PIP-I

2nd harmonic RF perpendicular biased cavity update

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Fermilab

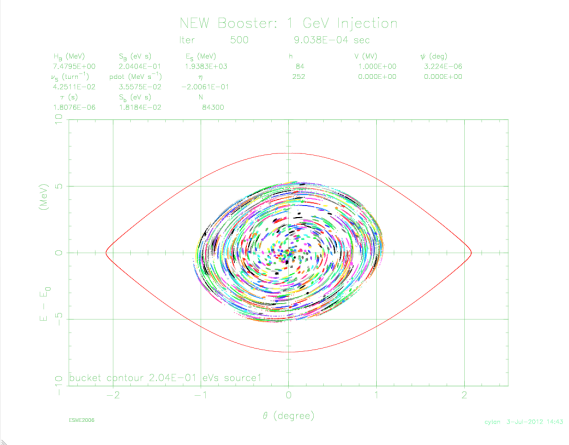
People who are doing the real work

- G. Romanov, simulations with CST Microwave Studio.
- R. Madrak and D. Wildman, measurements of the garnet material AL 400. (400 means $4\pi M_s$ = 400 gauss)

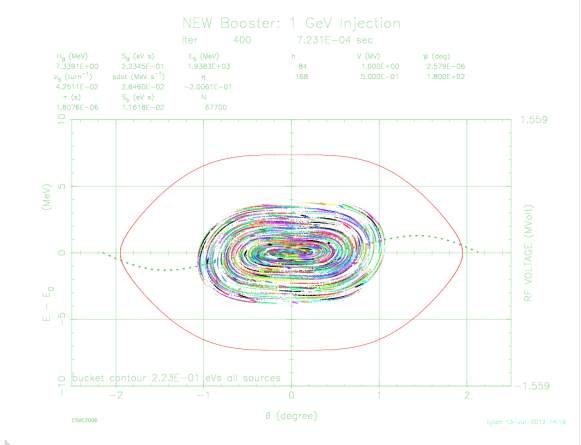
Goals of 2nd harmonic cavity

- To be used a injection and possibly at transition.
- R&D effort to see if this type of cavity can be used in a real rapid cycling synchrotron, i.e. Booster.

Why use 2nd harmonic cavity at injection?



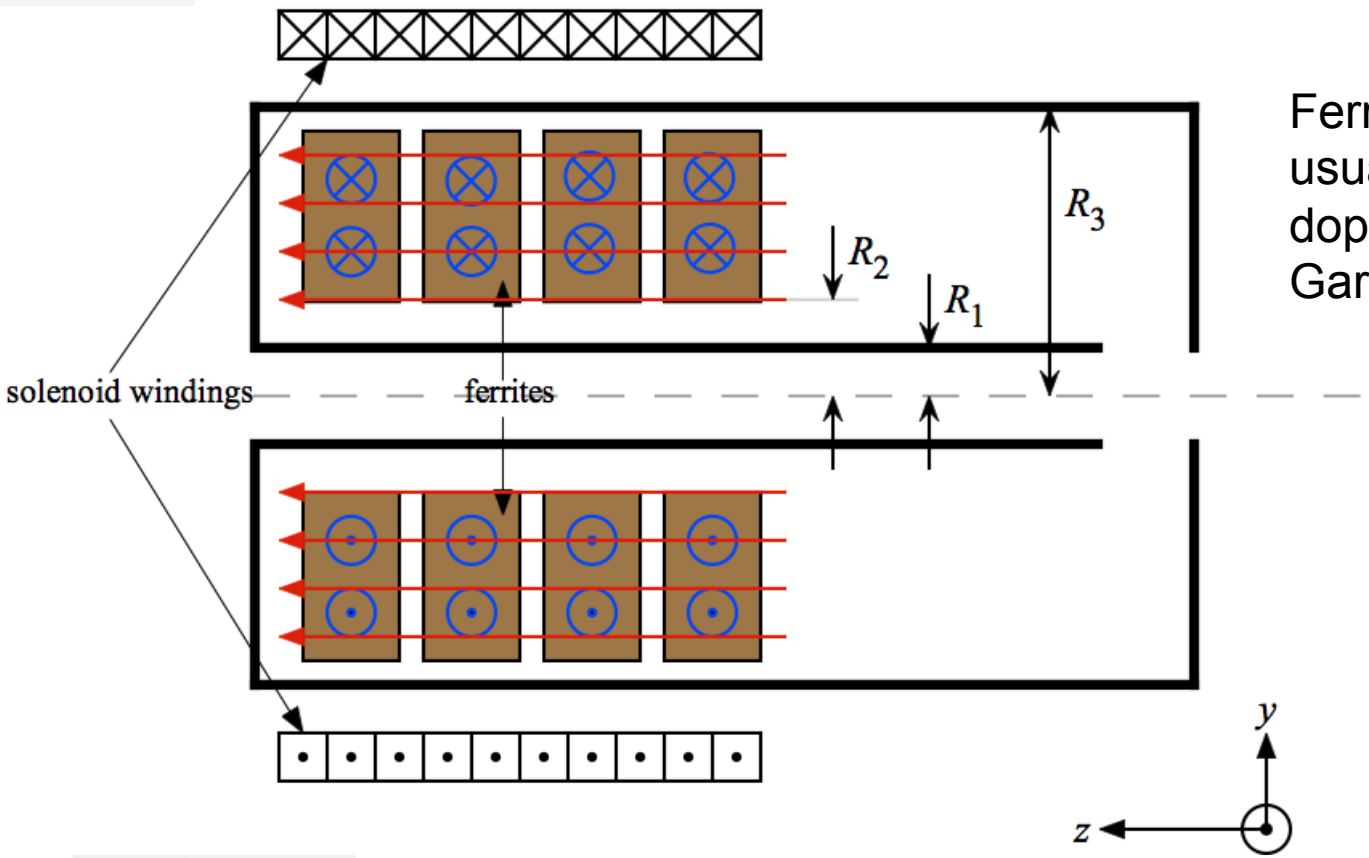
Fundamental only



Fundamental + 2nd harmonic (180 deg and 50% RF voltage w.r.t. fundamental

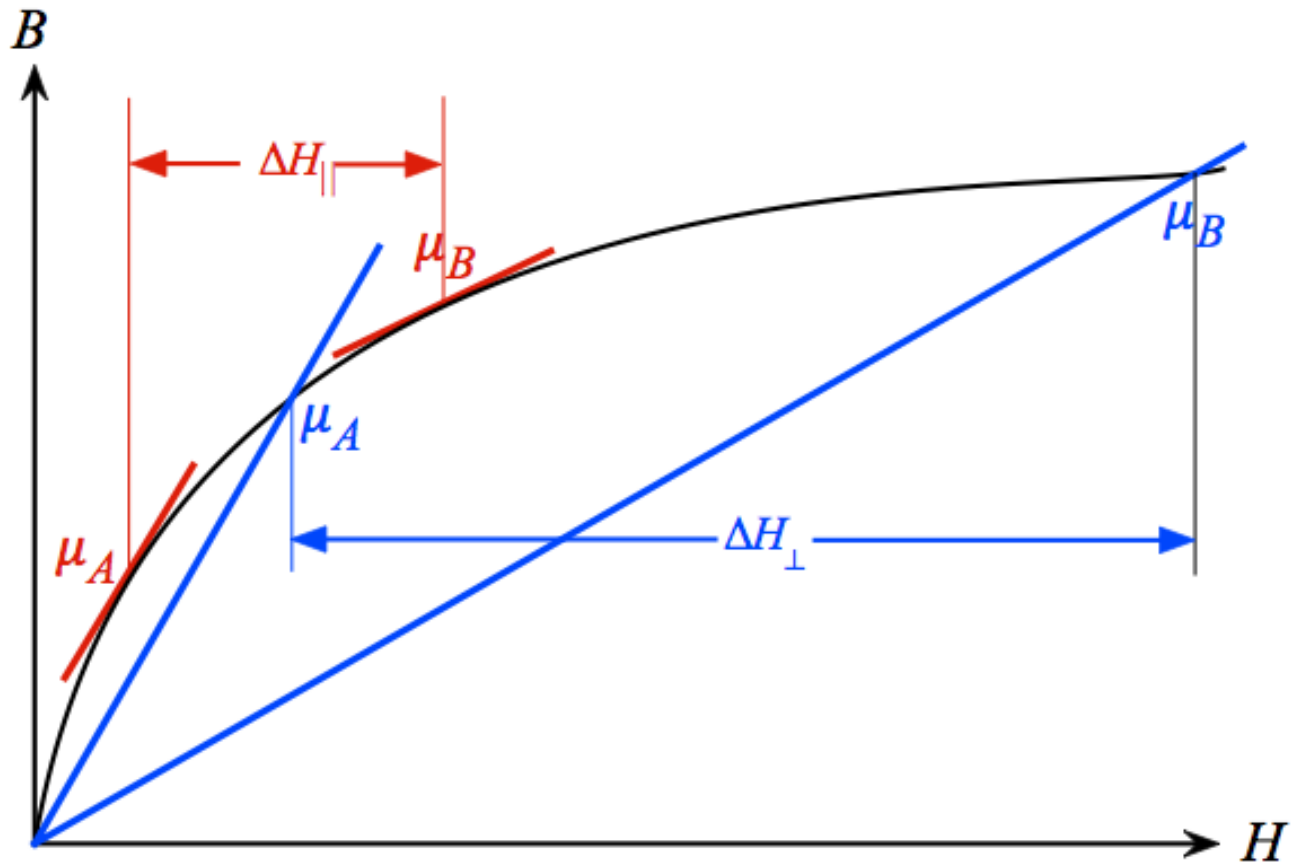
- Flattening of bucket increases RF bucket area.
- Beam is flattened, reduces space charge effects.

What is a perpendicularly biased cavity?

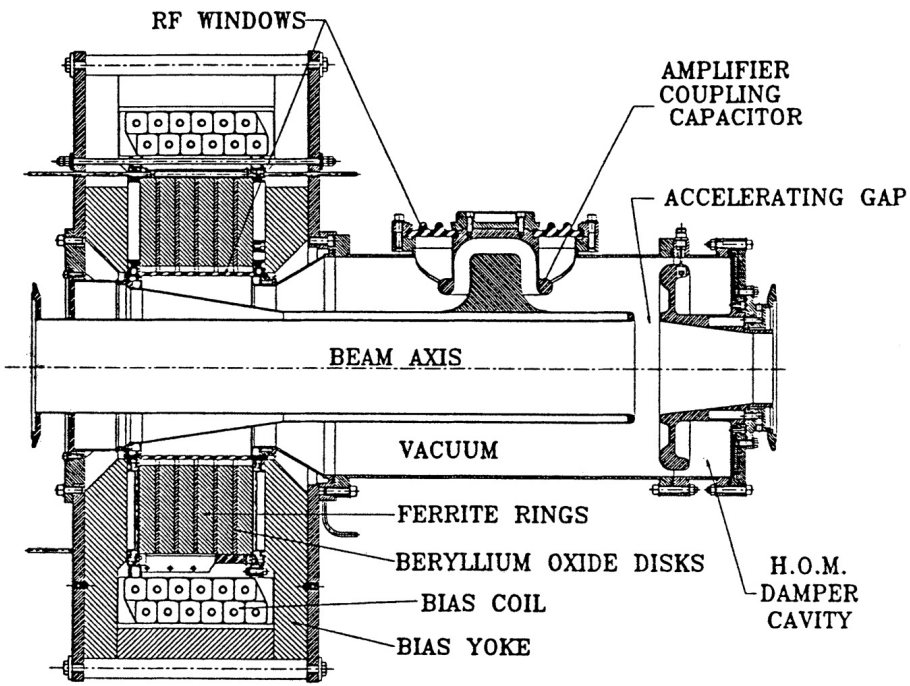


Ferrite material is usually a “garnet”: Al doped Yttrium Iron Garnet “YIG”.

μ values in parallel and perpendicular biasing



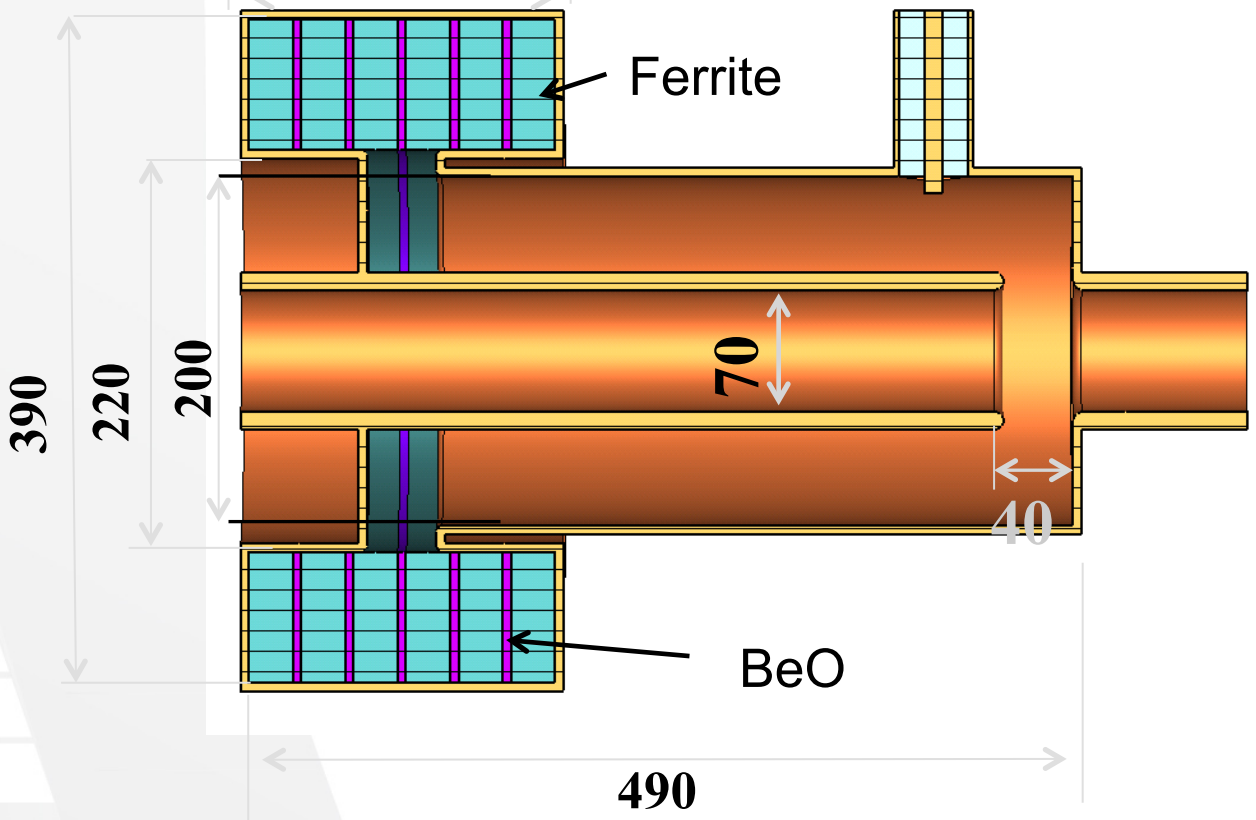
TRIUMF cavity



Note: Recycler cavities used for slip stacking also has perpendicular biased tuners. But tuning range is small ~ 10 kHz

Proposed cavity.

solenoid not shown here



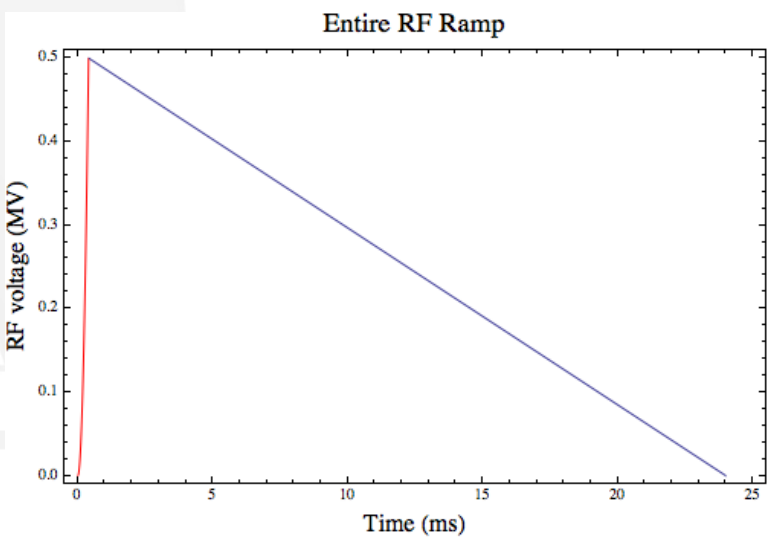
Name	Value	Description
Gap	40	
Gap_2	40	
Imped	1000	
L	405	pp
Linner	L-Gap	
Linner_2	50	
L_antenna	105	
L_ferr	175	
Mu	3.7	
Oe	1600	Magnetization
Rinner	90/2	
Router	200/2	
Router_2	R_ferr_in-5	
R_antenna	5	
R_ferr_in	230/2	
R_ferr_out	380/2	

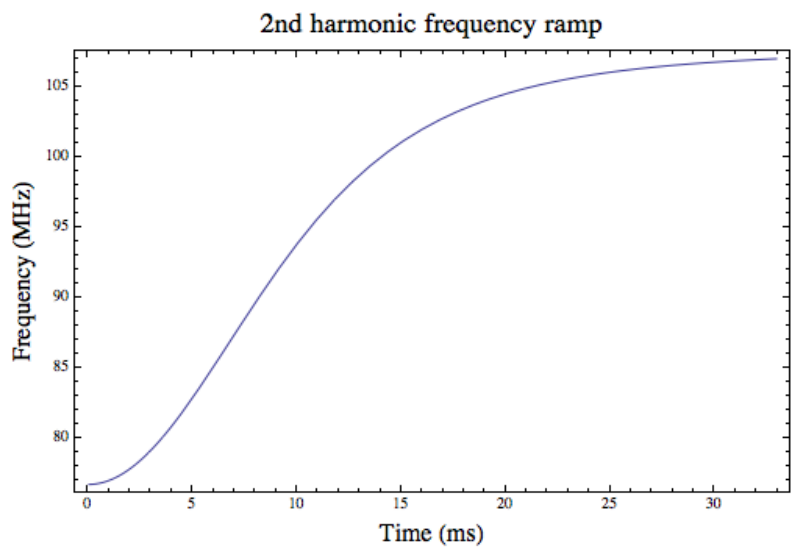
Ferrite disk: 380 mm outer diam., 230 mm inner diam., 25 mm thickness

BeO disk: 380 mm outer diam., 230 mm inner diam., 5 mm thickness

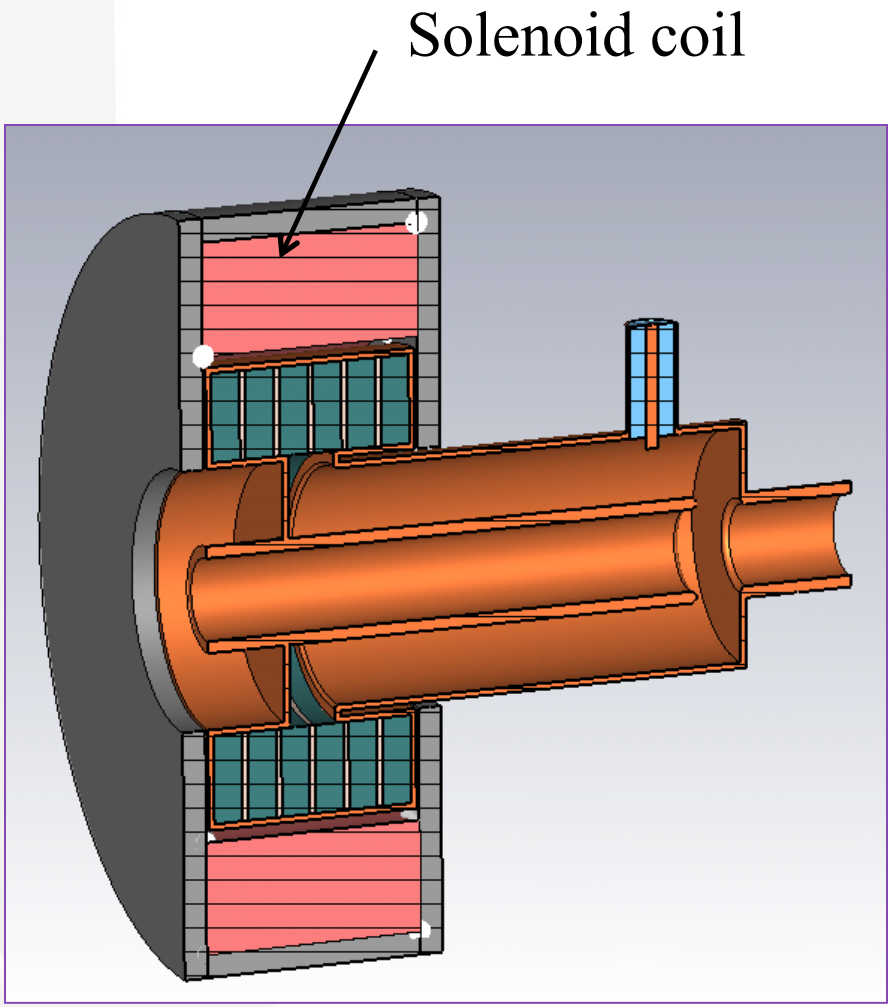
Some possible parameters

- Tuning range 76.7 − 107 MHz.
- Gap voltage. 100 kV per cavity.
- Ramp profile determines losses in the garnet.



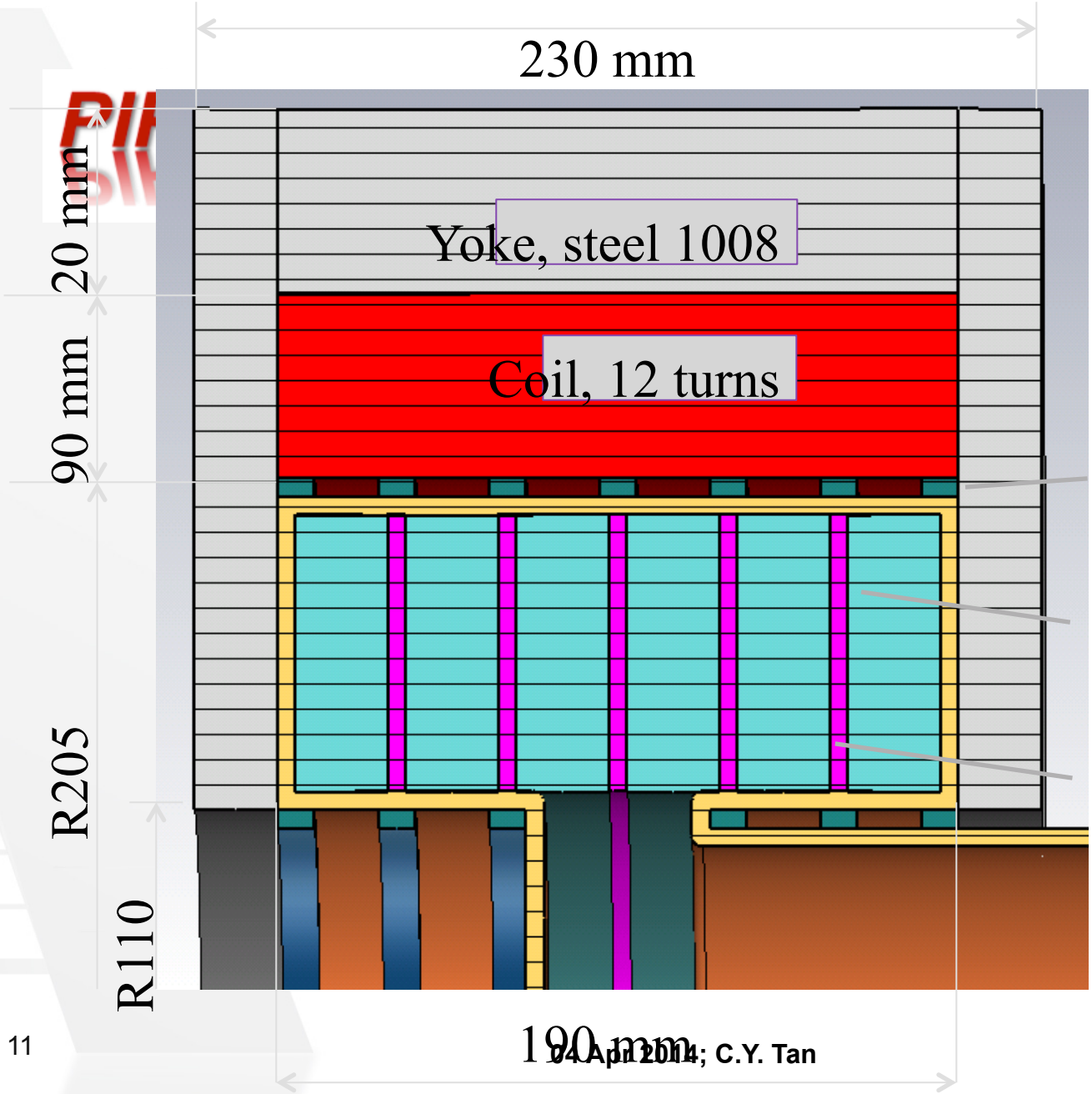


CST Model (done by G. Romanov)



Complete cavity model with magnetic field generated by solenoid

Ferrite tuner details



This is old picture, not properly scaled. But the marked dimensions are current.

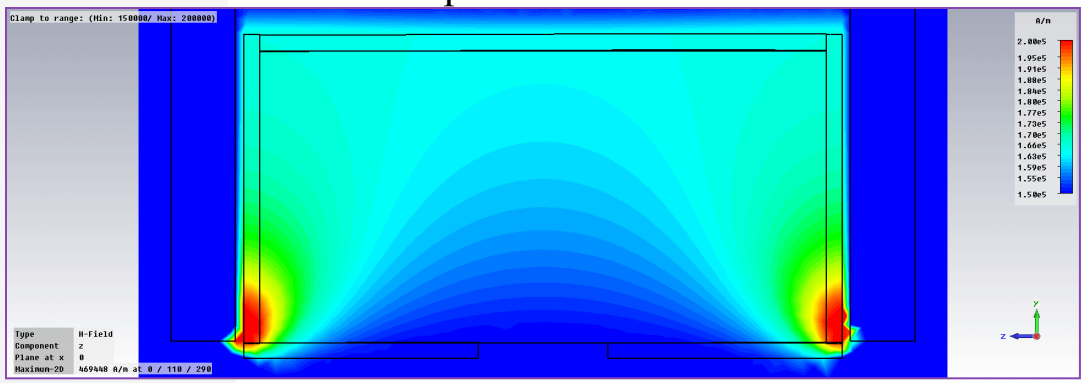
Water cooling channels, 10x5 mm

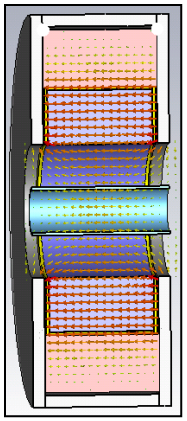
Ferrite G810, R=190 mm, r=115 mm, l=25 mm

Ceramic AlN, l=5mm

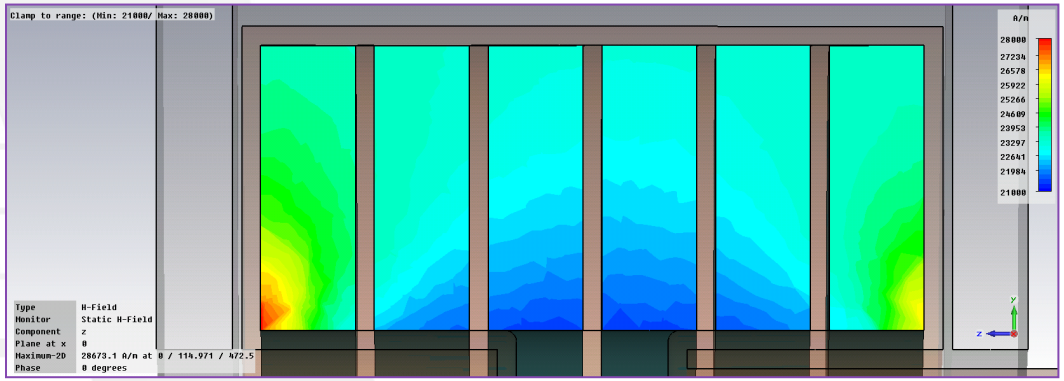
Static field distribution in ferrite

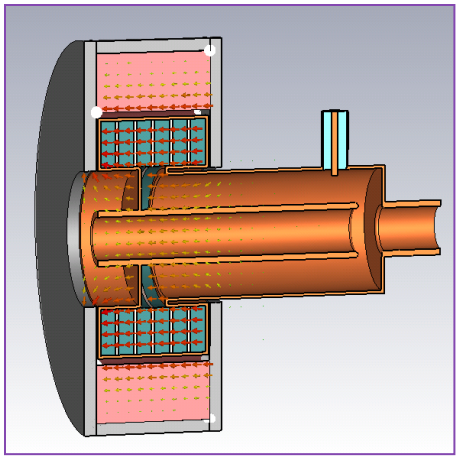
Separate solenoid model





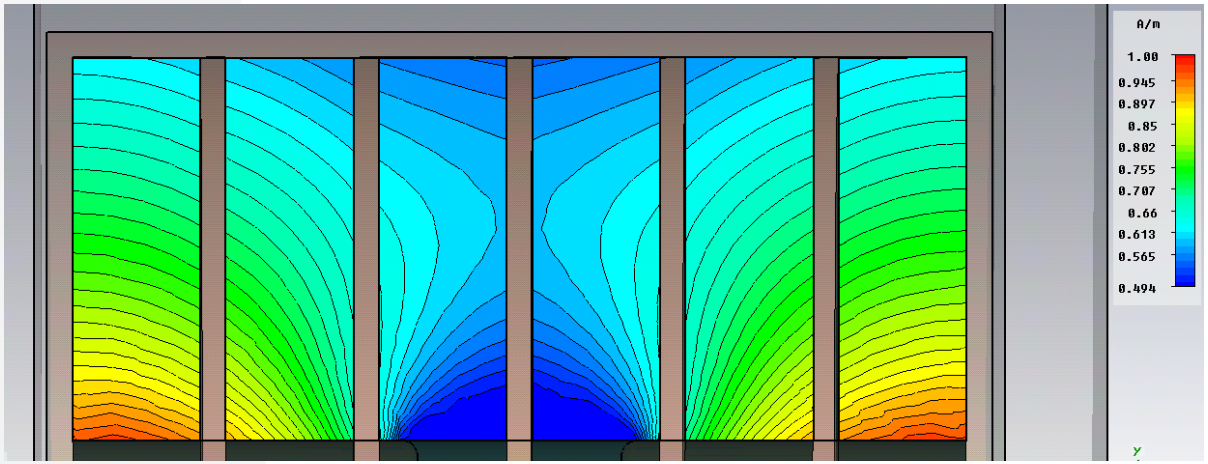
Complete cavity model



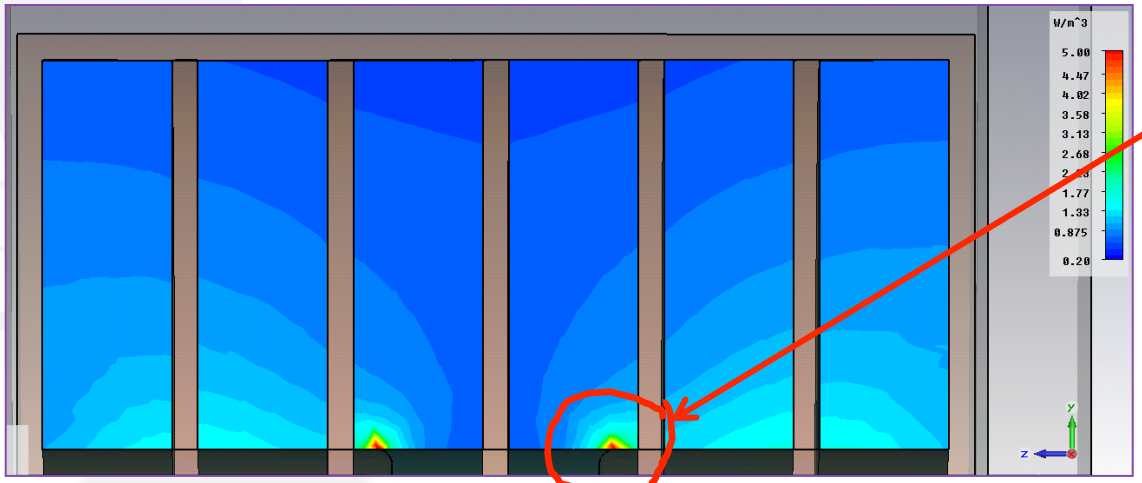


Field non-uniformity is about 25-30%

RF magnetic field distribution in ferrite and losses



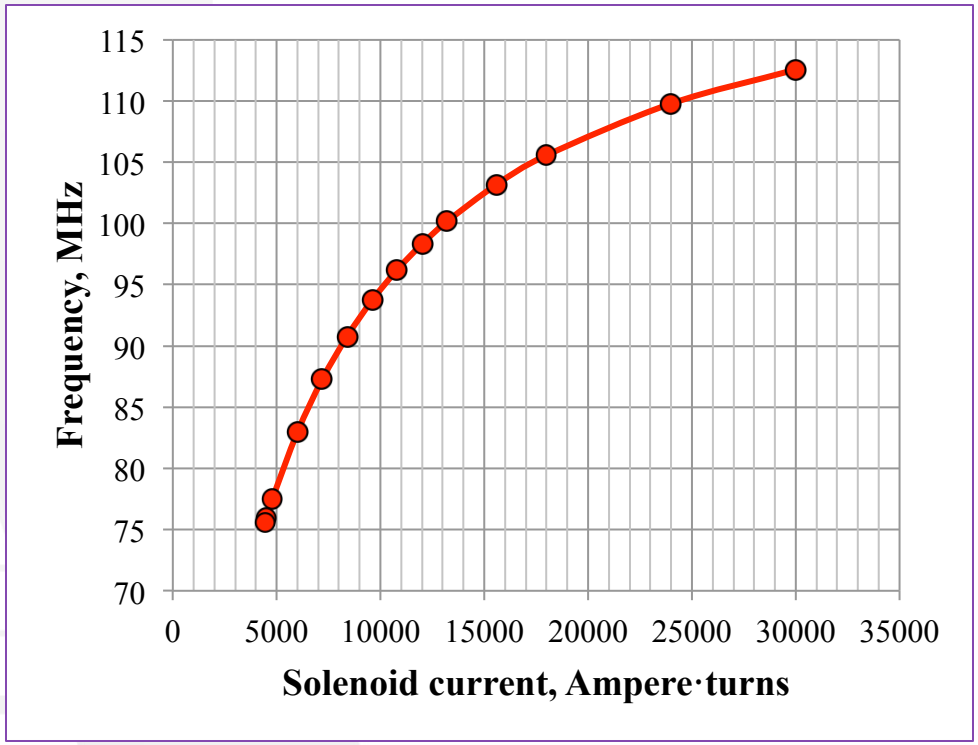
f=75.6 MHz

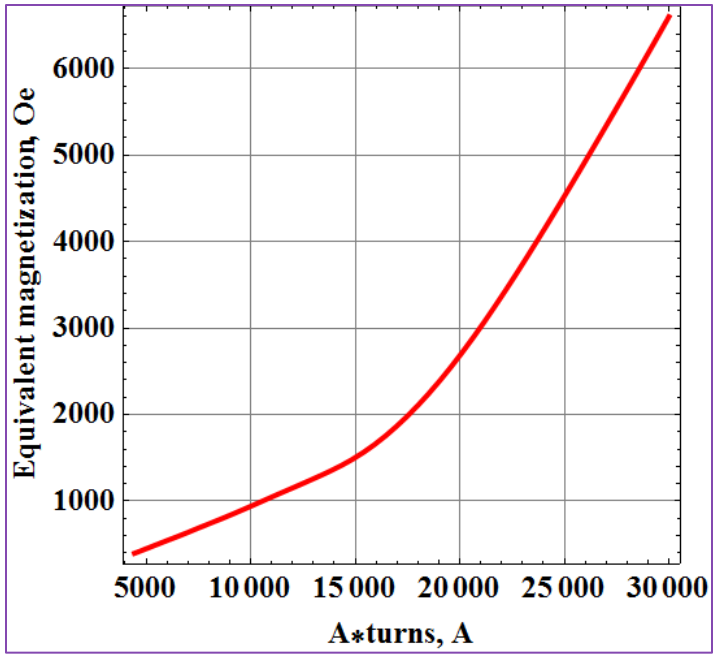


These power losses spikes are not real. They are due to the singularity of low frequency mesh that is used for thermal simulations

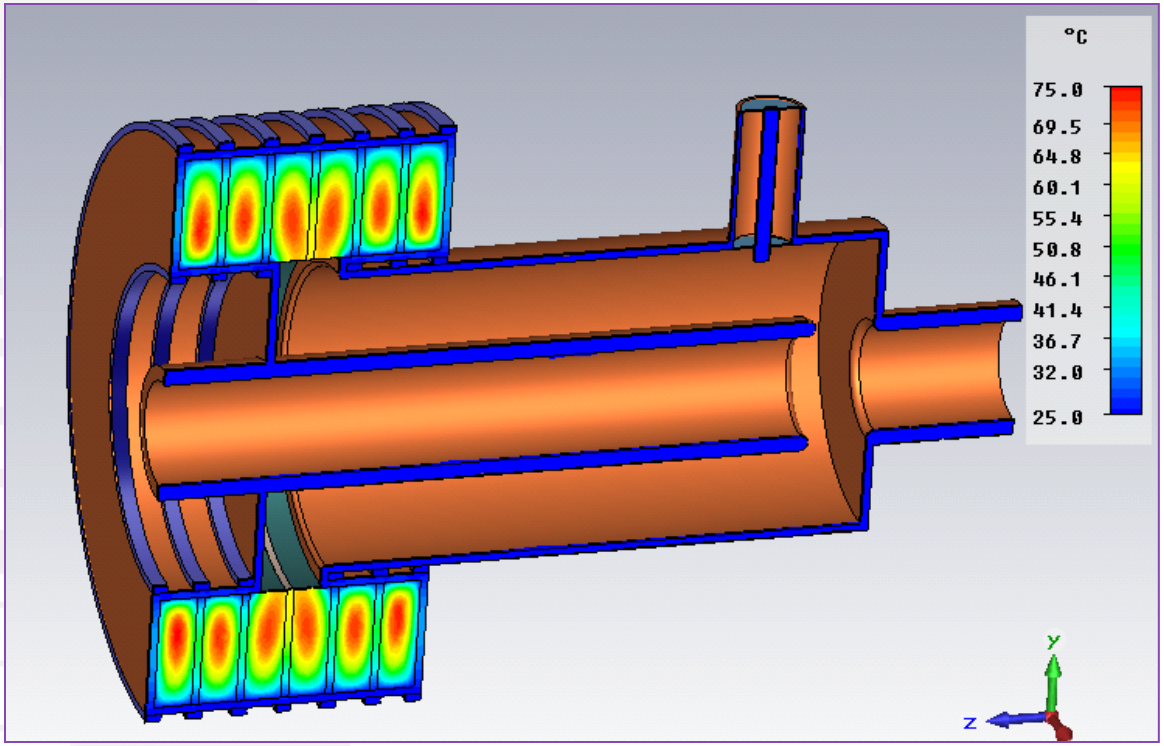
Tuning curves

Conversion of the solenoid current to the equivalent uniform field. We can continue to use uniform magnetization – the results are very close.



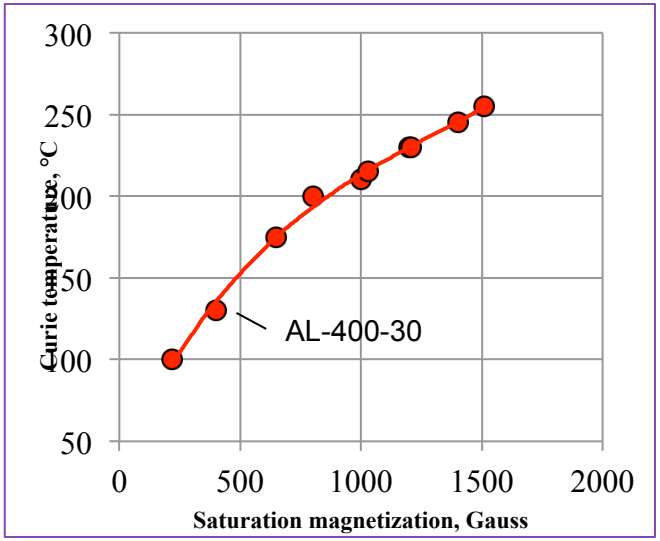


Thermal analysis

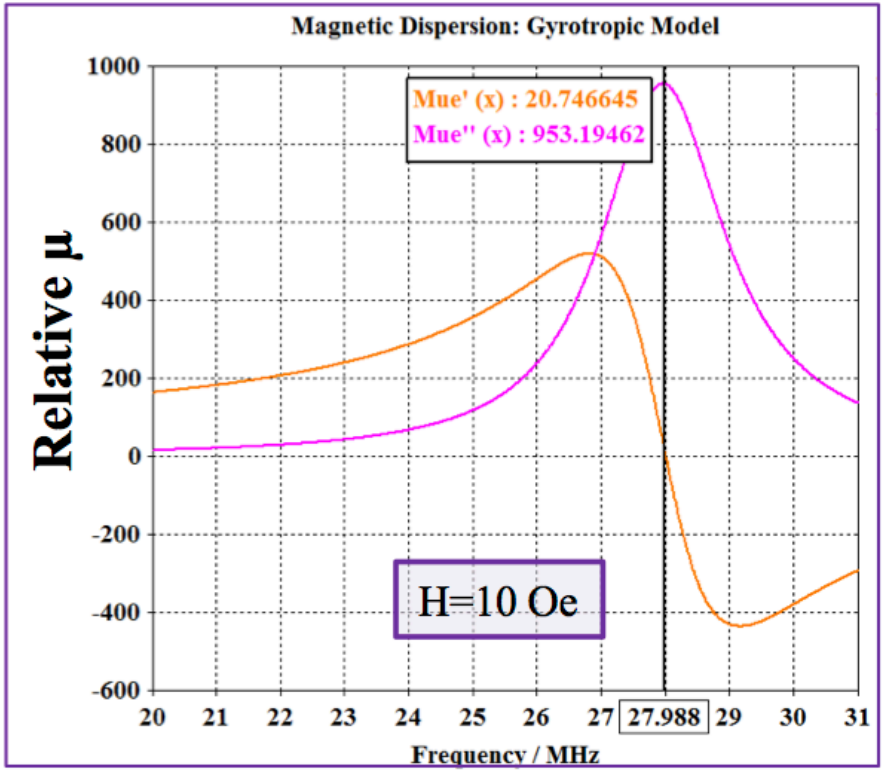


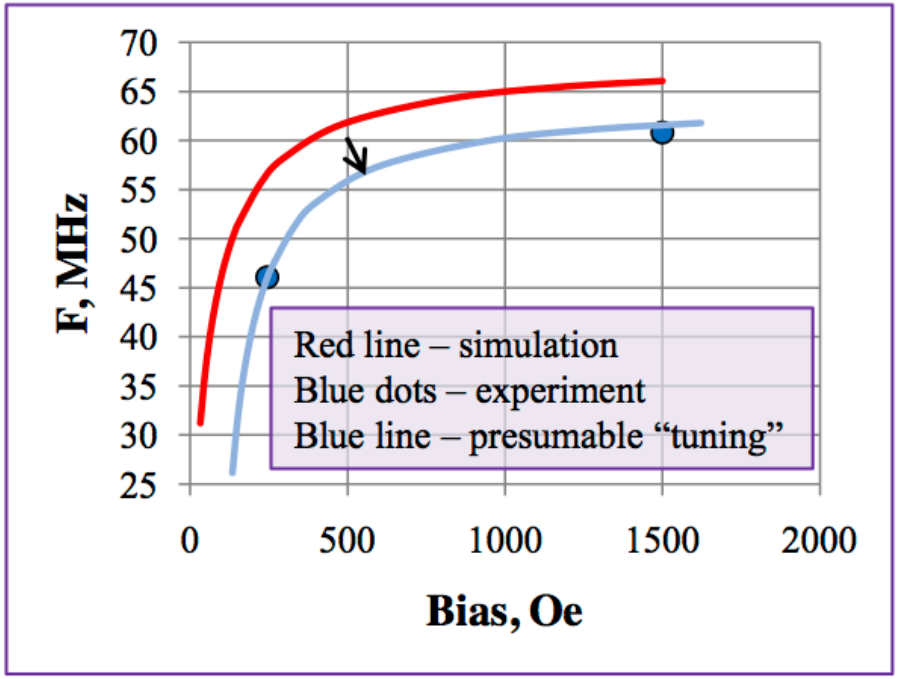
AlN cooling disks. Thermal losses in the ferrite are 14 kW for V=100 kV. Max T ≈ 75°C with cooling water temperature of 25°C.

Curie temperature

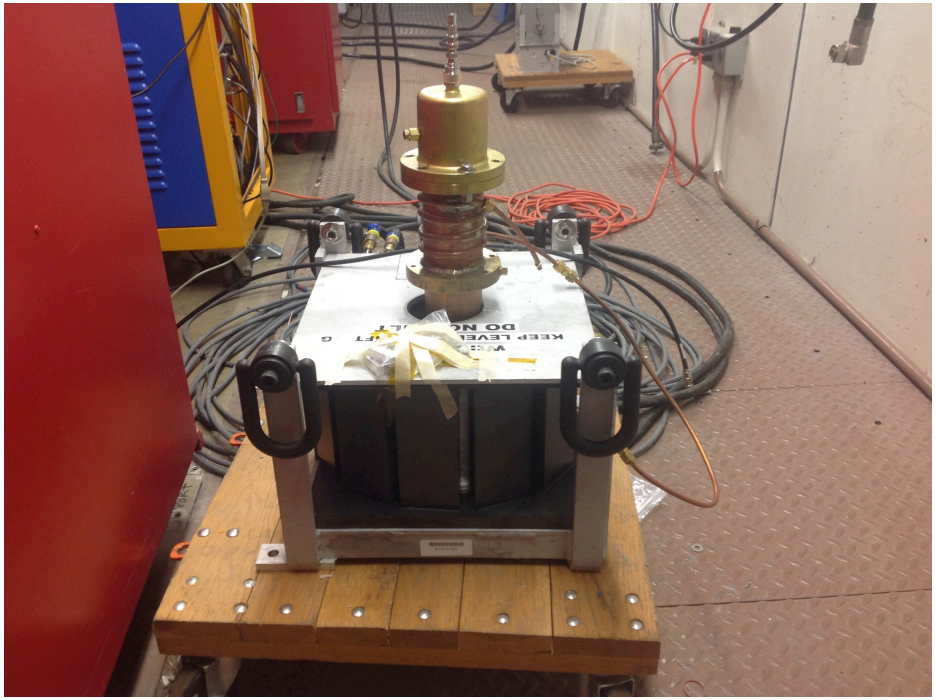


Magnetic permeability (Gyrotropic model)

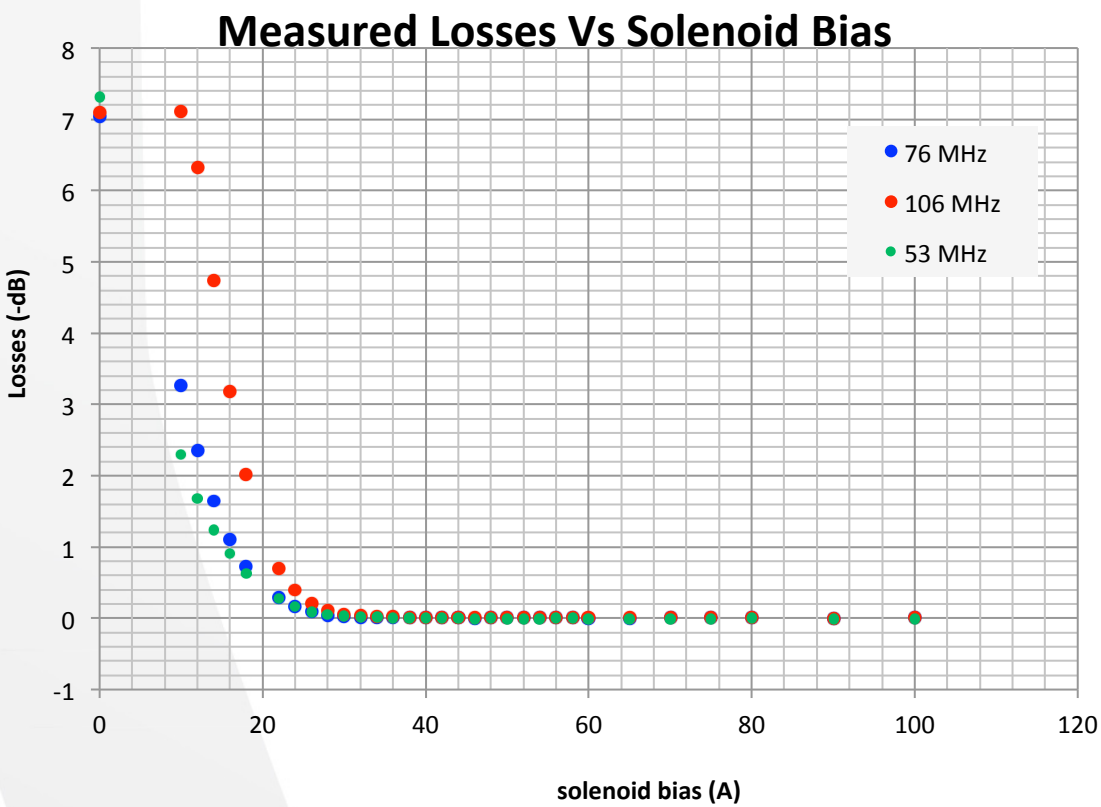




Measuring AL400 (R. Madrak and D. Wildman)



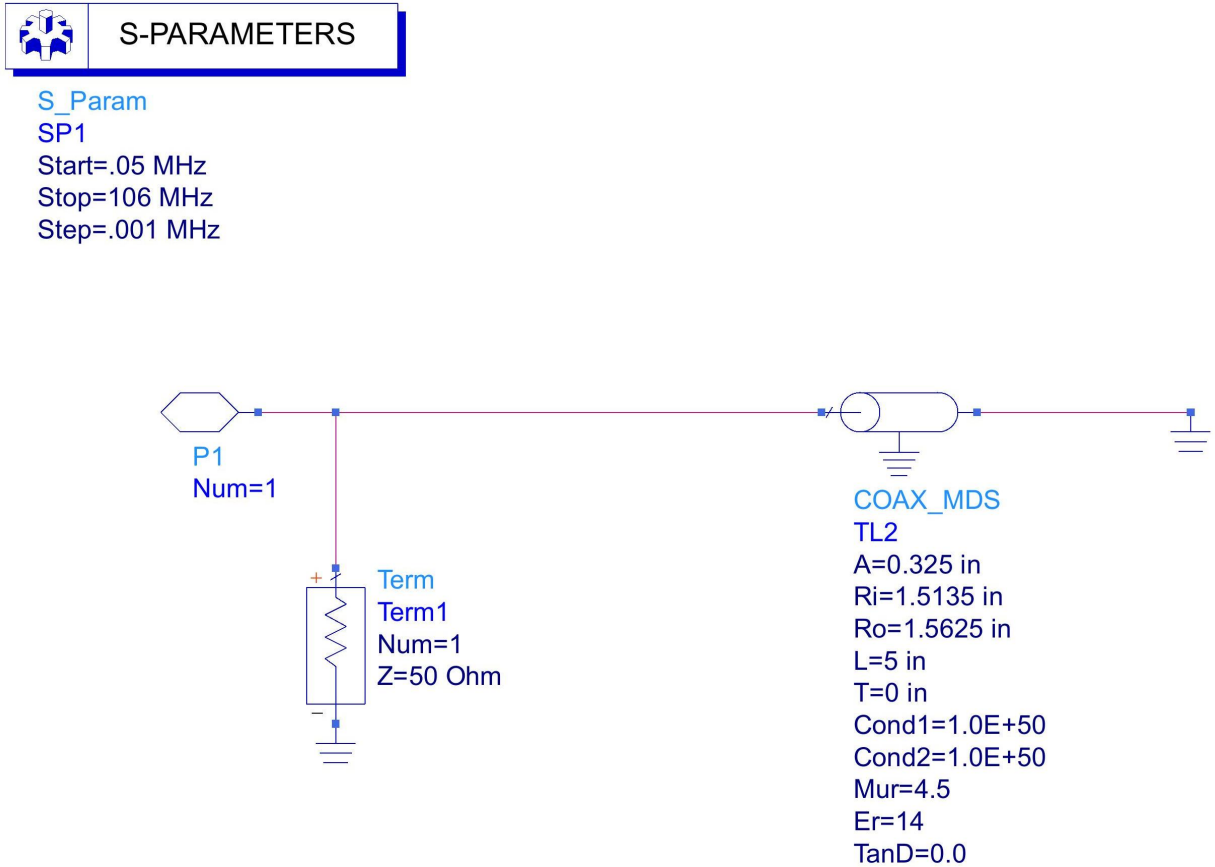
Measured losses



method looks at s11 and from there calculate the loss in the garnet.

This number will scale with the length of the garnet.

Model in ADS used to calculate μ' from s11 phase data

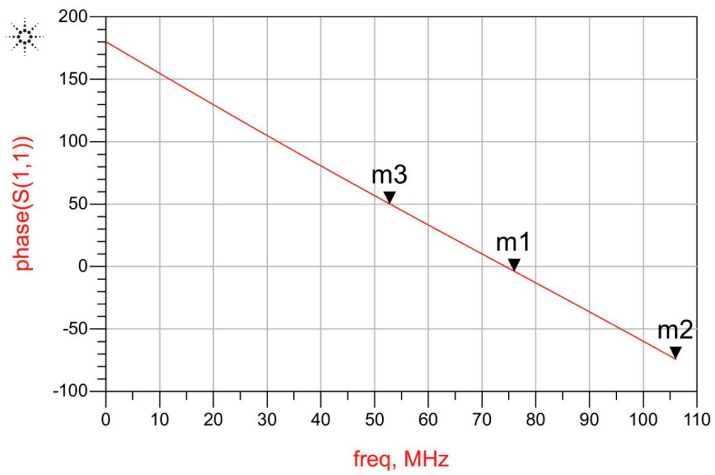


Fits to the s11 phase data

m1
indep(m1)=75.98500M
plot_vs(phase(S(1,1)), freq)=-3.782489

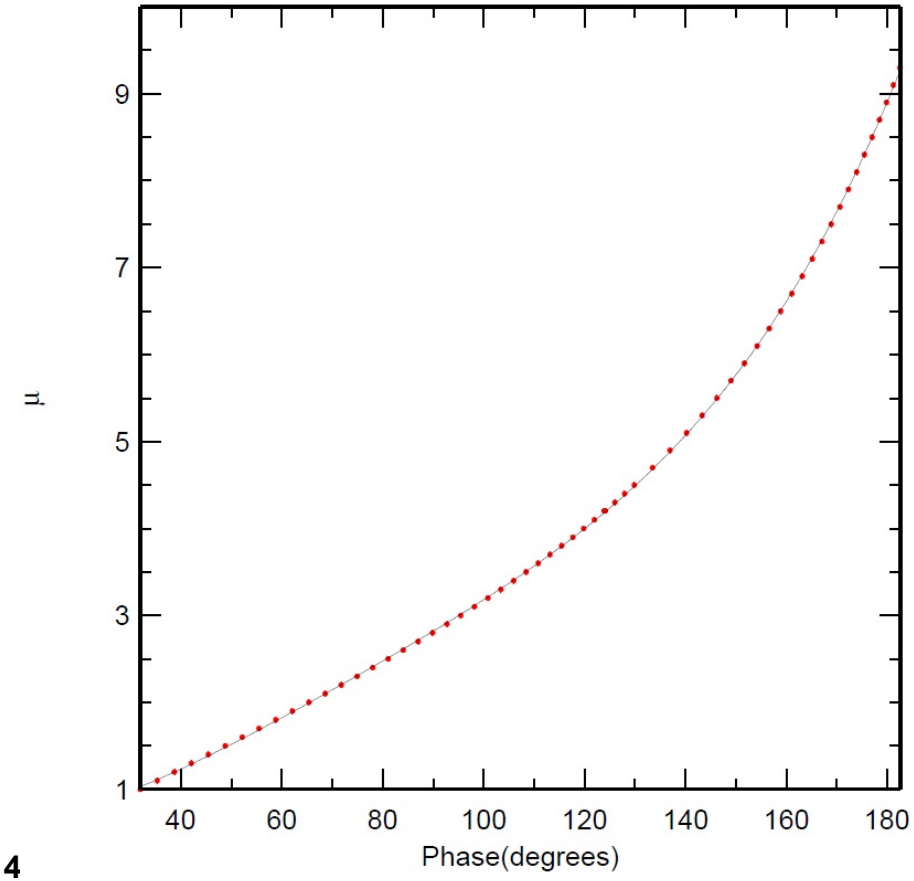
m2
indep(m2)=106.0000M
plot_vs(phase(S(1,1)), freq)=-74.13425

m3
indep(m3)=52.80900M
plot_vs(phase(S(1,1)), freq)=50.15084

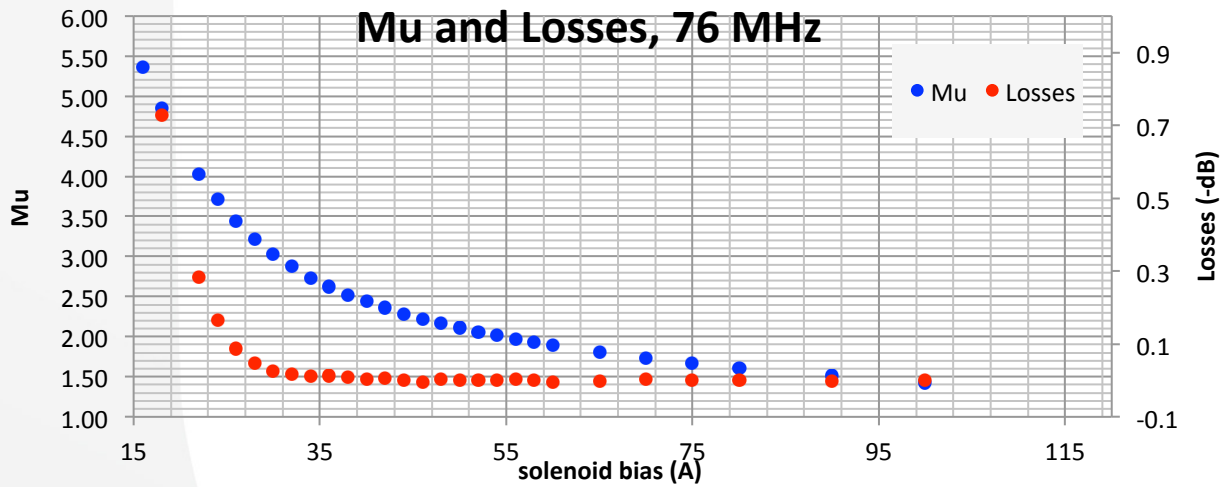


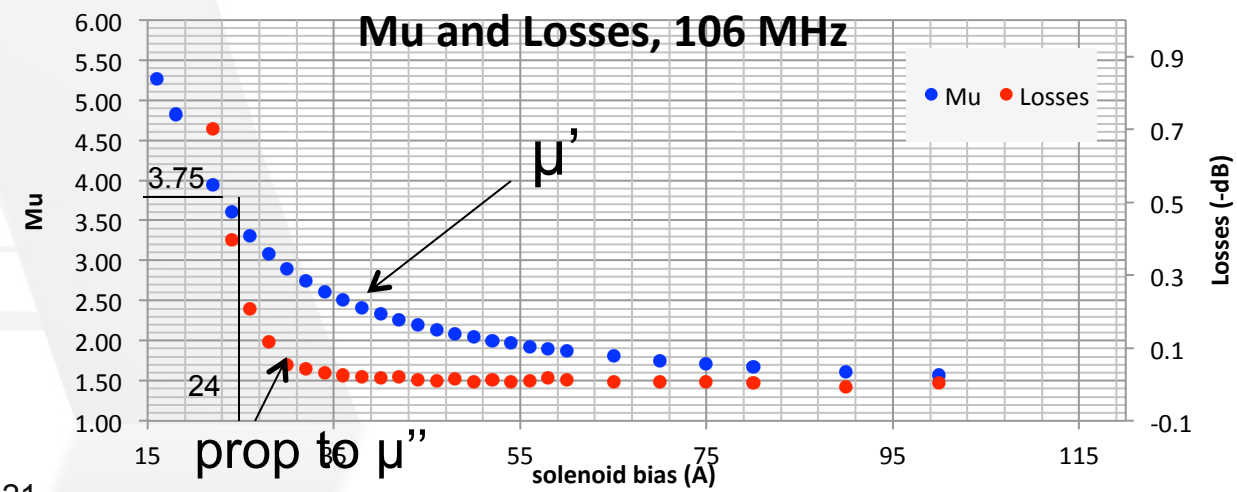
Function 1: Polynomial of Order 4

NORM	0.65046	±	7.2205E-04	-	0.000	+	0.000
POLY01	-2.78015E-03	±	9.7118E-06	-	0.000	+	0.000
POLY02	6.47197E-04	±	7.4738E-08	-	0.000	+	0.000
POLY03	-5.55882E-06	±	4.9602E-10	-	0.000	+	0.000
POLY04	1.94192E-08	±	2.6230E-12	-	0.000	+	0.000
OFFSET	1.2770	±	1.8036E-02	-	0.000	+	0.000



Measured μ





recall $\mu_e = \mu' - i\mu''$.

Back of the envelope requires

$\mu_{max}/\mu_{min} = (f_{max}/f_{min})^2 = (106/76)^2 \approx 2$.

Sims say ratio is 2.5, then if μ_{min}=1.5, then μ_{max}=1.5×2.5 = 3.75

-0.4 dB loss @ μ'=3.75

Conclusion

- CST simulations show that a 2nd harmonic cavity is doable.
- Small working group started that includes collaborators from IIT
  - Possibly a PhD graduate student later
- Goal is to get a preliminary design by the end of the year.