ARTIFICIAL DIELECTRIC QUARTER WAVE RESONATOR

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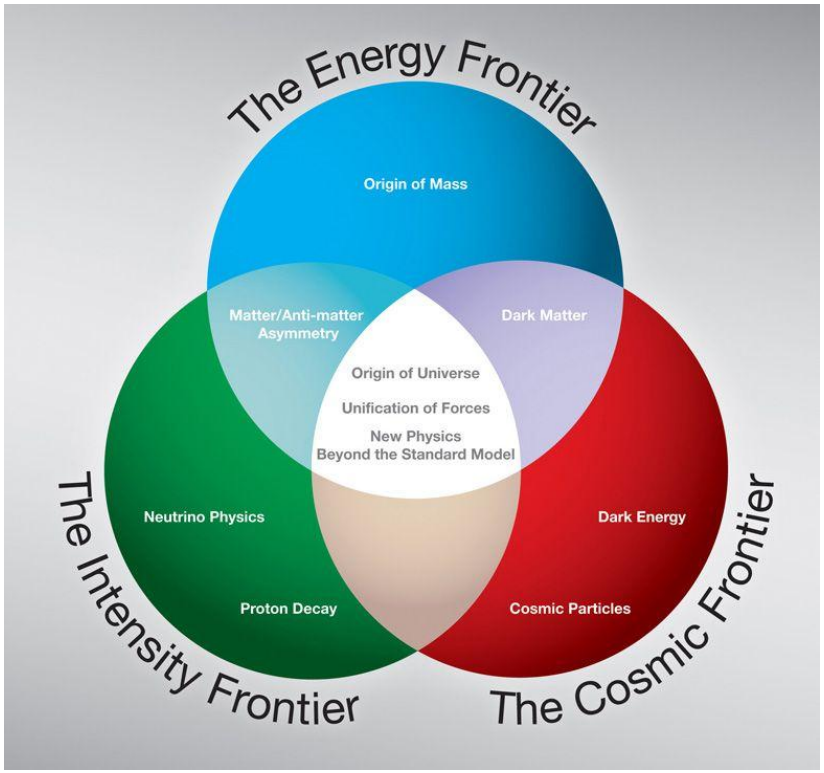
Outline

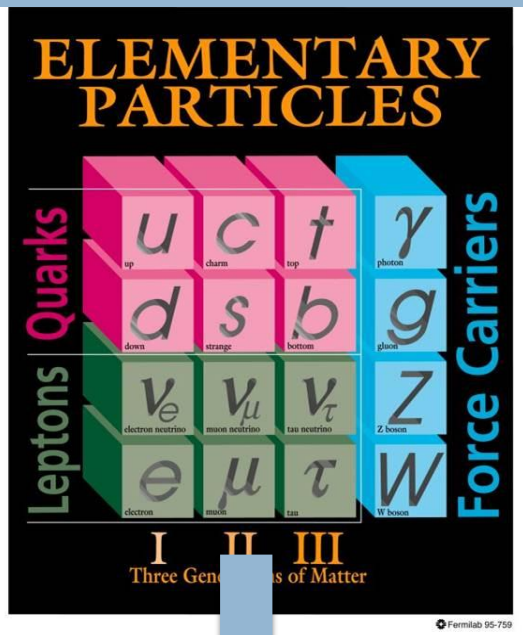
- Background Information
  - Purpose
  - Muons / G-2 Experiment
  - Overview of an RF Cavity
- Summary of Three Cavities
  - Unloaded Cavity
  - Ferrite Loaded Cavity
  - Artificial Dielectric Cavity
- Conclusion
- Questions

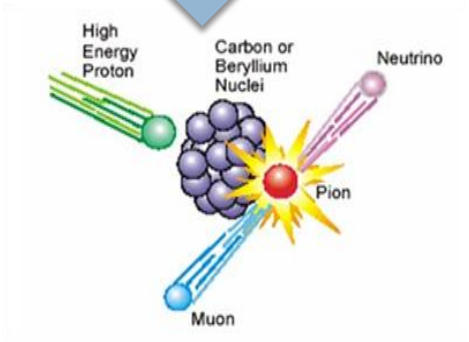
Purpose



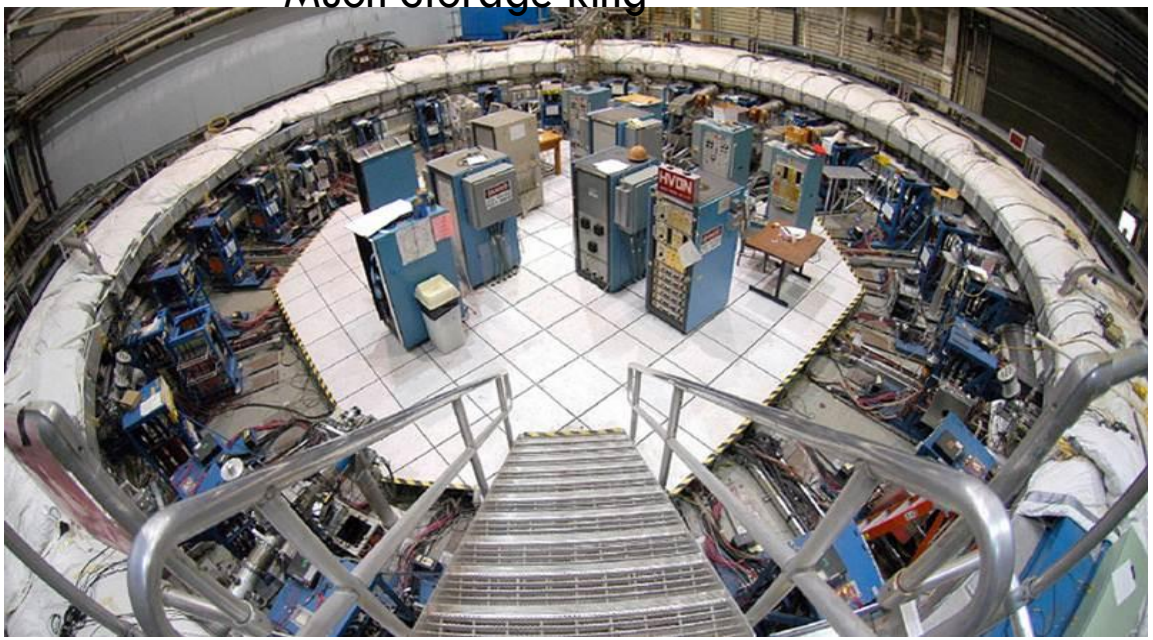
- To Discover New Physics!
- Advance the Intensity Frontier

The G-2 Experiment





- Muons
  - ½ spin, negative charge
  - Produced by colliding protons and target nuclei
- Brookhaven Laboratory
  - E821 Experiment
  - Muon Storage Ring



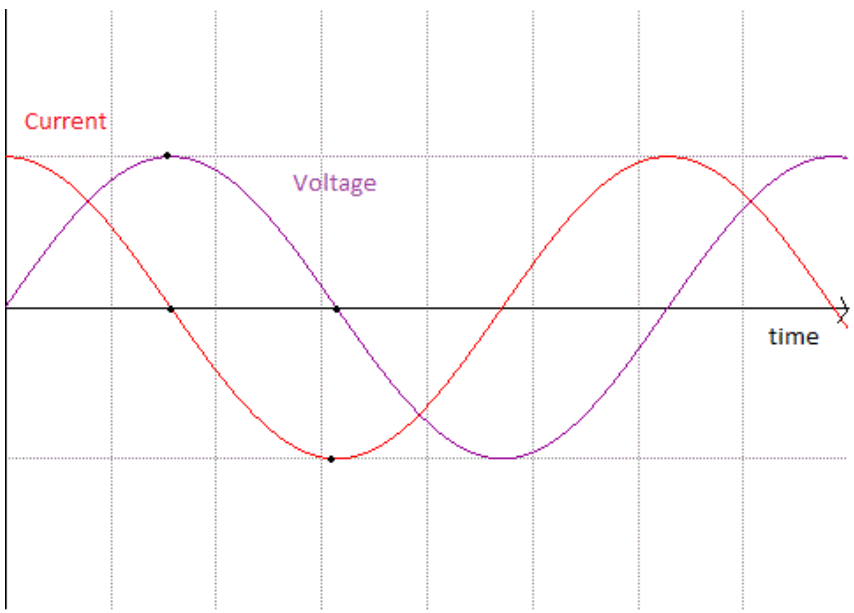
RF Cavity Overview

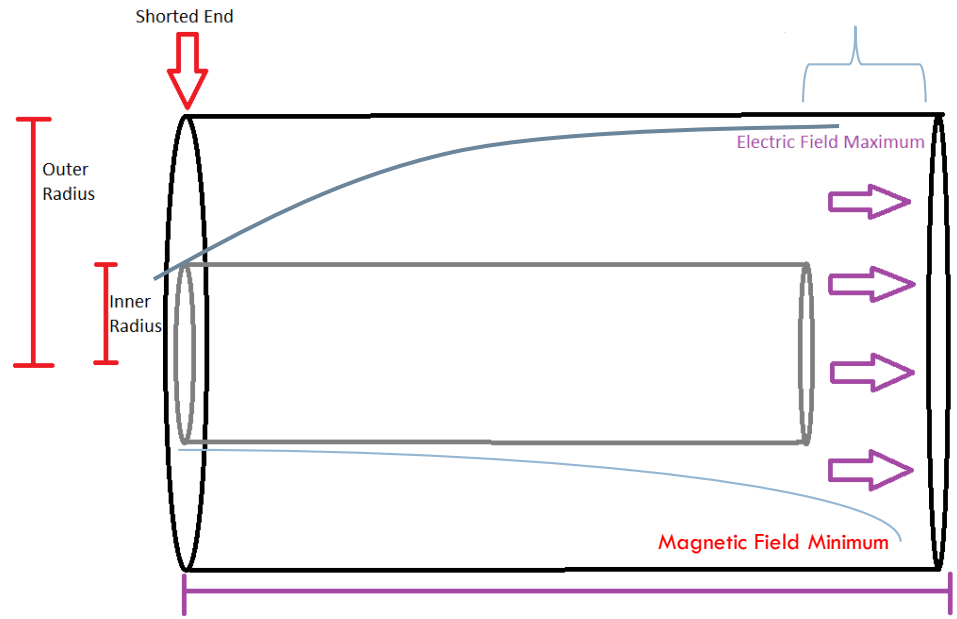
Lorentz Force Equation

$$\vec{F} = \frac{d\vec{p}}{dt} = q(\vec{E} + \vec{v} \times \vec{B})$$

RF Cavity Overview

Quarter Wave Resonator



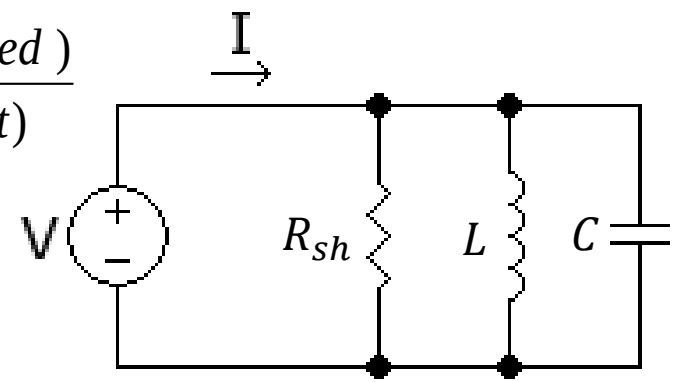


$$l_r = \lambda/4$$

Magnetic field ~ Current
Electric Field ~ Voltage

RF Cavity Overview

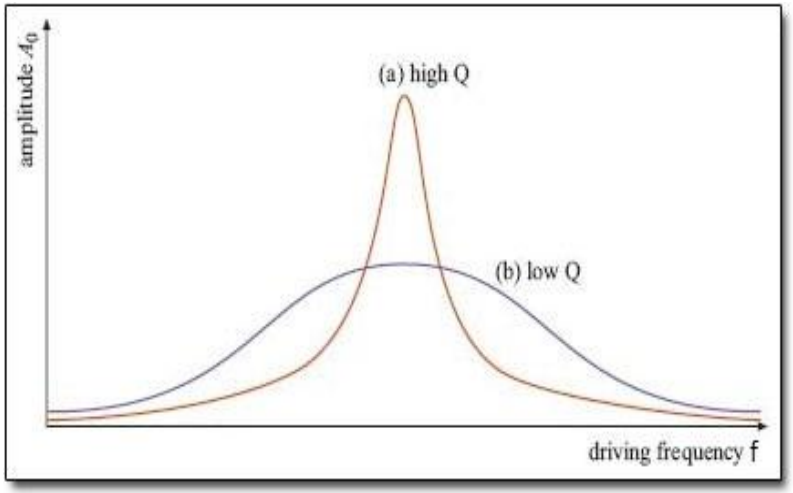
$$Q = 2\pi \frac{(Energy\ Stored)}{(Energy\ Lost\ Per\ Cycle)} = 2\pi f \frac{(Energy\ Stored)}{(Power\ lost)}$$



$$R_{sh} = \frac{(VV^*)_{gap}}{2P_{lost}} = \frac{4}{\pi} R_c Q \left\{ \frac{\frac{\pi}{2}}{(1+q^2)\cot^{-1}(q) + q} \right\}$$

Foreshortening Factor

$$where\ \ q = \omega R_c C_{gap} = \cot(\beta\, l_r),\ \beta = \frac{2\pi}{\lambda},\ R_c = \sqrt{\frac{L_{eq}}{C_{eq}}}$$

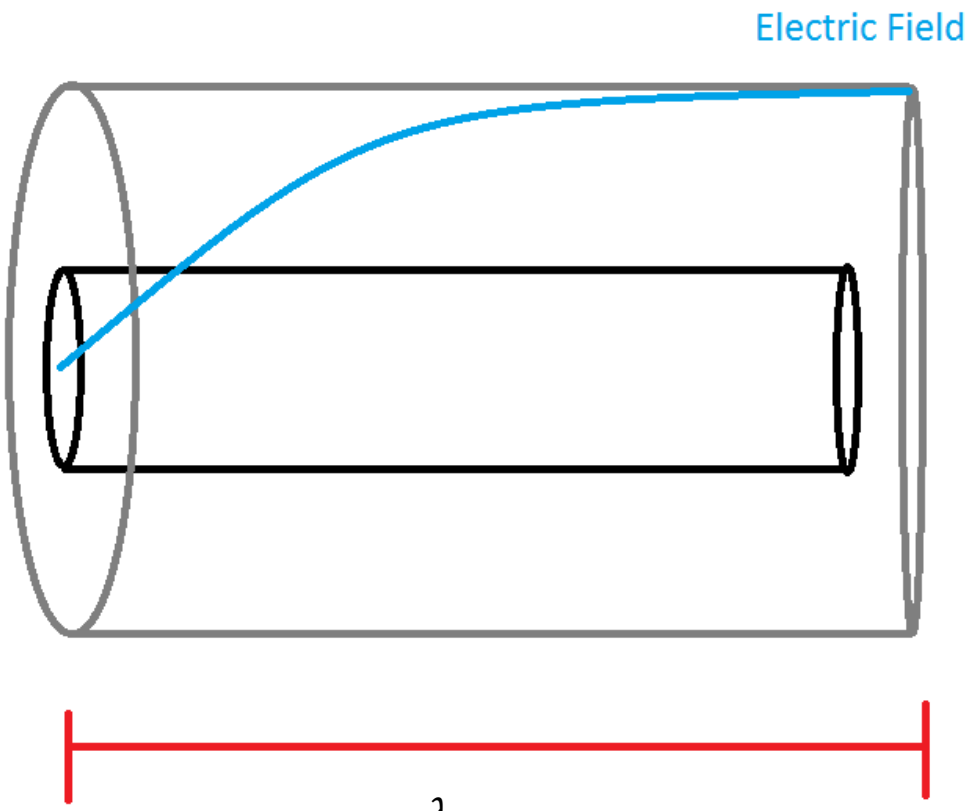


Modeling the Quarter Wave Resonator

- Studied three different models
  1. Unloaded copper cavity
  2. Cavity loaded by Nickel Zinc Ferrite
  3. Artificial Dielectric Cavity
- What to look for:
  - Low Power Loss
  - High Q value
  - High Shunt Impedance

Unloaded Copper Cavity

$$c = \lambda f, f = 2.5MHz$$



$$V_{peak} = 75\ kV$$

$$l_r = \frac{\lambda}{4} = 30\ meters$$

Results

Foreshortening Factor	Outer Radius	Q Value	Shunt Impedance	Power Loss
1	10 inches	3195.632	223.54 kΩ	12.581 kW
1	15 inches	5094.956	514.109 kΩ	5.471 kW
1	20 inches	6548.54	631.934 kΩ	4.451 kW
.2096	15 inches	1067.33	107.77 kΩ	26.1 kW

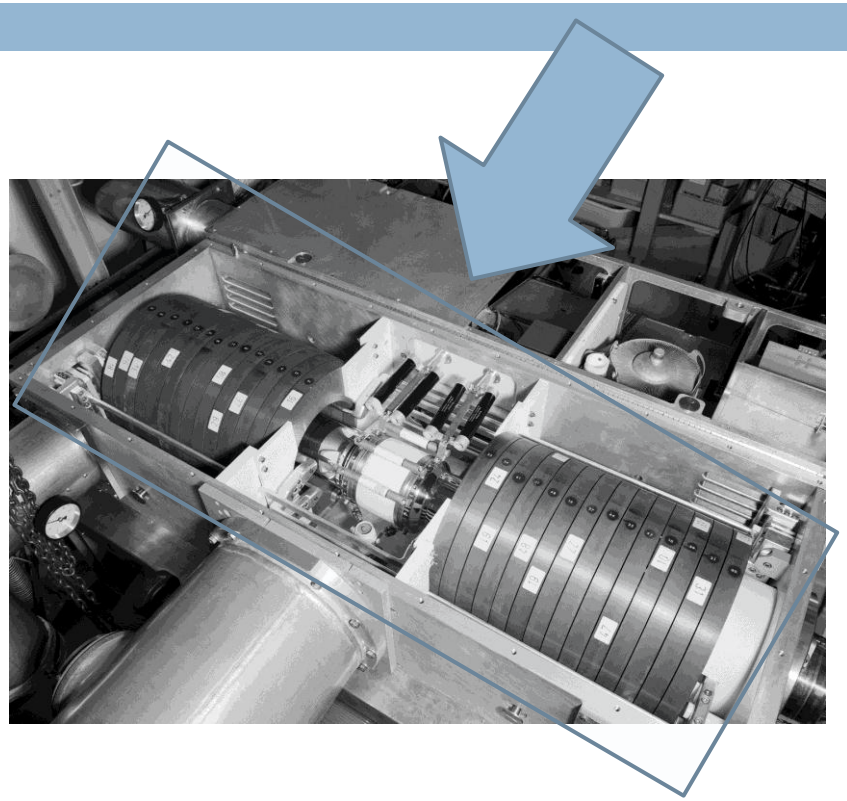
Based on inner radius of 4 inches

Results for the Unloaded Cavity

- Yes it is possible to create this cavity
  - Foreshortening the Cavity = adding gap capacitance
- Drawbacks:
  - Will not fit inside of the equipment drop hatch
  - Manufacturing and installation problems due to length and weight

Nickel Zinc Ferrite Cavity

- Why we chose Nickel Zinc Ferrite
  - Lower conductivity (to minimize power lost through cavity)
  - High resistivity (prevent shorting the cavity)
  - Why we chose the dimensions
    - inner radius= 10 cm
    - Outer radius= 25 cm



- Important Equations:

$$velocity = \frac{c}{\sqrt{\mu\varepsilon}} = \frac{\lambda f}{\sqrt{\mu\varepsilon}} = \lambda' f$$

$$Faraday's\ Law:$$

$$Peak\ Voltage = \frac{d\varphi}{dt} = \frac{d}{dt}\iint B \cdot dA = \frac{d}{dt}\int_{r_1}^{r_2}\int_{0}^{l_r} \frac{R_1}{r} B_{\max} \sin(\omega t)\cos(\beta z)\,dr\,dz$$

Approach

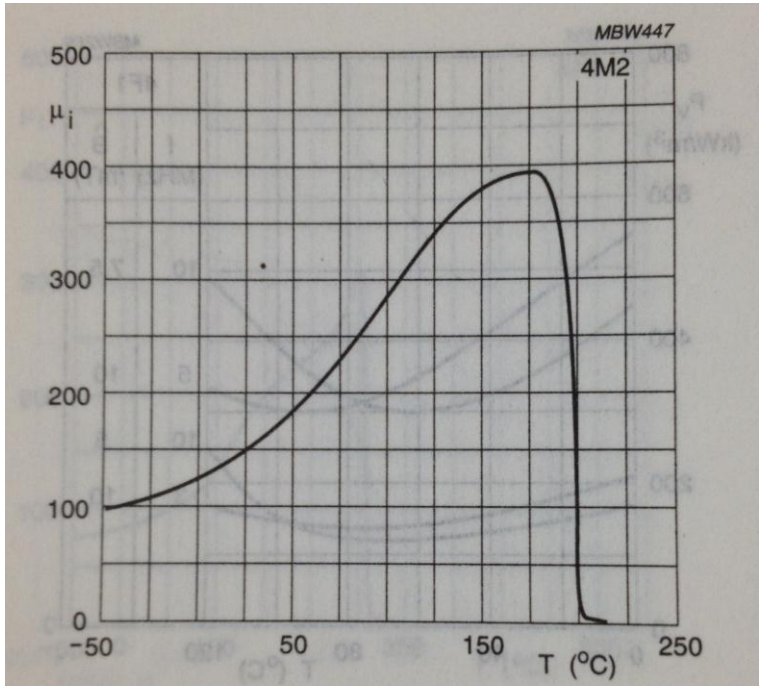


Fig.2 Initial permeability as a function of temperature.

- Voltage → Magnetic field→Q→ Power Loss
- Heat Equation

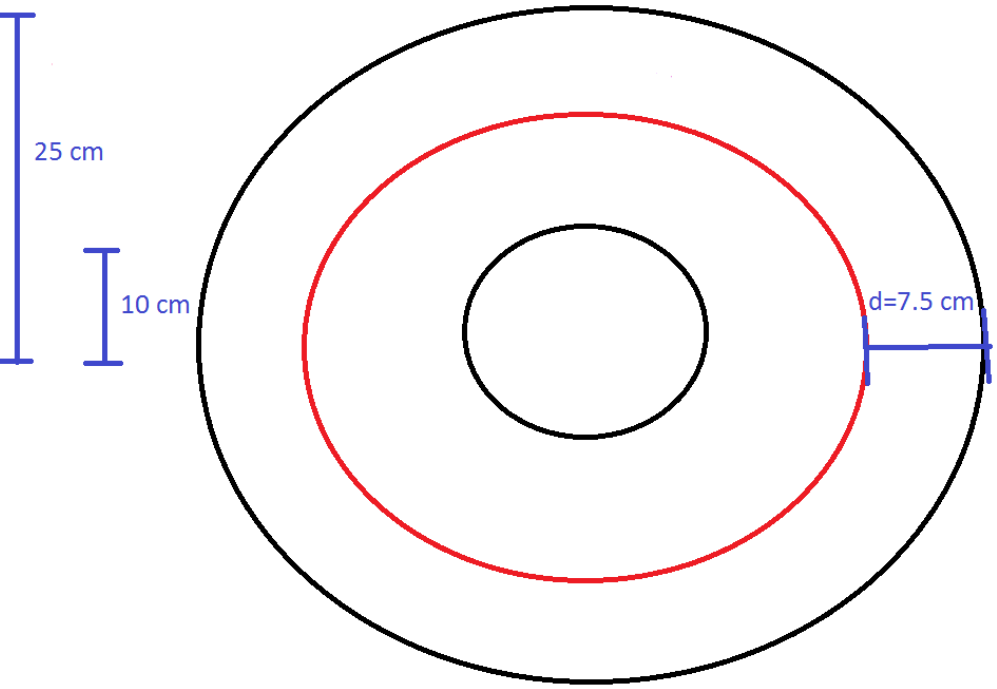
$$P_{loss} = \frac{K \cdot \Delta T \cdot A}{d}$$

- Curie Temperature
  - $T_c = 200°\mathrm{C}$
  - Above T_c the ferrite becomes paramagnetic and cavity is detuned

Temperature Calculations

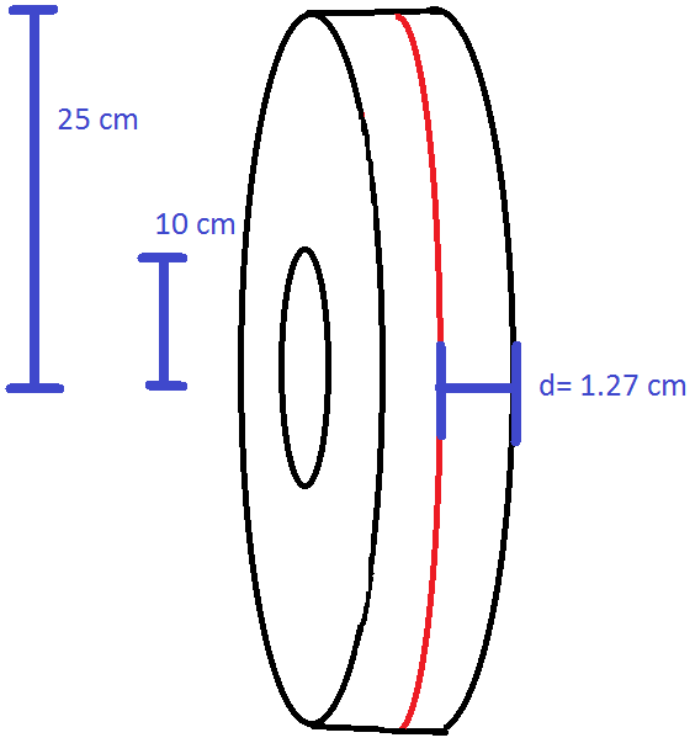
$$\Delta T = \frac{P_{loss} \cdot d}{A \cdot \mathrm{K}}$$

Cooling Radially Outward



$A = 2\pi(17.5\ cm)(1.27\ cm)$

Cooling With Copper Plates in the Z Direction



$A = \pi(\ (25cm^2) - (10\ cm)^2)$

Results

	Frequency	Shunt Impedance	Calculated Power Loss	Q
Nickel Zinc Ferrite Cavity	2.50 MHz	9.619 kΩ	292.366 kW	100

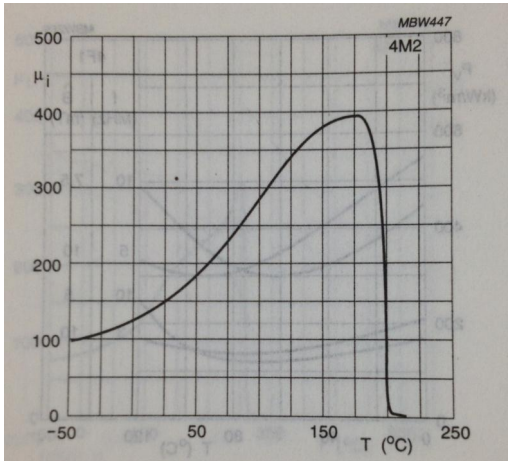


Fig.2 Initial permeability as a function of temperature.

$$\frac{c}{\sqrt{\mu\varepsilon}} = \lambda \frac{f}{\sqrt{\mu\varepsilon}} = \lambda f'$$

No longer get desired proton intensity!

Artificial Dielectric RF Cavity

Measured vs. Calculated

	Frequency	Shunt Impedance	Calculated Power Loss	Q
Calculated	14.128 MHz	15.075 kΩ	186.567 kW	759.8
Measured	14.5 MHz	17.1 kΩ	164.473 kW	848
Percent Error	2.56%	12.8%	10.4%	11.8%

$$R_{sh} = \frac{(VV)^*{}_{peak}}{P_{loss}}, V_{peak} = 75\ kV$$

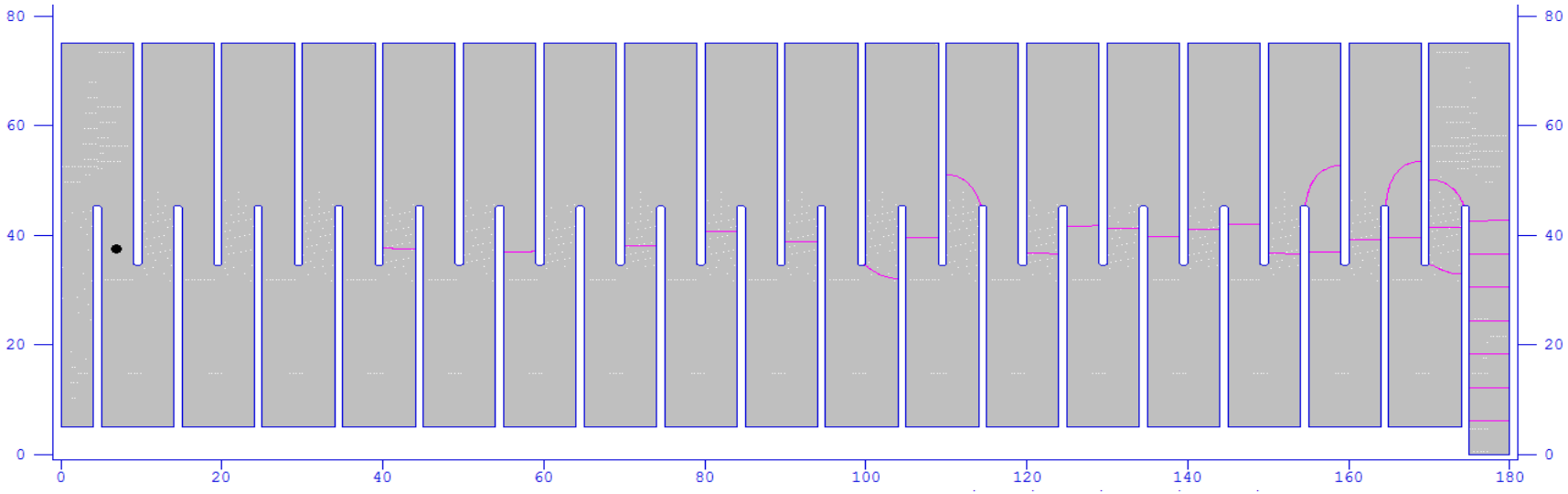
Results

- Pros:
  - Size
  - Temperature
- Next Step
  - Apply what we learned to produce a 2.5 MHz Cavity

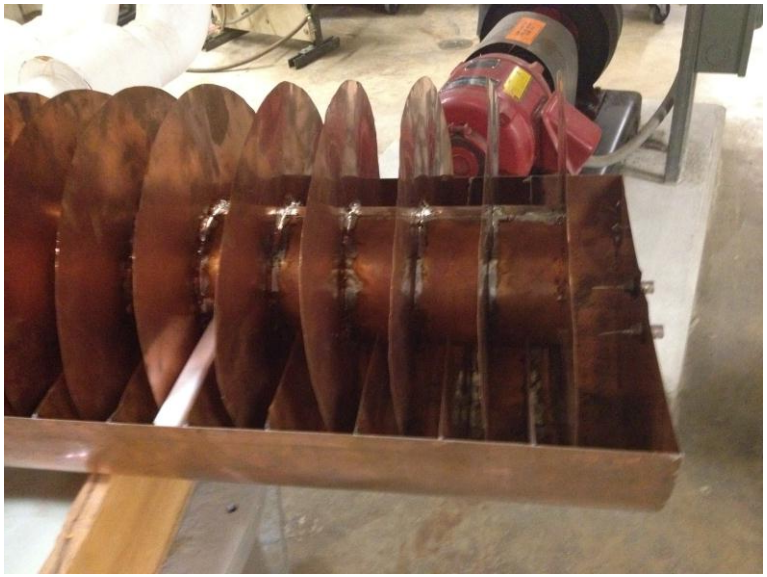
$$c = \lambda f$$

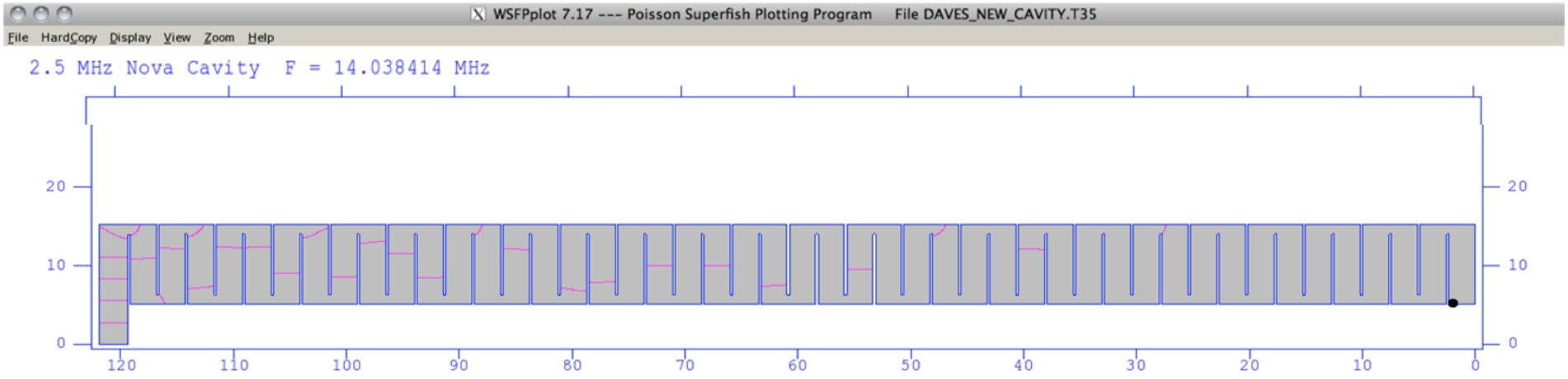
What is Superfish?

- A computer program for calculating EM fields for radio frequency Cavities
- 2 dimensional image of a 3-D cylindrical Cavity
  - (rotate about z axis)



Comparison



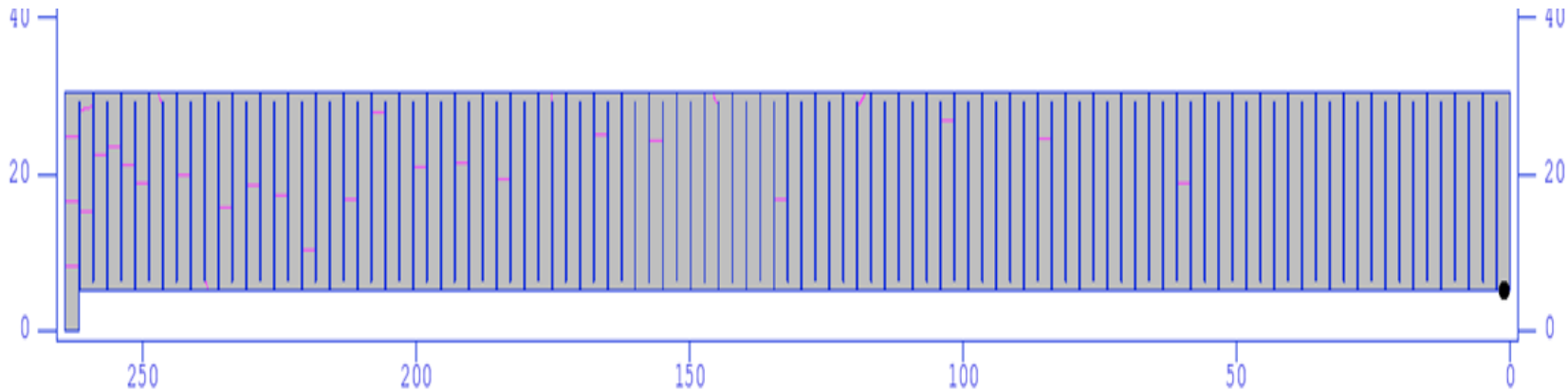

WSFPplot 7.17 --- Poisson Superfish Plotting Program File DAVES_NEW_CAVITY.T35
File HardCopy Display View Zoom Help
2.5 MHz Nova Cavity F = 14.038414 MHz
20
10
0
120
110
100
90
80
70
60
50
40
30
20
10
0

Comparison

	Frequency	Shunt Impedance	Calculated Power Loss	Q
Calculated	14.128 MHz	15.075 kΩ	186.567 kW	759.8
Measured	14.5 MHz	17.1 kΩ	164.473 kW	848
SuperFish	14.23 MHz	17.983 kΩ	165.395 kW	774.408

$$R_{sh} = \frac{(VV)^*{}_{peak}}{P_{loss}}, V_{peak} = 75\ kV$$

The Final Product



- Dimensions:
  - Length: 264.16 cm
  - Inner radius: 5.08 cm
  - Outer radius: 30.48 cm
  - Disk thickness: 2 mm

The Final Product

	Frequency	Shunt Impedance	Calculated Power Loss	Q Value
SuperFish Simulation	2.49987 MHz	11.6586 kΩ	55.3828 kW	521.665

$$R_{sh} = \frac{(VV)^*{}_{peak}}{P_{loss}}, V_{peak} = 75\ kV$$

Conclusion

	Frequency	Shunt Impedance	Calculated Power Loss	Q
Unloaded Copper	2.50 MHz	216.416 kΩ	12.996 kW	6112.342
Nickel Zinc Ferrite Cavity	2.50 MHz	9.619 kΩ	292.366 kW	100
Artificial Dielectric	2.49987 MHz	11.6586 kΩ	55.3828 kW	521.665

All three cavities are possible however, the Artificial Dielectric Quarter Wave Resonator is our best option.

Acknowledgements

- David Wildman and Robyn Madrak
- Dave Peterson and Elmie Peoples-Evans
- Diane Engram
- Dr. Davenport
- And the entire SIST Committee

QUESTIONS?