Crab Cavity and Cryomodule Prototype Development for the Advanced Photon Source

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for the team of

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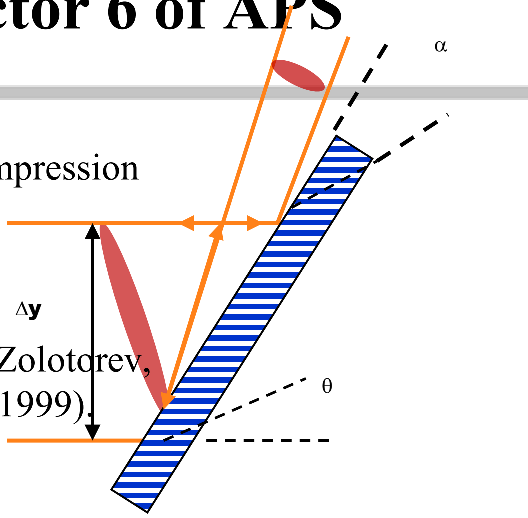
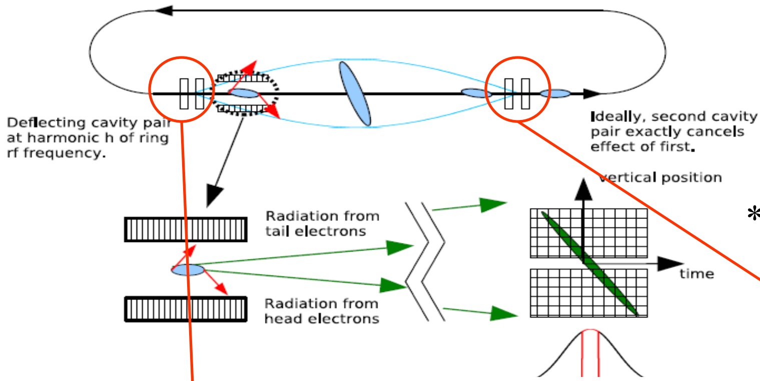
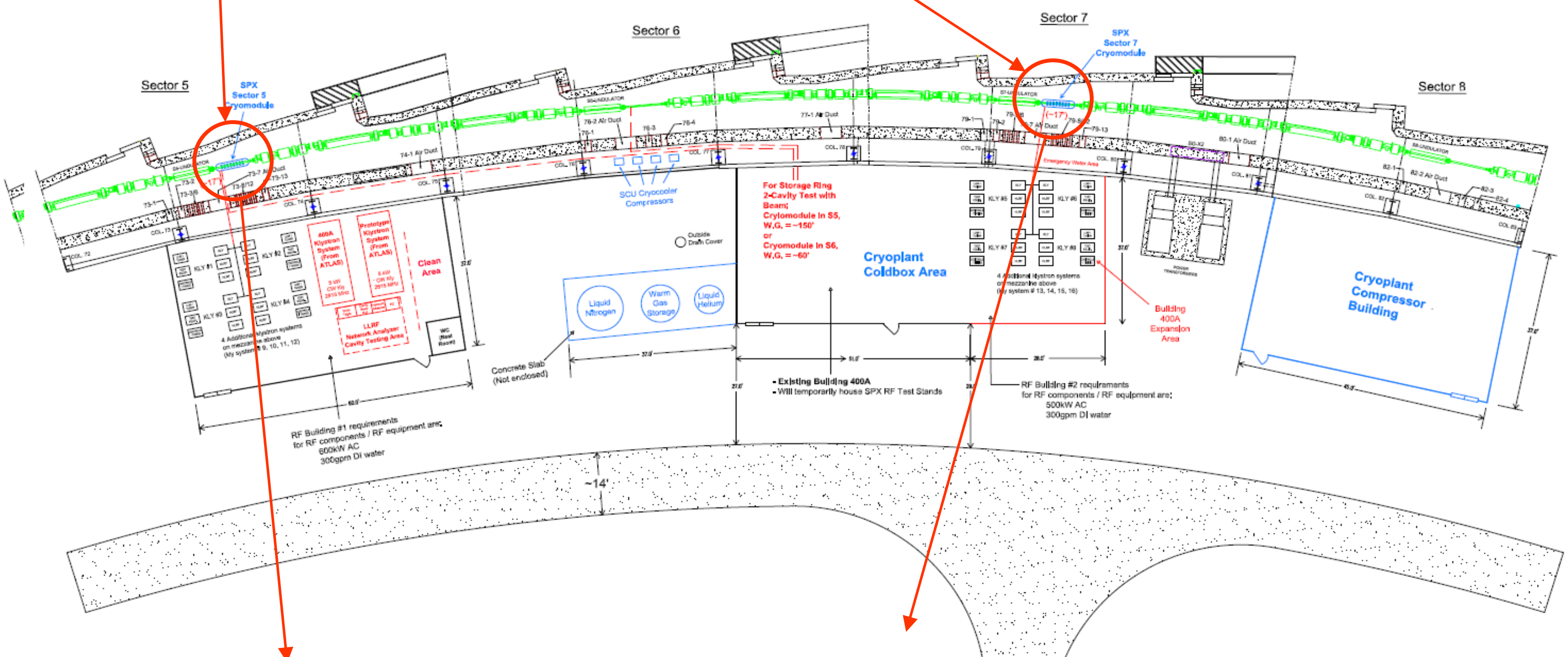
(WEOBS05, about SPX project status) (THP212, about cavity and high power RF load designs)

Short X-Ray Pulse Generation Scheme* at Sector 6 of APS



*A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, NIM A 425, 385, (1999).



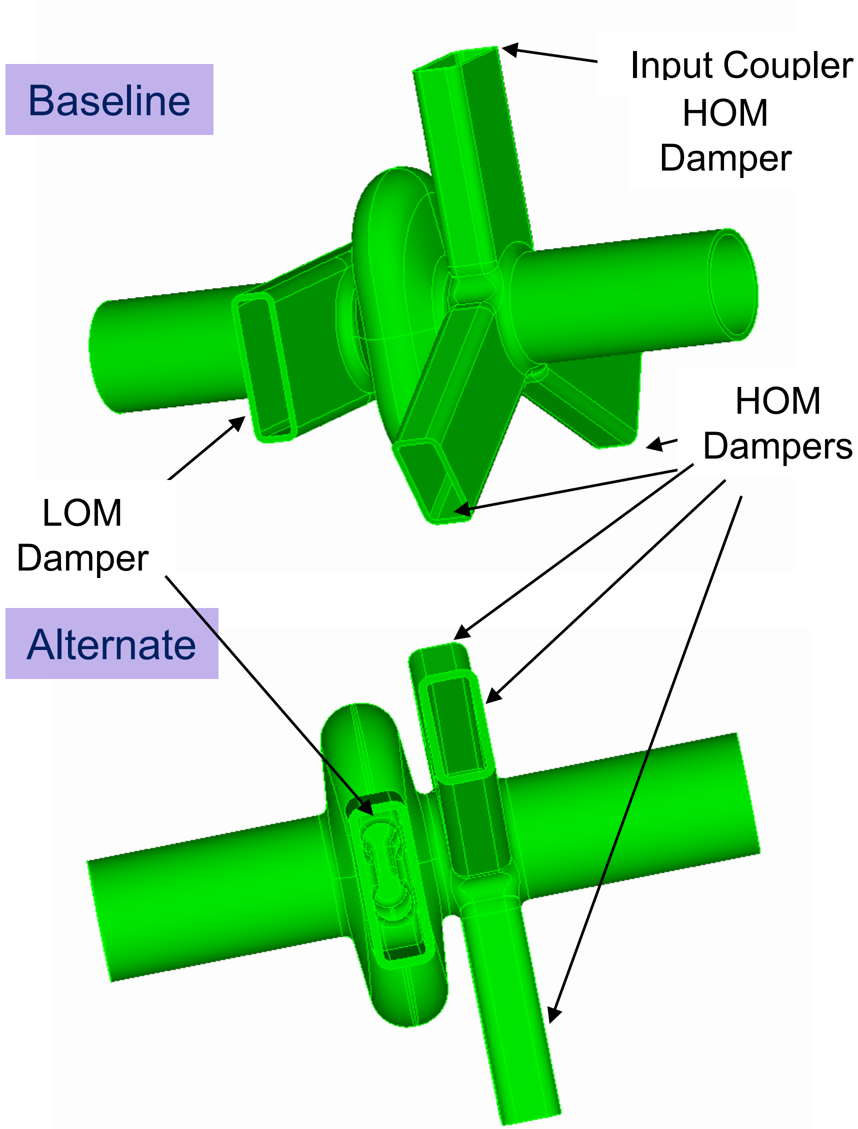


Sector 5, 2MV, 4 crab cavities

Sector 7, 2MV, 4 crab cavities

Cavity Design Choices

Baseline verses Alternate cavity, single-cell verses multi-cell

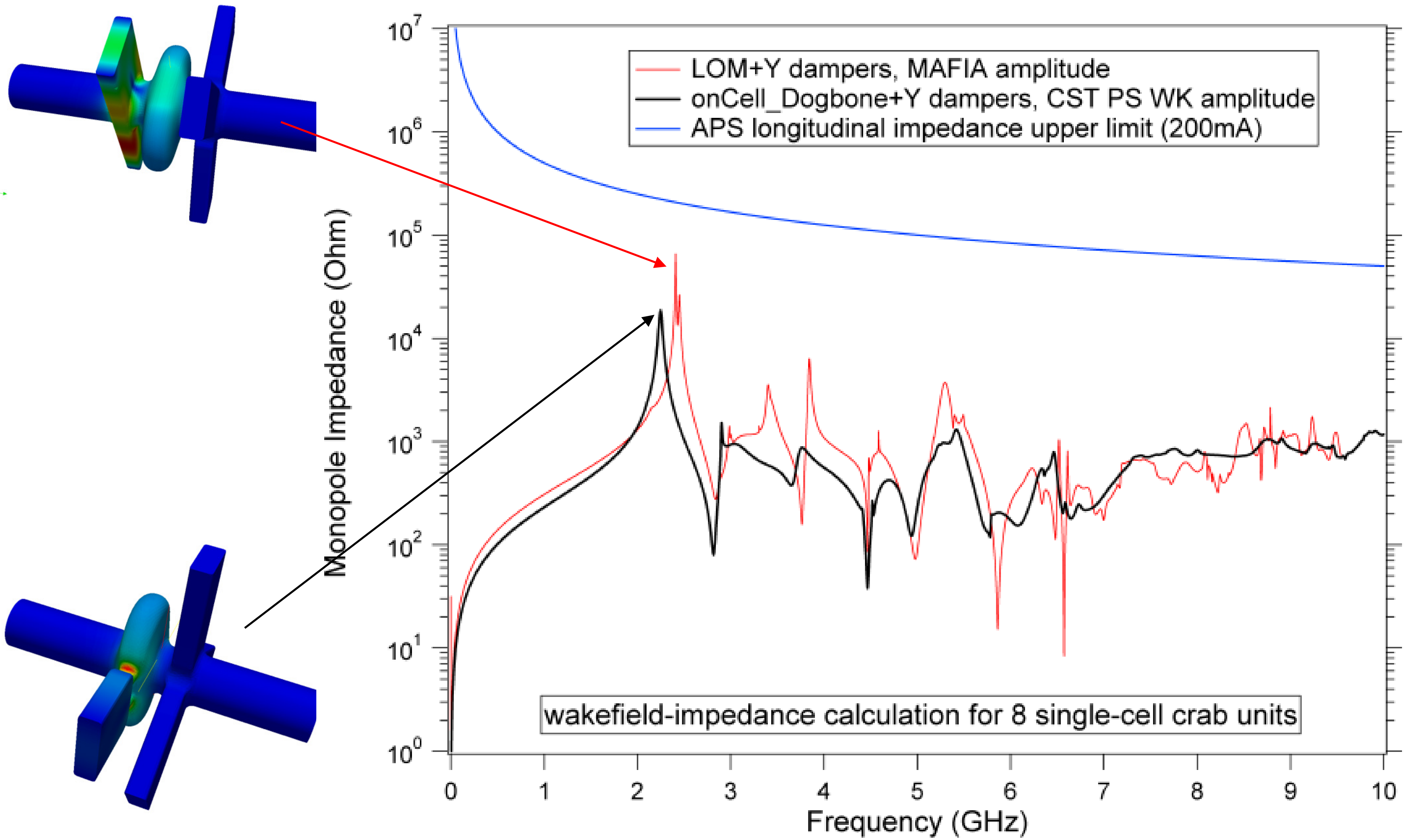


Parameter	Value	Unit
Basline Cavity		
Frequency	2.815488	GHz
Cavity Type	elliptical	
Fundamental Mode	TM110-y-0	vertical kick
Rt/Q including TTF	35.8	Ω
Crabbing Voltage Vt at Bs=100mT	0.5	MV
Peak Surface Bs Field/Vt	195.6	mT/MV
Peak Surface Es Field/Vt	82	1/m
Geometry Factor	227.5	Ω
Material Thickness	4	mm Nb
Cavity Iris Radius	25	mm
Cavity Active Gap Distance	53.24	mm
Operational Q0	>1.0E+09	at 2K
Cell Number	1	
HOM + FPC Couplers	3	"Y" WGs
LOM Coupler	1	WG+stub
TM110-x Mode	3.56	GHz

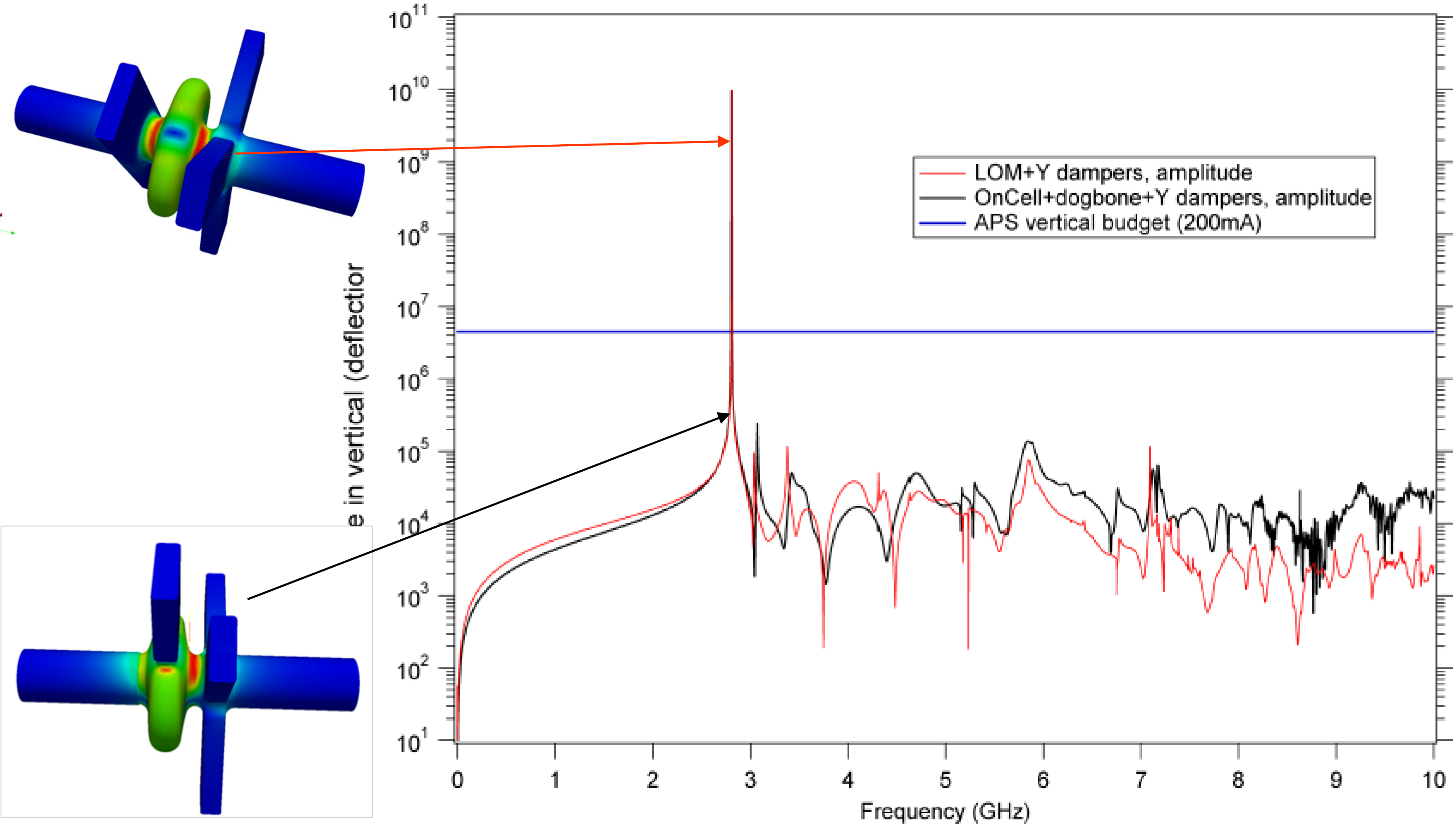
Alternate Cavity		
Rt/Q including TTF	37.1	Ω
Crabbing Voltage Vt at Bs=100mT	0.5	MV
Peak Surface Bs Field/Vt	200.8	mT/MV
Peak Surface Es Field/Vt	81.5	1/m
Geometry Factor	227.8	Ω
Material Thickness	4	mm Nb
LOM Coupler	1	On-cell

All other parameters are same as Baseline

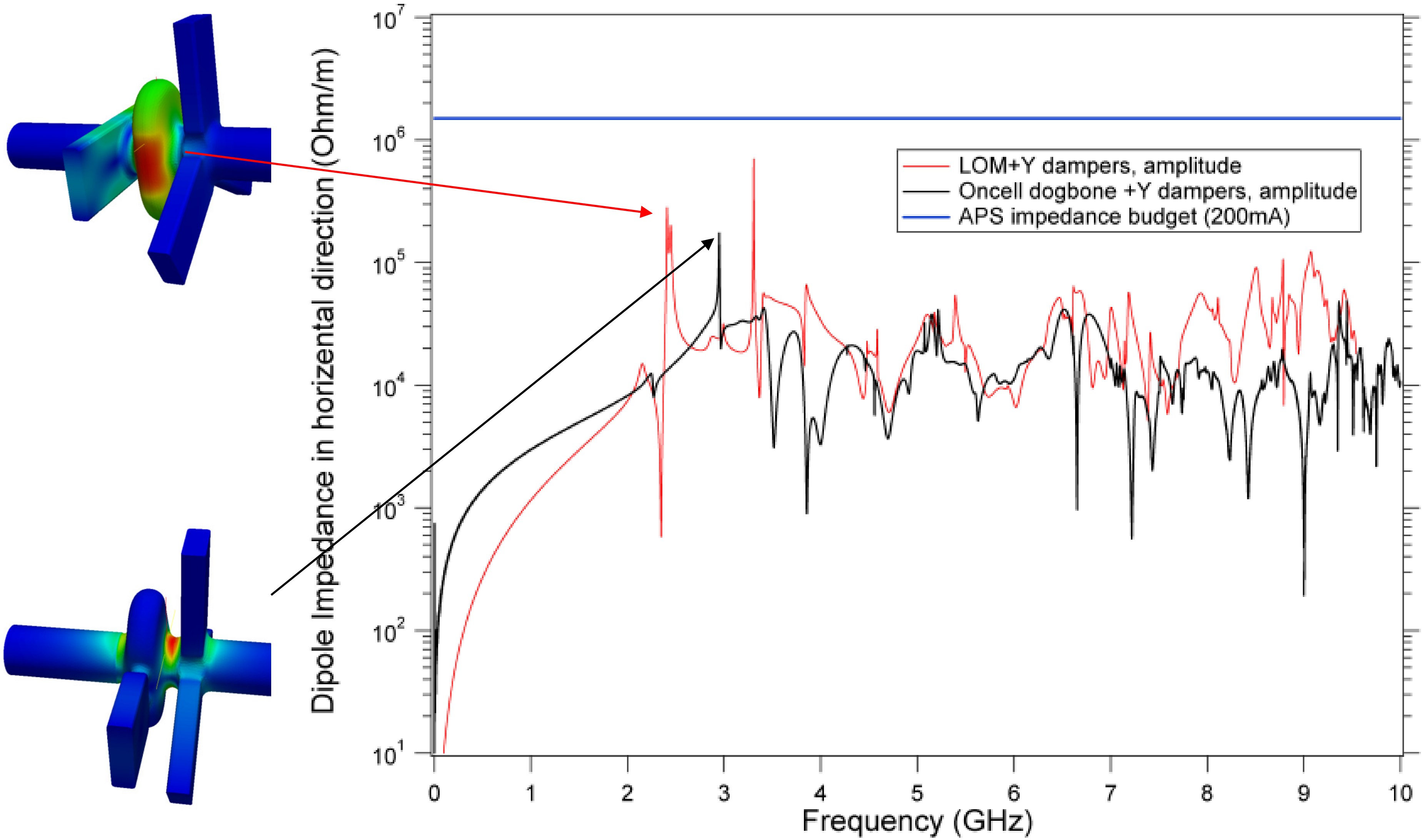
Longitudinal Monopole Impedances between Baseline and Alternate Designs



Vertical Dipole Impedances between Baseline and Alternate Designs

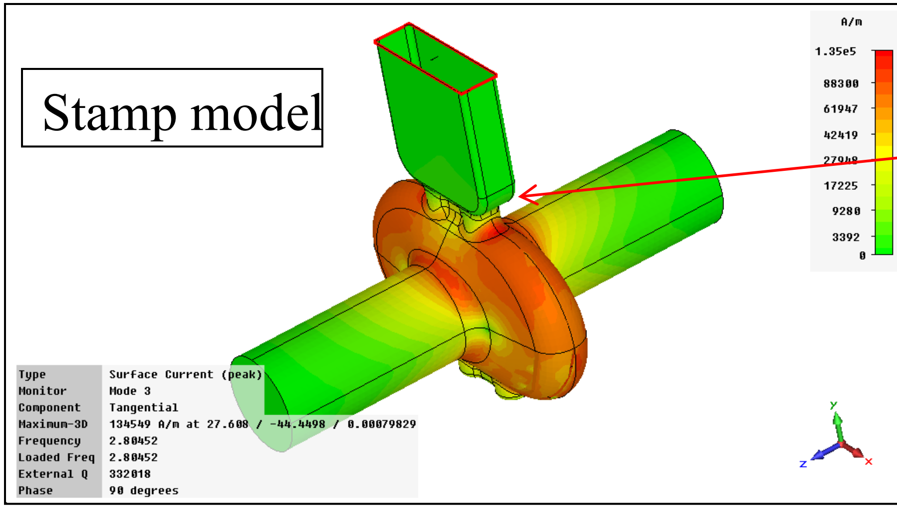


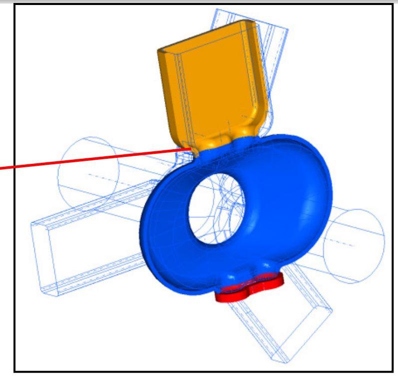
Horizontal Dipole Impedances between Baseline and Alternate Designs

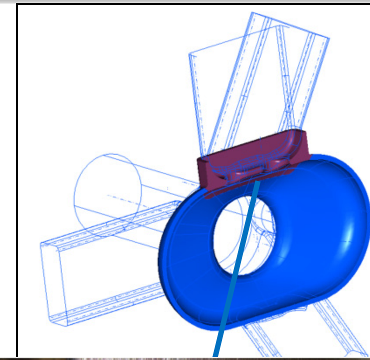


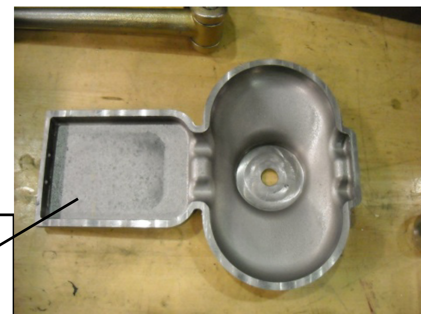
Cavity Fabrications, Processes and Test Results

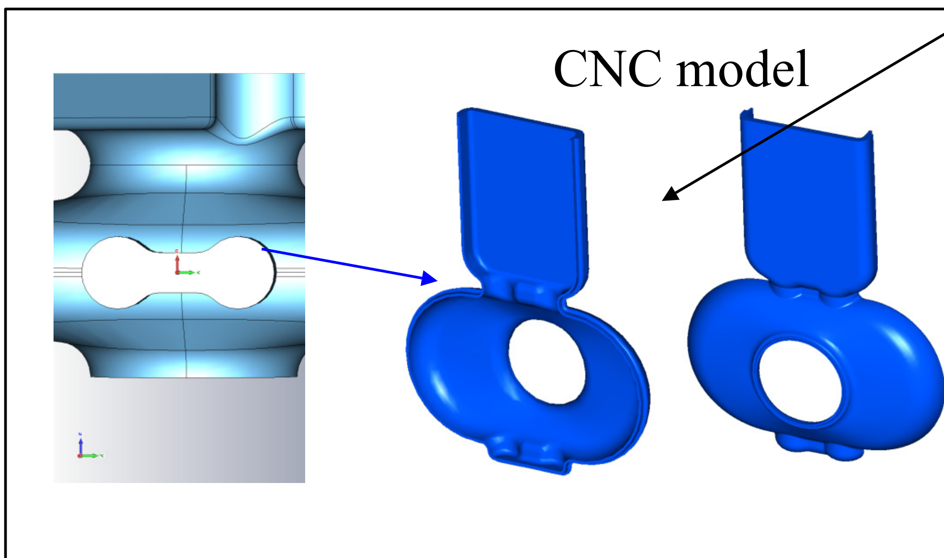
On-cell Damper Dog Bone Coupler Design and Fabrication

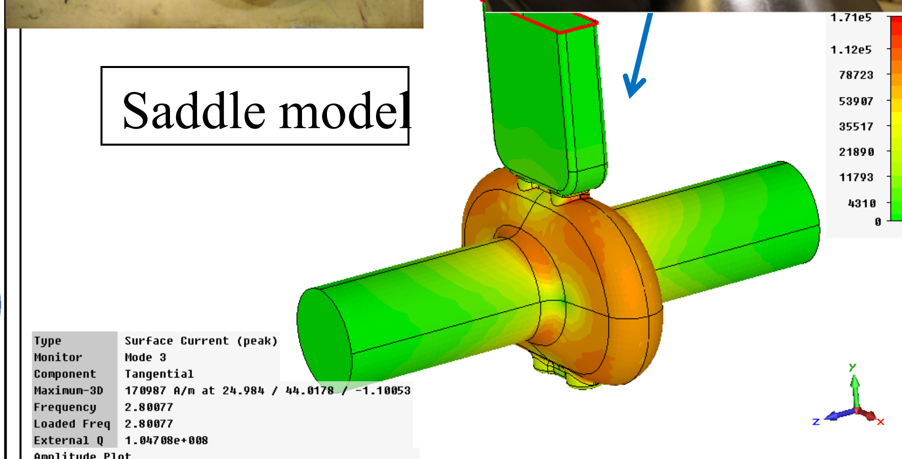




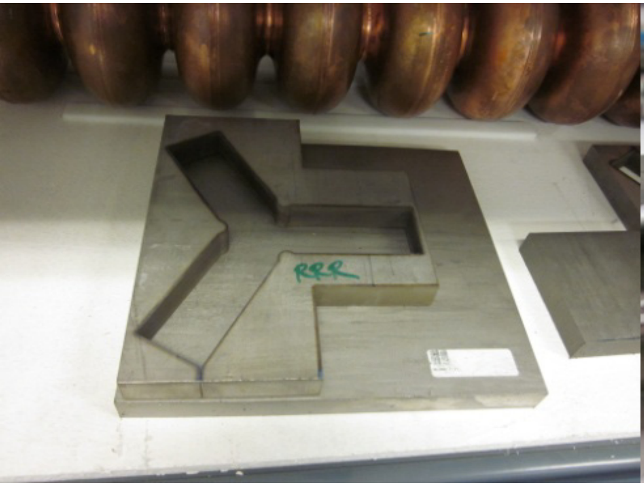






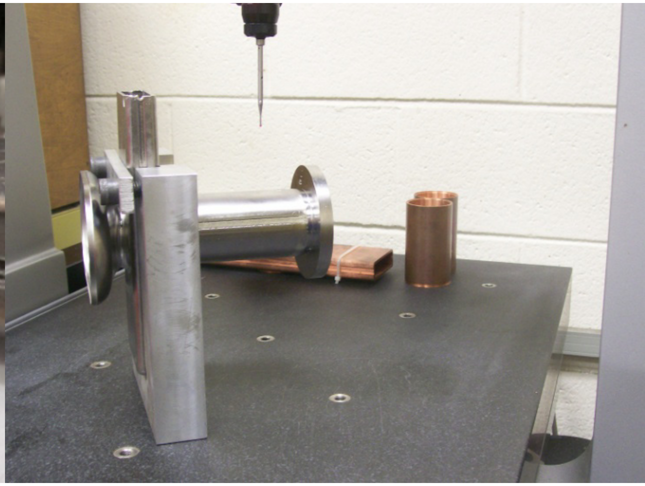


Baseline CCB1 Cavity Fabrication in 2010



EDM cut Y Nb fine grain RRR>250 plate

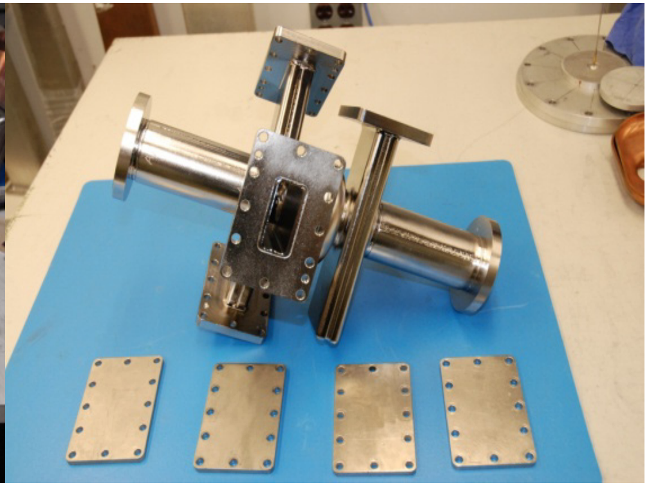
CNC machine two halves and EBW



Survey on LOM WG pre-alignment

Finished Y waveguide group

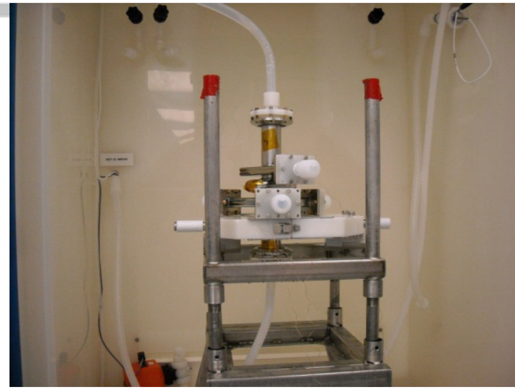
Finished two half groups before final equator EBW

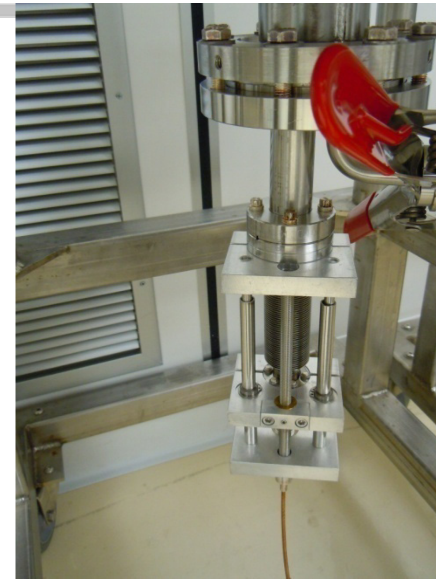
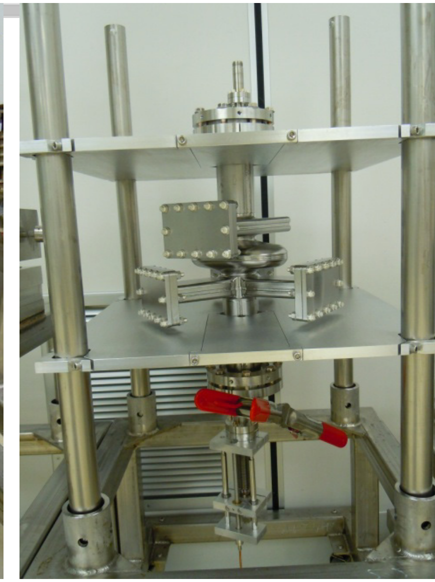
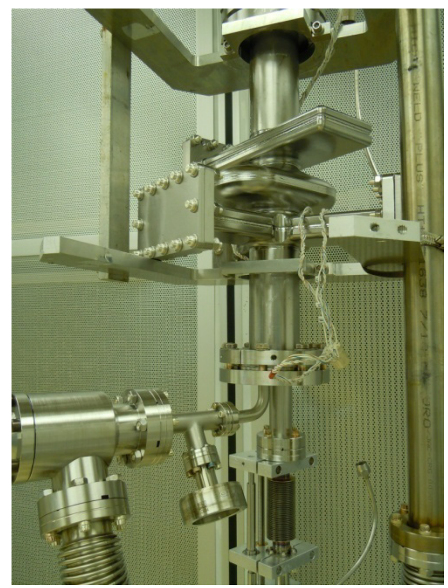
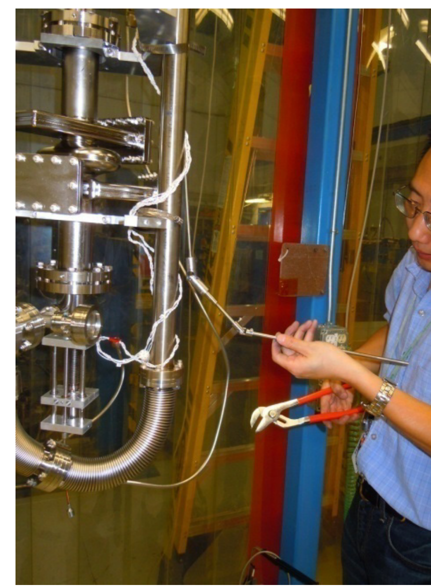


CCB1 cavity with Nb blank offs

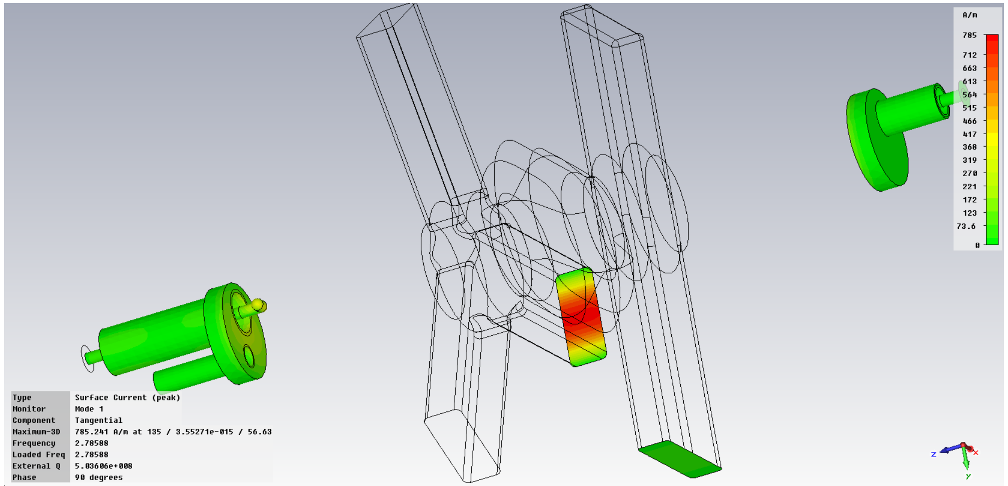
Surface Treatment and Clean Room Assembly of Baseline CCB1 Cavity

- 90+10+80um Buffer Chemistry Polish (BCP) with ΔT <10° C, etching rate=1um/min to allow equal amounts of material removal from iris and equator. Inlet to outlet acid ΔT<1.5° C
- 600°C bake for 10hrs
- Final 5um BCP on bench
- Ultrasonic degreasing
- High Pressure Rinsed (HPR) in R&D system for ~1hr
- Dried in a class-10 clean area overnight
- Assembled with indium seals on RRR~ 80 Nb blank- off flanges in class-10 clean area
- Attached to test stand, leak checked and evacuated to <5e-8 mBar in class-100 room
- Set up variable coupling in vertical staging area



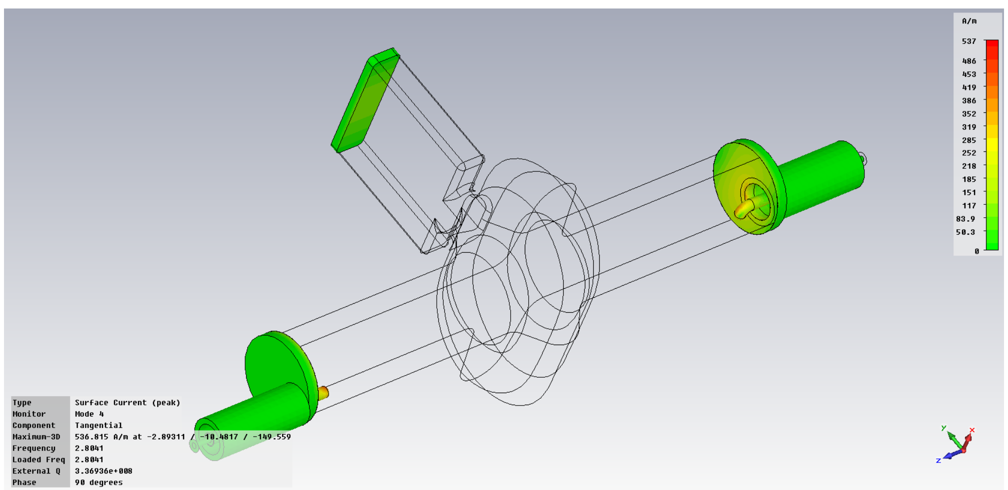






Coupler Flanges (SST 316) and Antenna (Copper) Loss Calculations



Q-Factor ASCII Export
Project "D:\ANLcrab_MWS\crab6\Model\3D\Model.mod"
H-Field "Mode 1"
Frequency/Hz 2.78588436e+009
Energy/J 9.99999999e-001
Input Qext 5.03606000e+008

Layer	Solid	Conductivity	Mue	Loss/W(peak)	Q
Crab Cavity Body		2.2017e+018	1.0000e+000	1.0990e+001	3.1853e+009
Stainless Steel 316		1.8600e+006	1.0000e+000	1.0302e+001	3.3984e+009
	default:Incoupler_tube			2.5483e+000	1.3738e+010
	default:Pumpout_tube			3.0623e-001	1.1432e+011
	default:bpflange_in			2.9477e+000	1.1877e+010
	default:bpflange_tube			9.1975e-001	3.8063e+010
	default:bpflange_out			3.5796e+000	9.7799e+009
Copper (hard-drawn)		3.0000e+008	.0000e+000	2.8334e-001	1.2356e+011
	default:ant_in_Ltip			2.7529e-001	1.2717e+011
	default:ant_out_Ltip			8.0413e-003	4.3536e+012
Sum				2.1575e+001	1.6226e+009



Q-Factor ASCII Export
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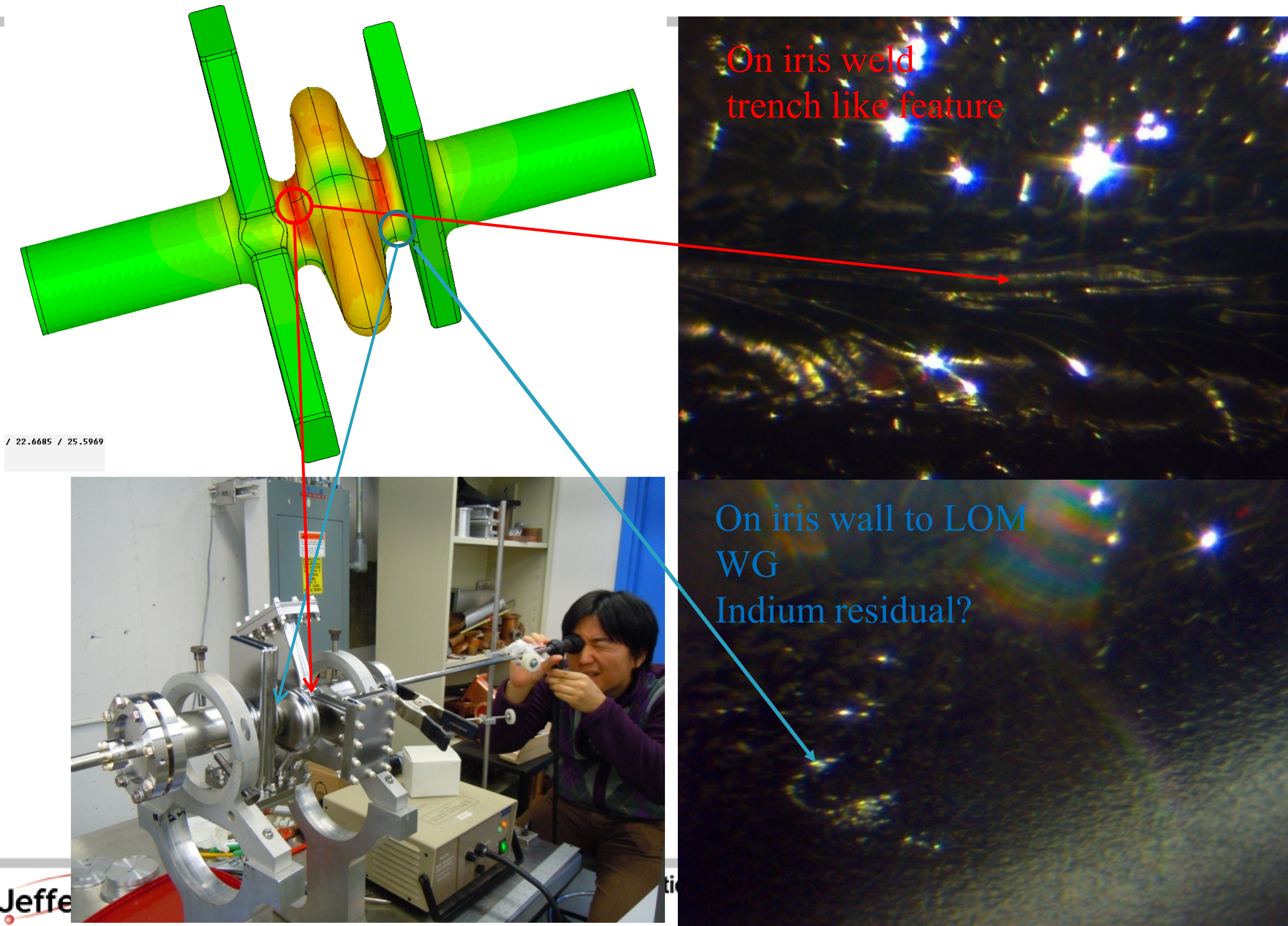
H-Field "Mode 4"
Frequency/Hz 2.80409876e+009
Energy/J 1.00000000e+000
Input Qext 3.36936000e+008

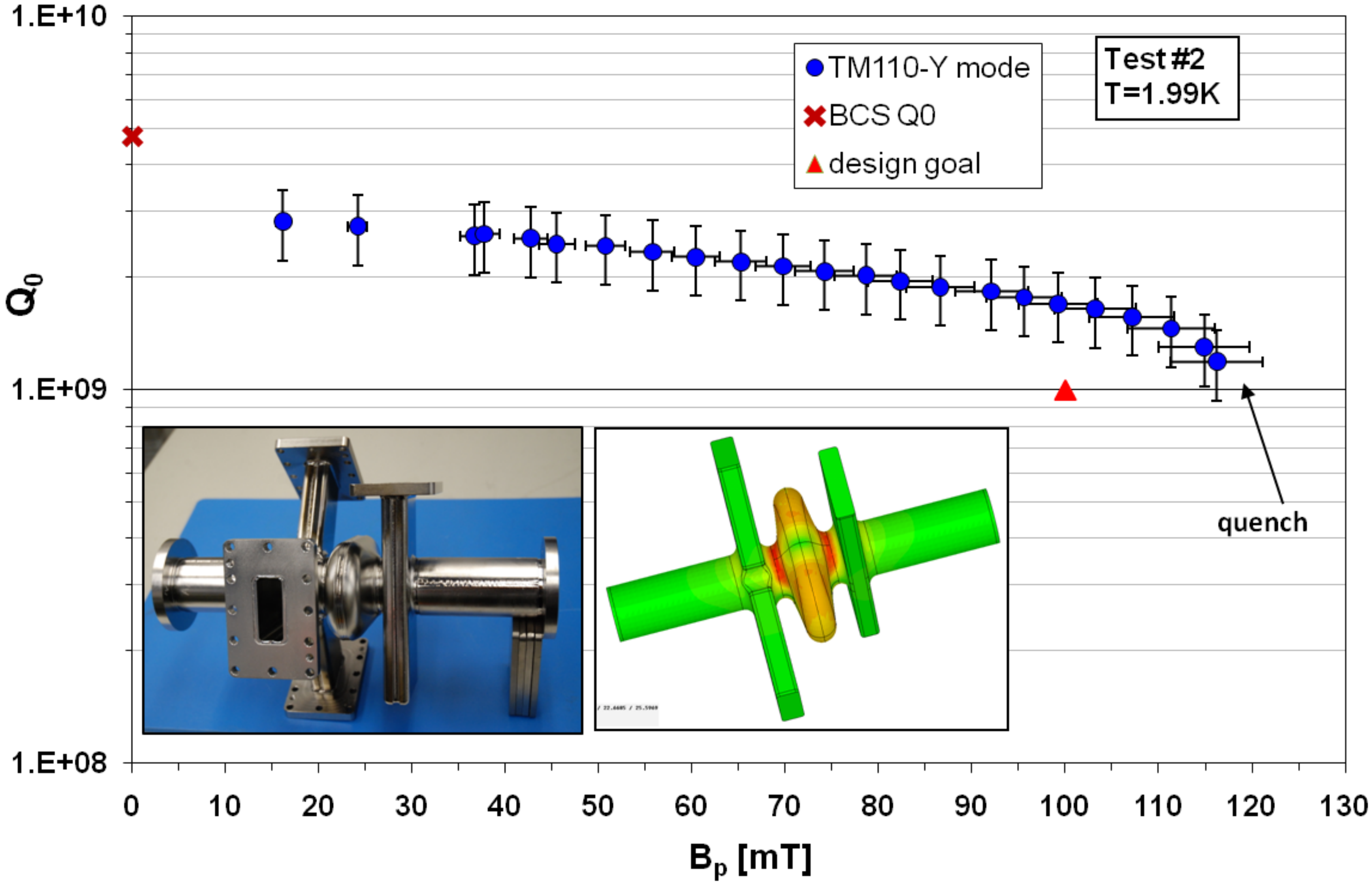
Layer	Solid	Conductivity	Mue	Loss/W(peak)	Q
RRR Nb Cavity Body		2.2017e+018	1.0000e+000	1.0368e+001	3.3986e+009
Stainless Steel 316		1.8600e+006	1.0000e+000	9.3801e+000	3.7566e+009
	default:WG blankoff			5.4661e-001	6.4465e+010
	default:bpflange_in			2.8038e+000	1.2568e+010
	default:bptube_in			2.1190e+000	1.6630e+010
	default:bpflange_out			3.8968e+000	9.0426e+009
	default:bptube_out			1.3924e-002	2.5307e+012
Copper		3.0000e+008	1.0000e+000	3.3543e-001	1.0505e+011
	default:Ianten			2.2133e-001	1.5921e+011
	default:outputant			1.1410e-001	3.0883e+011
Sum				2.0084e+001	1.7545e+009

Cavity Surface Inspection by Bore Scope on Dec 07, 2010

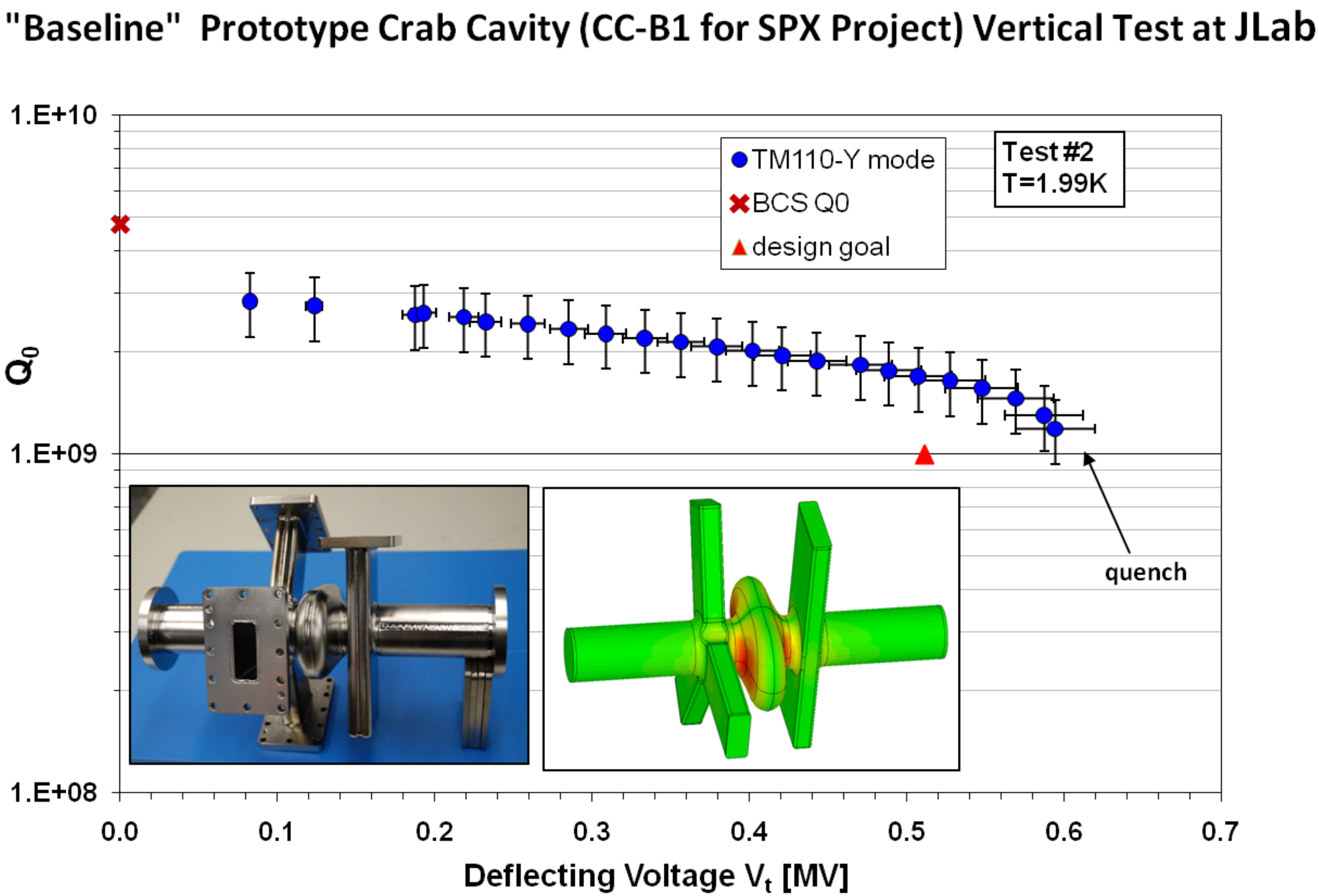


The Baseline Cavity CCB1was Qualified in the 2nd RF Test

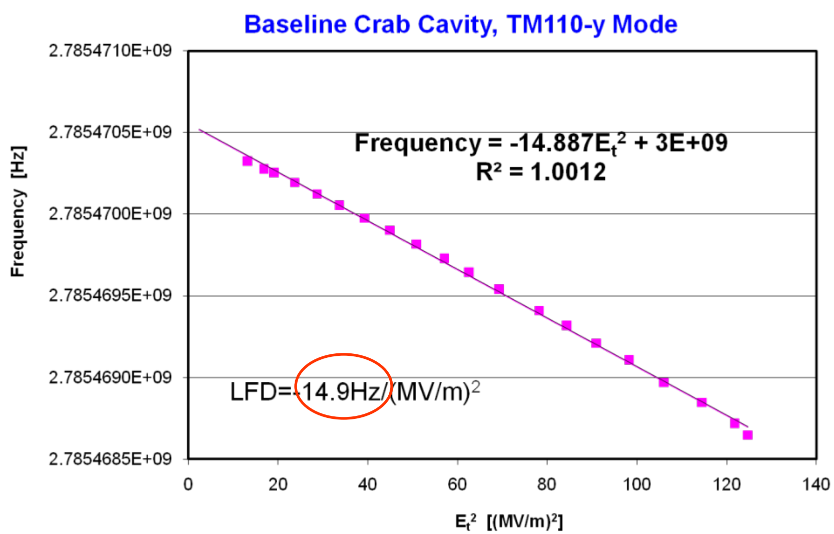
"Baseline" Prototype Crab Cavity (CC-B1 for SPX Project) Vertical Test at JLab



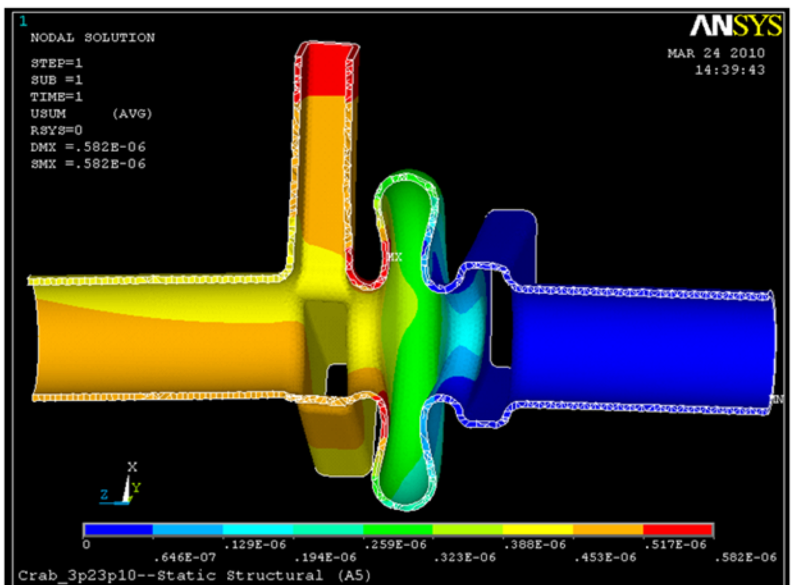
The Baseline Cavity CCB1was Qualified in the 2nd RF Test

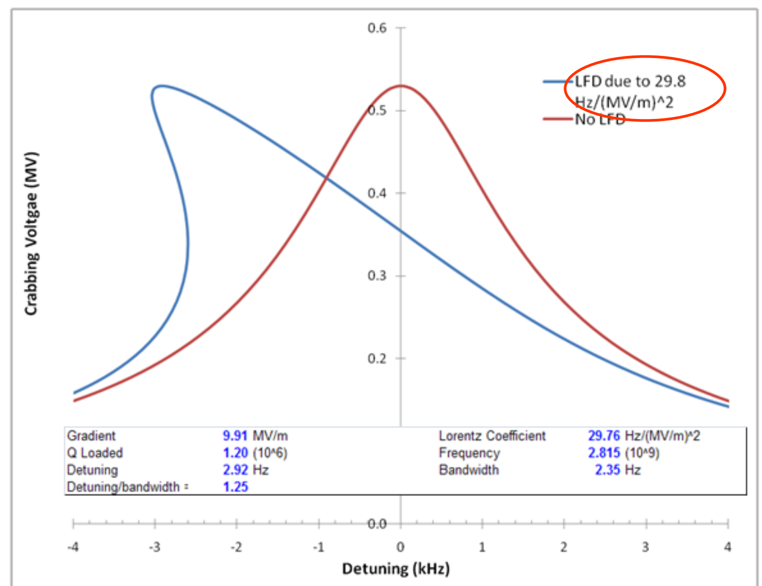


Lorentz Force Detuning Measurement versus Simulation



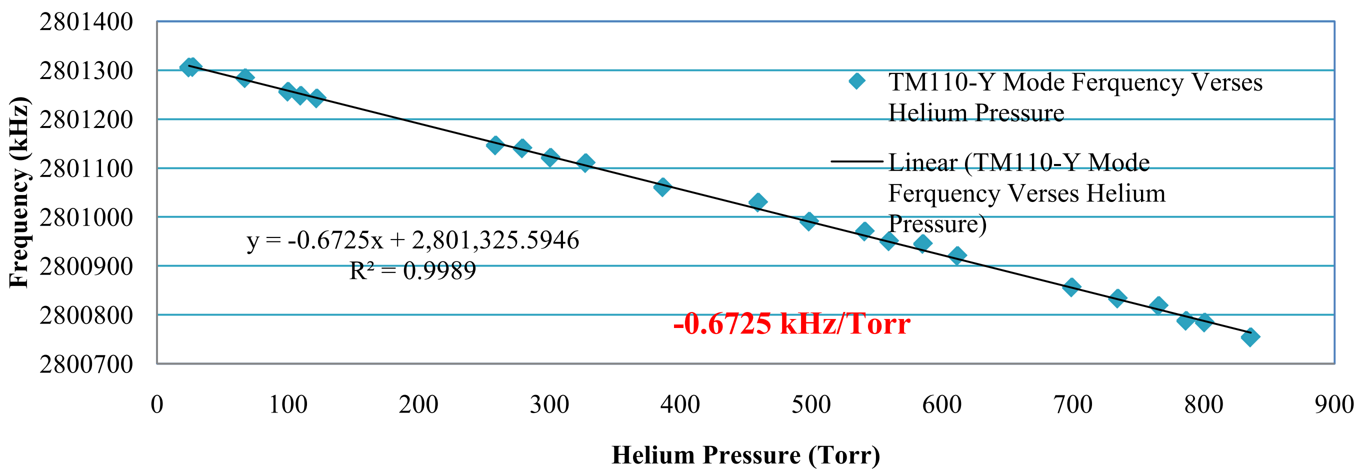
- Simulation was done by Geoff Waldschmidt with ANSYS in 3mm uniform niobium thickness and in free state
- The cavity in experiment was also in free hanging constraint
- Measured LFD is abut half of ANSYS simulation prediction





Helium Pressure Sensitivity of On-cell Prototype Crab Cavity

TM110-Y Mode Frequency verses Helium Pressure



Cavity is in free hanging constraint in the vertical test

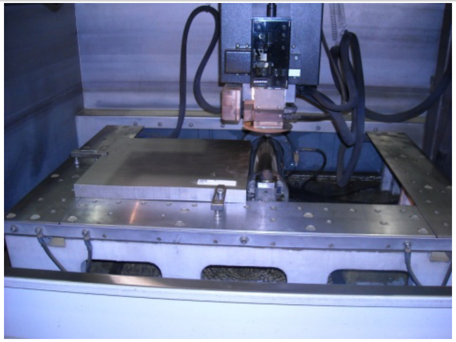
Single cell models	Tuning Boundary Condition*	Tuning sensitivity, Hz/lbf	Iris boundary condition during pressurizing**	Pressure sensitivity, Hz/torr
2.8 mm wall, no weld preps @ irises	free-free	6,649.42	Fixed-Fixed	38.63
2.8 mm wall, with weld preps @ irises	fixed-fixed	1,941.66	Fixed-Fixed	39.6
			Free-free	**665.87**
4 mm wall, no weld preps @ irises	free-free	2,237.09	Fixed-Fixed	6.64
	fixed-fixed	1,638.26		
4 mm wall, with weld preps @ irises	free-free	1,428.44	Fixed-Fixed	8.97
	fixed-fixed	1,323.89		

* free-free means irises are not restrained and equal pressures are applied at irises to extend the cell. Fixed-fixed means that irises are constrained from radial deformation and the same tuning distance is applied at irises.

** Fixed-fixed means irises are completely constrained. This is an approximation of cavity installed in CM. Free-free means no restraints at irises. This simulates VTA test of a cavity in free-hanging condition.

Experiment result agrees with Gary Chen's ANSYS simulation on the single-cell crab cavity

Fabrication of Alternate CC-A3 Cavity by CNC Machining



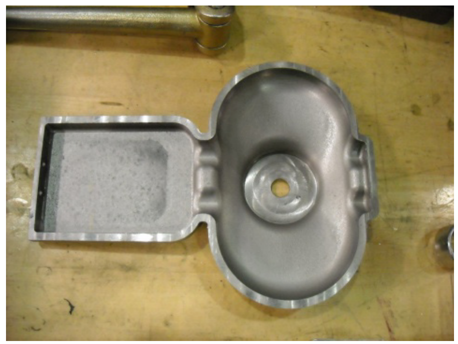
Cut fixture plate

machined fixture base

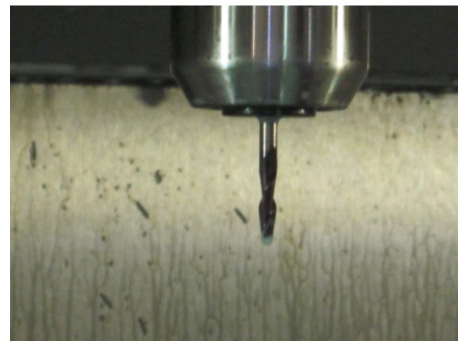
RRR>250 large grain Nb ingor

EDM wire cut Nb template

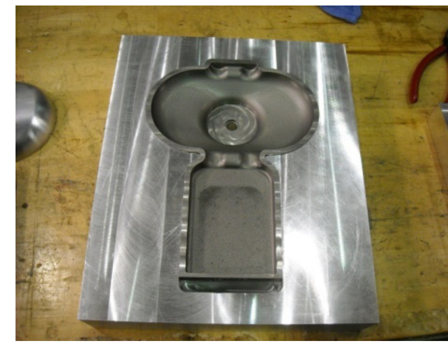
Machine outside surface



Machine inside surface with 30um unfinished



Milling tool head for last inner finish



Machine inner surface on the base

Finished first half with 4mm wall thickness

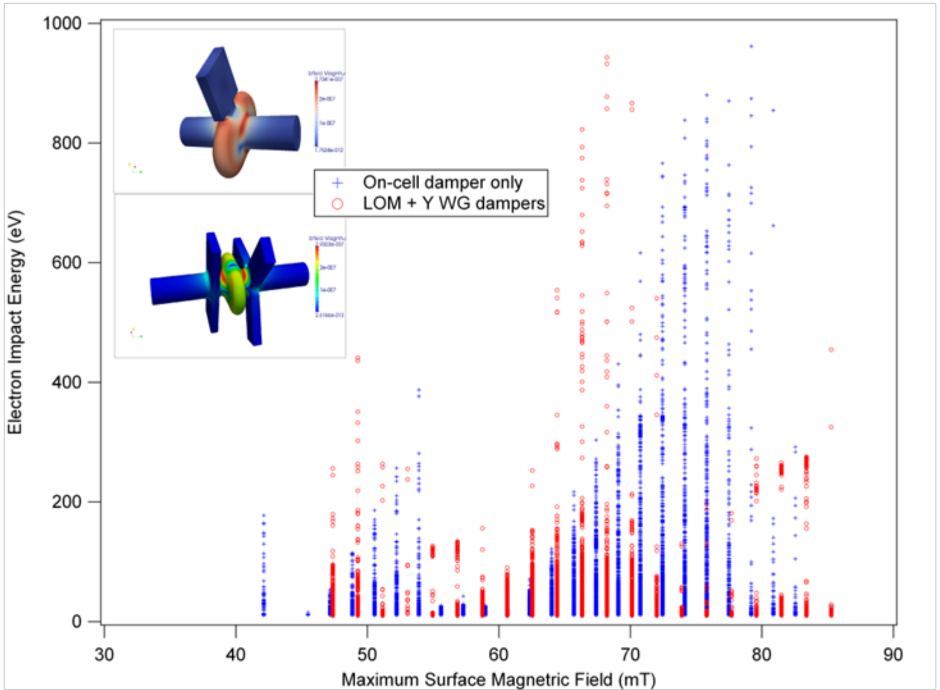
Match to other Al model half

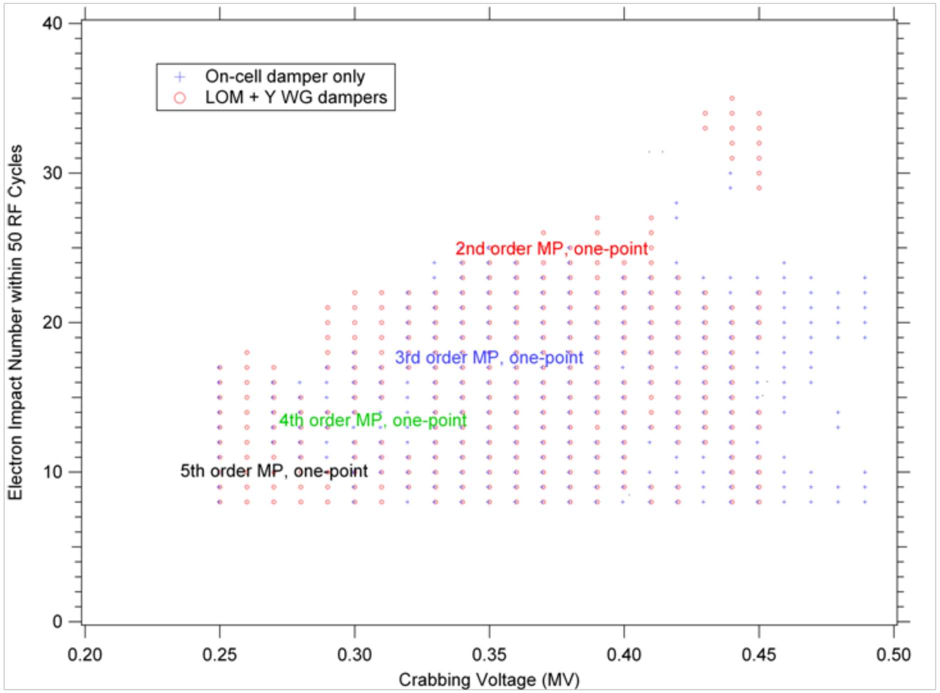
Outside finish of first half

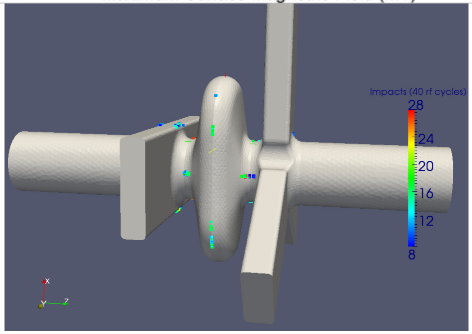
EDM wire cut Nb template for Y WG

Multipactoring simulation and experiment confirmation

Simulations using SLAC ACD's Omega3P/Track3P by Geoff Waldschmidt







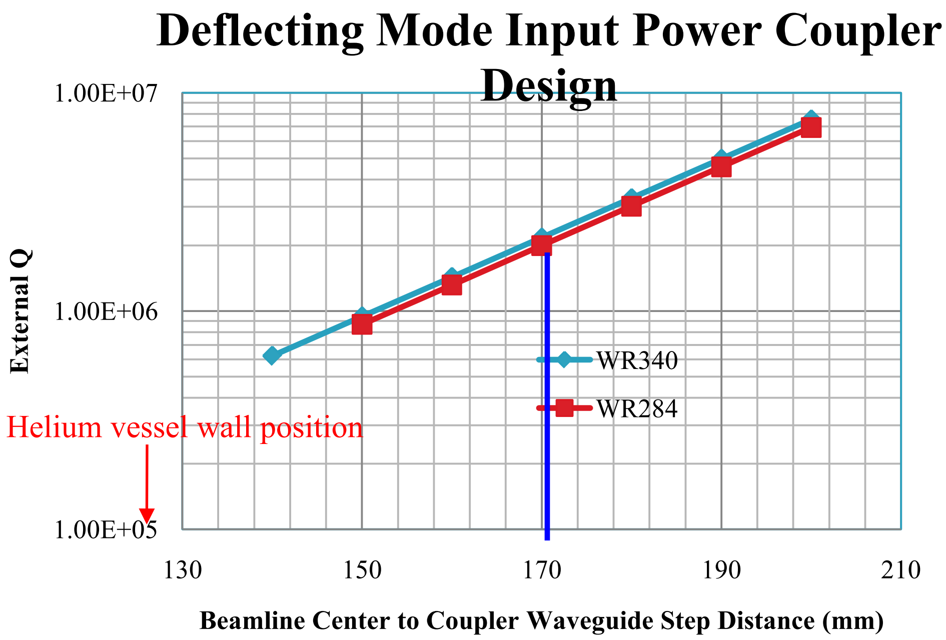
Locations of multipactors on based line cavity

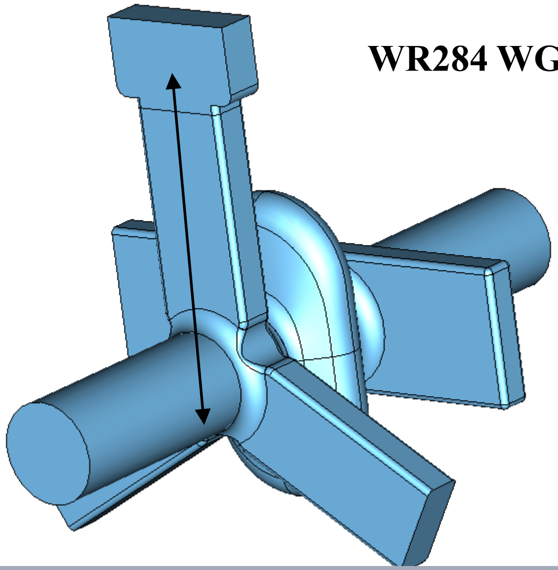
Cryomodule Structure Related Conceptual Designs

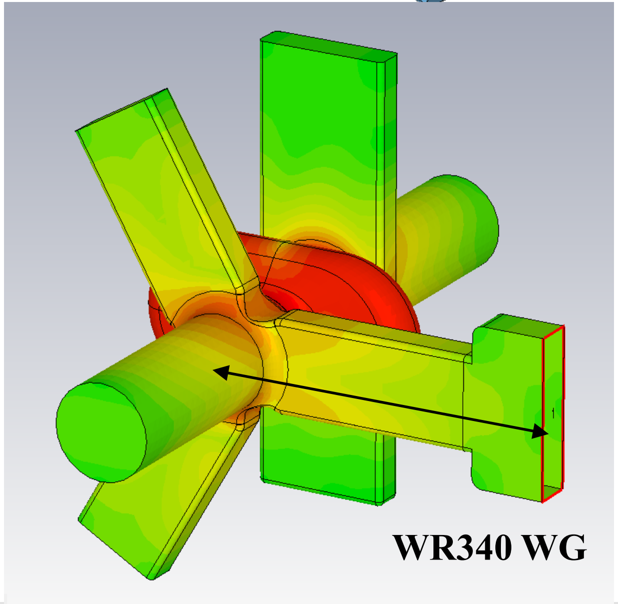
Cryomodule Specification Update

Cryomodule	Value	Unit
Lorentz Force Detune (cal. max. for Et)	<30	$Hz/(MV/m)^2$
Tuner Coarse Range, +/-	200	kHz
Tuner Fine Range, +/-	25	kHz
Tuner Fine Resolution	<4	Hz, with pieco
Helium pressure sensitivity	<5	Hz/Torr
Operational Crabbing/decrabing Voltage	2	MV
Module Number	2	
Cavity Number per module	4	
Qext, TM110-y-0	2.0E+06	
Klystron Power per Cavity	10	kW
Microphonic Amp. Limit +/- 6σ	100	Hz
Cavity Stiffener	may need	depends on tuner
Cavity to Cavity Center to Center Distance	>300	mm
Cavity to Cavity Misalignment Offsets, +/-	<100	µm
50K Static Heat Load (FPCs+Shield)	27+180	W
50K Dynamic Heat Load (FPCs+Shield)	76+108	W
2K Static Heat Load per Cavity	2.4	W
2K Dynamic Heat Load per Cavity	7	W
Magnetic Field due to Rebar	<0.1	mT
Axial Magnetric Shielding Factor	>100	
HOM Longitudinal Impedance Upper Limit Rs*fhom (monopole HOMs, Rs=V^2/(2P))	<0.5	MΩ-GHz
HOM Horizontal Impedance Upper Limit Rt (dipole x-HOMs)	<1.5	M Ω/m
HOM Vertical Impedance Upper Limit Rv (dipole y-HOMs)	<4.5	MΩ/m

Power Coupler Design Using One Branch of HOM Waveguide

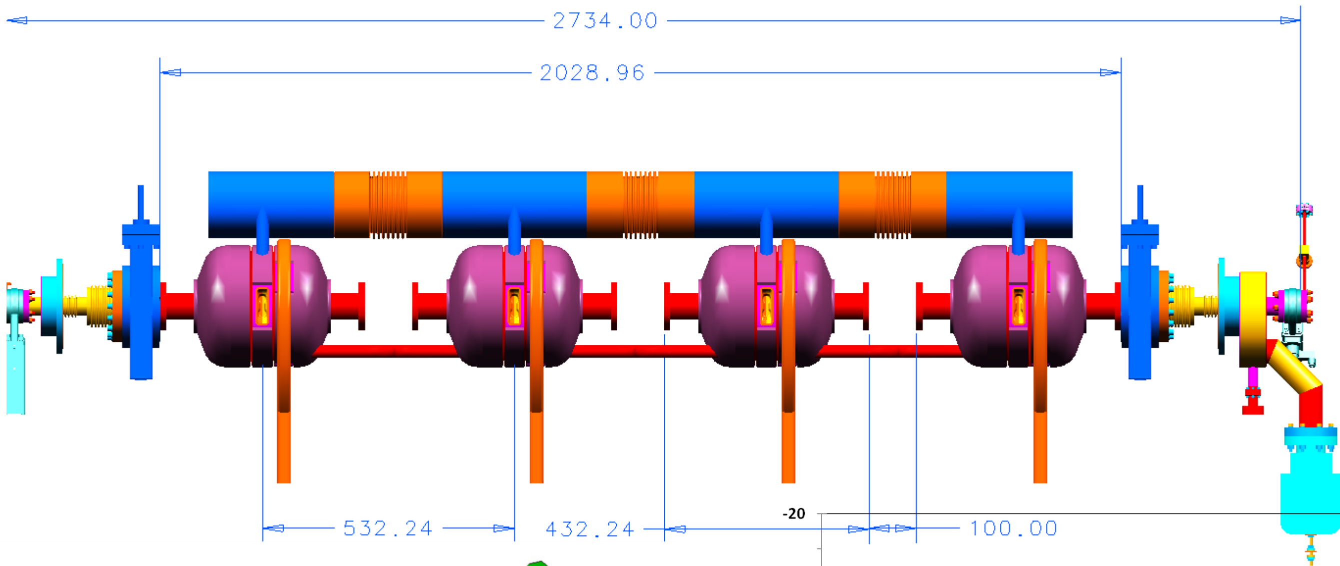




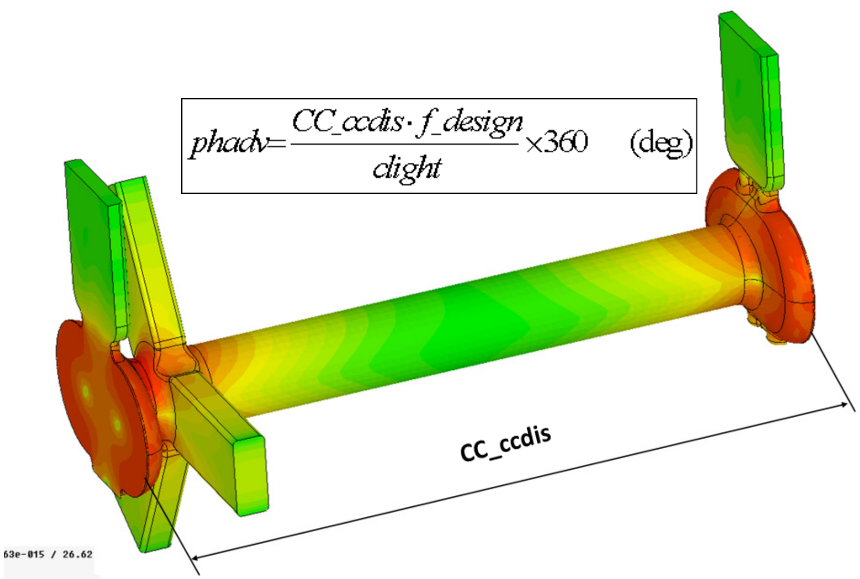


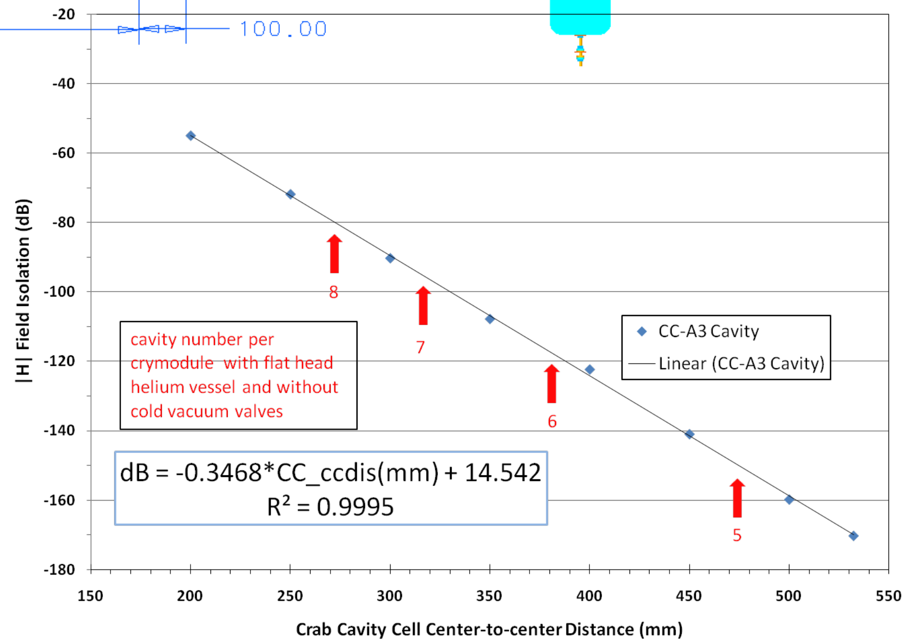
- Can use either WR284 or WR340 waveguide, depending the available high power window.
- Waveguide step is outside of helium vessel for Qext=2e6.

Cavity to Cavity RF Isolation Calculation and 4-Cavity String Layout

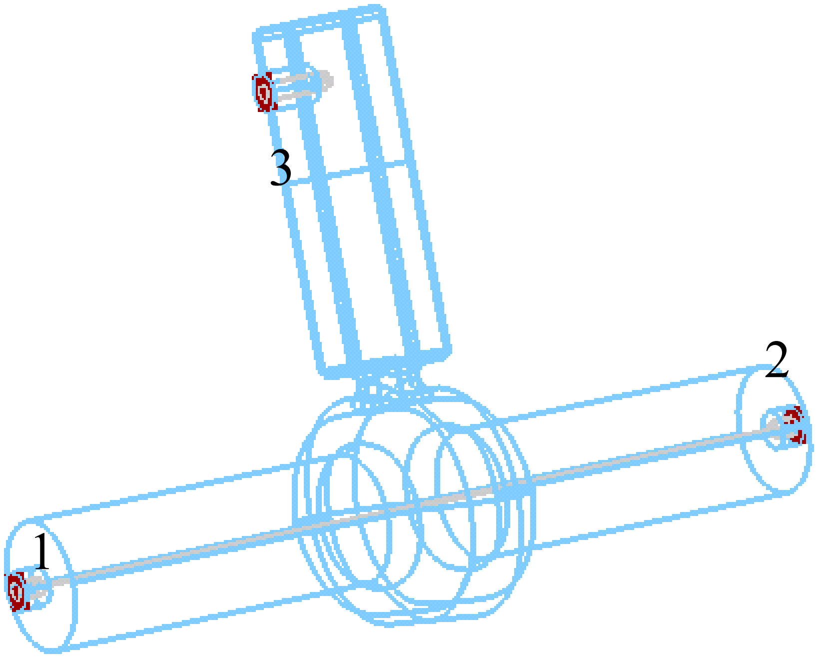


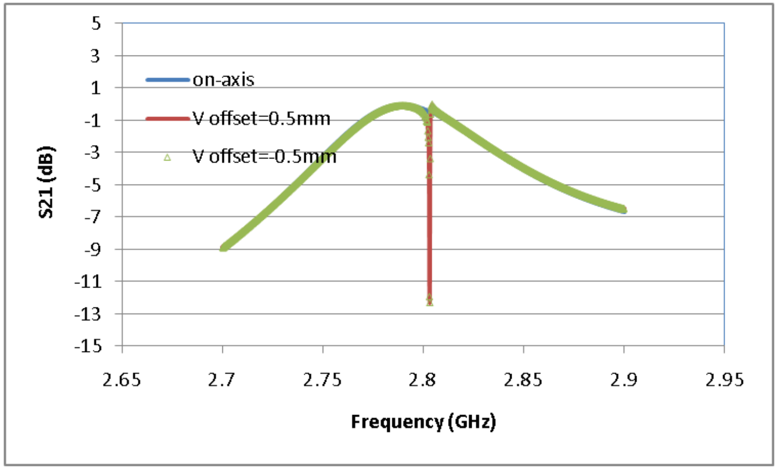
$$phadv = \frac{CC\_ccdis \cdot f\_design}{clight} \times 360 \quad (deg)$$

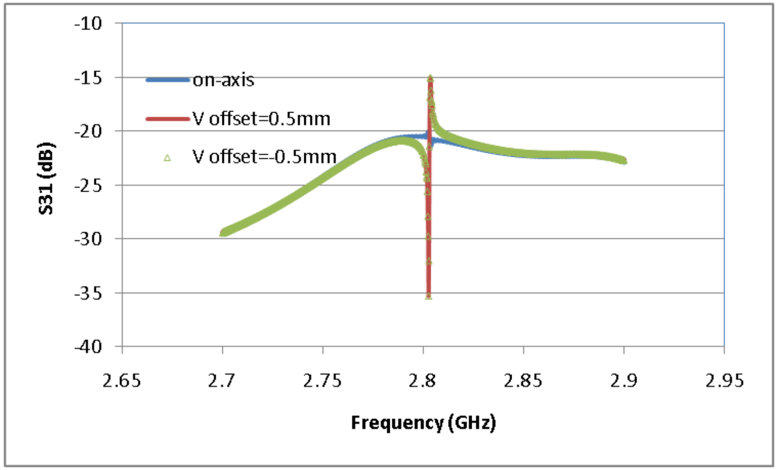


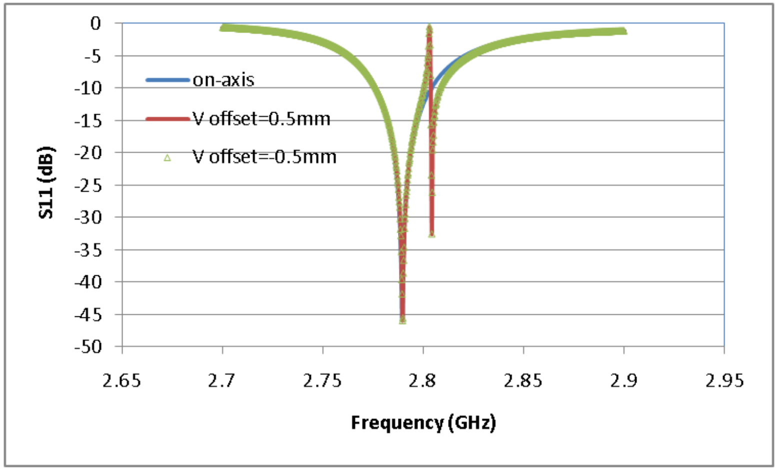


Proof of Principle Using Wire Stretching Technique for Pre-Alignment in Clean Room



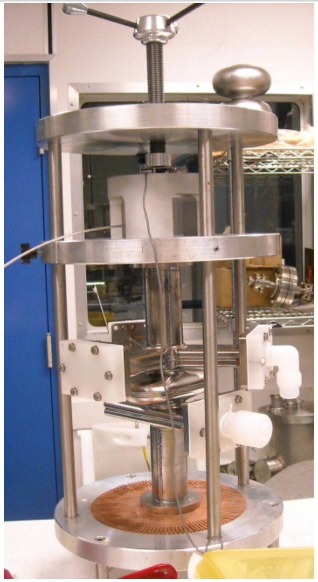


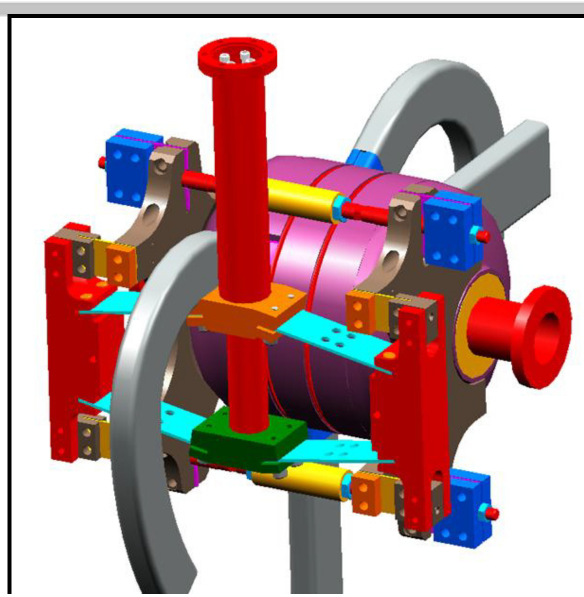


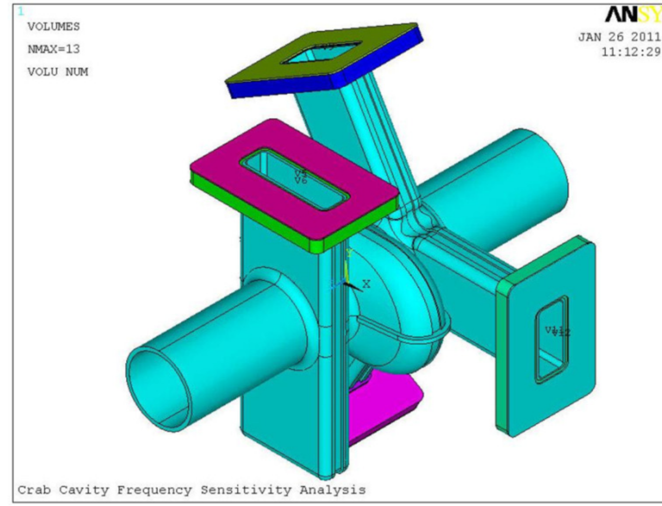


- RF signal sensitivity is 20dB/0.5mm, good enough for clean room warm alignment.
- A beam based alignment scheme using the crab cavity as the passive BPM has been proposed to reduce errors of offset, roll, pitch and yaw.

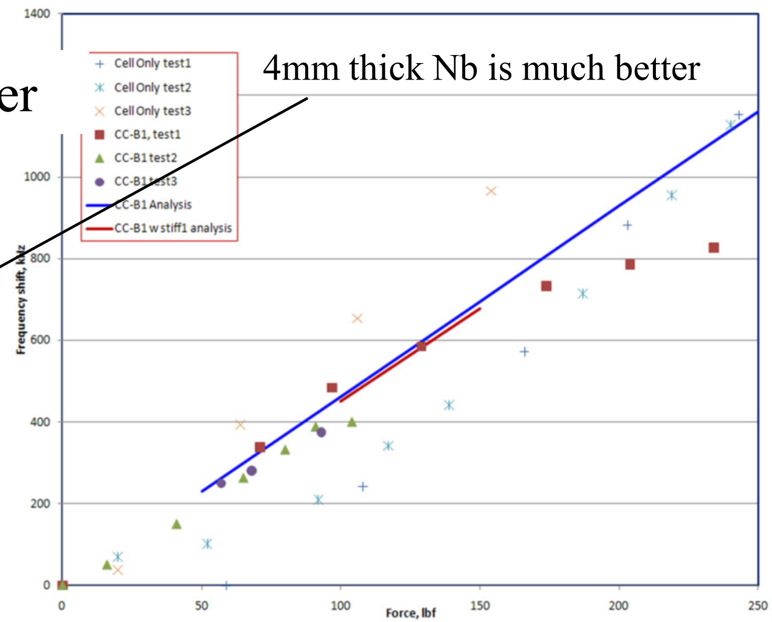
Tuning Sensitivity of CCB1 Cavity, Experiments vs. Simulations







Proposed scaled JLab C100 Scissor Jack Tuner



Comparison of tuning and pressure sensitivities

Design Descriptions	Hz/lbf	kHz/mm	Hz/torr
C100 7-cell*	1,073~1,386	408~420	N.A.
CC-B1 with LOM/HOM/FPC waveguides, wall thickness = 3 mm	4,637	8,844	N.A.
CC-B1 with LOM/HOM/FPC waveguides and 1/8" x 1/8" C-shape stiffener1, wall = 3 mm	4,518	8,569	N.A.
CC-A cell only and wall thickness = 2.8 mm	1,942	12,866	39.6
CC-A cell only and wall thickness = 4 mm	1,324	18,060	8.97

* Analysis data chage from one cavity to another. Testing suggests 300 kHz/mm sensitivity.

Summary

- Baseline cavity has be fully qualified for the cryomodule development.
- The “Alternate” cavity with on-cell damper feature gives us more safety margin on the LOM and HOM impedance budget.
- Cavity design down selection in May, 2011 will be based on the alternate cavity’s performance to be tested soon.
- So far no show stopper on our Baseline and Alternate designs of SRF crab cavities and cryomodule concept.
- Alignment tolerance is challenging but manageable by using wire stretching pre-alignment and beam based feedback alignment methods. We need more R&D and beam diagnostic instrumentation to reduce the alignment errors.
- The combination of HOM and DFM couplers and the double notch window are technical feasible.
- To demonstrate integrated cryomodule engineering design with chosen cavity within the confined space at the APS.
- To have cavity/cryomodule components engineering designed, prototyped and tested in a short period.
- Delivery the first ¼ test cryomodule to APS in October, 2013.