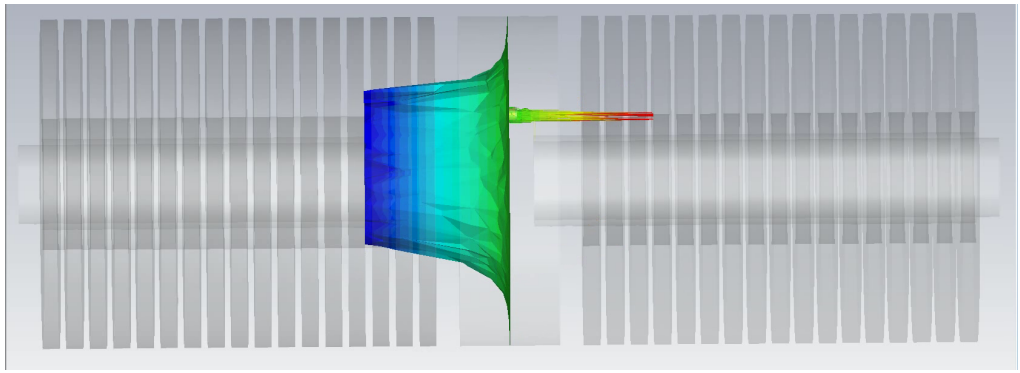


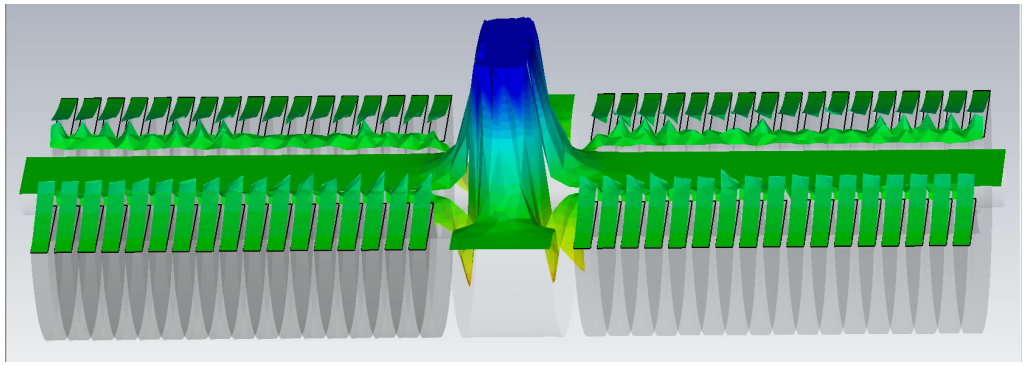


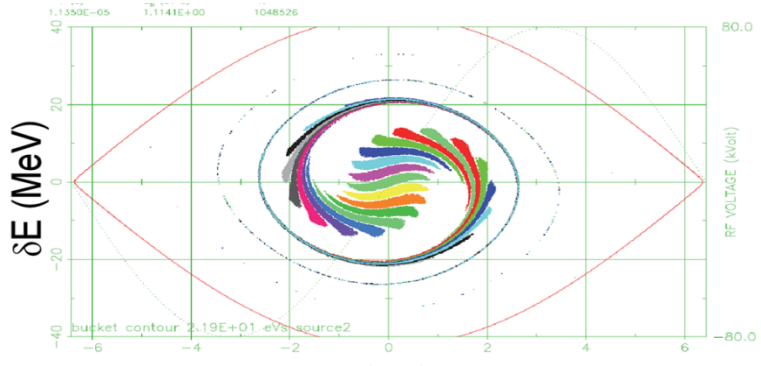
Z-directional Force



- The electric field across the gap is used to impose a force on the proton beam in the z-direction
- By creating a voltage difference on either side of the gap we create the electric field
- This electric field provides the force which causes the bunch rotation and maintains the beams structure

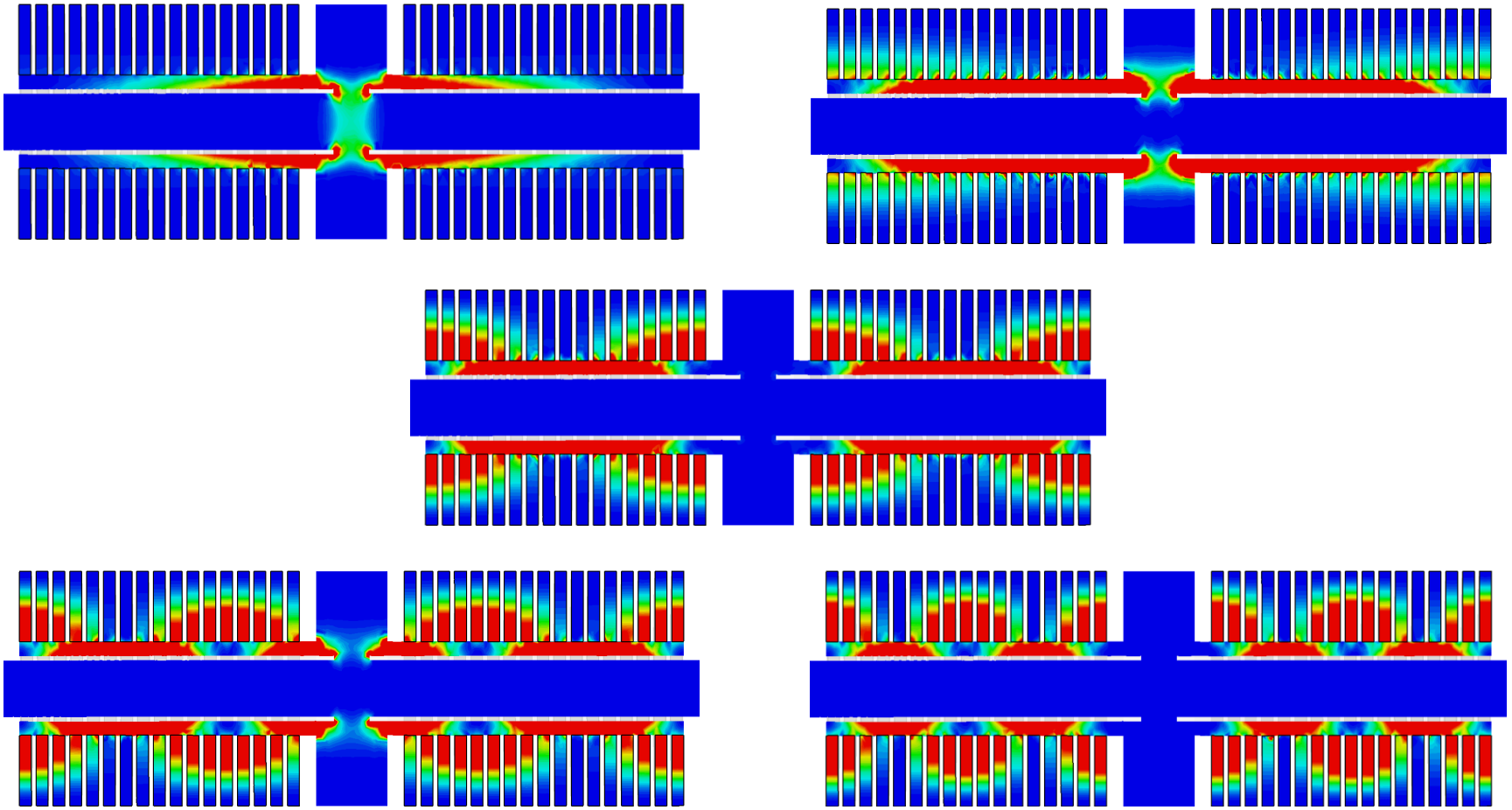






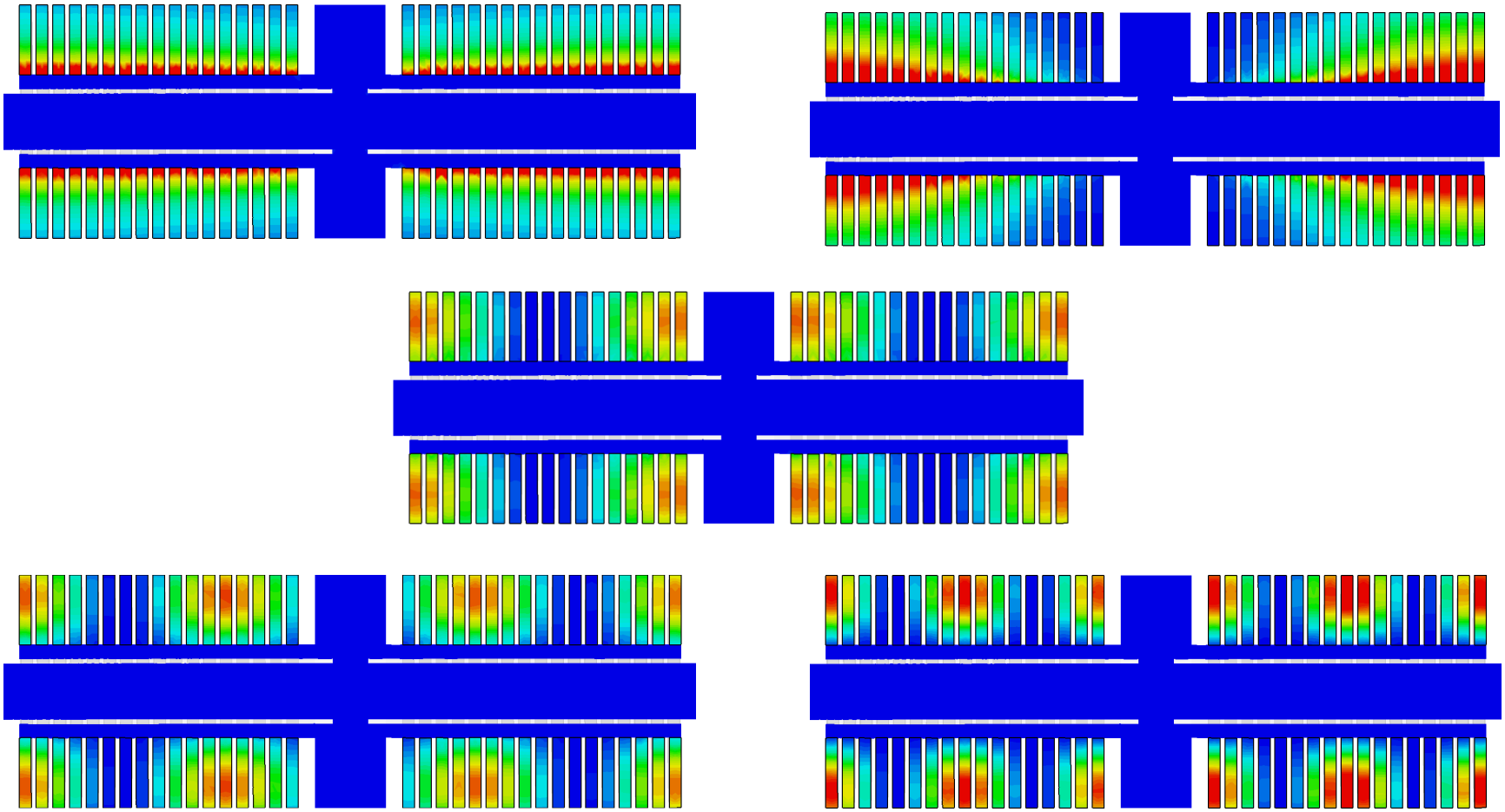
E-Field Harmonics

- First five harmonics @ 2.5, 6.5, 11.5, 12.7, 13.9 MHz



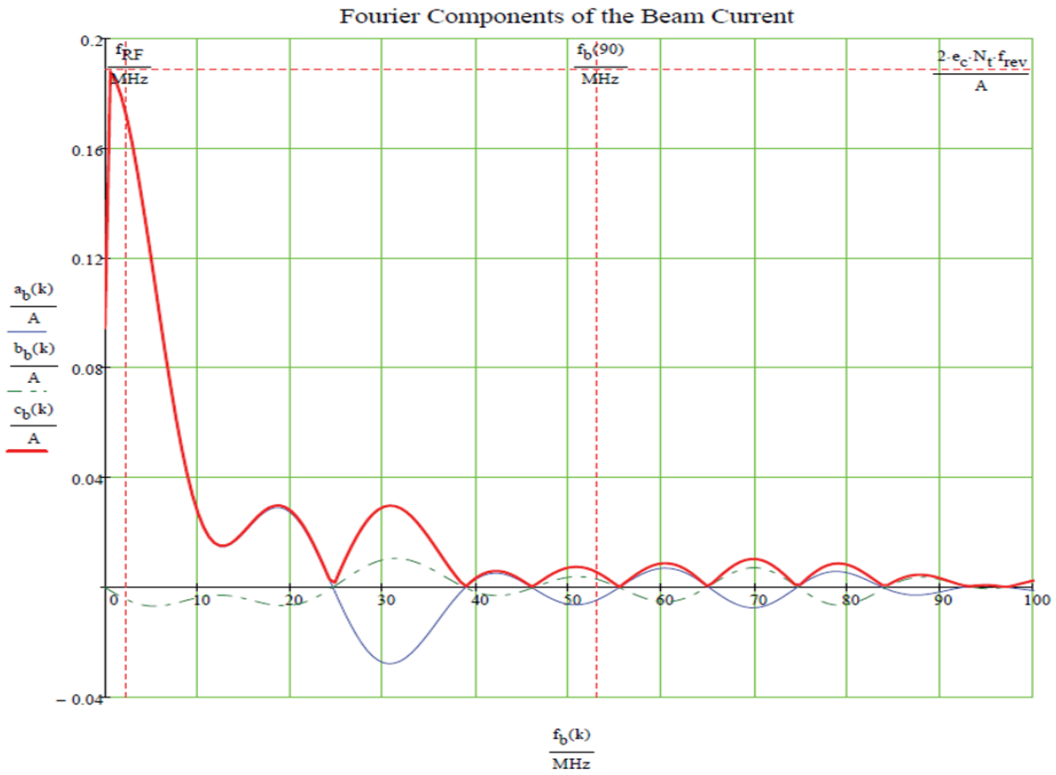
M-Field Harmonics

- First five harmonics @ 2.5, 6.5, 11.5, 12.7, 13.9 MHz



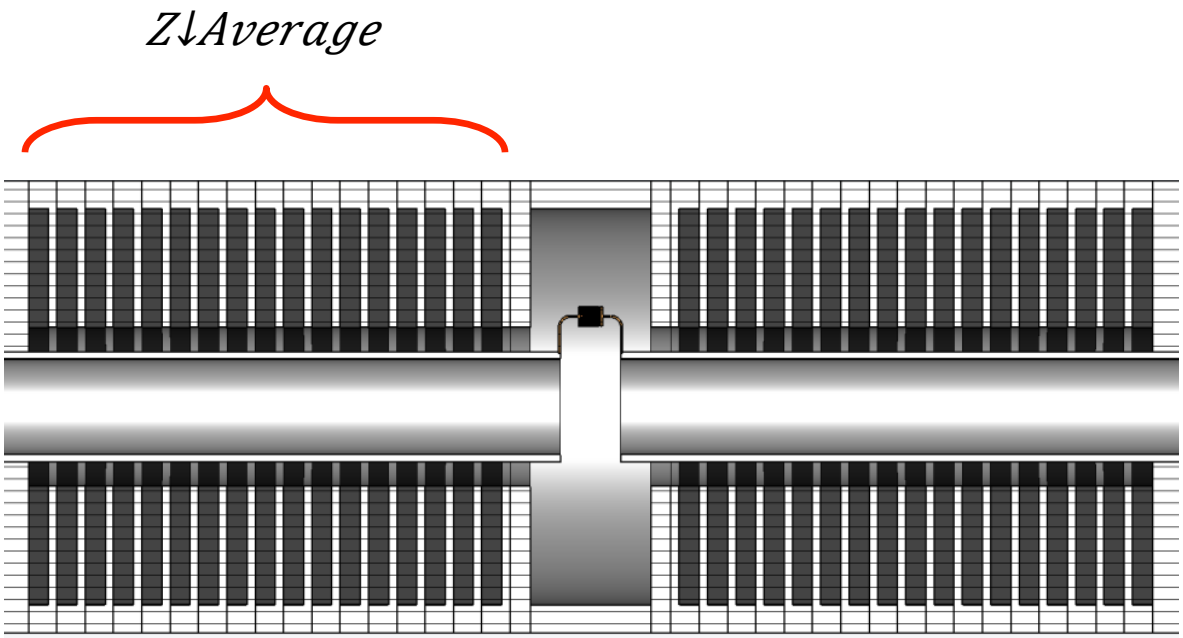
Induced Currents

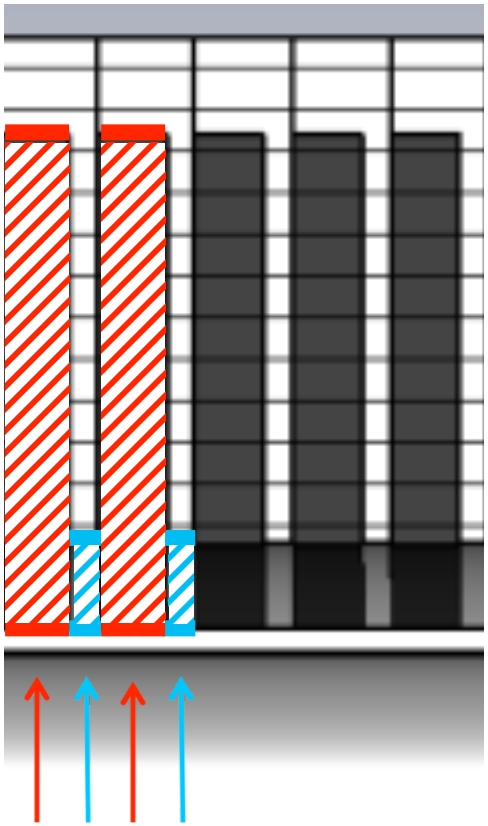
- Higher order modes are primarily delivered by the proton beam
- Can calculate induced currents on cavity due to beam
- Does not appear significant
- If issue, can implement harmonic dampeners



Characteristic Impedance (Z_o)

- Function of ratio between inner/outer conductors and the dielectric material
- Impacts gap voltage and necessary capacitor





.. Z_1 Z_2 Z_1 Z_2 ..

Quality Factor (Q)

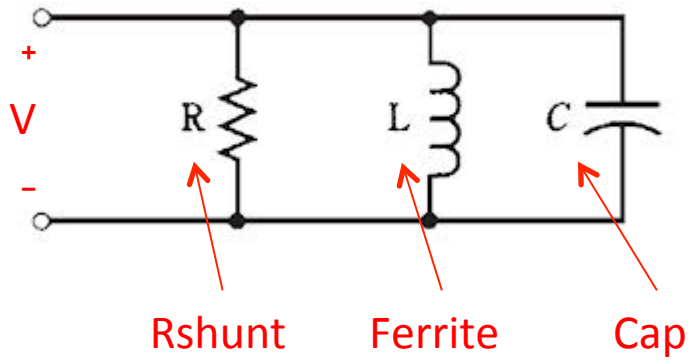
- The quality factor of a cavity is a ratio

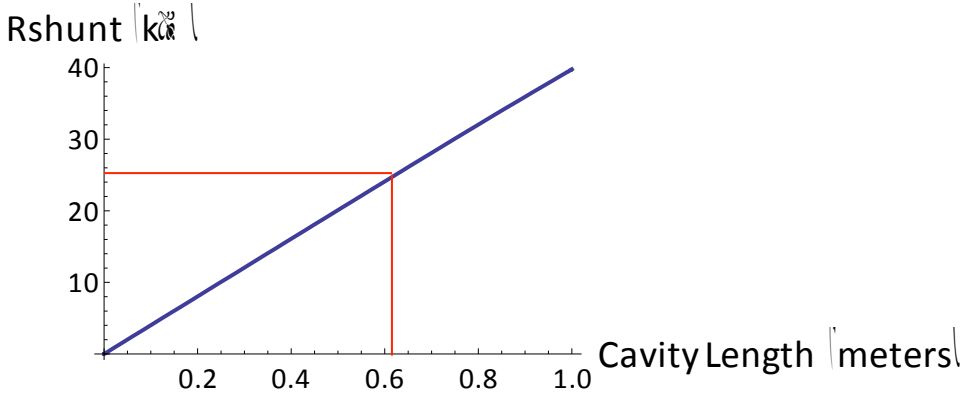
$$\textit{Energy Stored per Cycle} / \textit{Energy Loss per Cycle}$$

- Ferrite cavities have a low Q compared to super conducting cavities
- The Q of the cavity is dominated by the Q of the ferrite
- Test cavity results showed that the aluminum casing and tin finger stock did not have a significant impact on the Q of the cavity

Rshunt (Shunt Impedance)

- Rshunt of 25kΩ yields 10kV with 1kW input power
- Total cavity length ~1.5m
- Power distribution across 34 ferrite is acceptable





Conclusions

- By using circuit models, CST Microwave Studio and a five ferrite test cavity we
  - Showed proof of concept of the cavity design
  - Demonstrated the sufficiency of the water cooling system
  - Found the cavities characteristic impedance and Q factor
  - Determined an appropriate Rshunt for the needed voltage
  - Identified the size of the capacitors
  - Calculated the appropriate RF input point on the cavity
  - Determined the frequency of the higher order modes

Special Thank You

- Joseph Dey
- SIST Committee Members
  - Sandra Charles, Linda Diepholz, Dianne Engram, Gustavo Canselo, Bill Freeman, Elliott McCrory, Vivian O'Dell, David Peterson, and Mayling Wong-Squires
- RF Department

Questions?