Half-Wave Coaxial Test Cavities at ODU
Results and Plans

Work supported by NSF Grant PHY-1416051

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Introduction

- Our goal is not necessarily to achieve the highest fields and lowest surface resistance
- It is to get a better understanding of the physics of the mechanisms limiting the performance in the frequency range of interest for accelerators
- The research consists of experimental and theoretical parts to address the unresolved issues of the surface resistance of superconductors at high rf field, and in particular how the surface composition and structure can be modified and tuned in order to reduce surface resistance.
- One of the most effective ways to understand a physical process is to analyze its frequency dependence
- It is very much work in progress

Research Tool – Half Wave Coaxial Cavity

- Cavity designed to provide range of frequency particular interest of accelerators: 325, 650, 975, 1300 MHz.

- Field distribution almost identical in all TEM modes
  - The same surface will be exposed to the highest fields at all frequencies

- TEM modes should be sufficiently separated by other TM and TE modes.

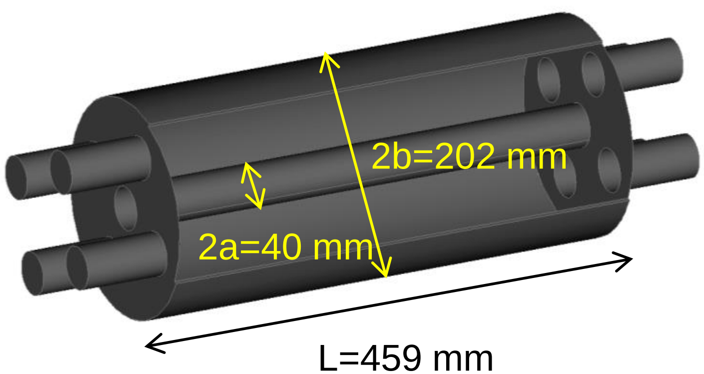
- Should be able to achieve high rf surface field.

- Should be free of multipacting.

Research Tool – Half Wave Coaxial Cavity

$$P_t = H_p^2 R_s \frac{\pi}{2} La \left[L \left(\frac{1}{a} + \frac{1}{b} \right) + 4 \ln \left(\frac{b}{a} \right) \right]$$

- Lowest power dissipation for a given H_p on center conductor
  - Smallest a possible, but big enough to be able to provide sufficient cooling
  - $b/L=0.25$, shallow minimum, tweak to separate TE and TM modes

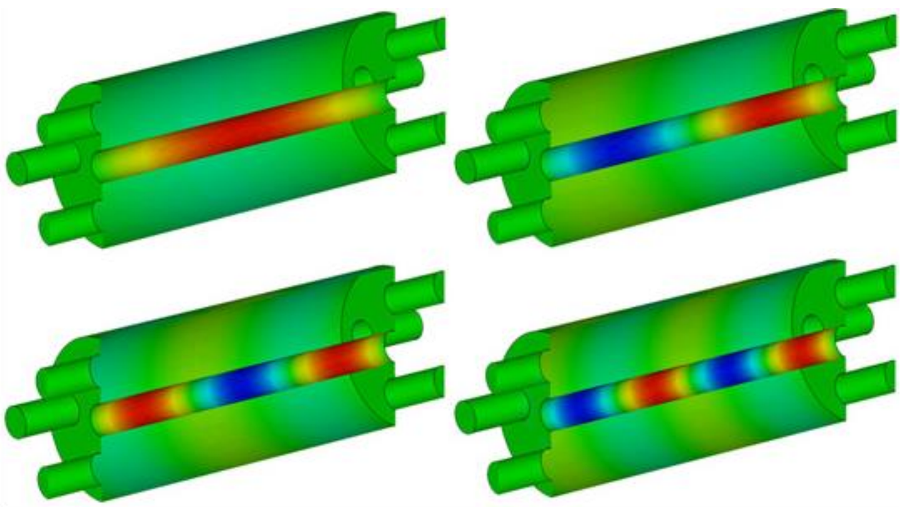


Mode	f (MHz)	G (Ohm)
TEM1	325.4	59
TEM2	650.8	119
TE111	869.6	
TEM3	976.1	179
TE112	1034.9	
TE113	1265.4	
TEM4	1301.3	239
TE211	1470.1	

Surface Fields of TEM Modes

Surface Electric Field

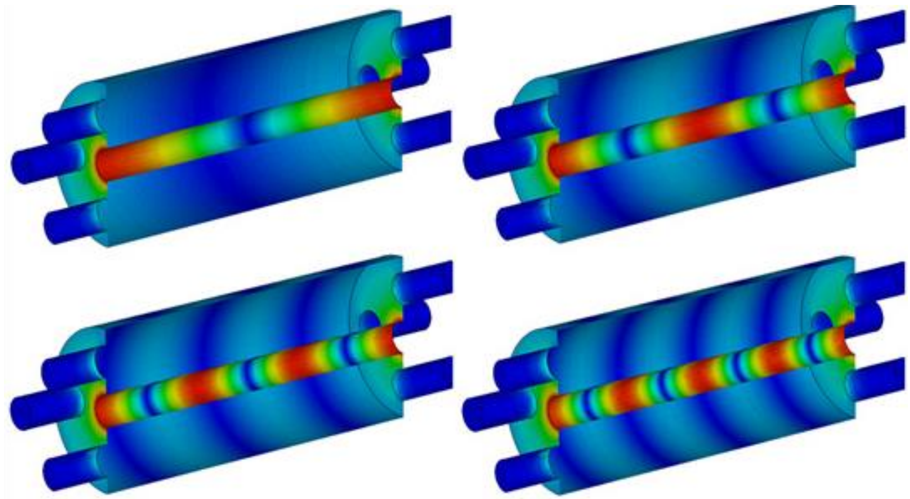
325 MHz 650 MHz



975 MHz 1300 MHz

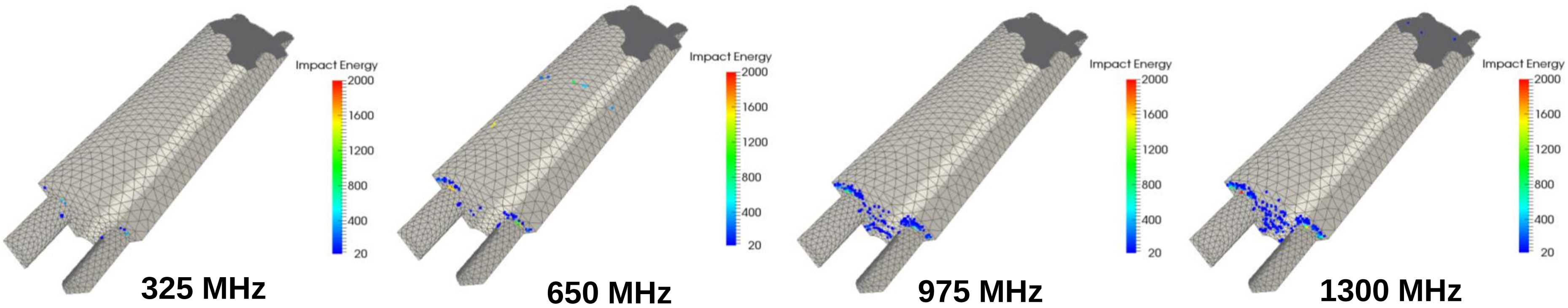
Surface Magnetic Field

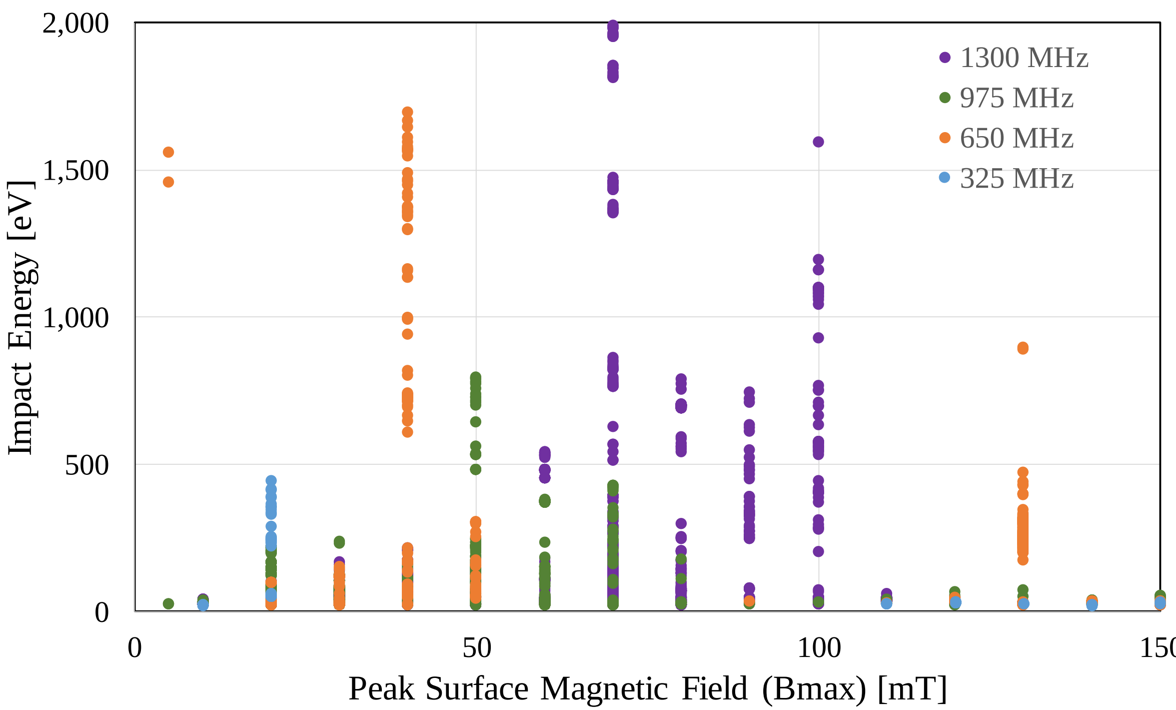
325 MHz 650 MHz



975 MHz 1300 MHz

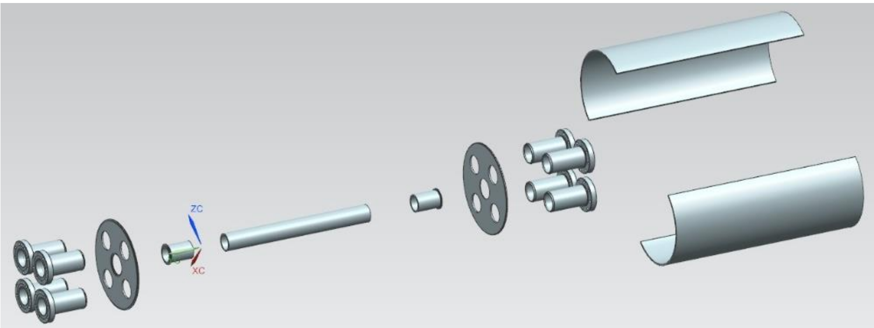
Multipacting Levels – Half-Wave Coaxial Cavity

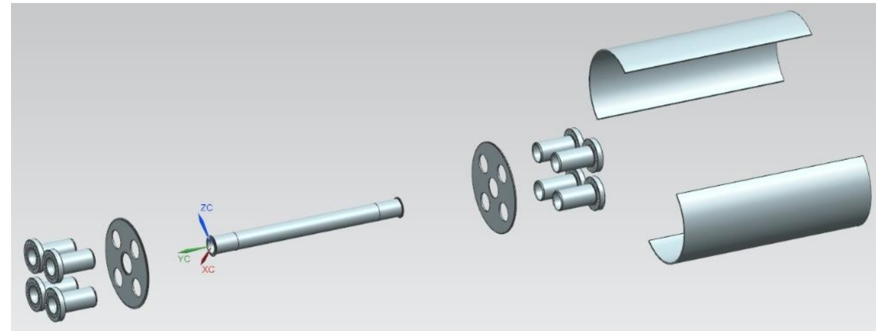


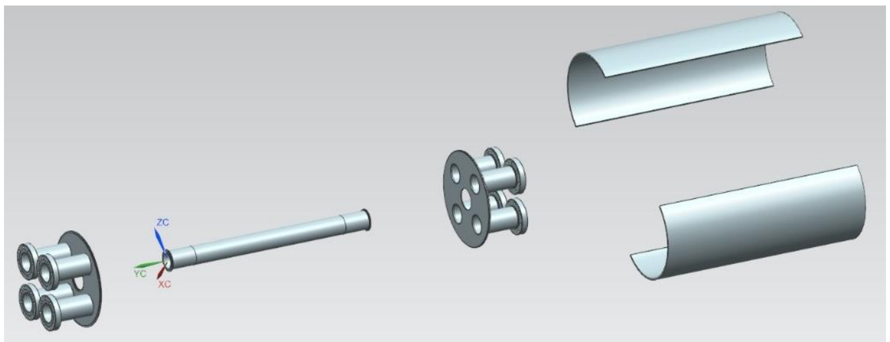


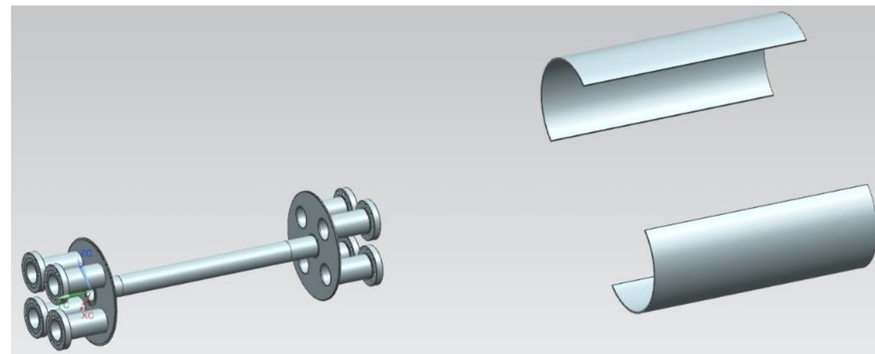
- Multipacting levels at the end plate in the cavity
- Higher multipacting levels at higher frequency
- Multipacting was processed gradually with increasing frequency

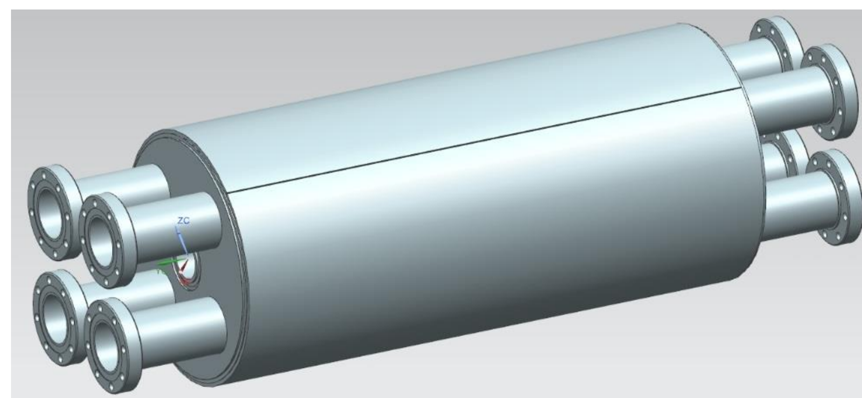
Fabrication Sequence



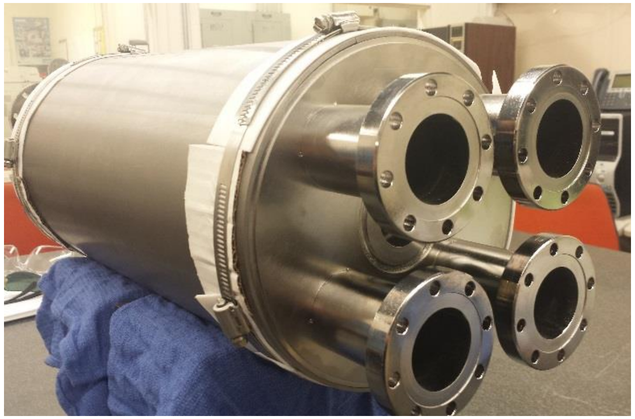








Research Tool – Half Wave Coaxial Cavity



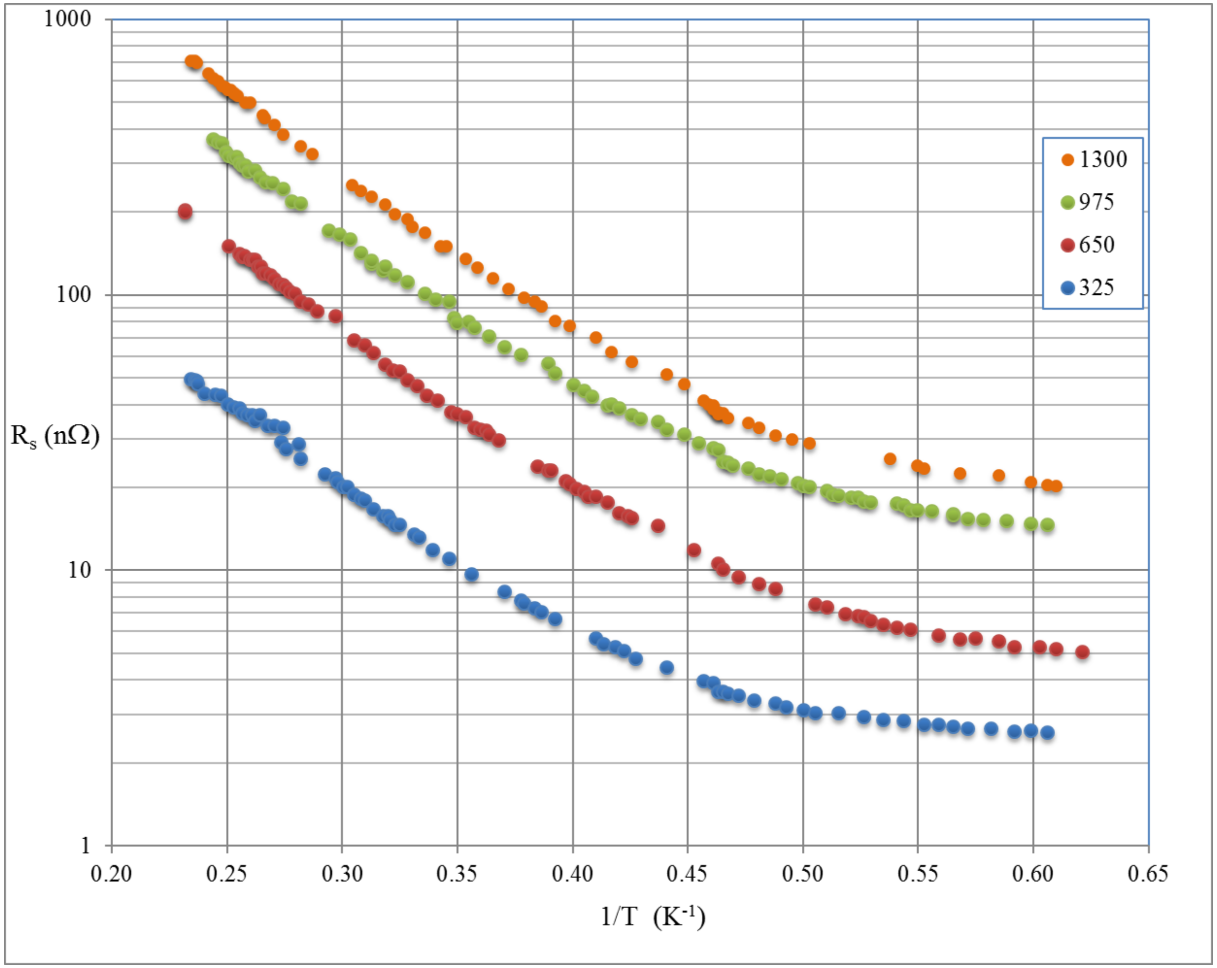
Fabricated cavity with many ports for diagnostics capability

Cavity ready for cold test

Clean room assembly

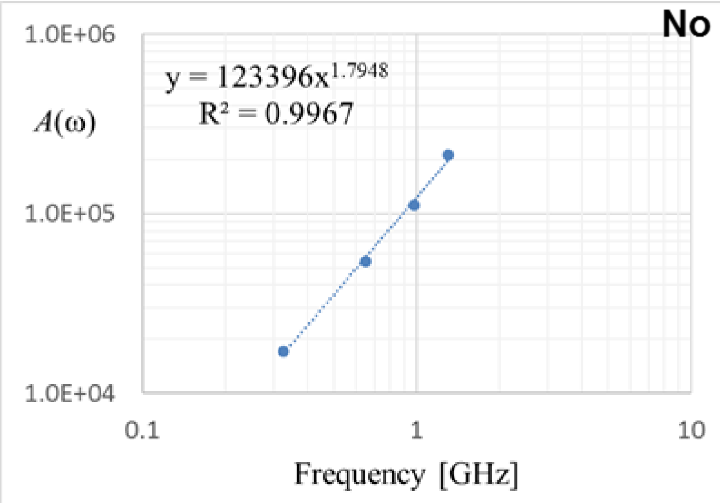
Low Field Frequency Dependence

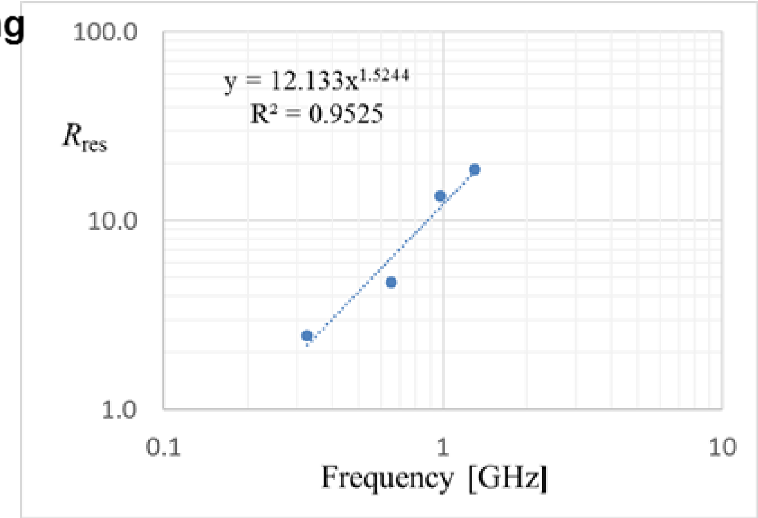
No low-T baking

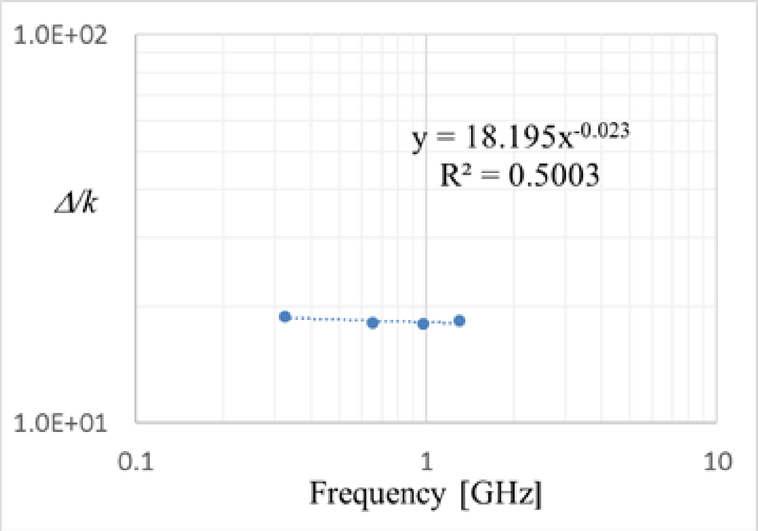


Low Field Frequency Dependence

No low-T baking







$$R_s(T) = \frac{A(\omega)}{T} \exp\left[-\frac{\Delta}{kT}\right] + R_{res}$$

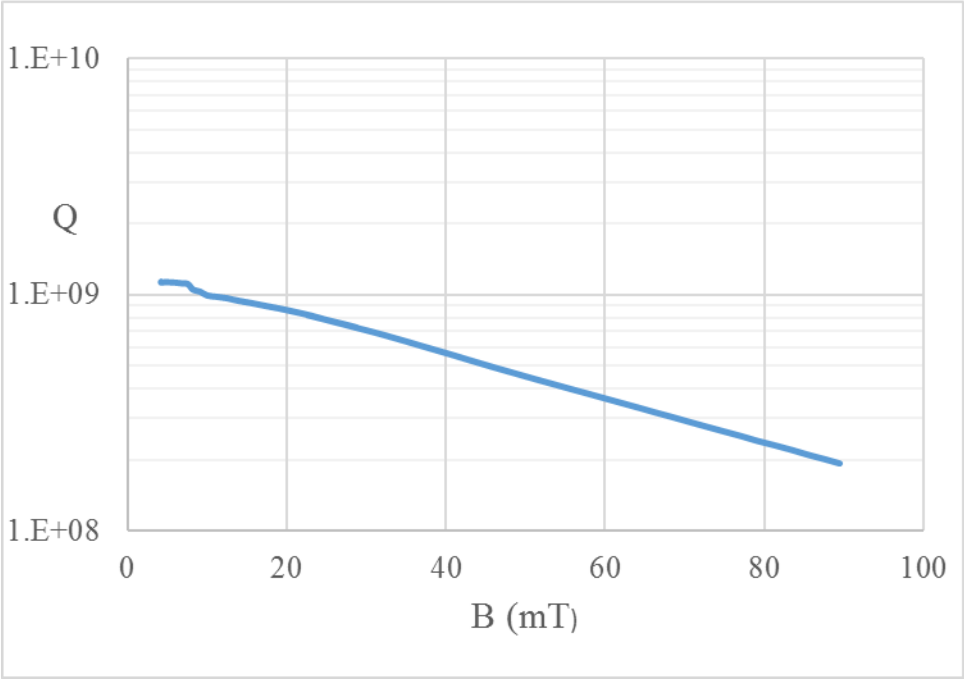
$$A(\omega) \propto \omega^{1.8}$$

$$\Delta / k \simeq 18.2\ \mathrm{K}$$

$$R_{res} \propto \omega^{1.5}$$

Field Dependence of Surface Resistance

No low-T baking



325 MHz

4.3 K

G=59 Ω

Extracting Real $R_s(H)$ from $Q(H_p)$

- Geometrical factor

$$G = \frac{\omega \int \mu_0 |\mathbf{H}|^2 \, \mathrm{d}v}{\int |\mathbf{H}|^2 \, \mathrm{d}a} \qquad G = QR_s \text{ only if } R_s \text{ (or } Q\text{) is constant}$$

- Average surface resistance $\overline{R_s}(H_p) = G / Q(H_p)$

$$\overline{R_s}(H_p) \int_S |\mathbf{H}(r)|^2 \, \mathrm{d}S = \int_S R_s [H(r)] |\mathbf{H}(r)|^2 \, \mathrm{d}S$$

- Define $a(h)$ as the fraction of the total cavity area where $|H| \le h H_p$
  - Continuous, monotonically increasing $\left.\frac{\mathrm{d}a}{\mathrm{d}h}\right|_{a=1} = \infty$
  - $a(0) = 0 \qquad a(1) = 1$

$$\overline{R_s}(H) \int_0^1 (hH)^2 \frac{\mathrm{d}a}{\mathrm{d}h} \mathrm{d}h = \int_0^1 R_s(hH)(hH)^2 \frac{\mathrm{d}a}{\mathrm{d}h} \mathrm{d}h$$

Extracting Real $R_s(H)$ from $Q(H_p)$

- Model $\overline{R}_s(H)$ by $\overline{R}_s\left(\frac{H}{H_0}\right)=\overline{R}_0\sum_{\alpha_i} r_{\alpha_i}\left(\frac{H}{H_0}\right)^{\alpha_i}$
  - H_0 arbitrary, to make coefficients dimensionless
  - α_i : suite of non-negative real numbers
- Assume $R_s\left(\frac{H}{H_0}\right)=R_0\sum_{\alpha_i}\beta(\alpha_i)\, r_{\alpha_i}\left(\frac{H}{H_0}\right)^{\alpha_i}$

$$\beta(\alpha_i)=\frac{\int_0^1 h^2 \frac{\mathrm{d}a}{\mathrm{d}h}\,\mathrm{d}h}{\int_0^1 h^{2+\alpha_i}\frac{\mathrm{d}a}{\mathrm{d}h}\,\mathrm{d}h}=\frac{2\int_0^1 h\left[1-a(h)\right]\mathrm{d}h}{(2+\alpha_i)\int_0^1 h^{1+\alpha_i}\left[1-a(h)\right]\mathrm{d}h}$$

  - Continuous, monotonically increasing $\beta(0)=1,\quad \beta(\alpha_i)>\beta(\alpha_j)\text{ if }\ \alpha_i>\alpha_j$
  - $[1\text{-}a(h)]$ is the fraction of the total cavity area where $\left|H\right|>h\,H_p$

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Application to Half Wave Coaxial Cavity

$$\rho = a/b$$
$$\delta = b/L$$

Center conductor

$$A_1(h) = 4\rho\delta L^2 \arcsin(h) \qquad \frac{dA_1}{dh} = \frac{4\rho\delta L^2}{\sqrt{1-h^2}}$$

Outer conductor

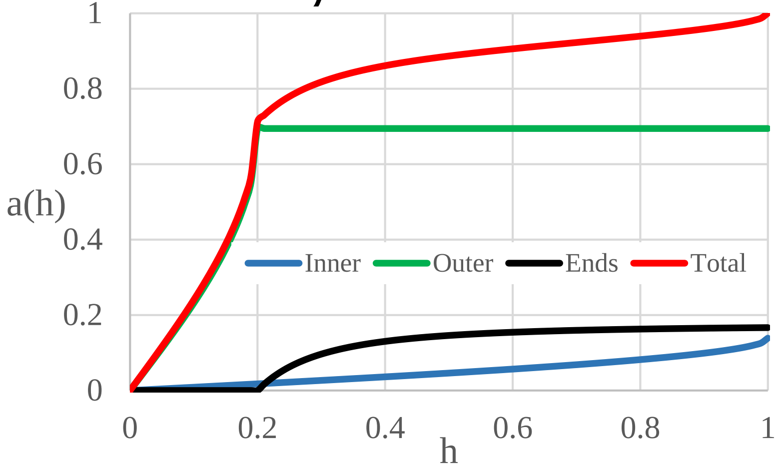
$$A_2(h) = \begin{cases} 4\delta L^2 \arcsin(h/\rho) \\ 0 \end{cases} \qquad \frac{dA_2}{dh} \begin{cases} \dfrac{4\delta L^2}{\rho\sqrt{1-(h/\rho)^2}} & 0 \le h < \rho \\ 0 & \rho \le h \le 1 \end{cases}$$

End Plates

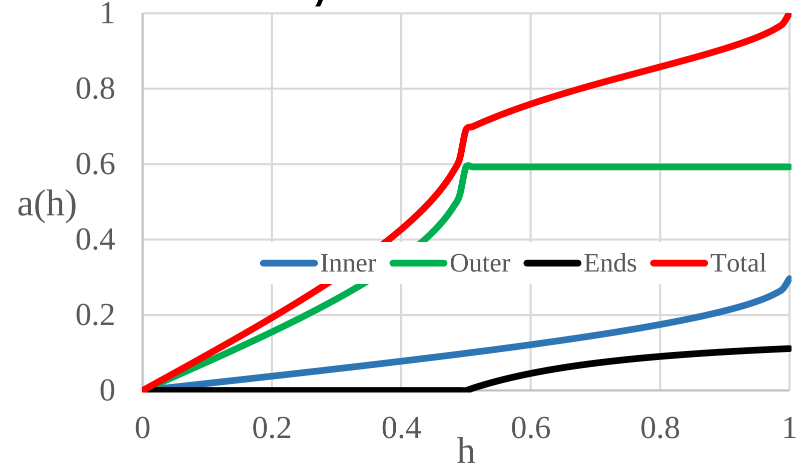
$$A_3(h) = \begin{cases} 0 \\ 2\pi\delta^2 L^2 \left(1 - \dfrac{\rho^2}{h^2}\right) \end{cases} \qquad \frac{dA_3}{dh} \begin{cases} 0 & 0 \le h < \rho \\ \dfrac{4\pi\rho^2 L^2}{h^3} & \rho \le h \le 1 \end{cases}$$

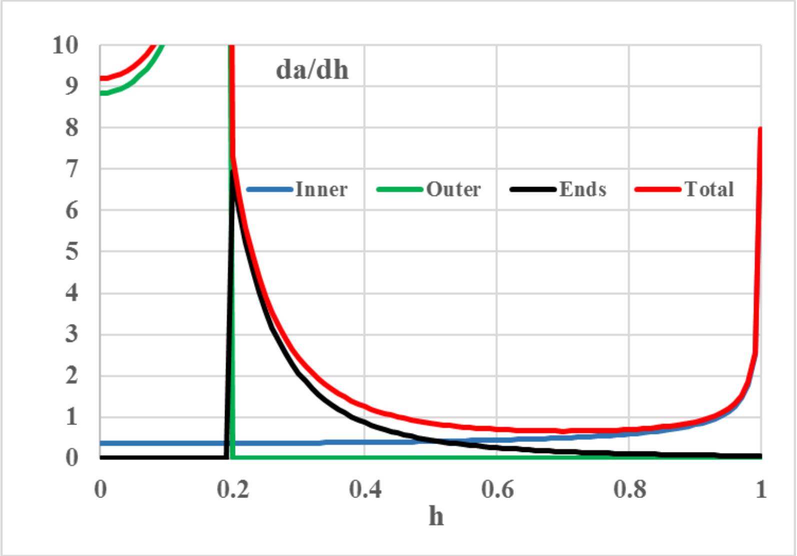
Application to Half Wave Coaxial Cavity

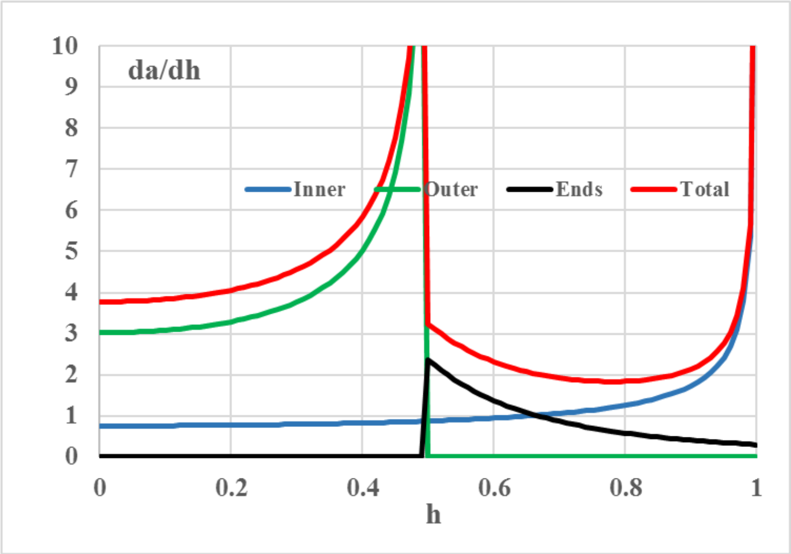
$$\rho = a / b = 0.2$$



$$\rho = a / b = 0.5$$





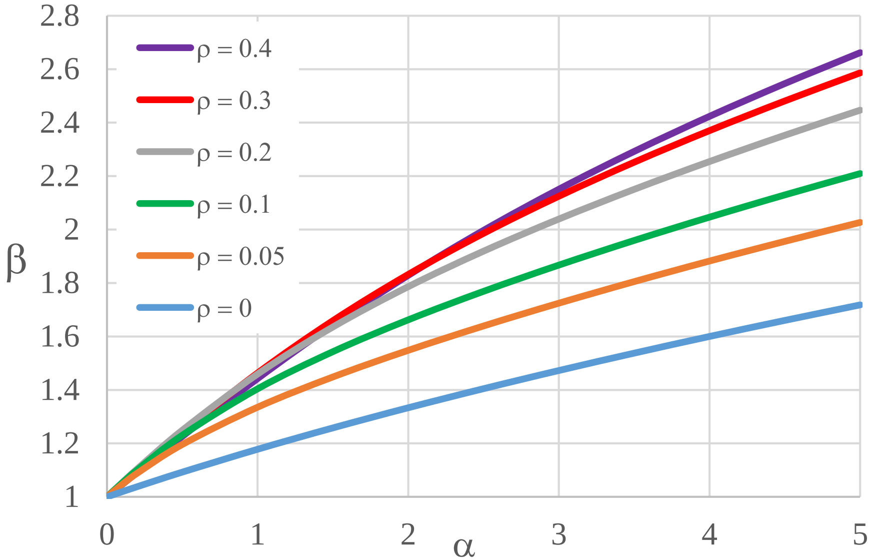


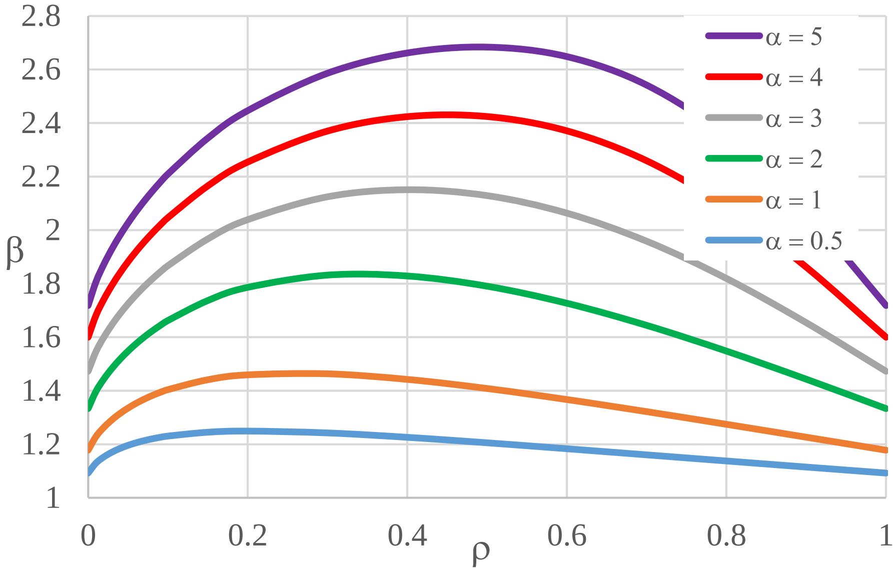
Application to Half Wave Coaxial Cavity

$$\beta(\alpha_i) = \frac{(1+\rho)/4 + \rho\delta\ln(1/\rho)}{\frac{1+\rho^{1+\alpha_i}}{2\sqrt{\pi}}\frac{\Gamma(\alpha_i/2+3/2)}{\Gamma(\alpha_i/2+2)} + \frac{\rho\delta}{\alpha_i}(1-\rho^{\alpha_i})}$$

$$\rho = \frac{a}{b}$$

$$\delta = \frac{b}{L}$$





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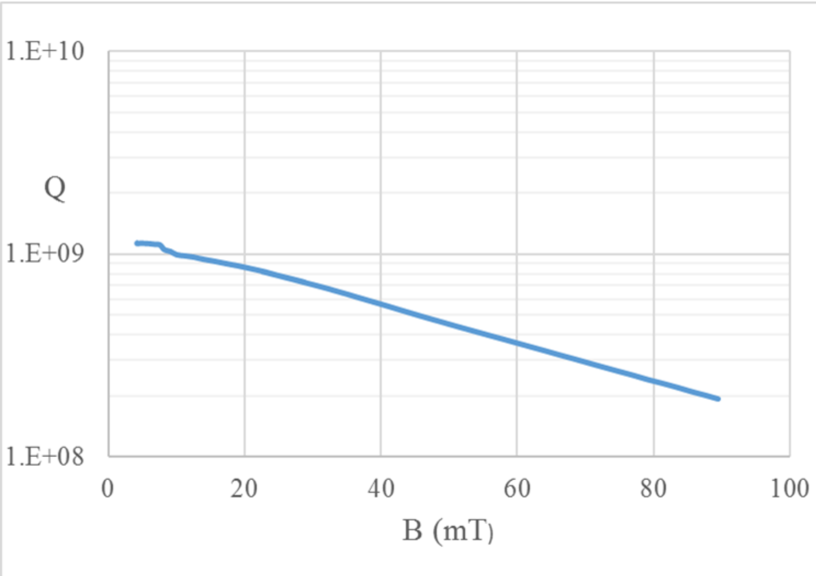
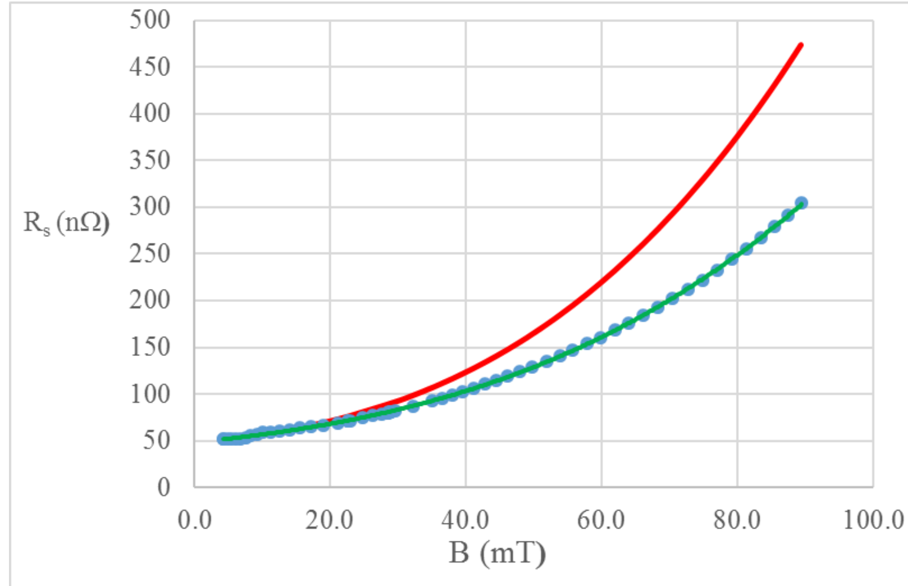
Field Dependence of Surface Resistance





325 MHz

4.3 K

G=59 Ω

$$B_0 = 100 \text{ mT}$$

$$\bar{R}_s\left(\frac{B}{B_0}\right) = 48.2\left[1 + 1.54\left(\frac{B}{B_0}\right) + 2.03\left(\frac{B}{B_0}\right)^2 + 3.20\left(\frac{B}{B_0}\right)^3\right]$$

$$\beta_0 = 1, \ \ \beta_1 = 1.46, \quad \beta_2 = 1.79, \quad \beta_3 = 2.04$$

$$R_s\left(\frac{B}{B_0}\right) = 48.2\left[1 + 2.24\left(\frac{B}{B_0}\right) + 3.63\left(\frac{B}{B_0}\right)^2 + 6.52\left(\frac{B}{B_0}\right)^3\right]$$

On-going Work and Plans

- Influence of low temperature baking on $A(\omega)$, Δ/k, R_{res}, $R_s(H)$
  - No baking, 6 hours, 6+6 hours, 6+6+12 hours, 6+6+12+24 hours
- Next:
  - same thing with N infusion
  - Trapping of magnetic field
  - …..
- Now building 2 new almost identical HW cavities
  - OD slightly bigger for ease of assembly
  - Entirely made of Nb to be able to go to high temperature
    - Nb_3Sn coating
    - High temperature heat treatment