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Modeling and Simulation of Booster Cavity

Mohamed Hassan

PIP Review

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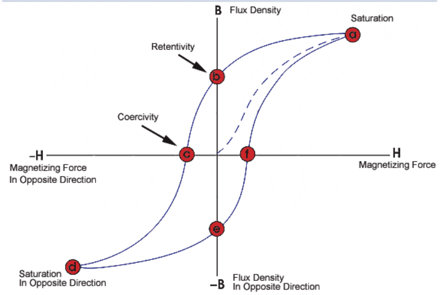
Introduction

How to Attain Tunability

Frequency Tuning	Tuning Mechanism	Tuning Range
Variable Volume	Piezoelectric Magnetostrictive	<0.05%
Variable Permeability	Ferromagnetic	~40%
Variable Permittivity	Ferroelectric	~10%

Slow versus Fast Frequency Tuning

Slow	Fast	Faster	Fastest
• Using motor driven mechanism • Response time ~60 s	• Using piezoelectric/ magneto-strictive element • Response time ~10 ms	• Using a ferromagnetic material • Response time ~ ms **Mature**	• Using Ferroelectric material • Response time ~ ns **Very early developments for phase shifters**



Classical way of tuning microwave components using bias current that will change the permittivity of the material

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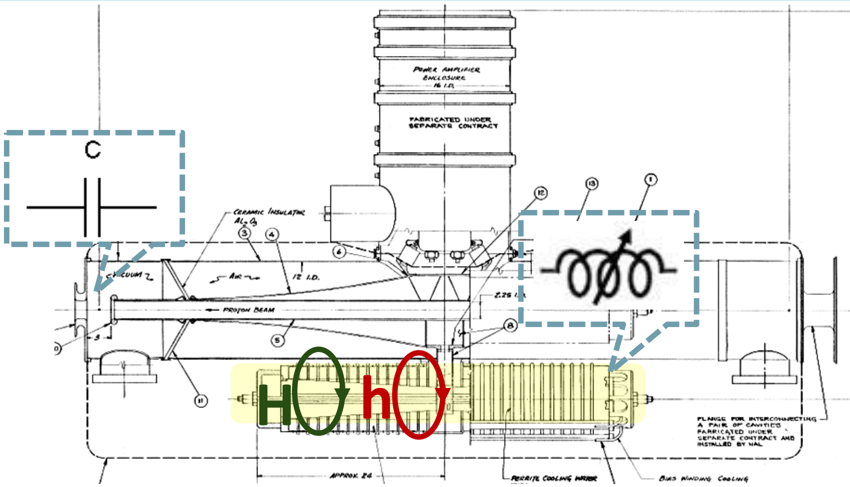
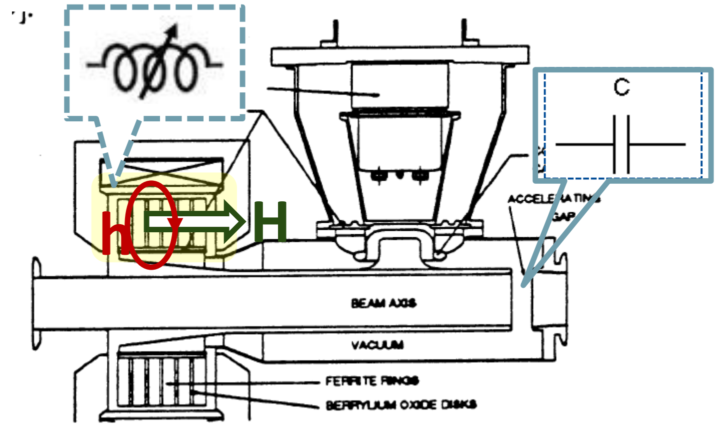
Tunable Booster Cavities





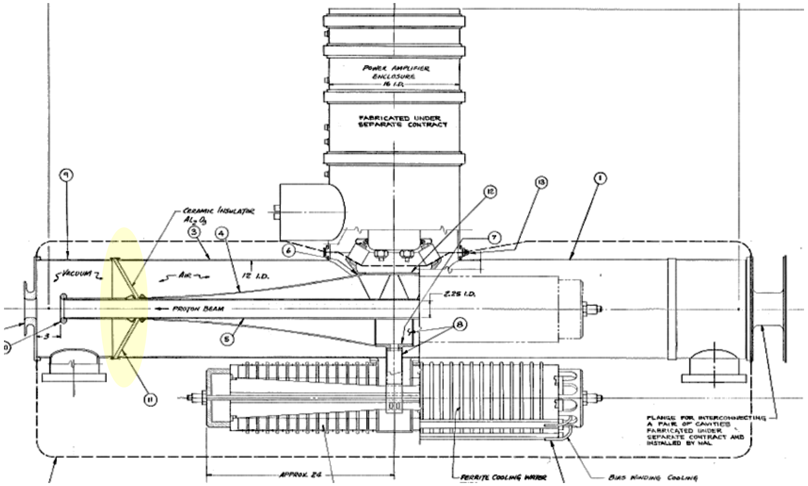
Parallel Biased	Perpendicular Biased
Bias Field is Parallel to the RF Field	Bias Field is Perpendicular to the RF Field
$H\widehat{\varphi} + h\widehat{\varphi} = (H + h)\widehat{\varphi}$	$H\hat{z} + h\widehat{\varphi} =$ rotating (on cone) magnetic vector – Gyromagnetic Resonance H=f/2.8
Ferrites with High Saturation Magnetization (Ni-Zn)	Ferrites with Relatively Low Saturation Magnetization (Mn-Zn)
Larger values of Mu (Larger Losses, Lower Q)	Smaller values of Mu (Smaller Losses, Larger Q)

Comparison Between Existing Booster Cavities

	FNAL Booster	TRIUMF	SSCL LEB	EHF-Booster
Energy Range [GeV]	0.4-8.0	0.45-3.0	0.6-11	1.2-9.0
Bias	Parallel	Perpendicular	Perpendicular	
Frequency [MHz]	37.7-53.3	46.1-60.8	47.5-59.8	50.5-56.0
Peak Gap Voltage [kV]	2*27	62.5	127.5	2*36
Cavity Length [m]	~2.4	~1.23	~1.25	~3.25
Accelerating Time [ms]	35	10	50	20
Repetition Rate	7	50	10	25
Ferrite Material	Ni-Zn	Yttrium Garnet	Yttrium Garnet	
Ferrite Material	Toshiba, Stackpole	TT-G810	TT-G810	
Cavity Q	250-1200	2200-3600	2800-3420	
Cavity R/Q	50	35	36	
Status	Operating	Prototype	Prototype	

Development of perpendicular-biased cavities didn't pass prototype stage

Why Perpendicular Biased Cavity Could Achieve Higher Voltage Gradient?



- Air fills most of the cavity volume (breakdown ~30 kV/cm)
- Vacuum windows are nearby the gap
- Tuner is filled with air

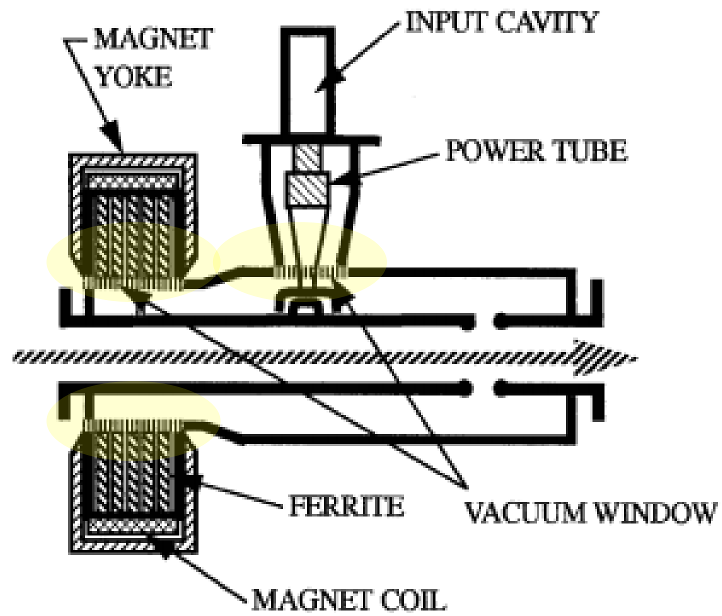
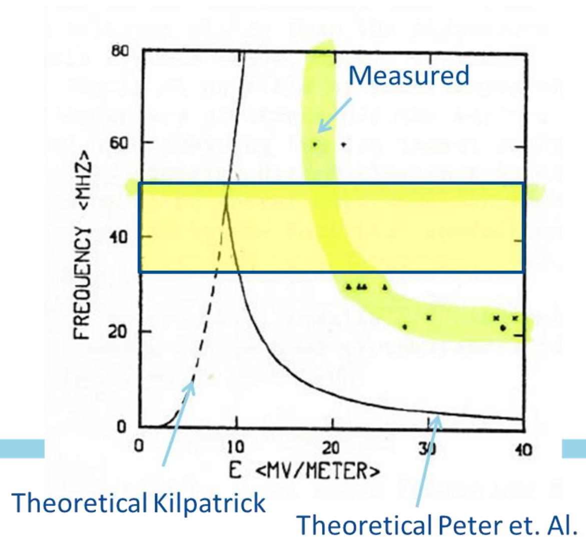


Figure 1. LEB prototype cavity.

- Vacuum fills most of the cavity volume (breakdown ~ 100 kV/cm)
- Vacuum windows are right away on the tuner connection
- Tuner is filled with dielectric



In Air ~ 3 MV/m (30 kV/cm)
In Vacuum (according to Kilpatrick) is ~ 10 MV/m (theoretical) 18 MV/m (measured)

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Current Booster Cavity

Challenges of the PIP for the Booster Cavity

	Current, Refurbished	New
Frequency Range	37.80-52.82 MHz	Same
V_{acc}	55kV	60 kV
R/Q	~50	~50
Duty Cycle	Effectively 25%, 50%	50%
Repetition Rate	Effectively 7.5Hz, 15Hz	15 Hz
Cavity Tuning	Horizontal Bias	Same
Beam Pipe Diameter	2.25”	>3”
Higher Order Mode Impedance	<1000 Ohm	<1000 Ohm
Cooling	LCW at 95 F, Water flow up to 21 gpm	Same

Activation Problem

- Current beam pipe (2.25”) is vulnerable to activation
- Need to increase the beam pipe size (3”)

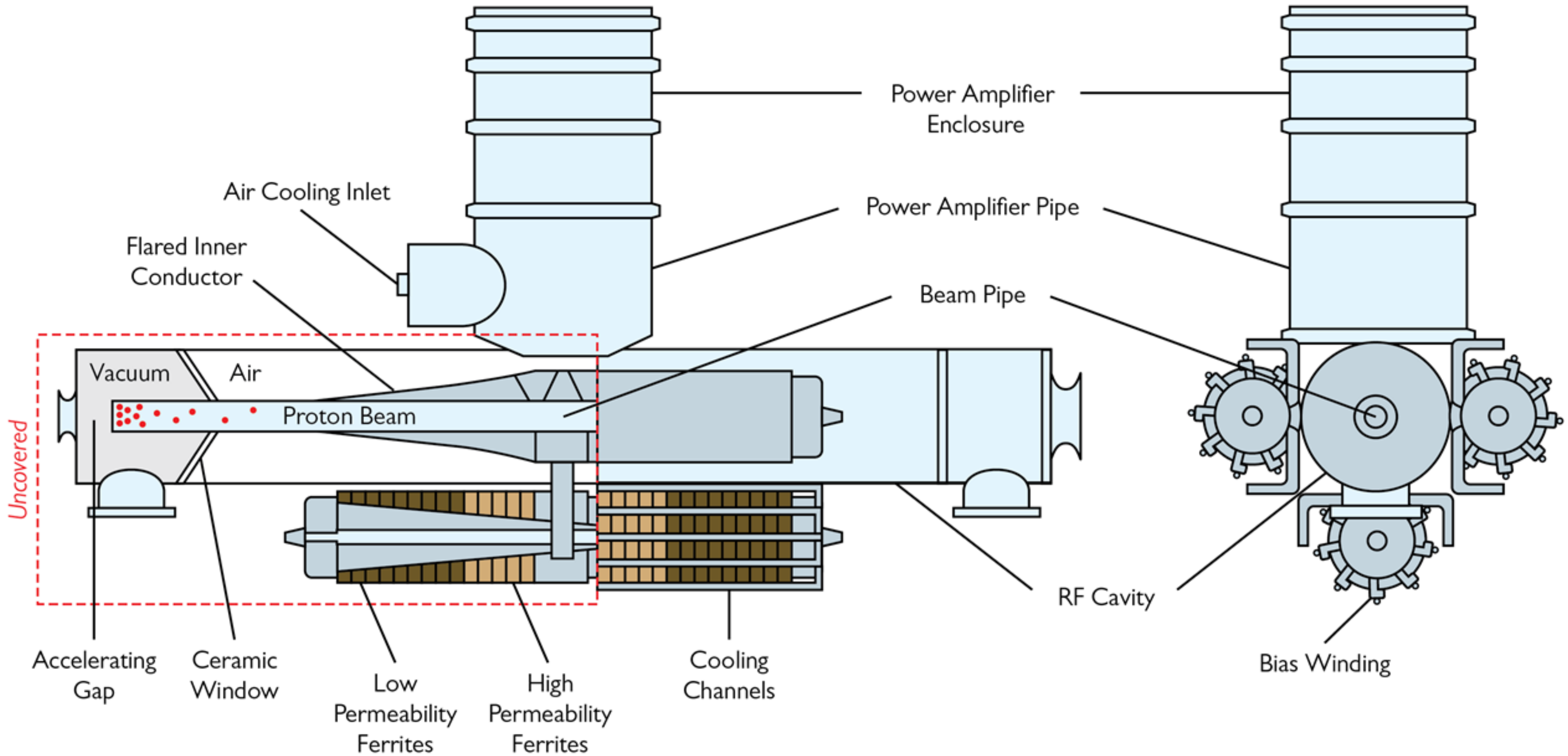
Heating Problem

- Need to double the repetition rate to 15 Hz
- Better cooling mechanisms are adopted to meet 15 Hz operation
- Further improvements are needed in new cavities

Breakdown Problem

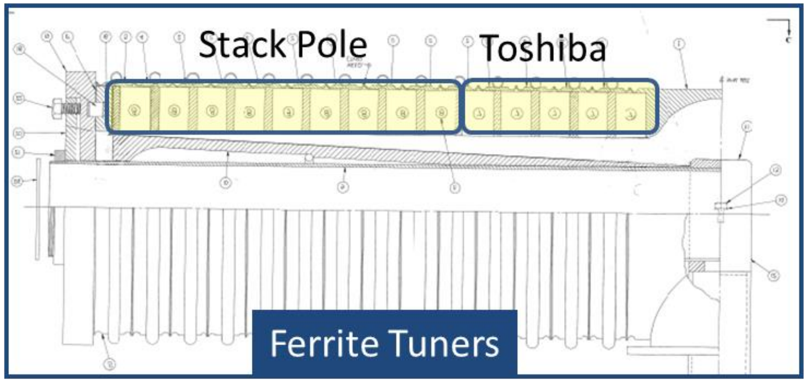
- Need to increase the current Gap Voltage
- Weak points of max fields in Vacuum and Air will be more susceptible to break down

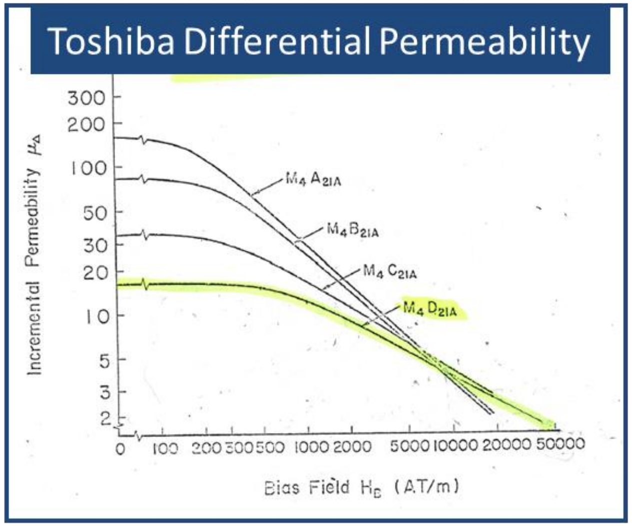
Geometry of Booster Cavity

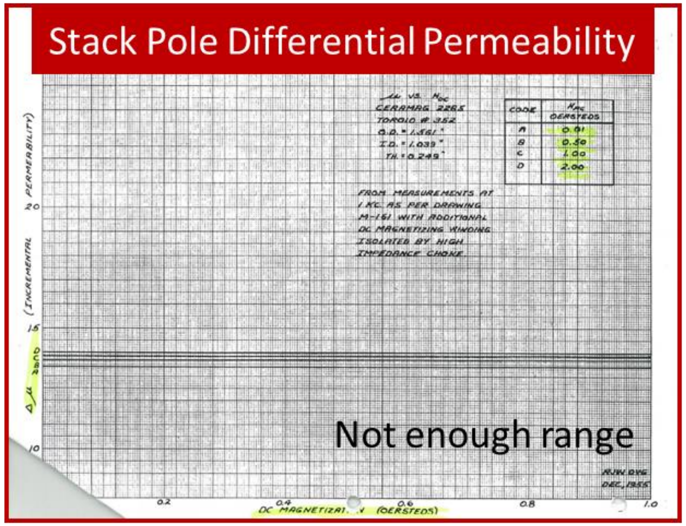


Ferrite Material Properties

	Stack Pole	Toshiba
μ_{max}	12.5	20
Magnetic Loss Tangent @ 50 MHz	0.005	0.007
Dielectric Const	10.5	12
Dielectric Loss Tangent @ 50 MHz	0.005	0.005





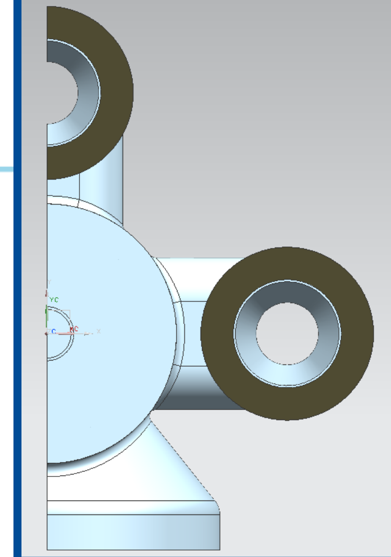


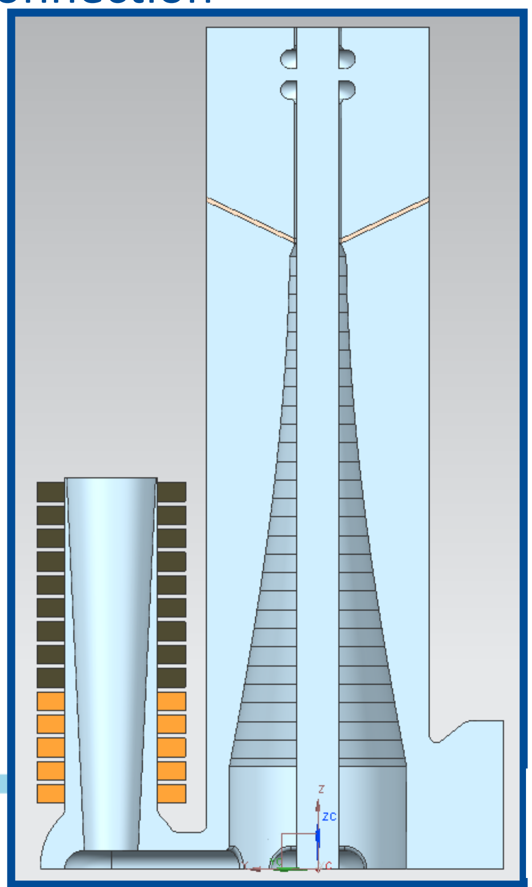
Due to the lack of available material info, typical properties of Ni-Zn ferrites are assumed

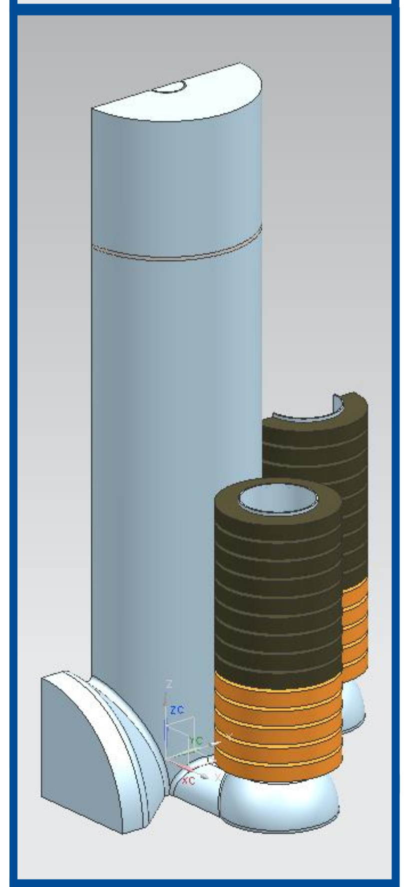
Some Material Properties are Still Missing

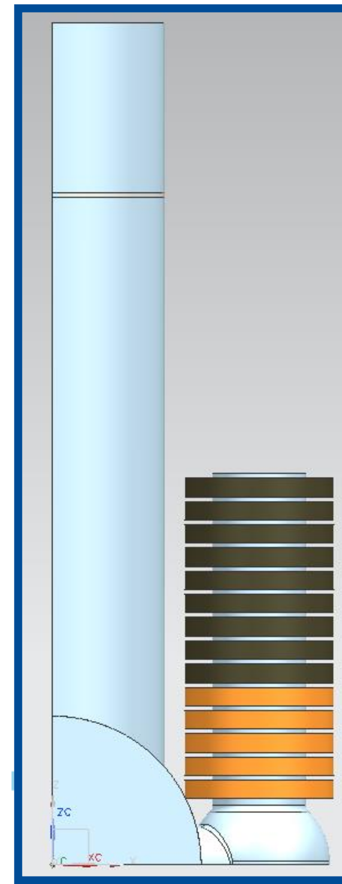
Full 3D Model

- Realistic Tuner with all the fine details
  - 5 Toshiba Ferrites
  - 9 Stackpole Ferrites
  - Flared Inner Conductor
- Realistic Tuner Connection





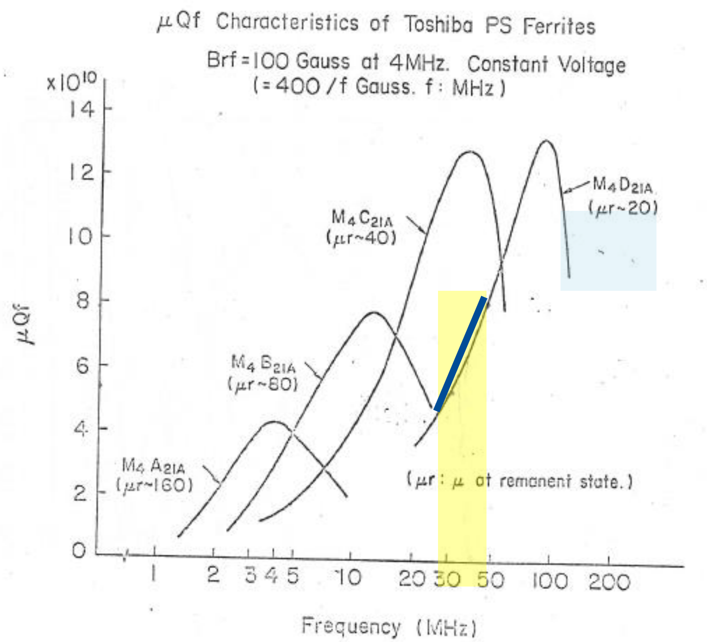


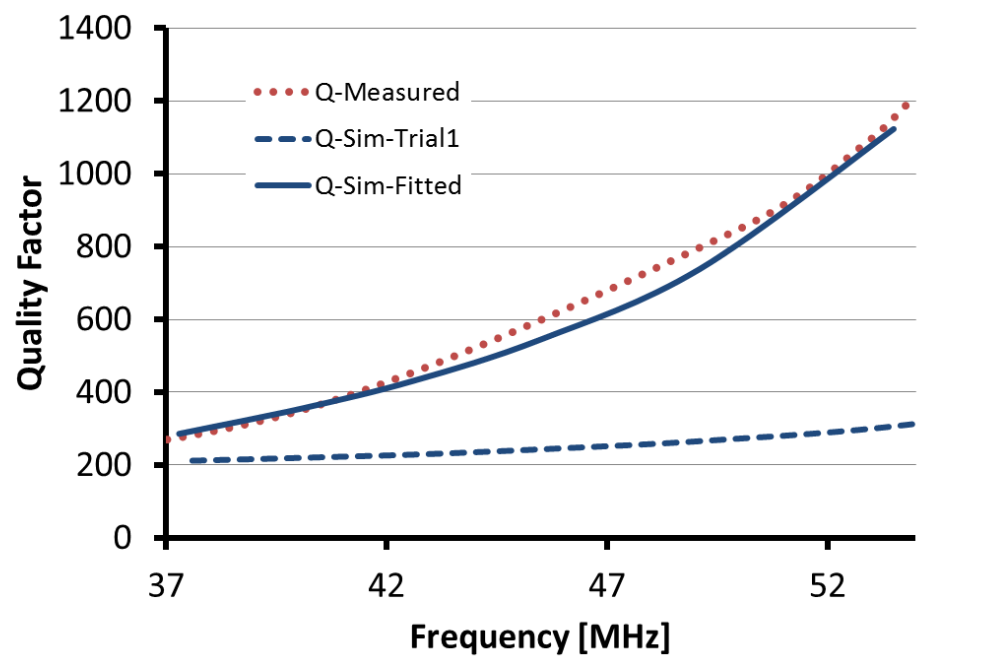


Adjusting the Simulated Q-Curve

- Total power loss is a higher than expected mainly because the simulated Q factor is lower than the measured values
- Losses of the Ferrites are strongly dependent on frequency
- Simulated Q has been fitted to the measured one by adjusting the magnetic loss tangent

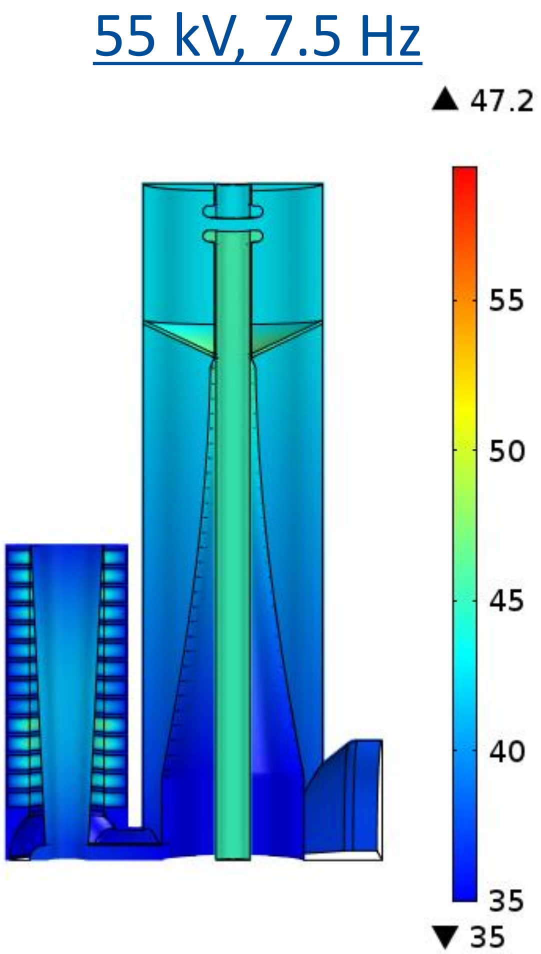
- $\mu_{toshiba}=8.4$
- $\mu_{stackpole}=\mu_{toshiba}*12.5/20$
- $\delta_{m\text{-}toshiba0}=0.007$
- $\delta_{m\text{-}stackpole0}=0.005$
- $\delta_{m\text{-}toshiba}=\delta_{m\text{-}toshiba0}*\mu_{toshiba}/11.5$
- $\delta_{m\text{-}stackpole}=\delta_{m\text{-}stackpole0}*\mu_{stackpole}/(11.5/20*12.5)$



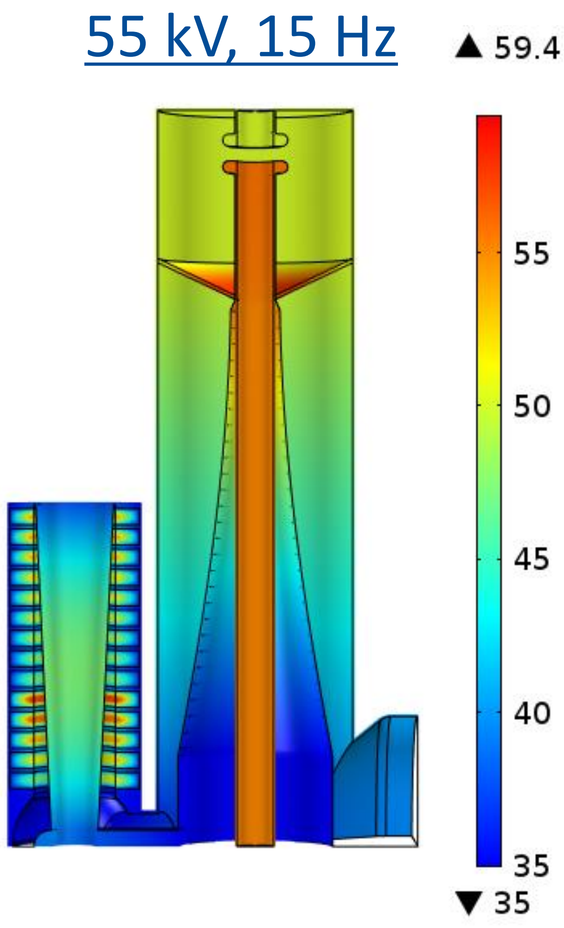


Regular Cycle 7.5Hz vs 15Hz

Max T=47.2° C



Constant Temp Boundaries



Constant Temp Boundaries

Possible Changes to the Current Design

- Rounding the stem corners with large radius >0.25” to reduce the risk of voltage breakdown in air-filled regions
- Enlarging the stem connection between the tuner and the cavity would help to reduce tuner losses
- Improve the connection of the vacuum window and cavity to reduce ceramic window failures
- Can we fill the tuner with another medium other than air?

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Verification of Current Booster Cavity Model

How to get a better comparison between simulation and measurements?

- Run at a fixed frequency
- Run without blower (air cooling is not included in the model)
- Run to reach a steady state
- Find an accurate way to measure the power loss and temperatures
- We should be able to compare then three vital quantities; quality factor, power loss, and temperature for a certain gap voltage (perhaps 22 kV)
- Repeat the measurements for several frequencies (40 MHz, 45 MHz, and 50 MHz)

CW Simulation vs Measurments Results

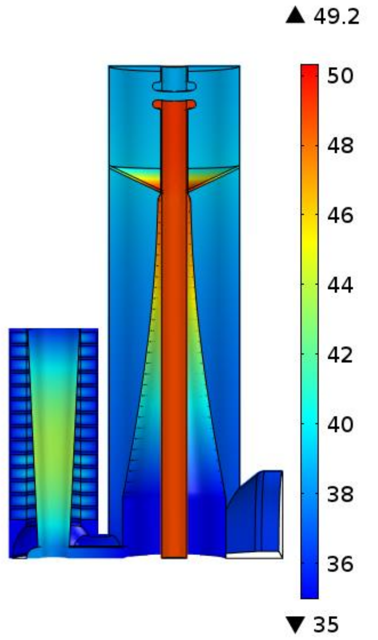
Simulations	50 MHz	45 MHz	40 MHz
Frequency [MHz]	**49.998**	**45.0163**	**39.979**
Unloaded Quality Factor	**773**	**513**	**348**
Gap Volatge [kV]	22.00	22.00	22.00
Volume Losses [kW]	5.01	9.25	16.88
Surface Losses [kW]	1.03	1.09	1.18
Total RF Losses [kW]	**6.04**	**10.34**	**18.07**

Measurements	50 MHz	45 MHz	40 MHz
Bias Current [A]	1290	640	325
Bias Voltage [V]	5.296	2.544	1.286
Pbias [kW]	6.83	1.63	0.42
Anode Volatge [kV]	10	10	10
Plate Current [A]	2.2	2.4	3.06
Input RF Power [kW]	22	24	30.6
Frequency [MHz]	**49.898**	**44.878**	**40.056**
Unloaded Quality Factor	**678**	**435**	**330**
Gap Volatge [kV]	22	22	22
f_water [Hz]	200.2	200	197.7
K-Factor	938	938	938
Water Flow [gpm]	12.81	12.79	12.65
dT_bias	1.95	0.45	0.12
P_bias [kW]	6.59	1.52	0.40
dT_withAir	3.28	2.70	4.19
dT_noAir	3.57	2.99	4.25
P_air [kW]	0.98	0.98	0.20
P_Water [kW]	12.07	10.10	14.19
P_RF [kW]	**5.48**	**8.58**	**13.79**

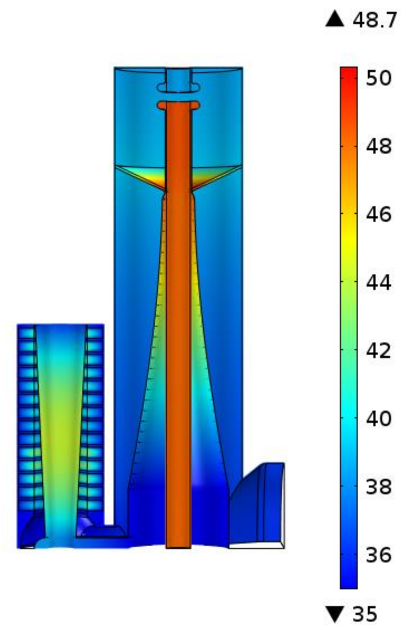
	50 MHz	**45 MHz**	**40 MHz**
Total RF Losses [kW]	6.04	10.34	18.07
P_RF_Water [kW]	5.48	8.58	13.79
Descrepancy %	**10.34**	**20.56**	**31.02**

Simulation vs Measurements

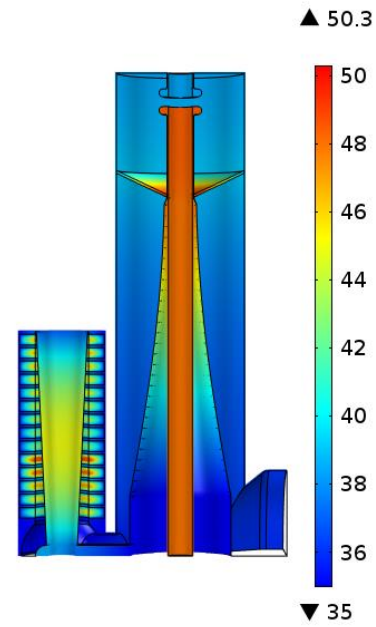
50 MHz, 22 kV, CW



45 MHz, 22 kV, CW

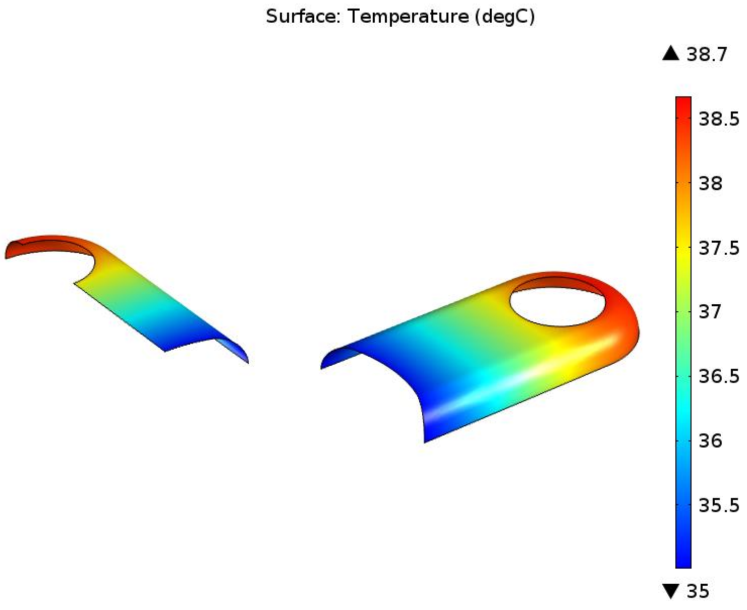


40 MHz, 22 kV, CW

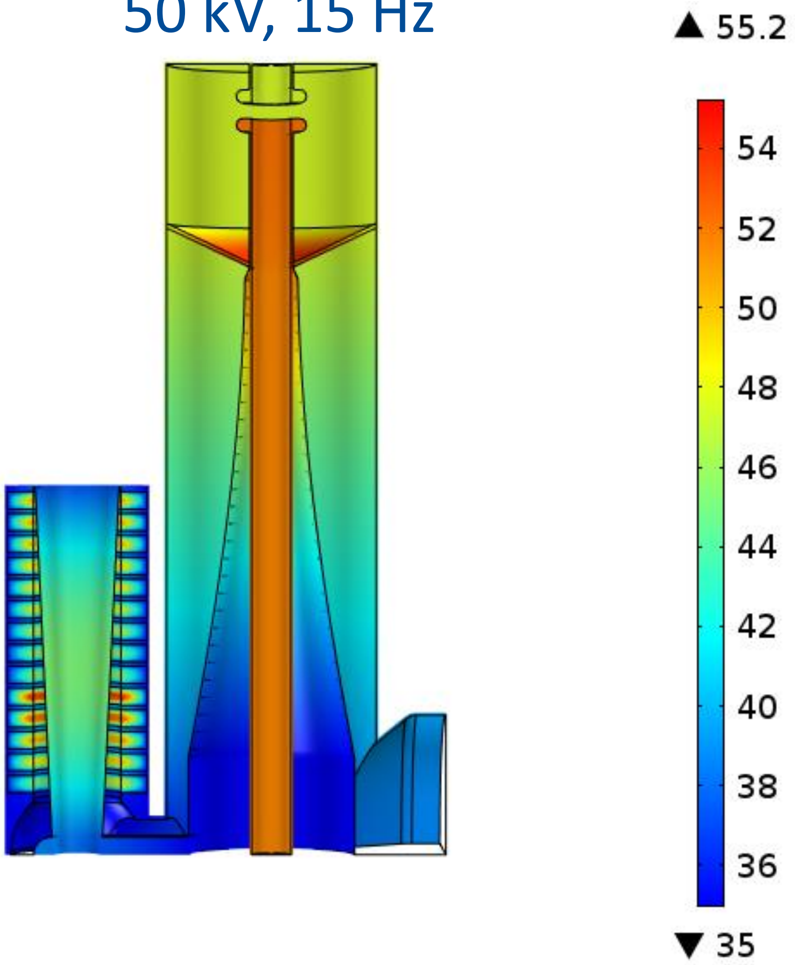


50 MHz	Twater [f]	Tfront [C] (FR99T)	Tback [C] (BA99T)	Tcavity [C] (BA99RT)	Tbottom [C] (AD99DT)
Base	88.7	34.02	33.49	32.49	32.72
Air is ON Steady State		40.55	38.07	36.52	36.74
Air is OFF Steady State		**49.18**	**46.11**	**47.44**	**41.01**
45 MHz	Twater [f]	Tfront [C] (FR99T)	Tback [C] (BA99T)	Tcavity [C] (BA99RT)	Tbottom [C] (AD99DT)
Base	88	32.47	31.97	30.31	32.15
Air is ON Steady State		38.44	36.33	34.88	35.41
Air is OFF Steady State		**45.96**	**43.32**	**44.57**	**39.25**
40 MHz	Twater [f]	Tfront [C] (FR99T)	Tback [C] (BA99T)	Tcavity [C] (BA99RT)	Tbottom [C] (AD99DT)
Base	89.5	31.66	31.15	29.61	31.27
Air is ON Steady State		38	36	34	35
Air is OFF Steady State		**43.57**	**41.36**	**42.3**	**38.28**

Simulation vs. Measurements



50 kV, 15 Hz



	15 Hz, 50 kV
Total RF Losses [kW]	23.34
P_RF_Water [kW]	10.50

Regular 15 Hz operation	**Twater [f]**	**Tfront [C] (FR99T)**	**Tback [C] (BA99T)**	**Tcavity [C] (BA99RT)**	**Tbottom [C] (AD99DT)**
24kV		49.71	46.06	44.28	42.92

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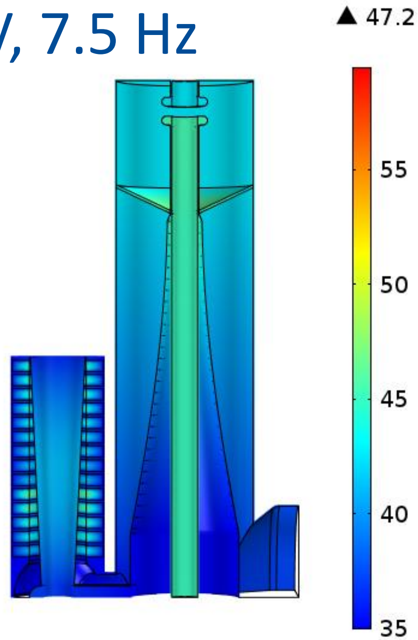
Perpendicular vs Parallel Biased Cavity

	Parallel Biased		**Perpendicular Biased	
Length [m]	2.3		1.1	
Height [m]	0.56		0.5	
Aperture [in]	2.25		3.25	
Volume of Ferrites [m^3]	0.04216		0.03626	
Cost				
Gap Voltage [kV]	55		55	
Frequency Sweep [MHz]	37.3	53.8	37.2	53.8
Permittivity	12.0*(1-j*0.005) 10.5*(1-j*0.005)		14.0*(1-j*0.00015)	
Permeability	8.40*(1-j*0.0051) 5.25*(1-j*0.0037)	3.00*(1-j0.0018) 1.88*(1-j*0.0013)	4*(1-j*0.003)	1.5*(1-j*0.00036)
Q	285	1102	385	4004
Energy [mJ] CW	171.59	59.40	95.79	68.35
Volume Losses CW	141.27	18.23	57.96	5.58
Surface Losses CW	6.98	5.92	0.36	0.72
Total Losses CW	148.25	24.15	17.1	3.0
E_{max} in Air [MV/m]	1.67	0.91	-	-
E_{max} in Vacuum [MV/m]	2.2	2.2	4.6	4.6
E_{max} in Ferrite [MV/m]	0.21	0.10	0.32	0.21
T_{max} [C] at 7Hz/15Hz	47.2/59.4		77.2/119.0	
Energy [mJ] at 7Hz/15Hz	0.25/0.5*66.86		0.25/0.5*47.51	
Total Power Loss [kW] at 7Hz/15Hz	14.4/28.9		7.23/14.5	

*Cycle Energy is assumed to be 0.579*Avg Energy **Cavity geometry is based on TRIUMF with no further optimization

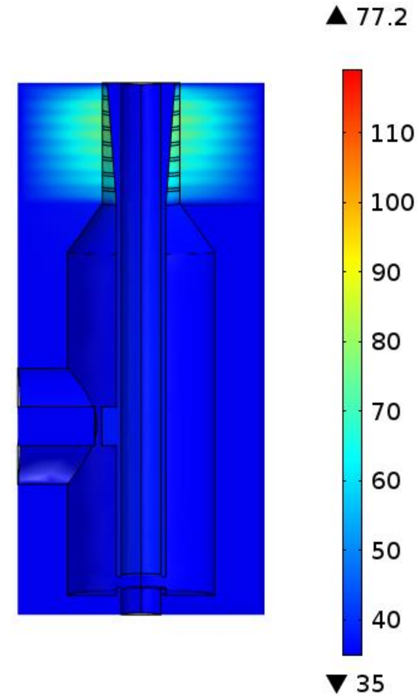
55 kV, 7.5 Hz

Constant Tem
Boundaries



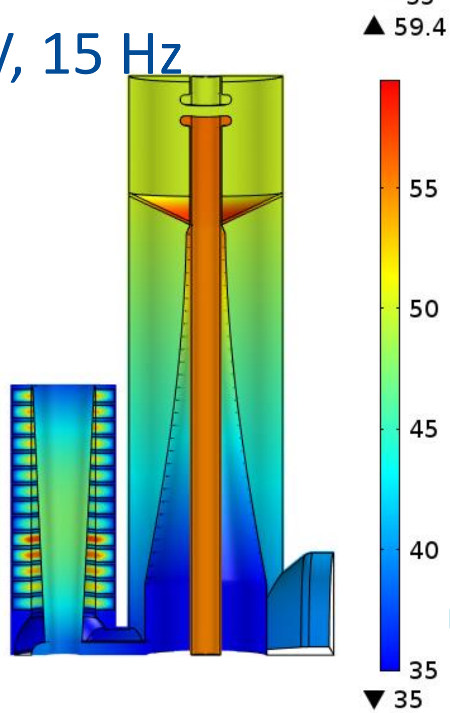
55 kV, 7.5 Hz

Constant Temp
Boundaries



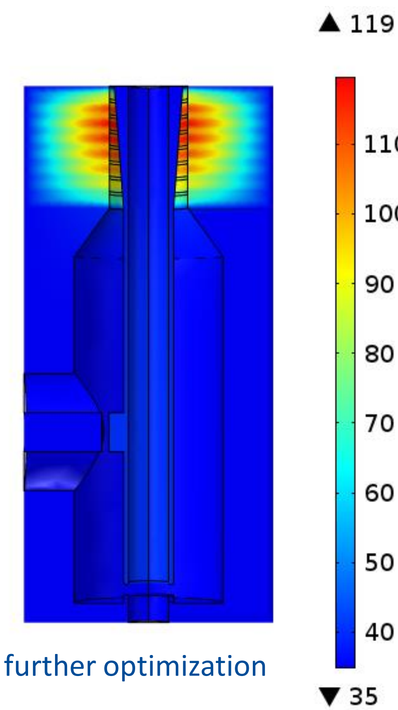
55 kV, 15 Hz

Constant Ten
Boundaries



55 kV, 15 Hz

Constant Temp
Boundaries



*Cavity geometry is based on TRIUMF with no further optimization

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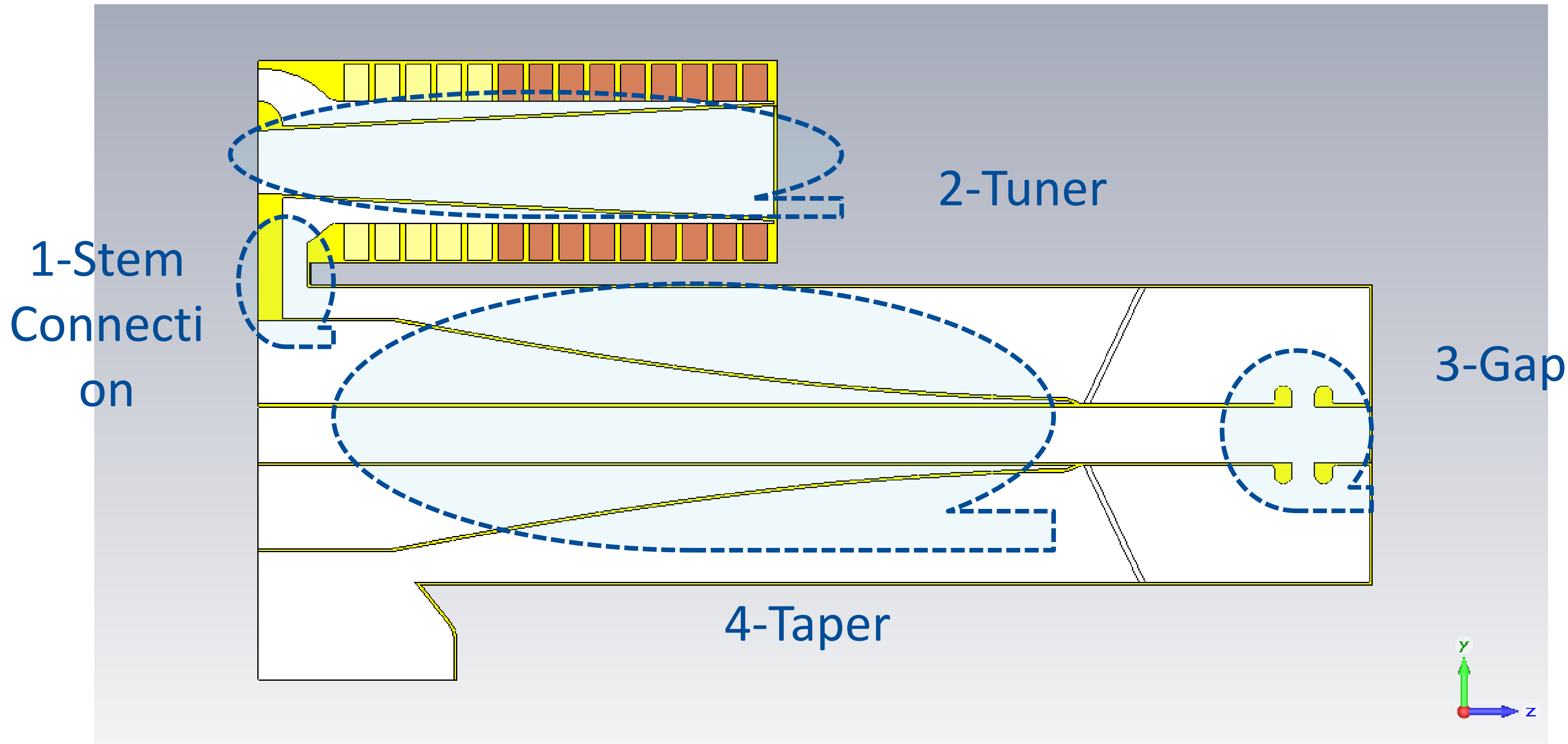
Parametric Study and a Proposed Design for New Cavity

Fermilab's Booster Cavity



Cavity is divided into four areas to easily identify the cavity parameters

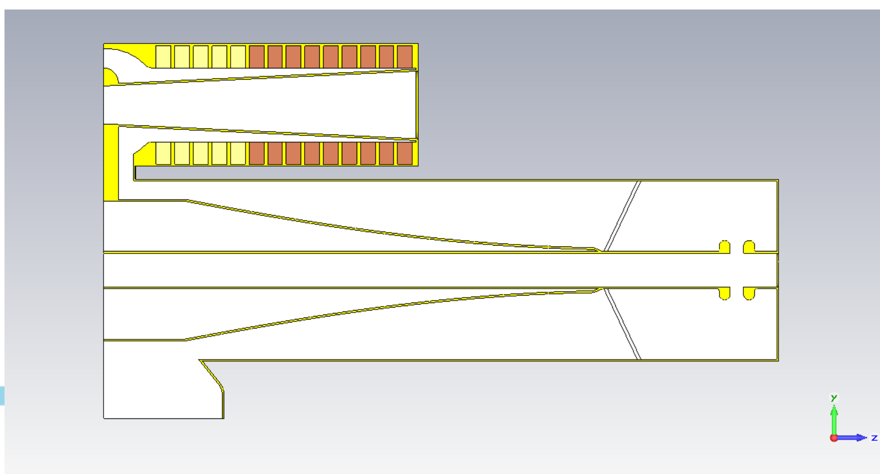
Gap Parameters don't have much effect on improving Q

Fermilab’s Booster Cavity

Criteria of Comparison?

- With eigen-mode simulation, the quality factor and energy (not the power) that would produce a required gap voltage could be calculated
- Decreasing the energy needed for 55 kV gap voltage (increasing the Q) simply means less power loss inside the cavity thus less heating
- These performance indicators will be calculated at two permeability values, namely; 8.4 and 3.0 that corresponds to the edge frequencies of the current booster operation

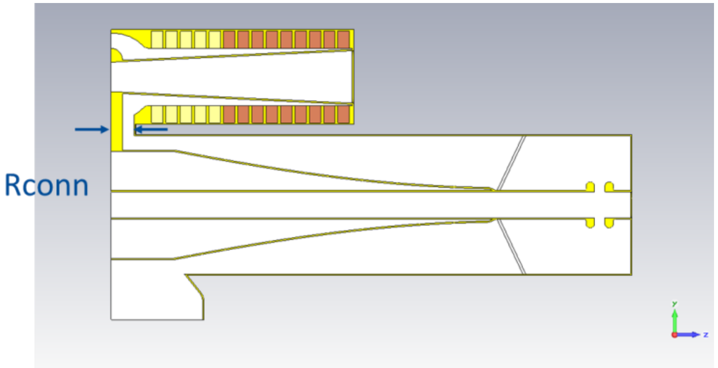
		mu=8.4	mu=3			Energy needed for 55 kV					
		f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]		BW[MHz]
Ref Cavity		37.3	53.5	286	1123	42.9	14.8	28.85	19.9065		16.2

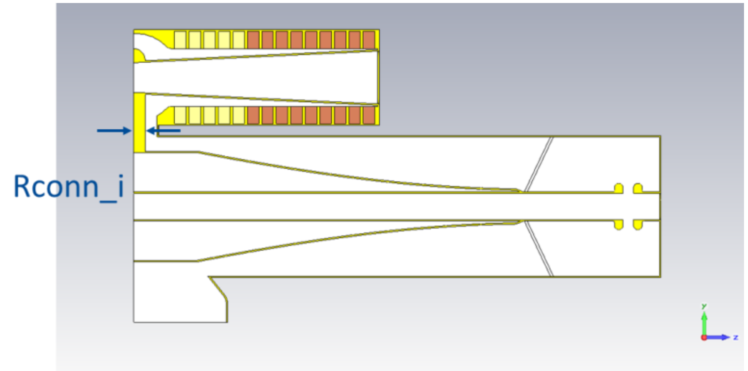


Simple Average

~Integral Average

Stem Connection Parameters





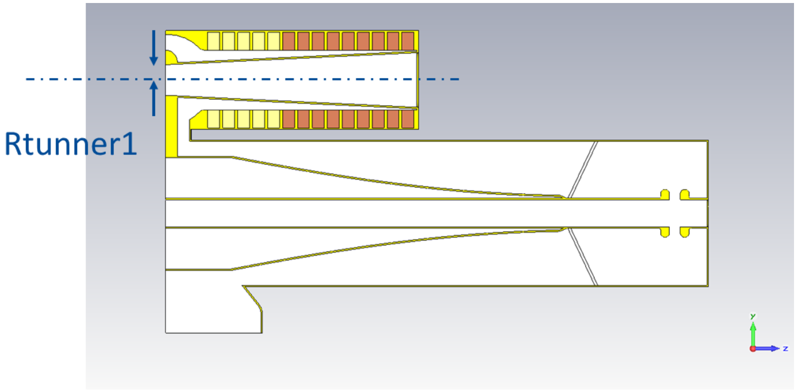
		mu=8.4	mu=3			Energy needed for 55 kV					
Rconn		f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]		BW[MHz]
1.5		36.4	52.6	282	1082	48.3	16.8	32.55	22.4595		16.2
2		**37.3**	**53.5**	**286**	**1123**	**42.9**	**14.8**	**28.85**	**19.9065**		**16.2**
2.5		37.7	53.7	290	1161	40.3	14.2	27.25	18.8025		16

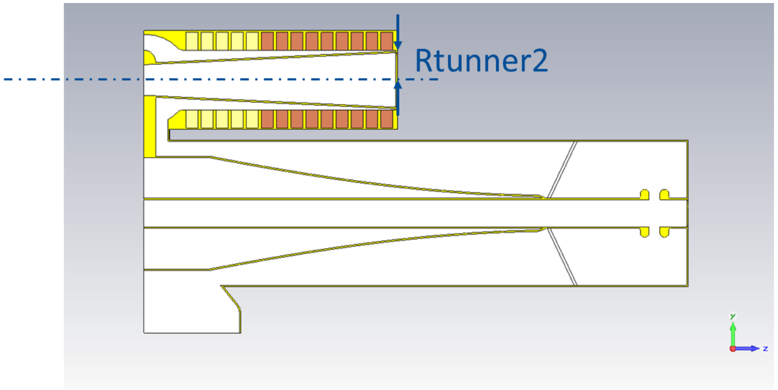
		mu=8.4	mu=3			Energy needed for 55 kV					
Rconn_i		f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]		BW[MHz]
0.5		37.7	53.1	296	1234	38.4	13.9	26.15	18.0435		15.4
0.8		37.6	53.5	290	1166	40.5	14.3	27.4	18.906		15.9
1		**37.3**	**53.5**	**286**	**1123**	**42.9**	**14.85**	**28.875**	**19.92375**		**16.2**
1.5		35.5	52	276	1009	56.6	18.8	37.7	26.013		16.5

Increasing the radius of the stem conn would help in decreasing the overall power loss inside the cavity

Decreasing the radius of the stem inner conductor would help in decreasing the overall power loss inside the cavity

Tuner Parameters





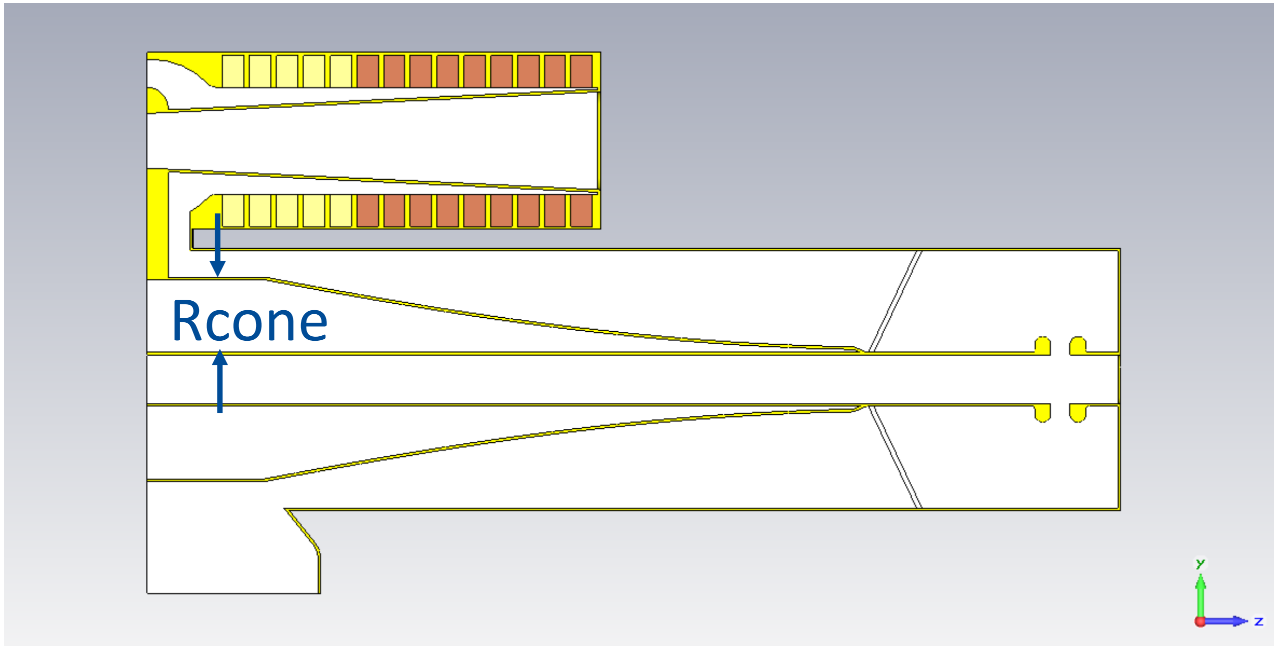
		mu=8.4	mu=3			Energy needed for 55 kV					
Rtunner1		f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]		BW[MHz]
1.4		**37.3**	**53.5**	**286**	**1123**	**42.9**	**14.85**	**28.875**	**19.92375**		**16.2**
1.2		37.9	53.4	295	1203	38.5	14.2	26.35	18.1815		15.5
1		38.3	53.2	303	1280	35.6	14	24.9	17.181		14.9

		mu=8.4	mu=3			Energy needed for 55 kV					
Rtunner2		f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]		BW[MHz]
2.4		**37.3**	**53.5**	**286**	**1123**	**42.9**	**14.85**	**28.875**	**19.92375**		**16.2**
2		37.7	52.4	303	1256	38.7	15.2	26.95	18.5955		14.7
1.6		37.6	51	319	1382	37.2	16.1	26.65	18.3885		13.4

Decreasing the radius of the tuner base radius would help in decreasing the overall power loss inside the cavity

Decreasing the radius of tuner top radius would help in decreasing the overall power loss inside the cavity, though would decrease the bandwidth quite a bit (sorted out)

Taper Parameters



		mu=8.4	mu=3			Energy needed for 55 kV					
Rcone		f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]		BW[MHz]
4.8		36.8	53	285	1100	46.1	16.1	31.1	21.459		16.2
4.642		**37.3**	**53.5**	**286**	**1123**	**42.9**	**14.8**	**28.85**	**19.9065**		**16.2**
4.5		37.7	53.9	288	1148	40.1	13.8	26.95	18.5955		16.2
4		38.8	54.7	293	1238	33.7	11.4	22.55	15.5595		15.9
3.5		39.5	54.9	298	1345	29.4	9.9	19.65	13.5585		15.4

Decreasing Rcone would help in decreasing the overall power loss inside the cavity

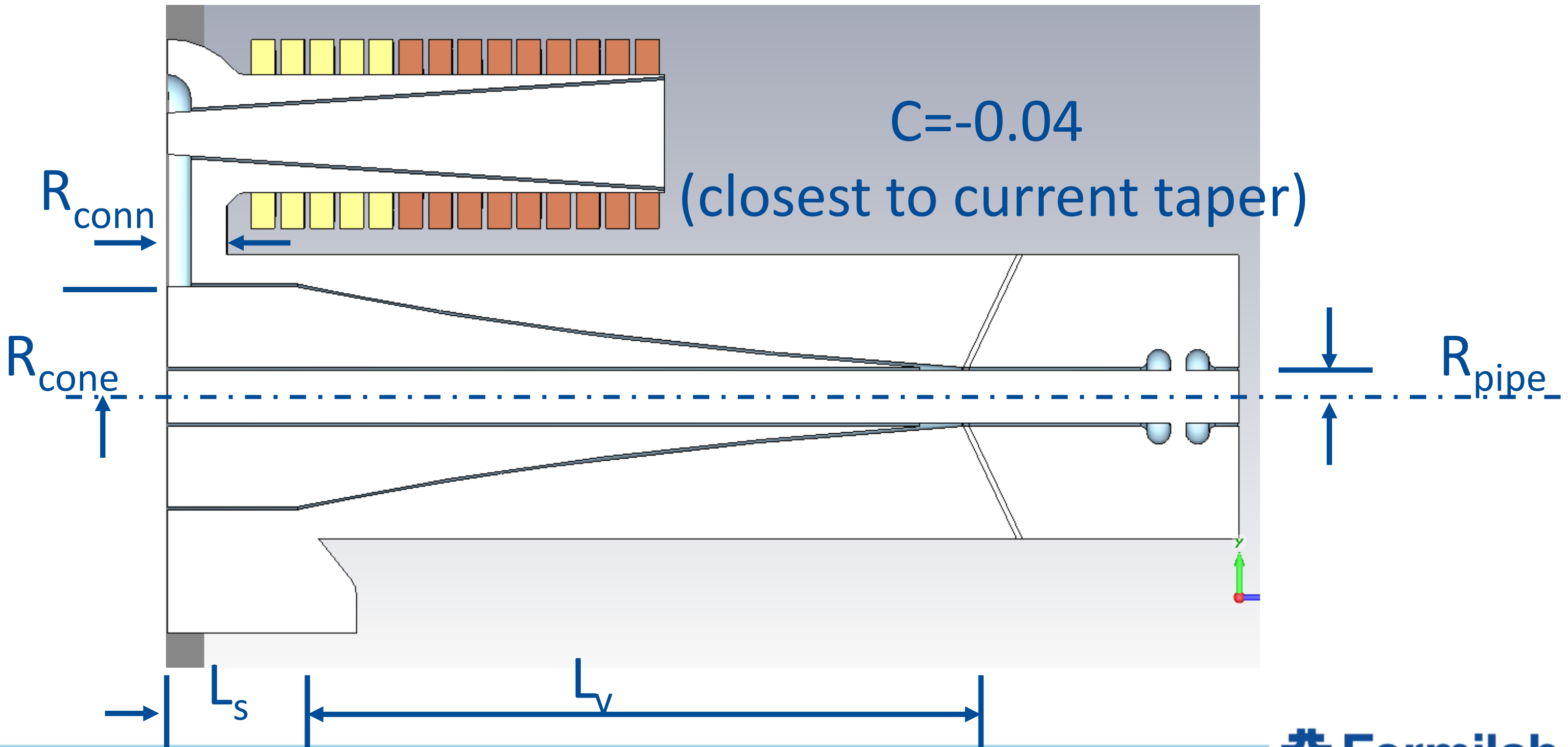
Vivaldi Taper

Taper could be approximated as exponential (vivaldi equation)

$$y(x) = A\left(1 - B\, e^{Cx}\right)$$

$$B = \frac{R_{pipe} - R_{cone}}{R_{pipe} - R_{cone} e^{CL_v}}$$

$$A = \frac{R_{cone}}{1 - B}$$

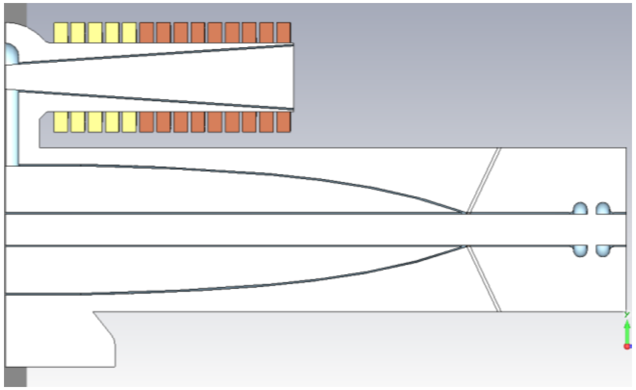


Vivaldi Taper Cont.

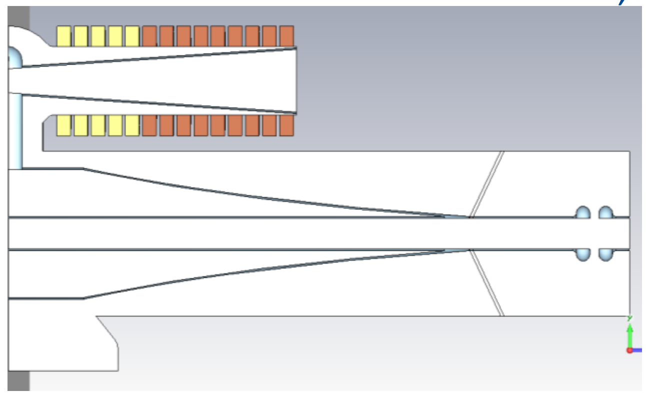
Taper curve eq $y(x) = A\left(1 - B\, e^{Cx}\right)$

Rpipe=1.125”, Rcone=4.375”, Lv=28.12”

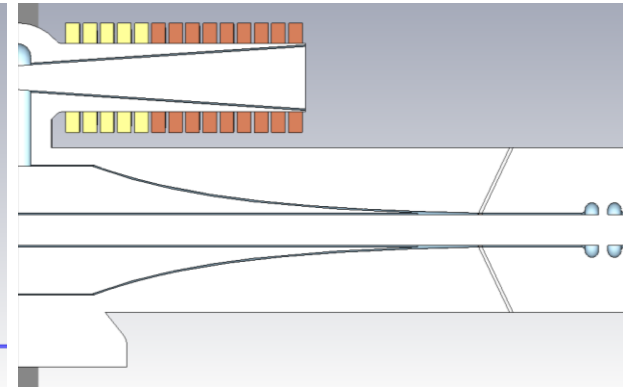
Ls=5.5”, Rconn=2”



C=0.1



C=-0.04



C=-0.1

		mu=8.4	mu=3		Energy needed for 55 kV						
C		f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]		BW[MHz]
0.1		33.9	48.6	288	1104	69.2	28.1	48.65	33.5685		14.7
0.05		35.1	50.6	287	1096	58.5	22.6	40.55	27.9795		15.5
0.001		36.4	52.4	286	1103	48.8	17.8	33.3	22.977		16
-0.025		37	53.2	286	1115	44.8	15.8	30.3	20.907		16.2
-0.04		**37.3**	**53.5**	**287**	**1125**	**42.7**	**14.8**	**28.75**	**19.8375**		**16.2**
-0.05		37.5	53.8	287	1132	41.4	14.2	27.8	19.182		16.3
-0.075		37.9	54.2	288	1156	38.5	12.8	25.65	17.6985		16.3
-0.1		38.2	54.5	288	1183	36.2	11.8	24	16.56		16.3
-0.15		38.6	54.7	291	1241	32.9	10.3	21.6	14.904		16.1

Steeper negative taper would help in decreasing the overall power loss inside the cavity

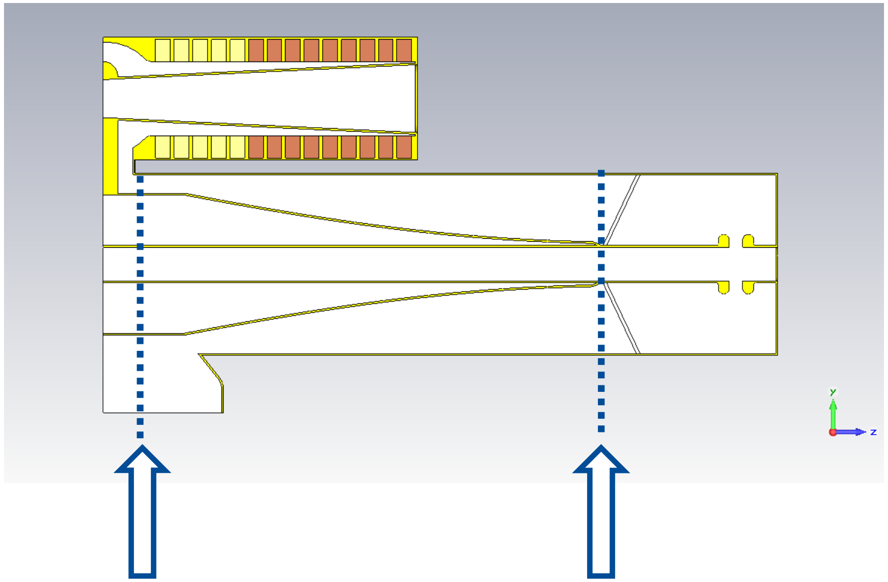
Taper as a Matching Section?

Rpipe=1.125
Rcavity=6

Zc=100Ω

Rconn=2
Rconn_i=1

Zs=42Ω



14Ω

100Ω

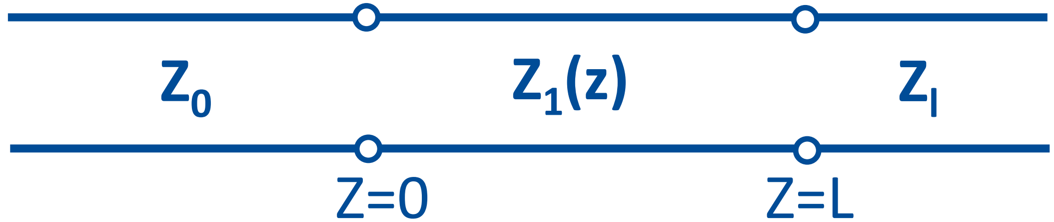
Three tuners in parallel are connected ⇒ 42Ω/3 = 14Ω

$$Z = \frac{\eta}{2\pi} \ln\left(\frac{R_o}{R_i}\right)$$

How to optimally match a 14Ω to 100Ω ?

Taper as a Matching Section?

How to optimally match a 14Ω to 100Ω?



Exponential Taper

$$Z_1(z) = Z_0 e^{az}$$

$$a = \frac{1}{L}\ln\left(\frac{Z_l}{Z_0}\right)$$

Triangular Taper

$$Z_1(z) = \begin{cases} Z_0 \exp\left[2\left(\frac{z}{L}\right)^2 \ln\left(\frac{Z_l}{Z_0}\right)\right] & z \le L/2 \\ Z_0 \exp\left[\left(4\left(\frac{z}{L}\right) - 2\left(\frac{z}{L}\right)^2 - 1\right)\ln\left(\frac{Z_l}{Z_0}\right)\right] & z > L/2 \end{cases}$$

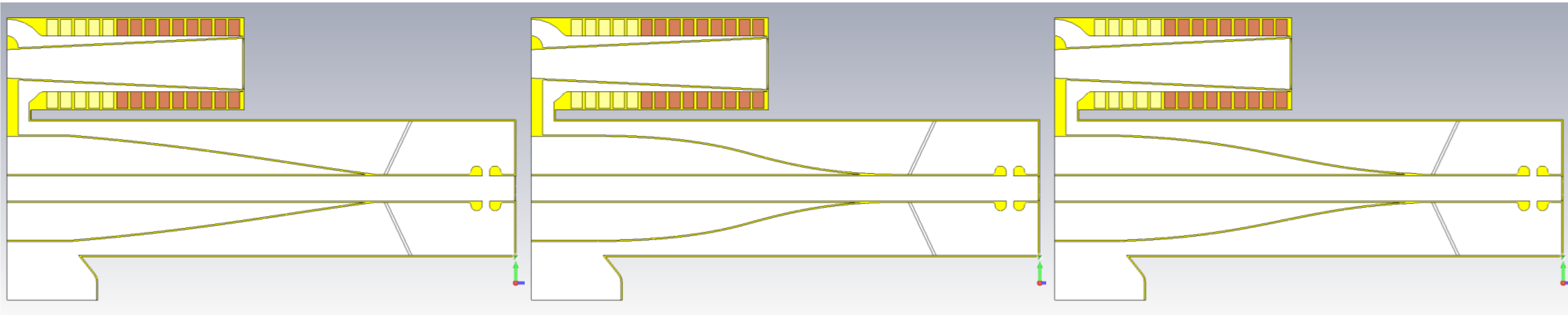
Klopfenstein Taper

$$\ln Z(z) = \frac{1}{2}\ln Z_0 Z_L + \frac{\Gamma_0}{\cosh A} A^2 \phi\left(\frac{2z}{L} - 1, A\right); 0 \le z \le L$$

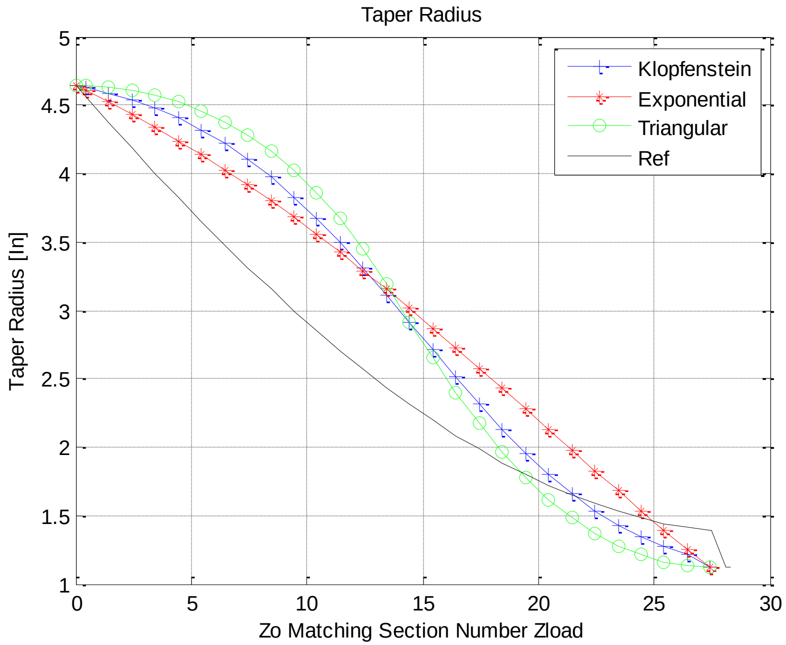
$$\phi(x, A) = -\phi(-x, A) = \int_0^x \frac{I_1(A\sqrt{1 - y^2})}{A\sqrt{1 - y^2}} dy; |x| \le 1$$

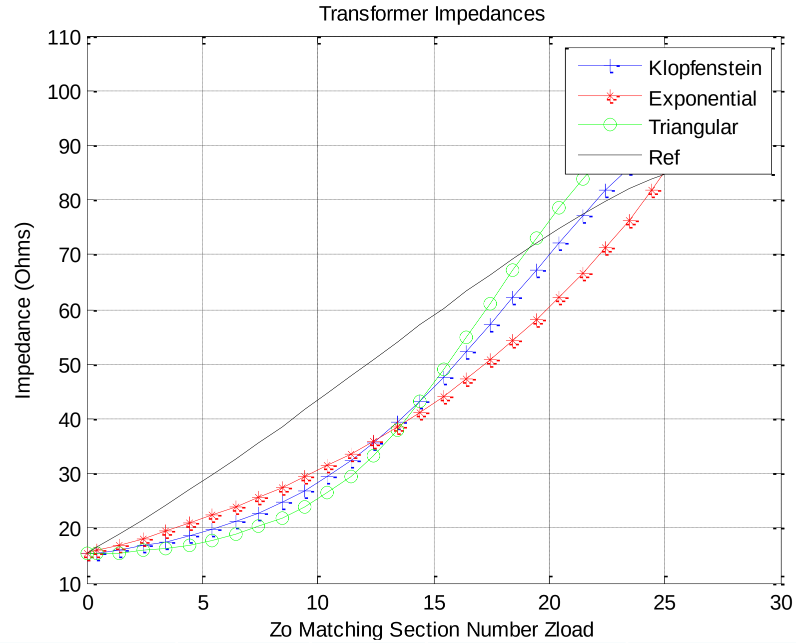
$I_1(x)$ is the modified Bessel function with the special values

$$\phi(0, A) = 0; \qquad \phi(x, A) = \frac{x}{2}; \qquad \phi(x, A) = \frac{\cosh A - 1}{A^2}$$



Taper as a Matching Section?





	mu=8.4	mu=3			Energy needed for 55 kV				
	f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]	BW[MHz]
Ref Cavity	**37.3**	**53.5**	**286**	**1123**	**42.9**	**14.8**	**28.85**	**19.9065**	**16.2**
Triangular Taper	35.6	51.2	285	1085	54.8	20.1	37.45	25.8405	15.6
Klopfenstein Taper	35.8	51.7	286	1088	52.8	19.4	36.1	24.909	15.9
Exponential Taper	36	51.8	286	1095	51.8	19.1	35.45	24.4605	15.8

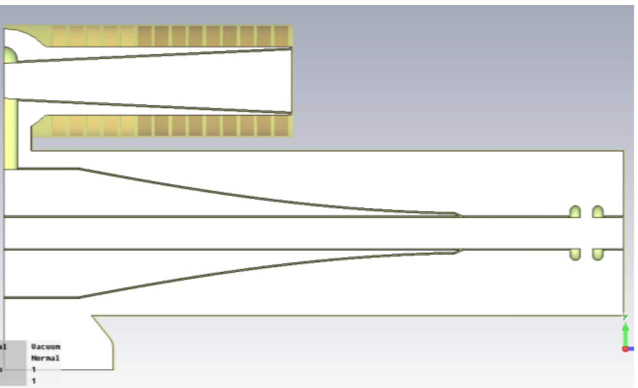
- Standard tapers are used to minimize the mismatch between two impedances over wide frequency band however, we have a different goal

Tuner Ferrites: Other Possibilities

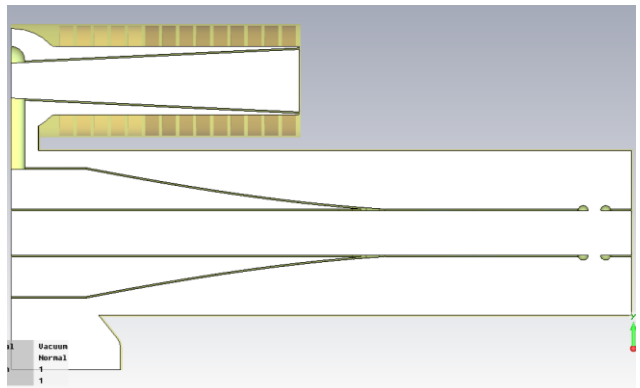
										Energy needed for 55 kV					
	fa1 [MHz]	f1 [MHz]	f2 [MHz]	fa2 [MHz]	Qa1	Q1	Q2	Qa2	Ea1[mJ]	E1 [mJ]	E2 [mJ]	Ea2[mJ]	Eav [mJ]	Eint [mJ]	BW[MHz]
		mu=8.4	**mu=3**												
Ref Cavity	**37.3**	**37.3**	**53.5**	**53.5**	**286**	**286**	**1123**	**1123**	**42.9**	**42.9**	**14.8**	**14.8**	**28.85**	**19.9065**	**16.2**
	mu=9.5	**mu=8.4**	**mu=3**	**mu=3.5**											
All Stackpole	37.3	39.2	55.6	53.3	284	329	1366	1072	45.4	39.6	13.5	15.6	30.5	21.045	16.4
	mu=8	**mu=8.4**	**mu=3**	**mu=2.9**											
Interleaved	37.5	36.8	53.1	53.7	293	277	1078	1135	43.1	45.5	15.4	14.9	29	20.01	16.3
	mu=7.1	**mu=8.4**	**mu=3**	**mu=2.65**											
Toshibas At End	37.6	35	51.7	53.6	297	245	921	1112	47.8	58	18	15.9	31.85	21.9765	16.7
	mu=8.1	**mu=8.4**	**mu=3**	**mu=2.95**											
Interleaved Two	37.5	36.9	53.2	53.9	292	279	1090	1118	43.1	44.8	15.3	15	29.05	20.0445	16.3
	mu=8.7	**mu=8.4**	**mu=3**	**mu=3.2**											
1Toshiba at End	37.6	38.2	54.7	53.7	289	301	1222	1104	45.5	43.8	14.4	15.4	30.45	21.0105	16.5

- With all stackpole ferrites we project to have about 2 MHz shift upward in frequency band that would necessitates biasing the ferrites less to increase mu by about 15% to recover that frequency shift
- Power loss will not decrease!, actually we project about 2% increase in power loss

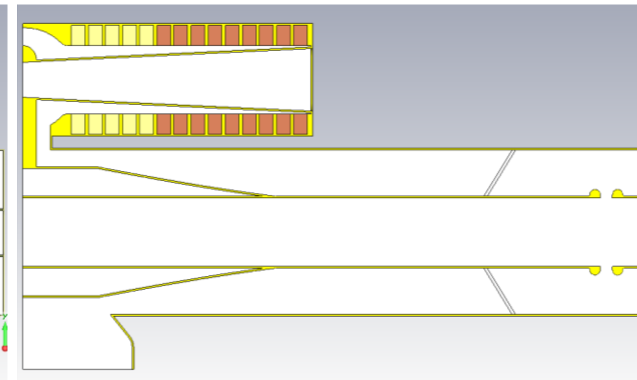
Bore Radius Effect on the Cavity Performance



Rpipe=1.125



Rpipe=1.625

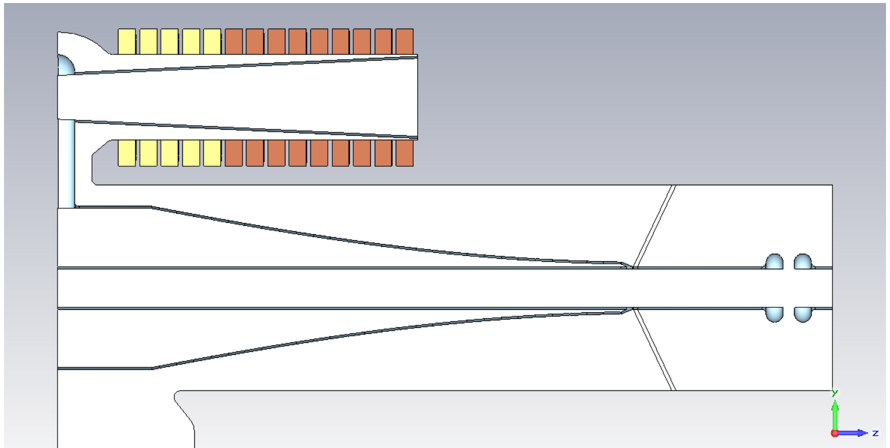


Rpipe=2.5

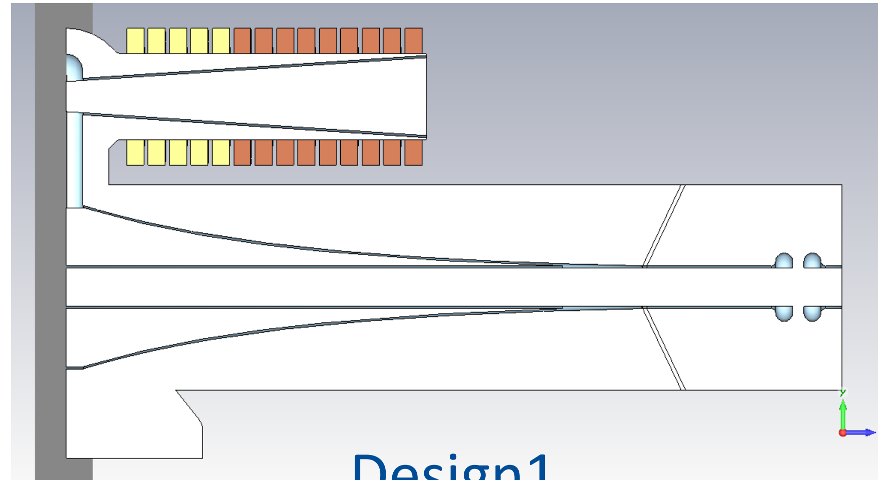
		mu=8.4	mu=3			Energy needed for 55 kV					
Rpipe		f1 [MHz]	f2 [MHz]	Q1	Q2	E1 [mJ]	E2 [mJ]	Eav [mJ]	Eint [mJ]		BW[MHz]
1		37.4	53.9	285	1100	43.6	15.2	29.4	20.286		16.5
1.125		**37.3**	**53.5**	**286**	**1123**	**42.9**	**14.8**	**28.85**	**19.9065**		**16.2**
1.625		37.1	53.2	287	1121	44.9	16	30.45	21.0105		16.1
2.5		35.3	49.4	297	1254	51.4	19.4	35.4	24.426		14.1

- Increasing the beam pipe radius has a considerable effect on both the bandwidth and Q factor

Preliminary New Design



Ref Cavity



Design1

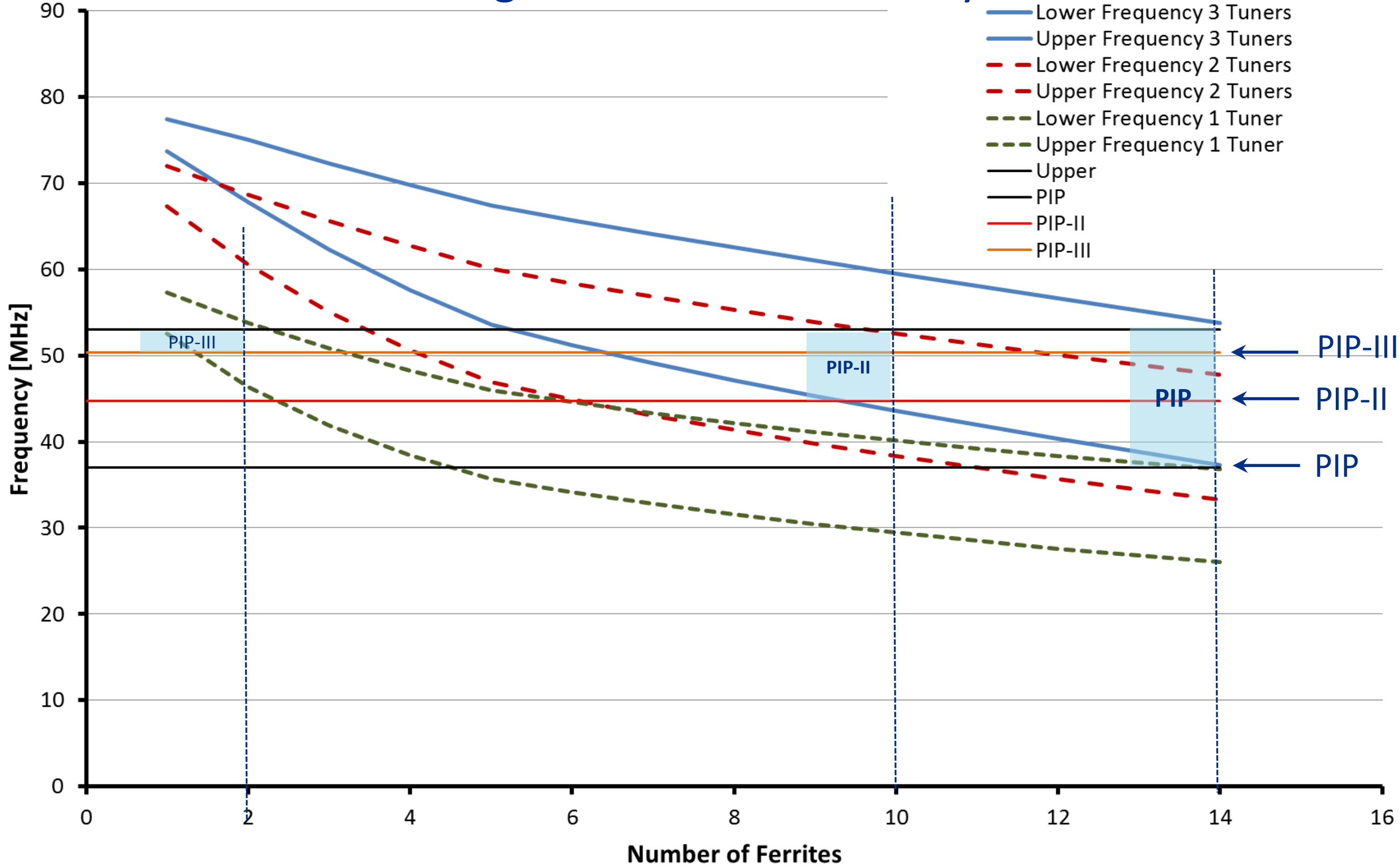
	fa1 [MHz]	f1 [MHz]	f2 [MHz]	fa2 [MHz]	Qa1	Q1	Q2	Qa2	Ea1[mJ]	E1 [mJ]	E2 [mJ]	Ea2[mJ]	Eav [mJ]	Eint [mJ]	BW[MHz]
		mu=8.4	mu=3							Energy needed for 55 kV					
Ref Cavity	**37.3**	**37.3**	**53.5**	**53.5**	**286**	**286**	**1123**	**1123**	**42.9**	**42.9**	**14.8**	**14.8**	**28.85**	**19.9065**	**16.2**
	mu=11	mu=8.4	mu=3	mu=3.5											
Design1: Rconn=2.5, Rtunner1=1 , Ls=1, Rpipe=1.125, C=-0.08	37.5	41.5	55.3	53.6	229	322	1616	1230	28.6	21.3	8.4	9.4	19	13.11	13.8

- Sacrifice for 2.4 MHz in bandwidth that will need to be compensated for by biasing less the ferrites
- About 30% saving in power loss

Fermilab

Booster Cavity and Future Operation

Mu of ferrites changes to mimic the bias cycle



	PIP [37-53 MHz]	PIP-II [44.7-53 MHz]	PIP-III [50.3-53 MHz]
3-Tuner Design [37-53 MHz]	✓	✓	✓
2-Tuner 10F/H [43.6- 53 MHz]		✓	✓
1-Tuner 2F/H [46.4-53.7 MHz]			✓

Conclusion

- A full 3D detailed model to the current cavity has been built
- Current cavity has been subject to extensive electromagnetic and thermal analysis
- We were able to compare simulation and measurements for CW operations with fairly good agreement
- Further measurements are planned
- We carried out a full parametric study to the current cavity geometry
- Modifications in the current cavity have been proposed
- We have also explored the possibility of operating the cavity under PIP-II and PIP-III frequency sweep scenarios