C75 options

F. Marhauser, J. Henry, R. Rimmer,
J. Benesch

Options for "C75"

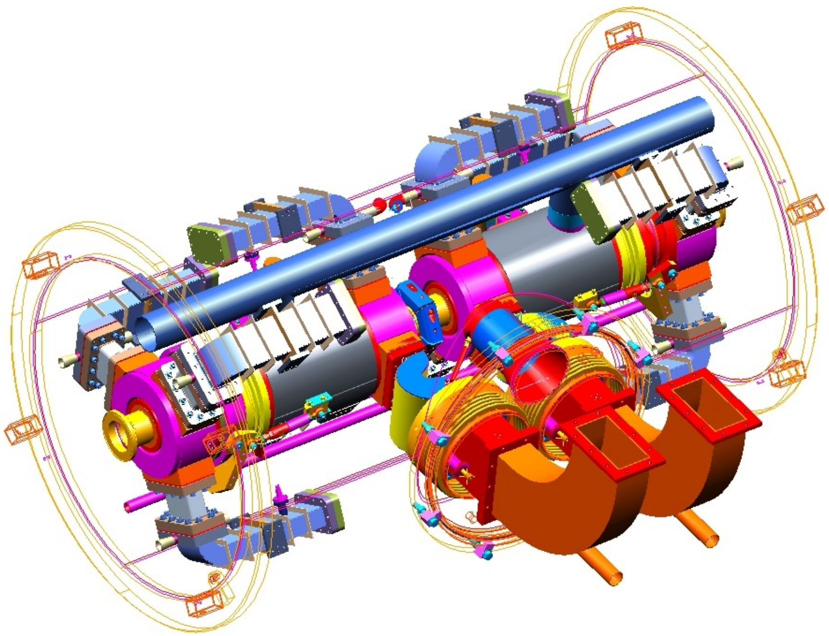
Goal is to investigate something between C50 and C100 with more "bang for the buck"

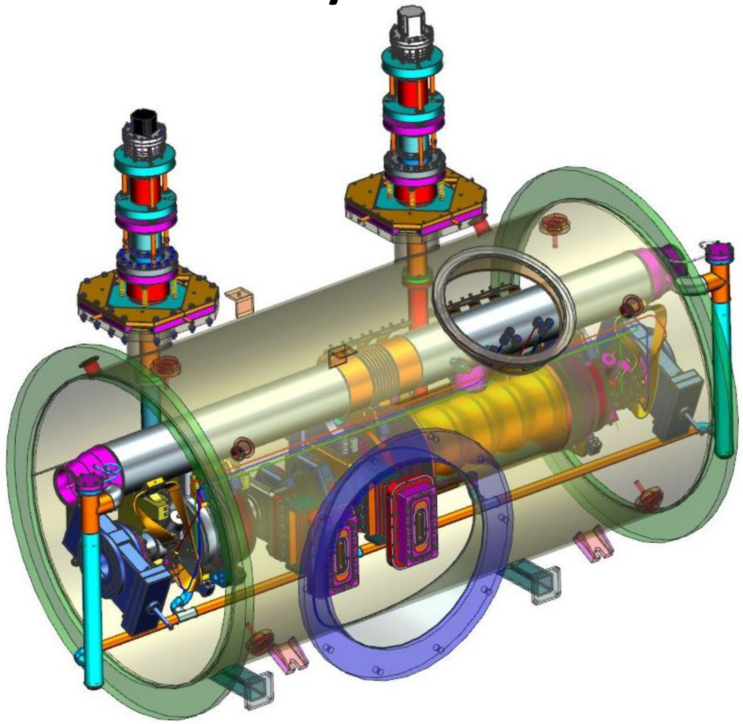
- Cost like C50, performance like C100
- "magic bullet": some process to transform old cavities
  - N_2 Doping, Nb_3Sn, ???
- New cavities in old CM
  - Add cost, but gain performance*
  - Could fix coupling kicks
  - Significant engineering required
  - What about "cell transplant"?
- New less expensive C100 CM
  - Major re-engineering needed. Synergy with MEIC?

* Need to find and fix the cause of Q loss to make this worthwhile

FEL HC design study

- For FEL upgrade we looked at a new high-current 5-cell cavities that would fit in old cryounits

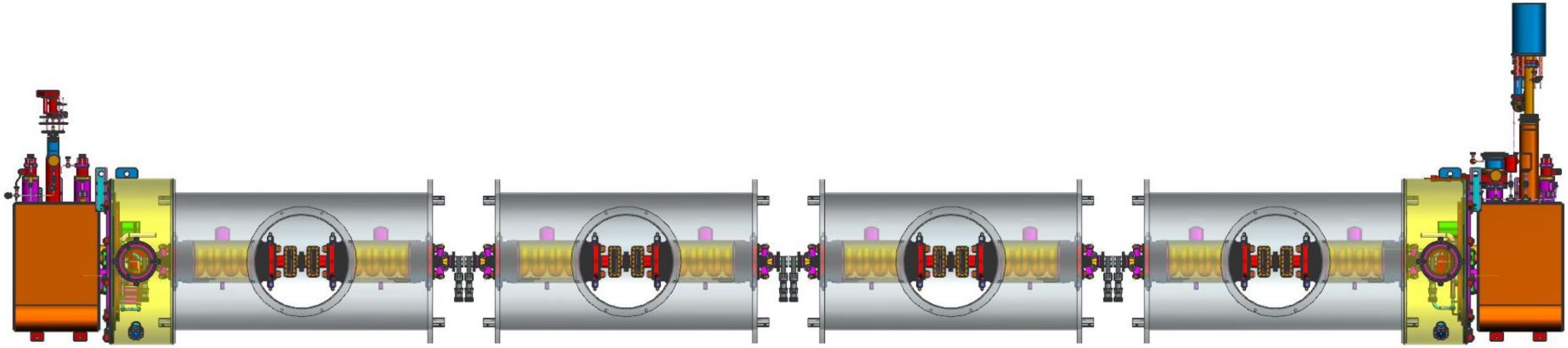




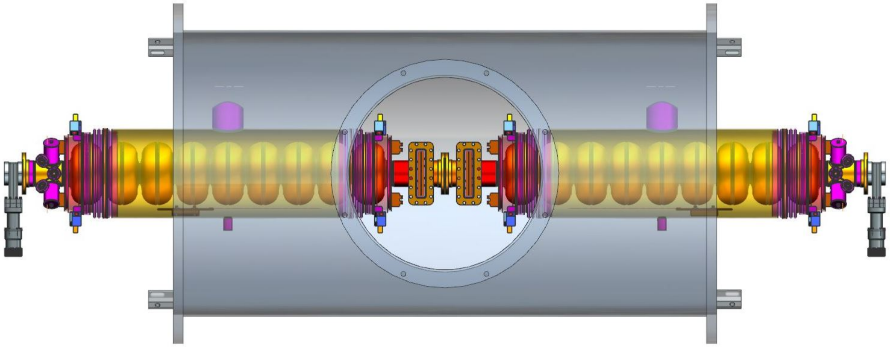
- Also for new CEBAF cryounit (same insertion length)

6-cell C75 cavity

- Squeeze 6-cell cavity into space in pair
  - Eliminate separate helium vessel hubs
  - Use C100 center type waveguide interface
  - Use C100 type HOM cans instead of waveguides
- Significant engineering needed to make it real
  - New tuner required? (Rock-crusher or blade type?)
  - Separate helium vessels



“J100”

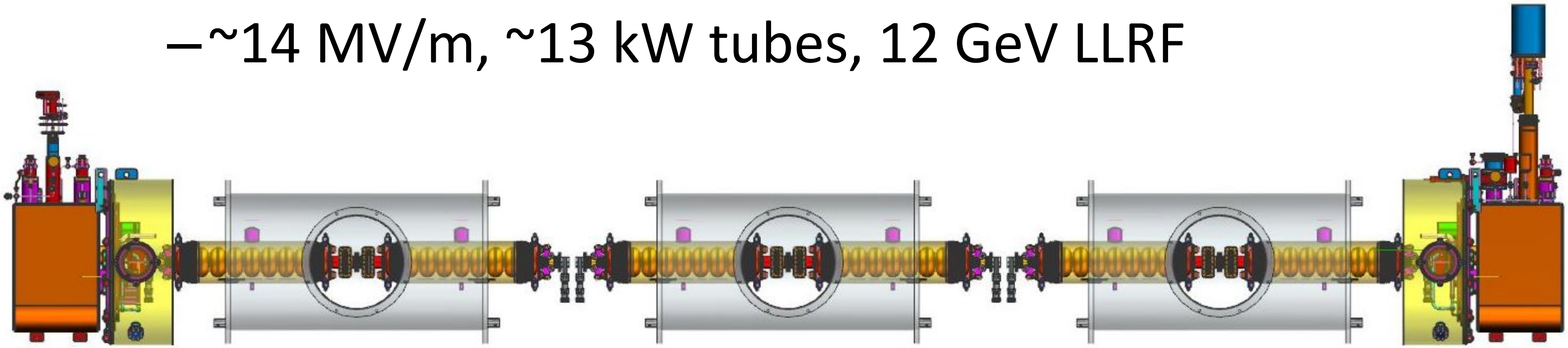


Jay’s 12 GeV proposal:

- 6 x 9-cell cavities
- ~18.5 MV/m average
- Stretched CEBAF type pairs, extended vessels
- Higher power ~17 kW FPC, klystrons (but fewer)

What about J75?

- ~14 MV/m, ~13 kW tubes, 12 GeV LLRF



CEBAF energy maintenance options

- Summary of options and estimated costs

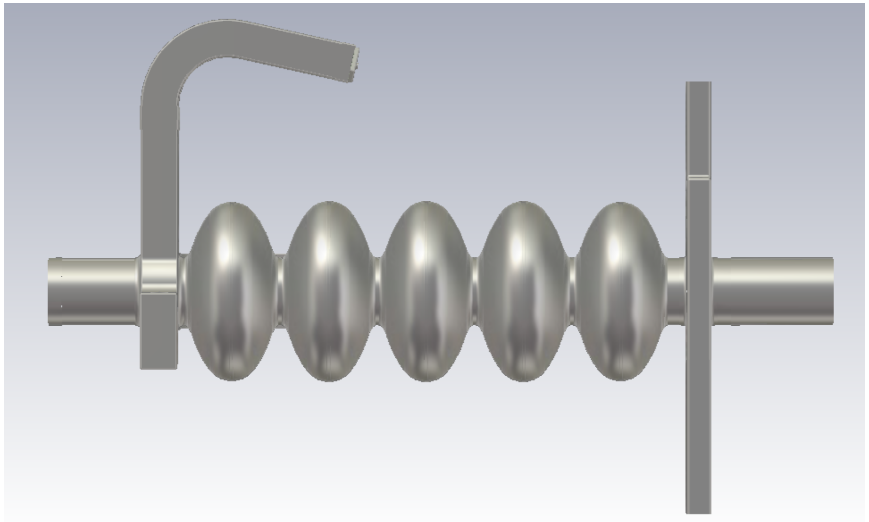
	cavities	cells/ cav	cav length m	Act. length m	fill factor %	voltage (MV)	volts/ cav (MV)	gradient (MV/m)	klystron power	unit cost (FY16 M$)	voltage gain (MV)	V/$
C50	8	5	0.5	4	48.1	50	6.25	12.5	6	1.51	20	13.3
C100	8	7	0.7	5.6	64.4	100	12.5	17.9‡	13	4.77	70	14.7
C75†	8	5	0.5	4	48.1	75	9.4	18.8‡	8	1.91	45	23.6
C75†*	8	6	0.6	4.8	57.8	75	9.4	15.6	8	2.31*	45	19.5
J100*	6	9	0.9	5.4	65.0	100	16.7	18.5‡	~17	???	70	???
J75*	6	9	0.9	5.4	65.0	75	12.5	13.9	13	???	45	???

†New cells or new processing required to achieve higher Q's and gradients

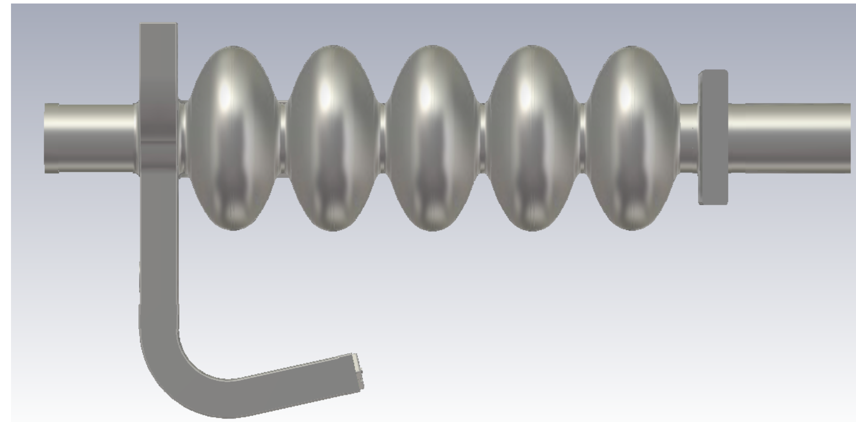
*Engineering required at additional cost (not included)

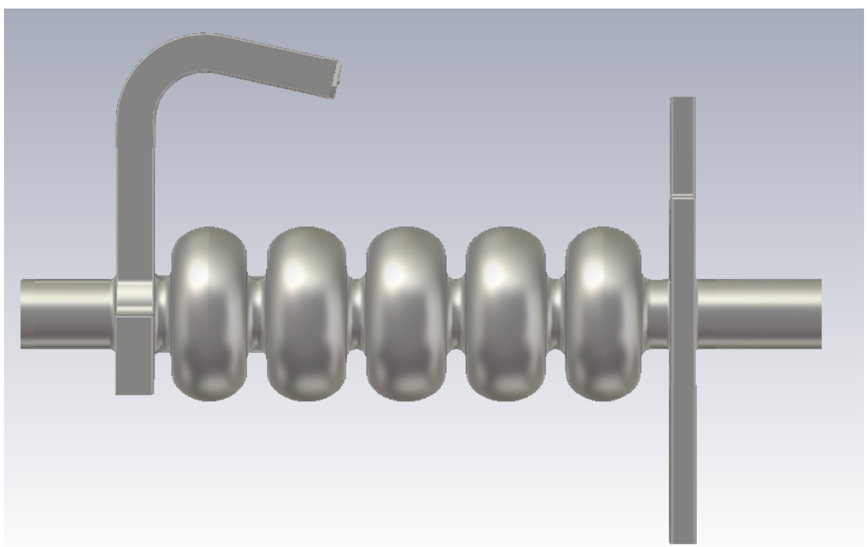
‡Digital LLRF required

Opt. 3:High Current (HC) Cavity for C50 Cryomodules?

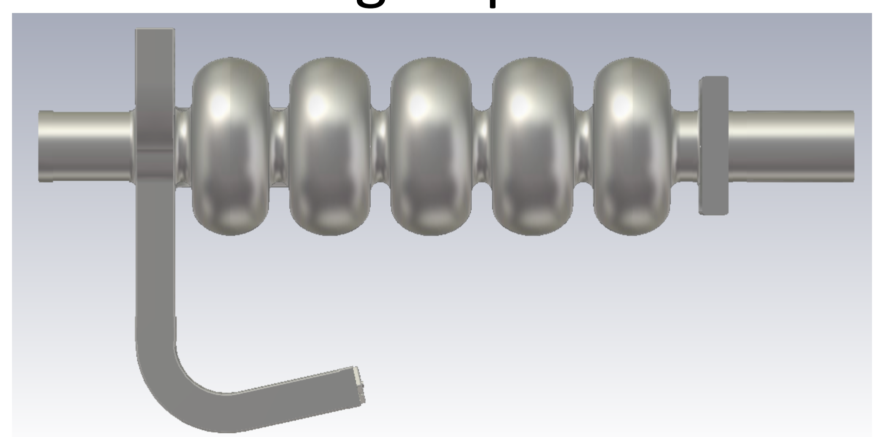


OC 5-cell cavity



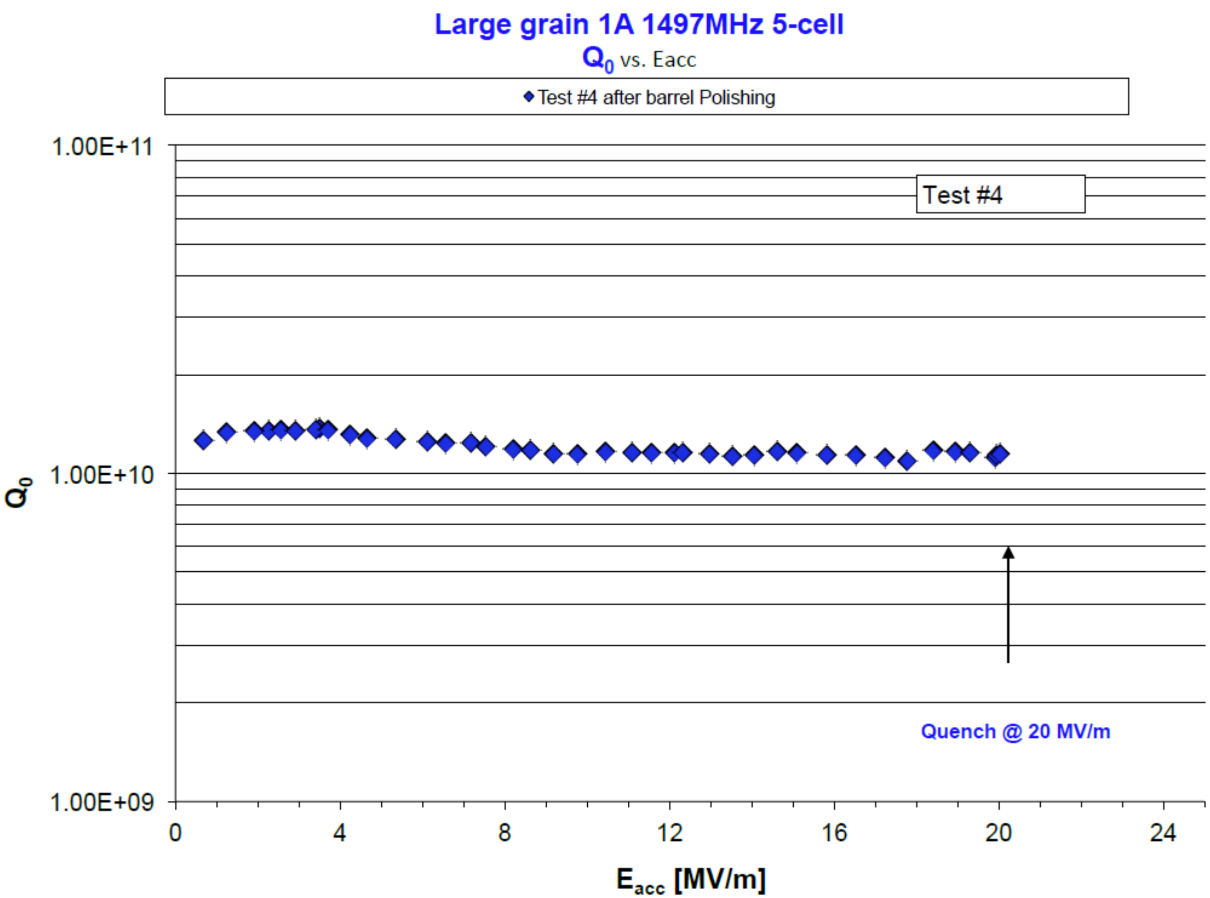


HC 5-cell cavity using C50 HOM and FPC endgroup - “HC50”



VTA test 1497 MHz HC 5-cell cavity

- Large grain with damaged cell from CBP, final BCP
- Q_0 ~ 1.1e10 up to 20 MV/m



Jefferson Lab

Cavity Parameters

Parameter	Unit	C50	HC50
Frequency @ 2 Kelvin	MHz	1497	1497
R/Q (β = 1)	Ω	482.5	525.4
G	Ω	274.0	275.6
R/Q*G	Ω^2	132205	144802
tube/iris ID	mm	70/70	70/70
TE11/TM01 cutoff	GHz	2.51/3.28	2.51/3.28
cell-to-cell coupling	%	3.15	3.15
U_{acc} (nominal, on crest)	MV	6.25	6.25
L_{active} (nominal)	mm	499.855	491.600
E_{acc} (nominal @ 50 MeV)	MV/m	12.50	12.71
E_{peak}/E_{acc}		2.56	2.45
B_{peak}/E_{acc}	mT/(MV/m)	4.56	4.18
E_{peak}	MV/m	32.0	31.1
B_{peak}	mT	57.0	52.3
P_{cav} (@ Q_0 = 6.8e9)	W	11.9	10.9
P_{CM} (@ Q_0 = 6.8e9)	W	95.2	86.9

- At same Q_0 about 1 W reduction of dynamic losses per cavity at 2 K (~10%) at 50 MeV based on cavity design

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E_{peak}	MV/m	32.0	31.1
B_{peak}	mT	57.0	52.3
P_{cav} (@ Q_0 = 1.1e10)	W	7.4	6.7
P_{CM} (@ Q_0 = 1.1e10)	W	58.9	53.7

- At same Q_0 about 1 W reduction of
  50 MeV based on cavity desi

Dynamic RF losses

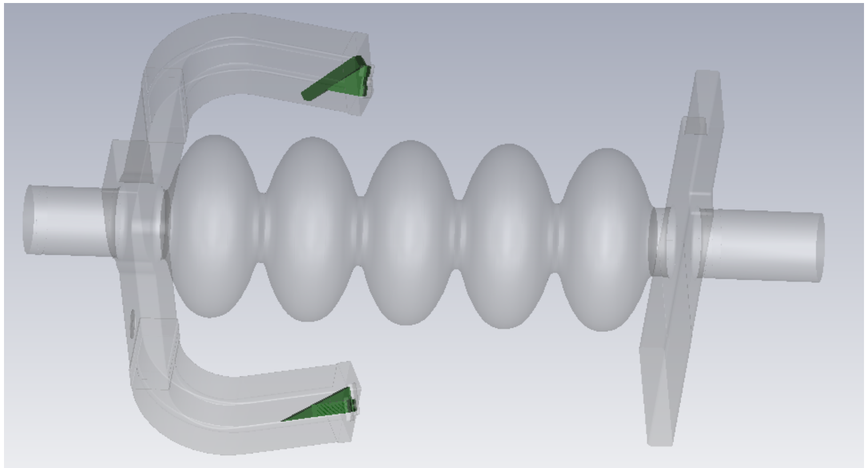
Parameter 50 MeV gain	Unit	C50	HC50	ΔP_{RF} (W)	ΔP_{RF}, max (W)
E_{acc} (nominal @ 50 MeV)	MV/m	12.5	12.7	-	-
P_{cav}(@ Q_0 = 6.8e9)	W	11.9	max. 10.9	1.0	-
P_{cav} (@ Q_0 = 1.1e10)	W	7.4	6.7	0.64	5.2

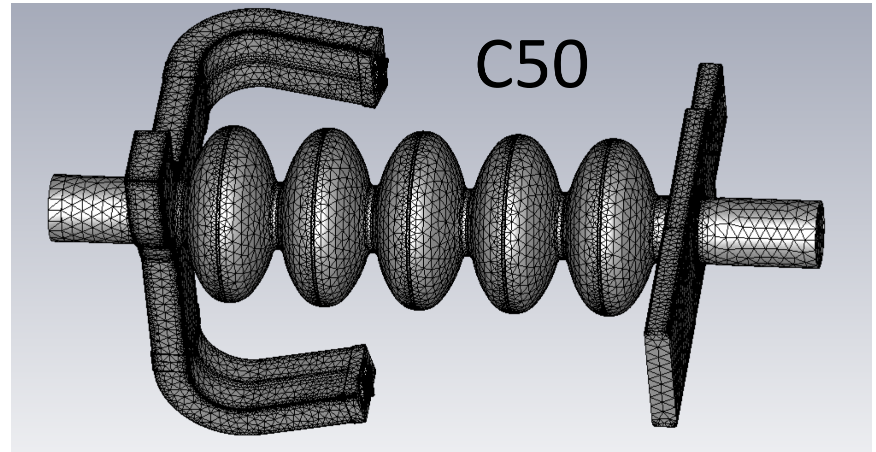
- 1.04 W/cav. reduction at same low Q_0 (8.3 W per CM)
- 0.62 W/cav. reduction at same high Q_0 (5.2 W per CM)
- 5.19 W/cav. max. reduction with Q_0 gain (41.5 W per CM)

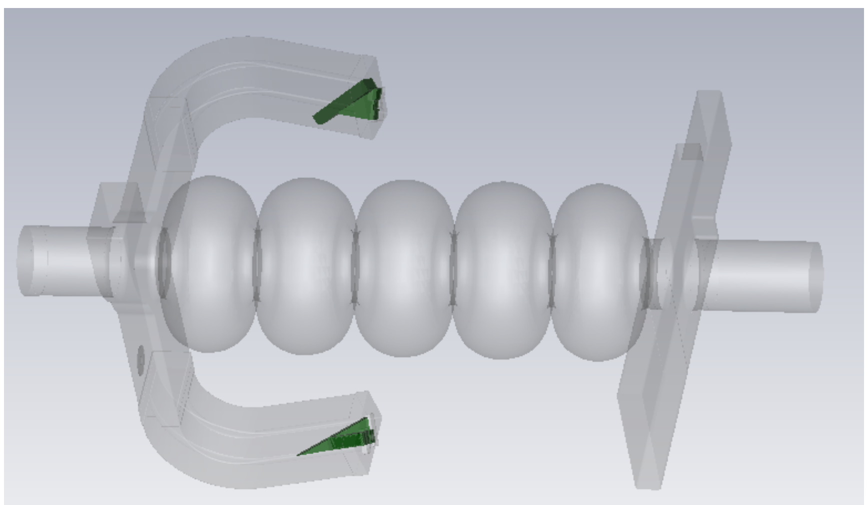
Parameter 70 MeV gain	Unit	C50	HC50	ΔP_{RF} (W)	ΔP_{RF}, max (W)
E_{acc} (nominal @ 70 MeV)	MV/m	17.5	17.8	-	-
P_{cav} (@ Q_0 = 6.8e9)	W	23.3	max. 21.3	2.0	-
P_{cav} (@ Q_0 = 1.1e10)	W	14.4	13.2	1.3	10.2

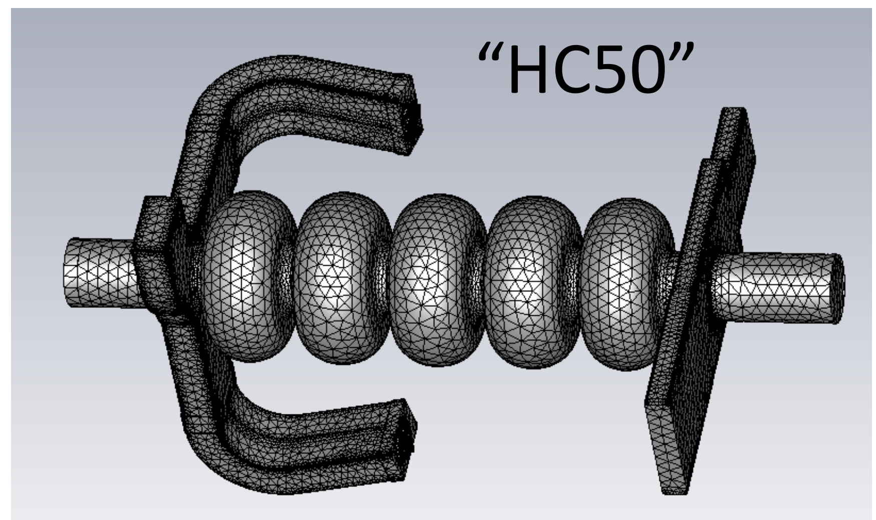
- 2.04 W/cav. reduction at same low Q_0 (16.4 W per CM)
- 1.26 W/cav. reduction at same high Q_0 (10.1 W per CM)
- 10.17 W/cav. max. reduction with Q_0 gain (81.4 W per CM)

What about HOMs?







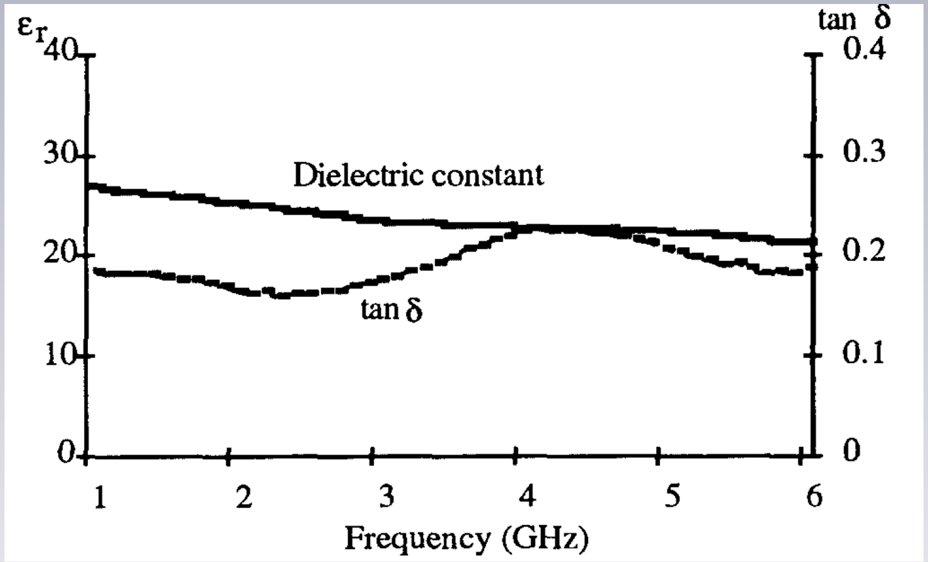


Can now model in CST Microwave Studio including HOM loads

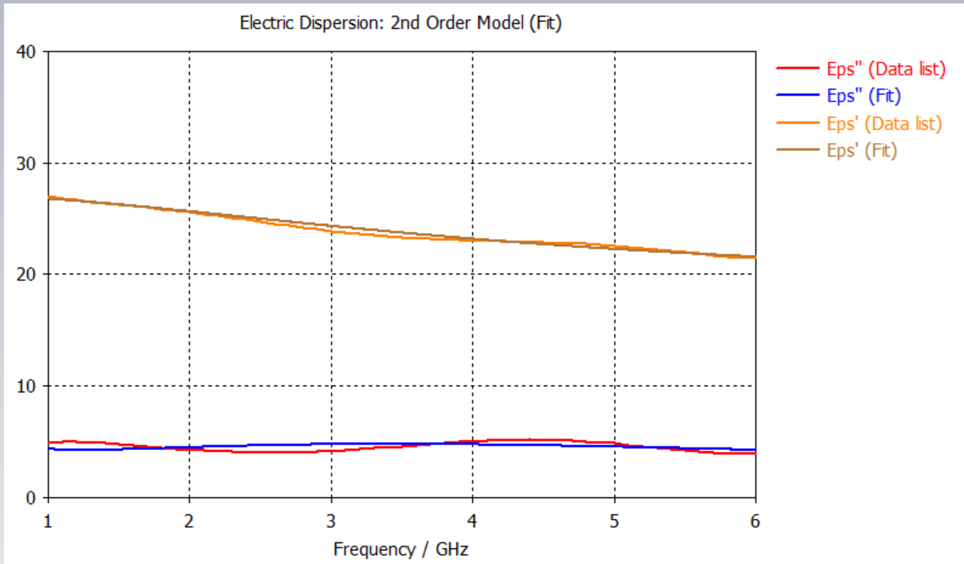
C50-style load

- Include material properties in calculation instead of perfect match

material data (I.E. Campisi 1993)

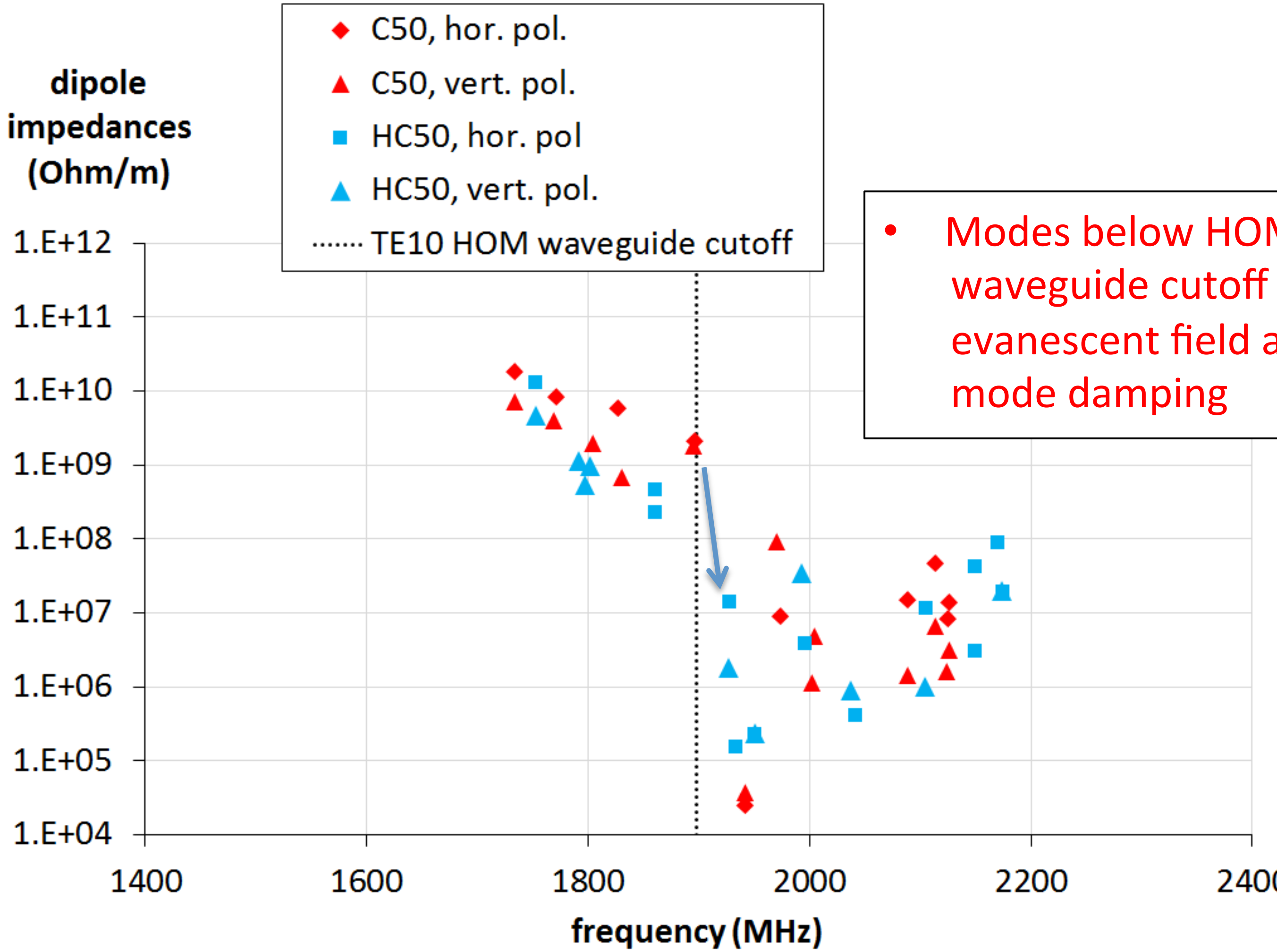


model data (ε', ε'')



HOM Damping

- Damping slightly improved for crucial dipole modes



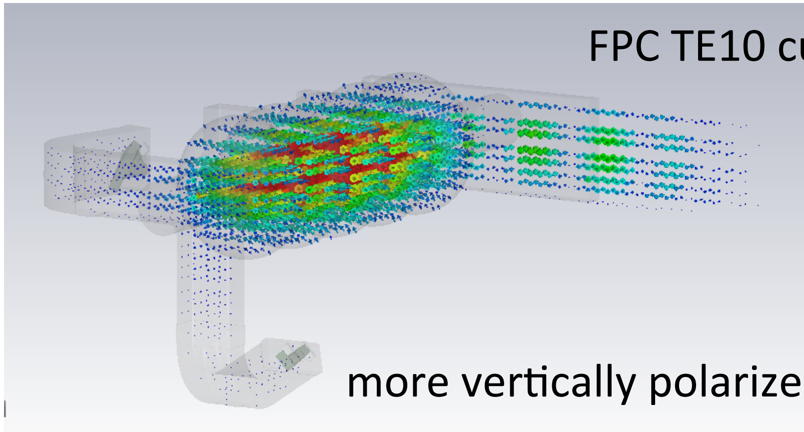
- Modes below HOM waveguide cutoff rely on evanescent field and FPC mode damping

TE111 HOMs below HOM Waveguide Cutoff

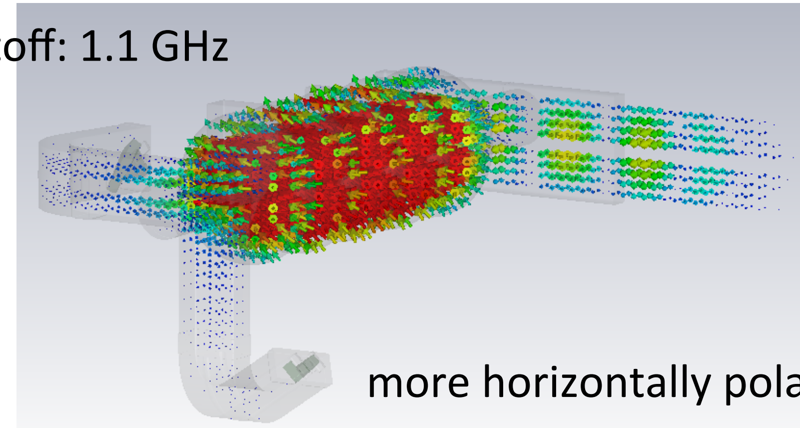
- 1^{st} TE_{111} mode pair (π/7): ~1725 MHz

scale similar throughout (electrical RF field)

FPC TE10 cutoff: 1.1 GHz

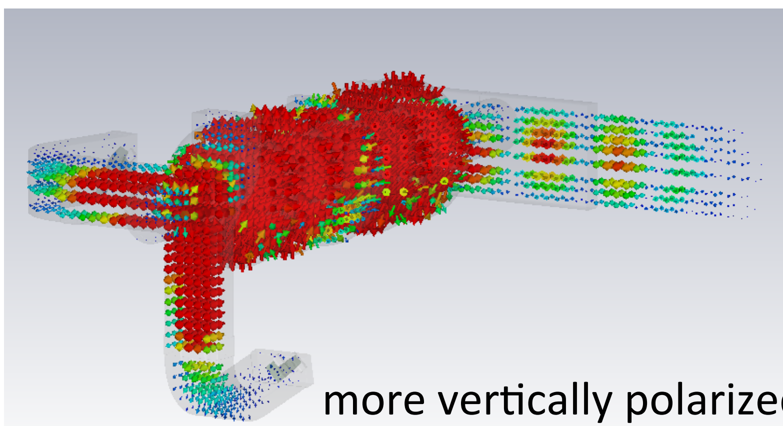


more vertically polarized

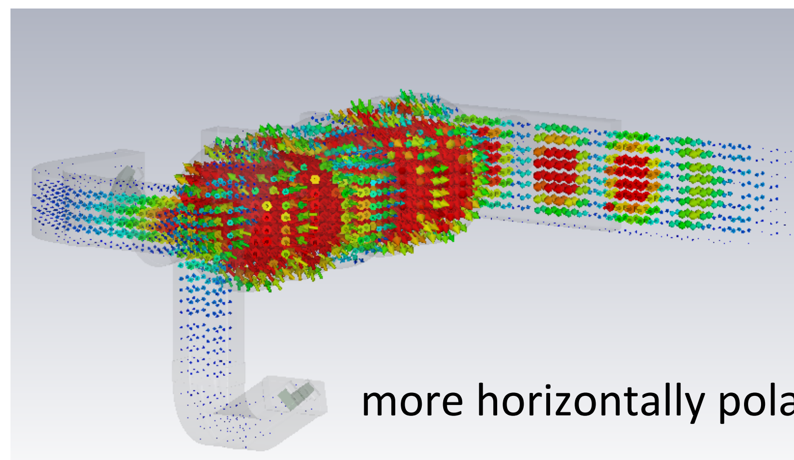


more horizontally polarized

- 2^{nd} TE_{111} mode pair (2π/7): ~1760 MHz



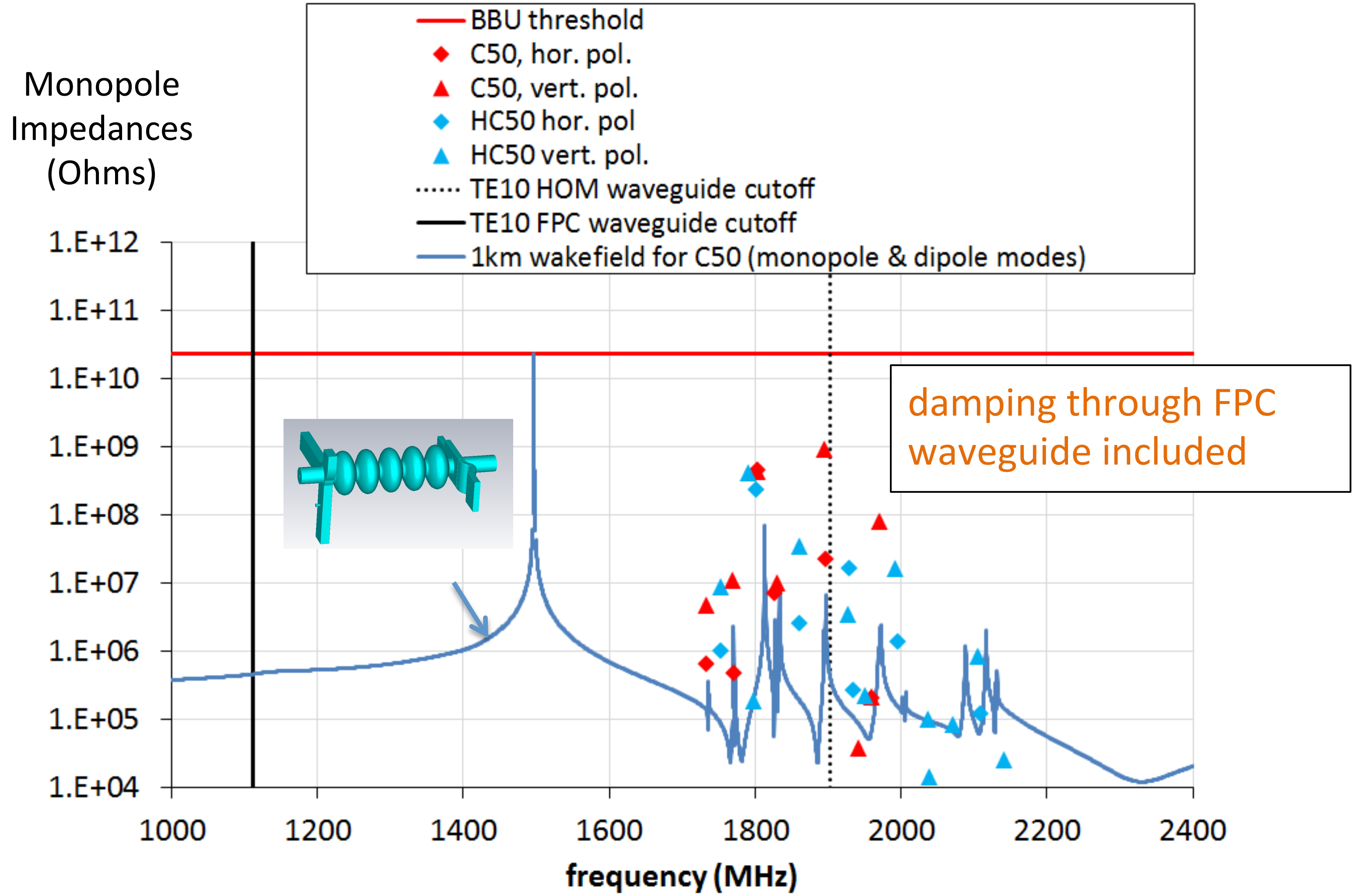
more vertically polarized



more horizontally polarized

HOM Damping (with FPC damping)

- Damping by FPC has impact on modes close to BBU threshold



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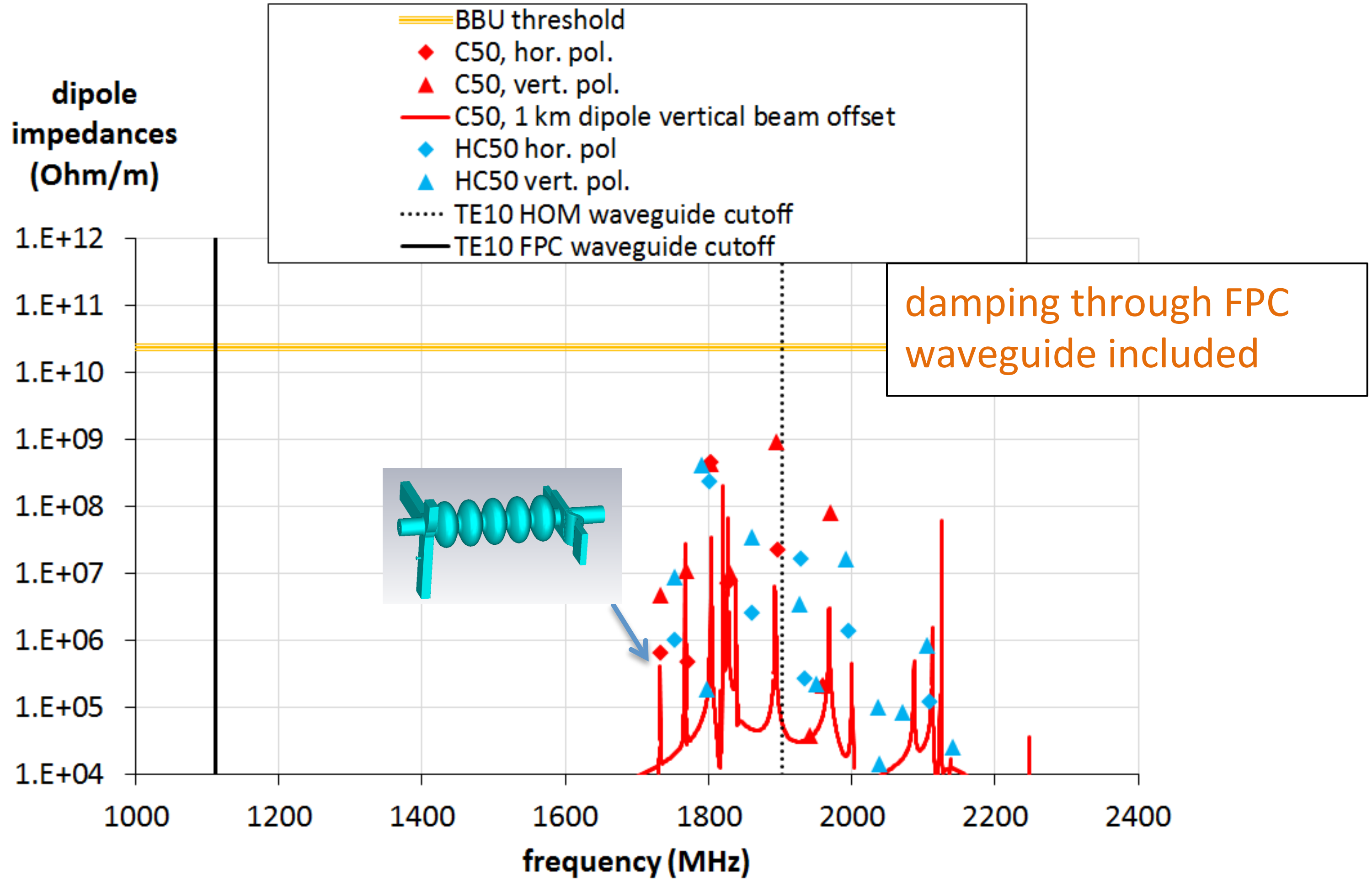
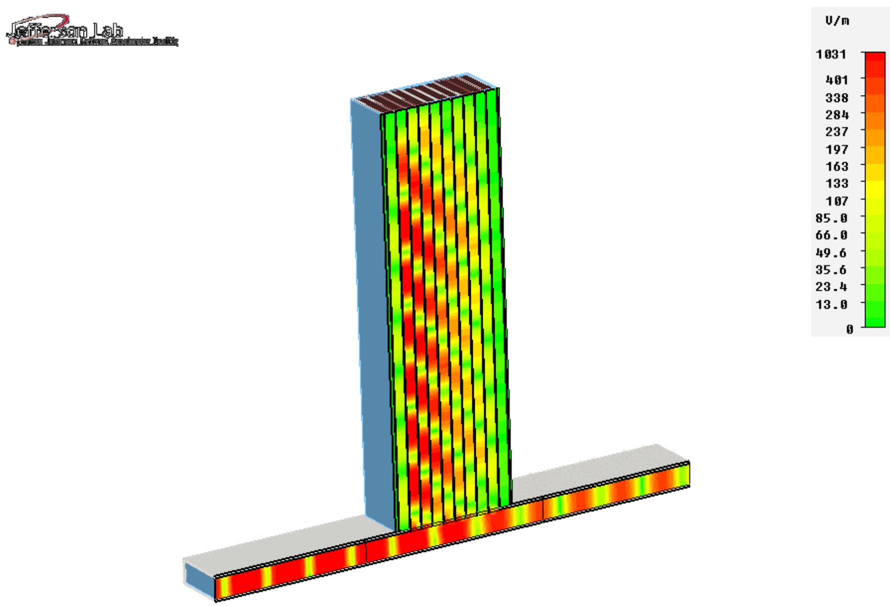
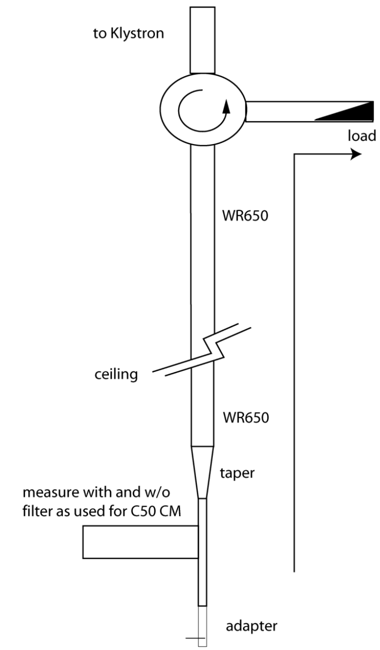


C50 external HOM filters

- This was one reason to utilize the CM-external CEBAF filters





Conclusions

Numerous options for improved cost-effectiveness

- Magic bullet (still looking…)
- Cell transplant
  - minimum perturbation
  - Best near term “bang for the buck”?
- New cavities
  - engineering required
  - Can fix other problems
- New cryomodule
  - more engineering required
  - May have synergy with MEIC
  - Possibly cost–effective long term

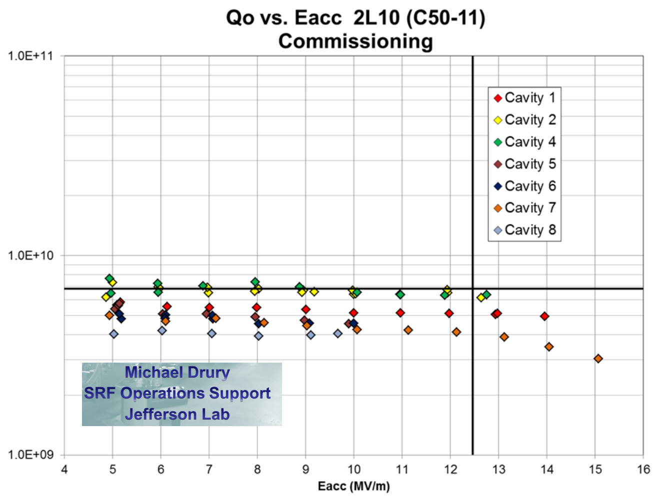
Proposal

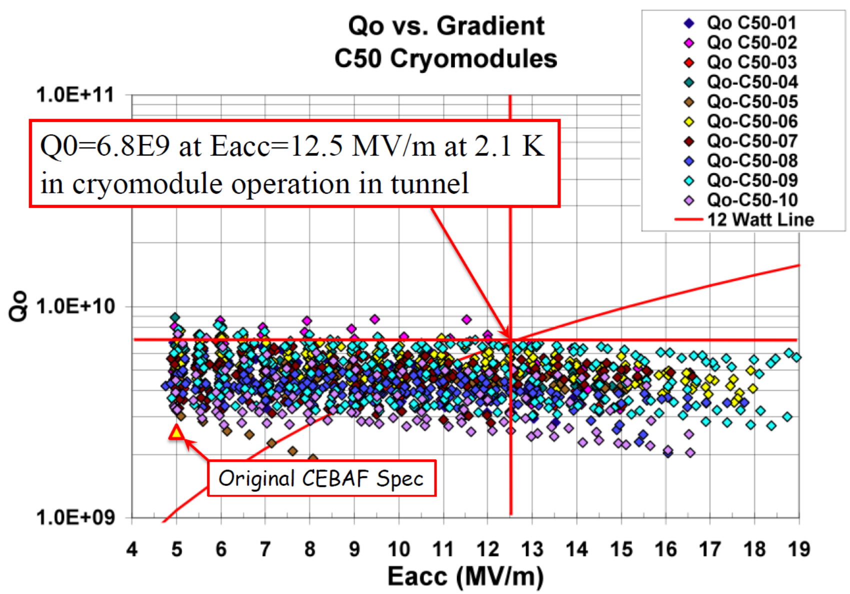
- Build two "HC50" cavities using in-stock ingot material and existing spare end groups
  - We have the dies
  - We have the material but needs slicing (~15k)
- Process and test in VTA
- If good insert into next available C50
- Cost ~50k, mostly shop, e-beam welding and chemistry/VTA

Back up

CEBAF SRF Workshop (April 2014)

- C20: met Q_0 = 2.4e9 at 5 MV/m at 2K → 45 W dynamic load per CM
- C50: Q_0 target 6.8e9 at 12.5 MV/m at 2.1 K →~100 W dynamic per CM (M. Drury, PAC07, WEPMS059)
- C50-11 Q0 Analysis (Rongli Geng): No cavity reached target Q_0 in CEBAF tunnel during commissioning, on average factor 2 lower Q_0
- Observation: Q_0 = 5e9 at 6 MV/m similar to 1992 commissioning, i.e. no improvement by refurbishment at 6 MV/m
- But Q_0 > 1e10 at 12.5 MV/m in VTA)



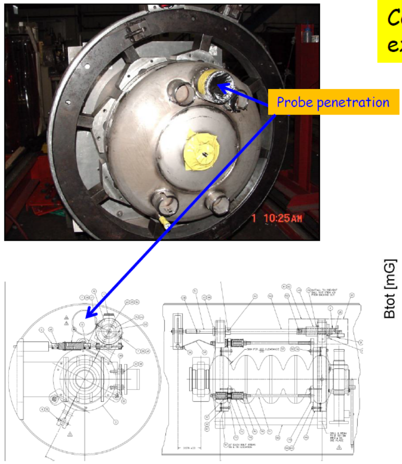


M. Drury et al., PAC2011, TUP108

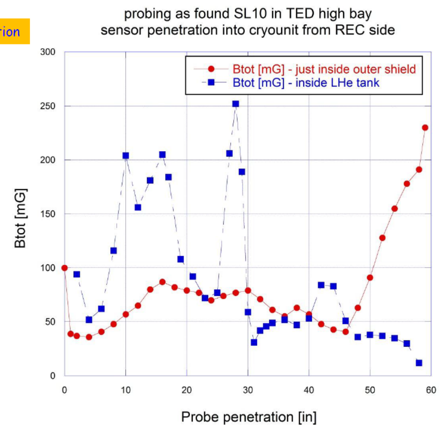
CEBAF SRF Workshop (April 2014)

- C50-11 Q0 Analysis (Rongli Geng)

Additional Probing in As-Found Condition

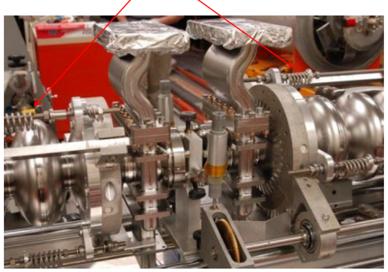


Components inside LHe tank generating excessive magnetic field further confirmed

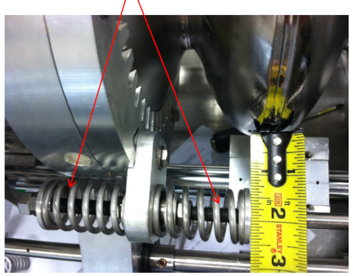


Discovery of Magnetized Strut Springs

High-μ and high remanent field springs from original module



New low-μ and low remanent field Springs acquired and implemented



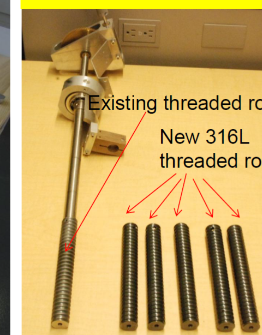
Mitigation of Magnetic Tuner Components

Threaded Rod being a Major Contributor

New 316L Threaded Rod has Significantly Lower Permeability

Tuner Assembly

For future C50 re-work Threaded rod should be replaced by new 316L threaded rod



Preliminary Conclusion

- Clear demonstration of magnetized components inside inner shield.
- Discovery of magnetized strut springs. Worst offending!
- New 316 SS springs implemented. 3 of 8 cavities preserved VTA Q0 at ~ 80% level.
- 4 of 8 cavities preserved VTA Q0 at ~ 50% level.
  - 3 cavities could be further improved by reducing ambient field.