DEVELOPMENT, PRODUCTION AND TESTS OF PROTOTYPE SUPERCONDUCTING CAVITIES FOR THE HIGH BETA SECTION OF THE ISAC-II HEAVY ION ACCELERATOR AT TRIUMF

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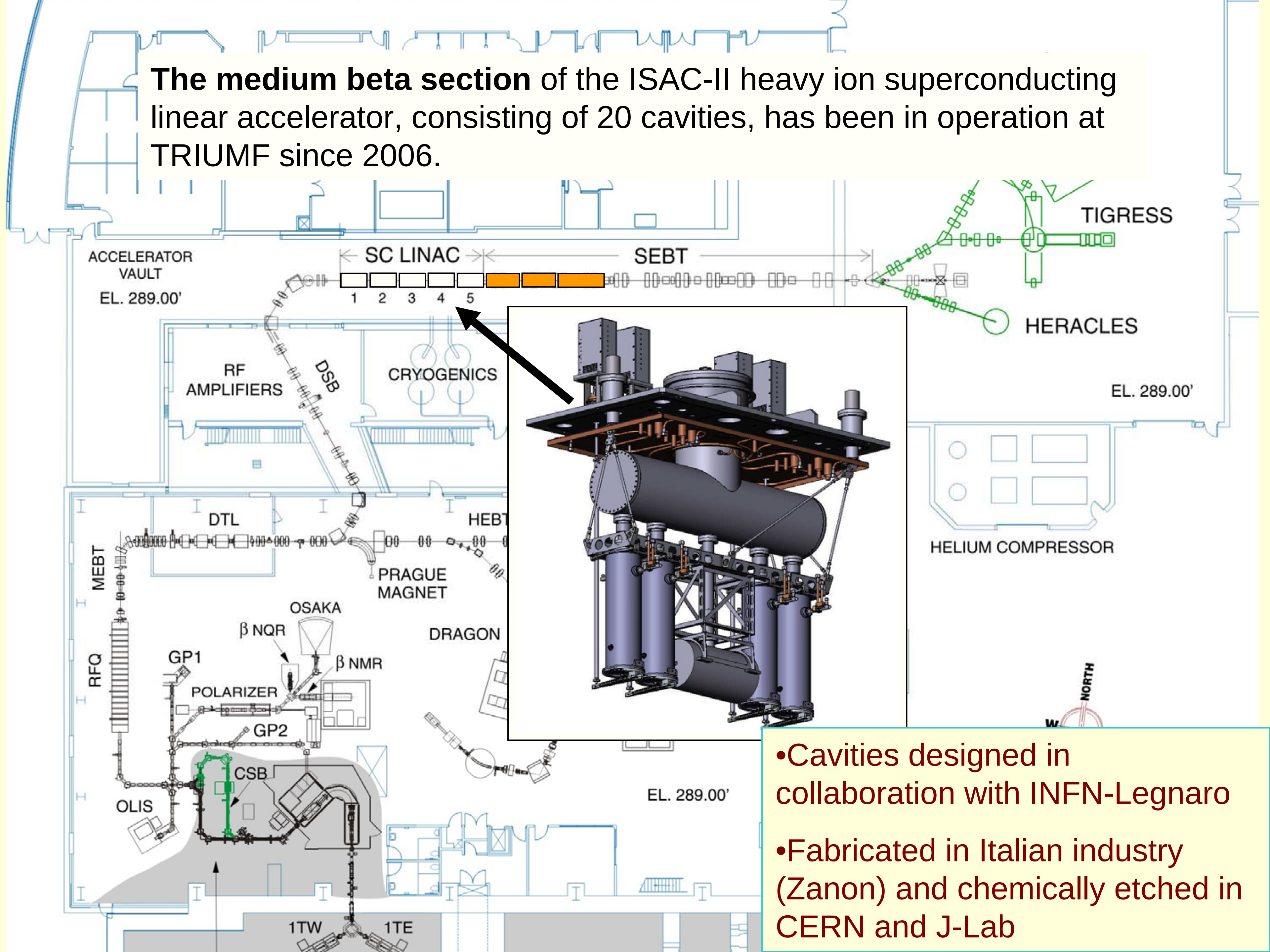
TRIUMF

VANCOUVER

Abstract

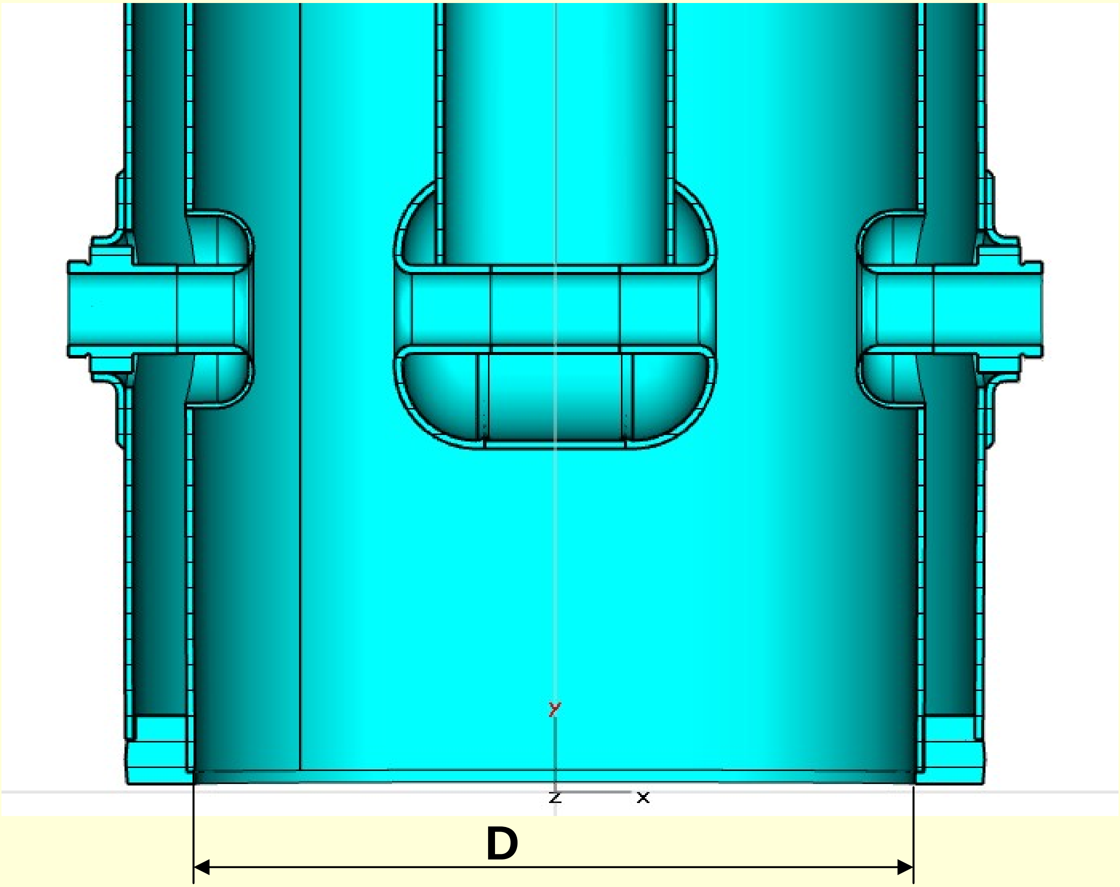
The medium beta section of the ISAC-II heavy ion superconducting linear accelerator, consisting of 20 cavities, has been in operation at TRIUMF since 2006. The high beta section of the accelerator, consisting of an additional twenty cavities, is currently under development and is scheduled for completion in 2009. The cavity is a superconducting bulk Niobium two-gap quarter-wave resonator for frequency 141 MHz, optimum β_o=0.11, providing, as a design goal, a voltage gain of Va=1.08 MV at 7 W power dissipation. The inner conductor is equipped with a donut drift tube. The cavity has a double wall mechanical structure with liquid Helium inside. Two prototype cavities for the ISAC-II high beta section were developed at TRIUMF and produced by a Canadian company, PAVAC Industries of Richmond, B.C. The prototypes are equipped with a mechanical dissipator to damp detuning environmental mechanical vibrations. An inductive coupler, developed at TRIUMF, provides low power dissipations to the liquid helium system. Superconducting RF tests of both cavity prototypes show that we have achieved the required frequency and exceeded the design goal parameters. Response of the cavity to liquid helium pressure fluctuations, Lorenz force detuning and microphonic sensitivity with and without the damper was tested. RF design, prototype production details and cavity test results will be presented and discussed.

The medium beta section of the ISAC-II heavy ion superconducting linear accelerator, consisting of 20 cavities, has been in operation at TRIUMF since 2006.



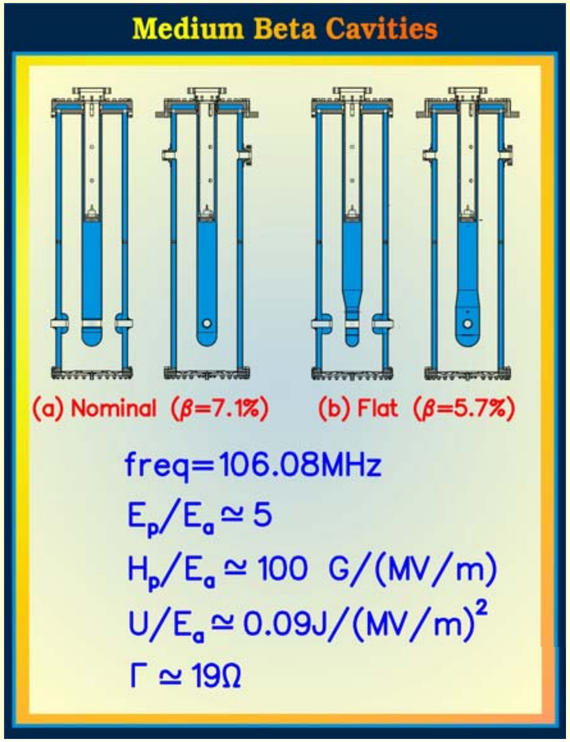
- Cavities designed in collaboration with INFN-Legnaro
- Fabricated in Italian industry (Zanon) and chemically etched in CERN and J-Lab

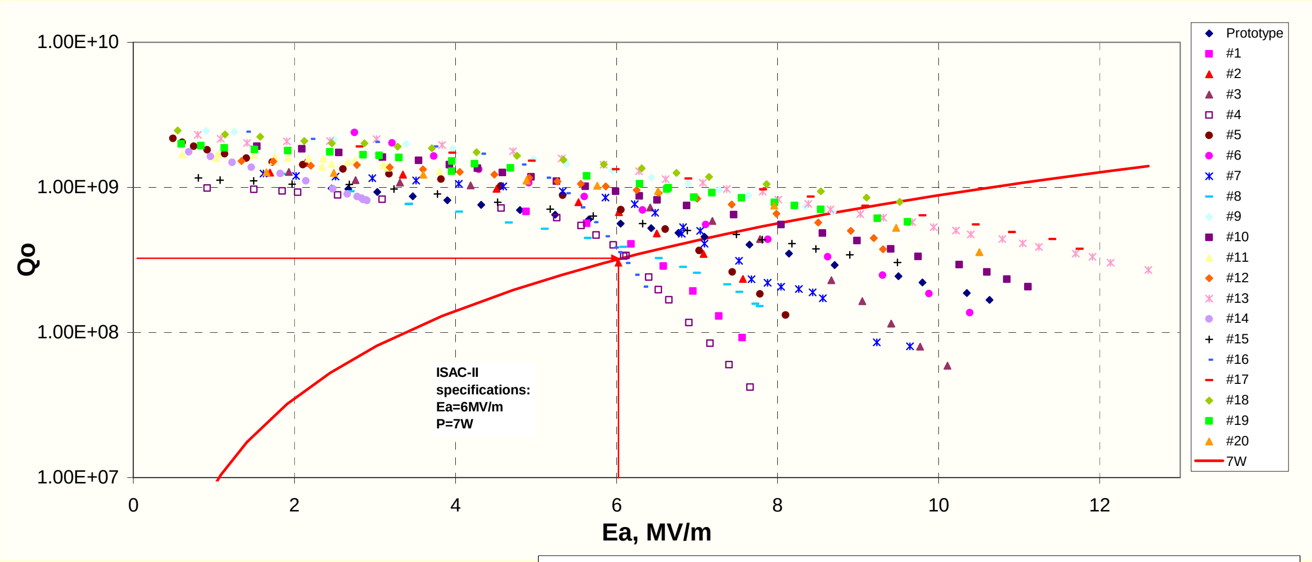
Acceleration Gradient Definition

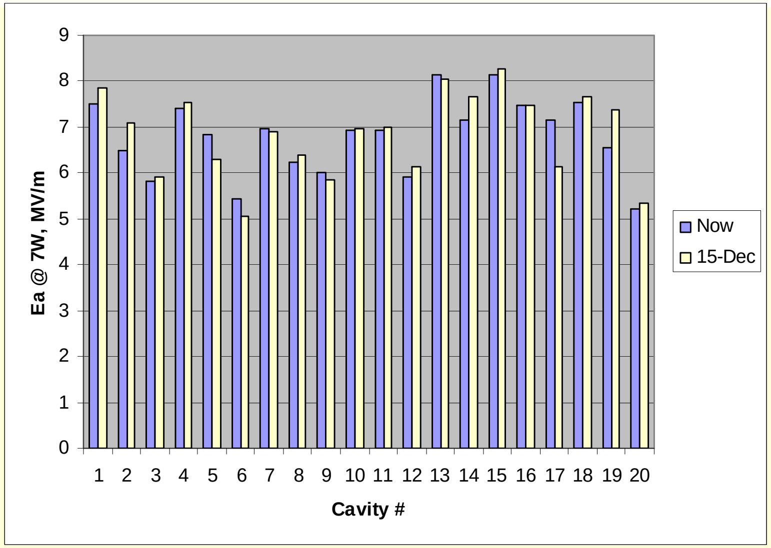


$$Ea=Va/D$$

Medium Beta ISAC-II Cavities





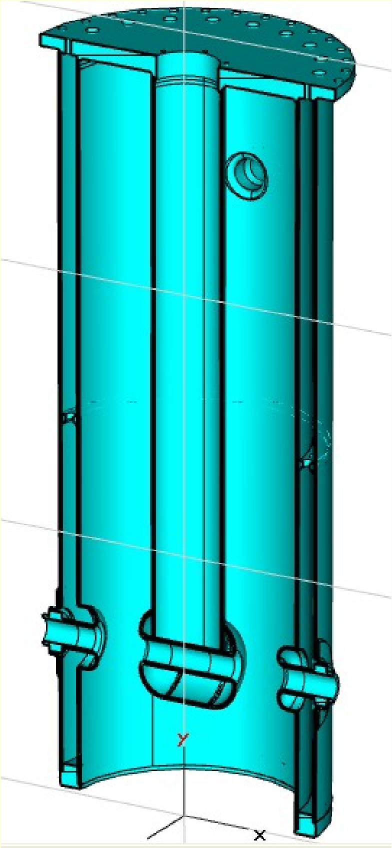


in operation since April 2006 and is reliable at an average acceleration gradient of 7 MV/m (1.26MV) at 7 W power dissipation

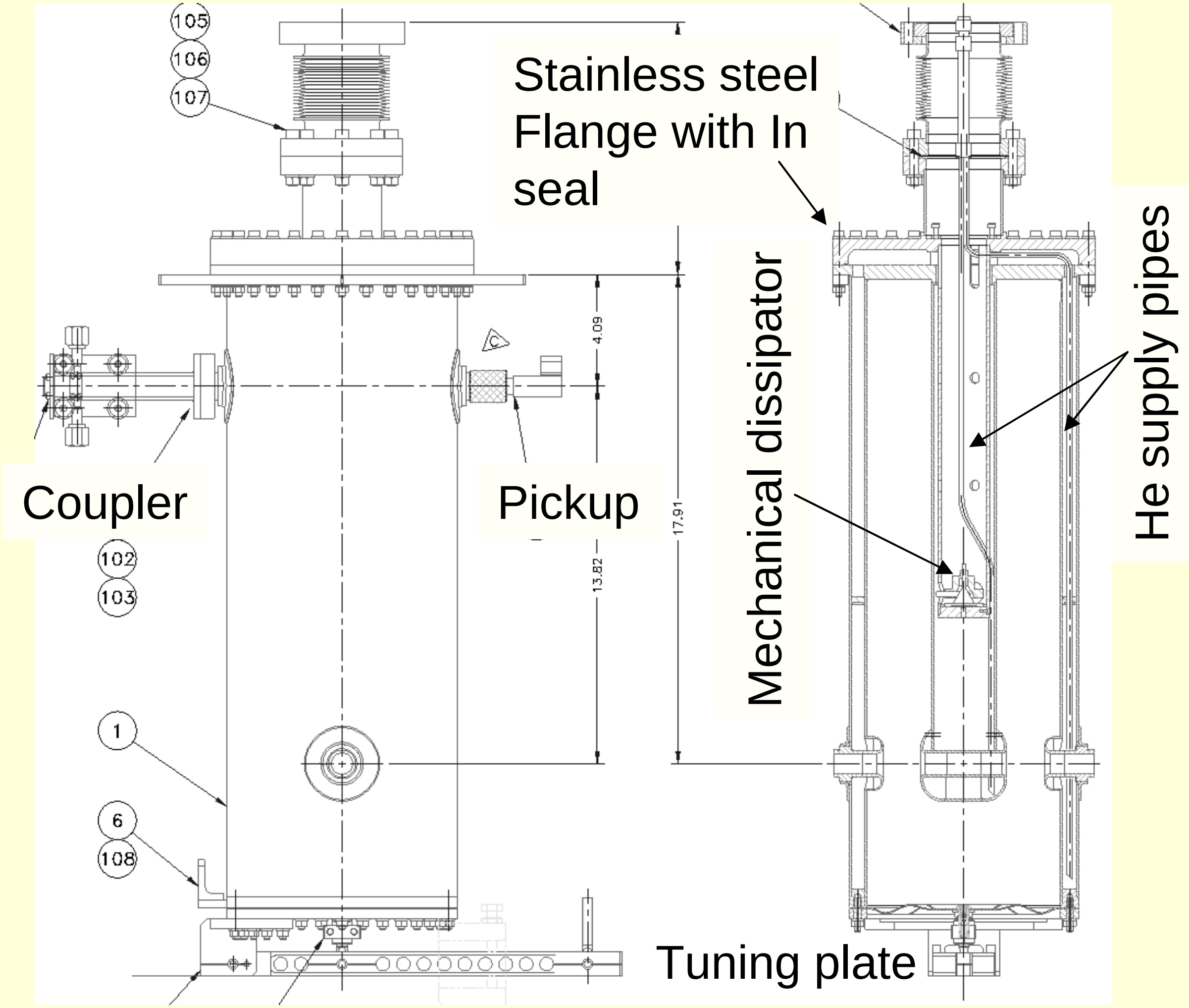
Ep= 35 MV/m and Bp=70 mT

The medium beta design was accepted as a basis for the design of the high beta section.

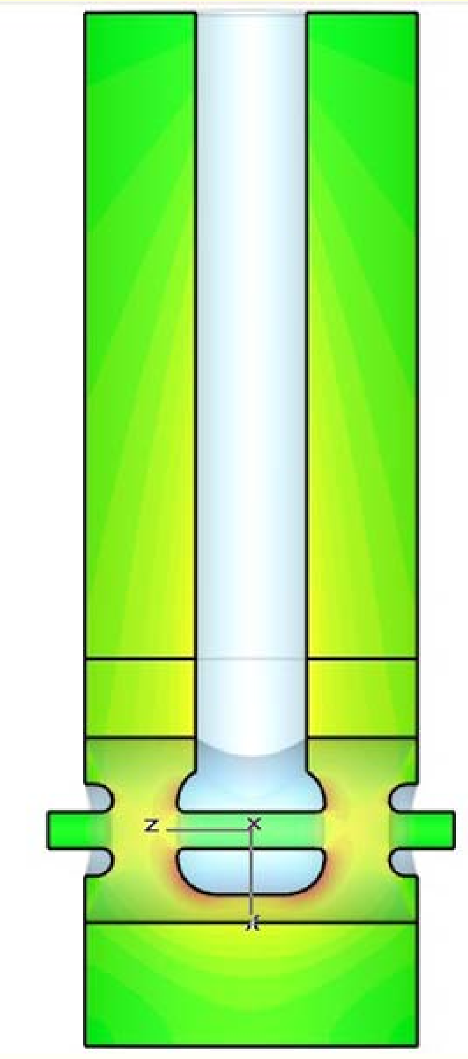
Cavity Design



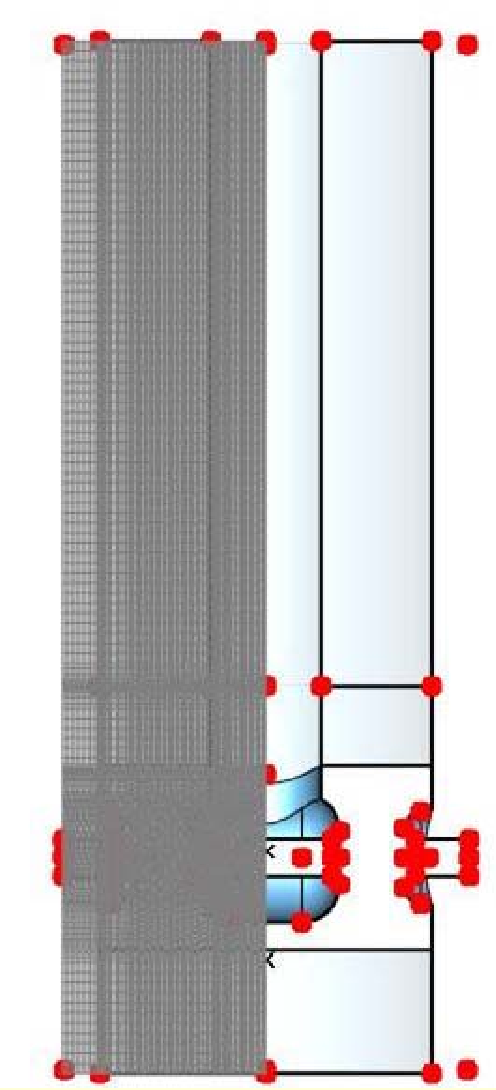
Cavity double wall structure



CST Model and Cavity Parameters

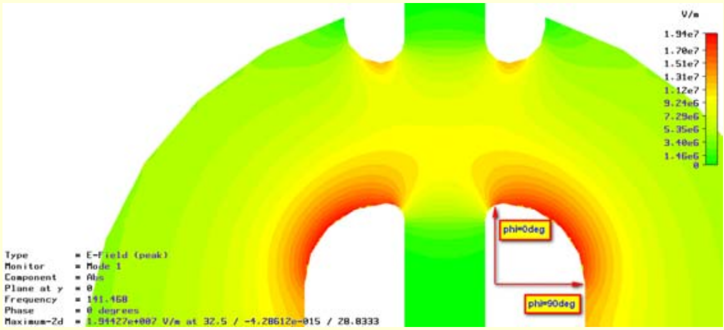


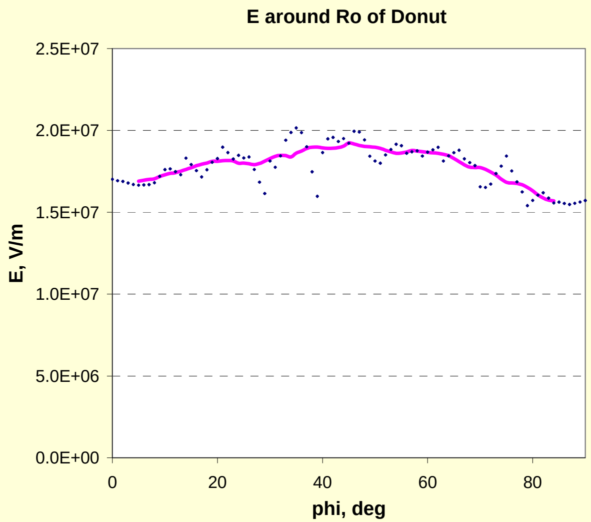
f	MHz	141.44
aperture	mm	20
gap	mm	35
drift	mm	80
Outer dia	mm	180
Inner dia	mm	60
Height	mm	560
bo		0.112
TTFo		0.936
U/Ea^2	J/(MV/m)^2	0.067
RsQo	Ohm	26
Ep/Ea		4.9
Bp/Ea	mT/(MV/m)	10
Bc/Ea	mT/(MV/m)	0.1
Df/Dx	kHz/mm	
beam ports		120
top		-268
bottom		10



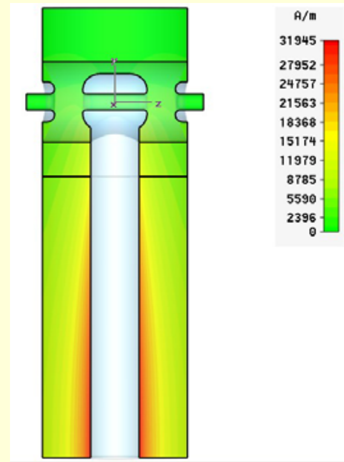
To avoid errors from mesh

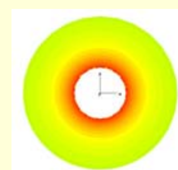
Ep and Bp Calculations





Ep is defined from geometry parameterization of the donut surface





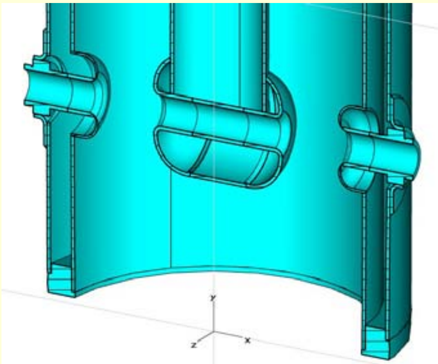
$$H(z,r) = Hp\frac{r_1}{r}\cos\left(\frac{2\pi z}{\lambda}\right)$$

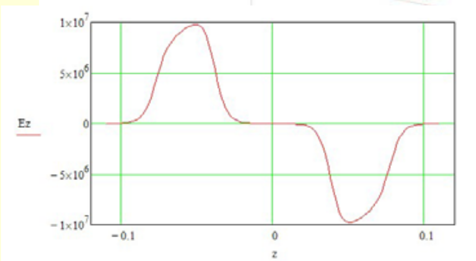
$$U_M = \frac{\mu_o}{2}\int_{r_1}^{r_2}\int_{z_1}^{z_2} H^2(z,r)\,dz\,d\pi r^2$$

$$H_p = \sqrt{\frac{U_M}{\mu_o \pi r_1^2 \int_{r_1}^{r_2}\int_{z_1}^{z_2}\cos^2\left(\frac{2\pi z}{\lambda}\right)\frac{dzdr}{r}}}$$

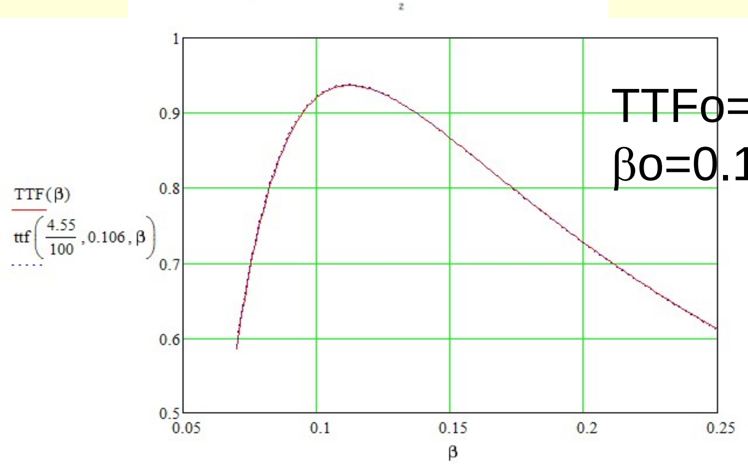
Assuming cosine longitudinal, hyperbolic radial magnetic field distribution and value of magnetic field stored in this volume we can calculate Bp.

For Cavity Beam Dynamics

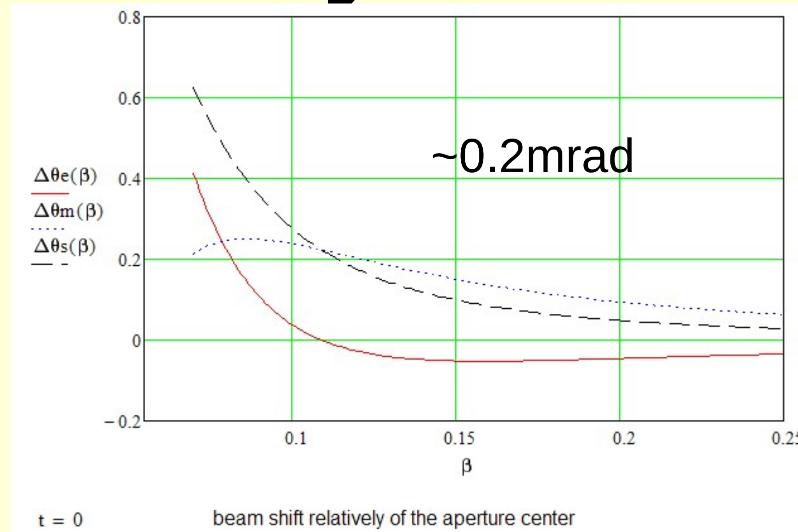


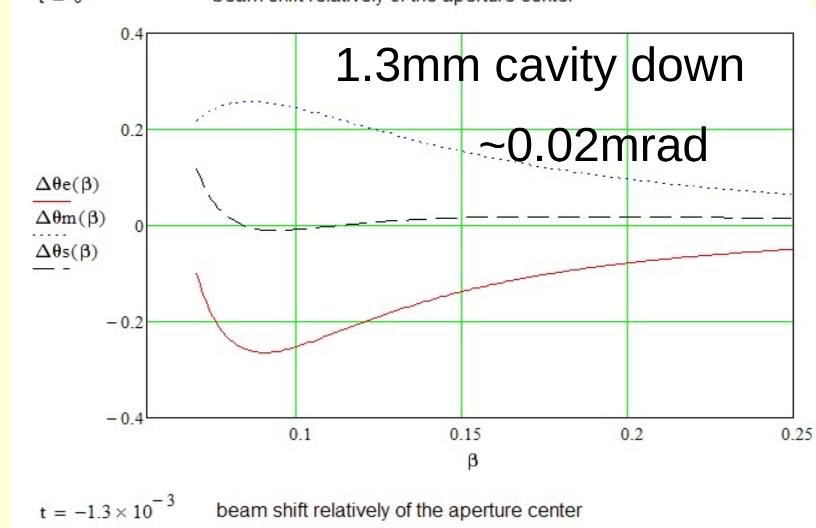


Acceleration component



TTFo=0.936
βo=0.112





Steering compensation: 6MV/m,-30deg,A/q=3

Copper Dummy Cavity

Before and after welds

Two copper dummy cavities were produced there for production preparation and training purposes for PAVAC Industries.

300-4K frequency shift

To define the cavity production it is necessary to foreseen frequency shift of cavity resonance frequency from room to helium temperature.

Let's consider experience with similar cavities.

ALPI cavities	ISAC-II medium beta cavities	
f=80 MHz	f=106 MHz	106/80~1.3
156 kHz frequency shift	190 kHz frequency shift	190/156~1.2

We can see that frequency shift is roughly proportional to operational frequency

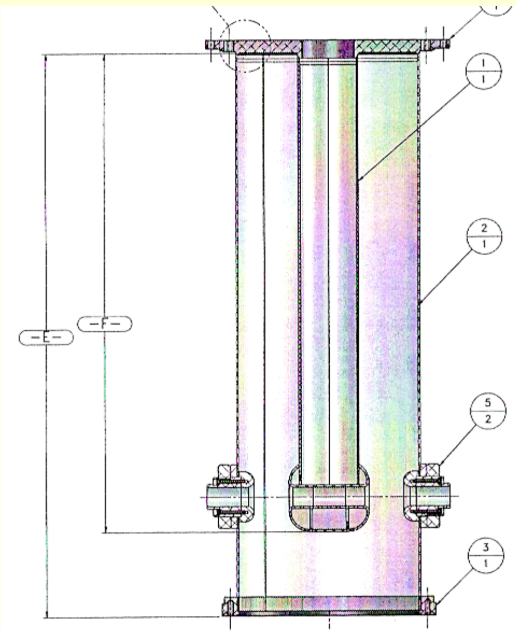
Frequency shift for high beta cavity=190*141/106=253 kHz

Goal cavity frequency at room temperature=
=141.440-0.253=141.187 MHz

Actual measured frequency shift is 4.5% more and is of 264 kHz

Fabrication and testing frequency summary for ISAC-II high beta QWR prototype

Frequency, MHz	Resonant frequency					Resonant freq. shifts		
	old goal	Cav#3	Cav#4	goal		old goal	Cav#3	Cav#4
Parts Machining	137.19	137.574	137.648	137.611				
Cuts	141.141	141.188	141.115		Cuts compensation	3.951	3.614	3.467
Flanges weld		141.298	141.222		Flange weld shift		0.11	0.107
Beam ports adjustment	141.195	141.195	141.203					
Beam ports weld		141.169	141.187		Beam ports weld shift		-0.026	-0.016
Jacket weld	141.174	141.148	141.168		Jacket weld shift		-0.021	-0.019
BCP	141.19	141.196	141.192		BCP shift	0.016	0.048	0.024
4K	141.44	141.467	141.456		300-4K shift	0.25	0.271	0.264
3mm bottom flange cut		141.173	141.18		3mm cut shift		-0.023	-0.012
BCP		141.16	141.156		BCP shift		-0.013	-0.024
4K	141.44	141.423	141.42		300-4K freq.shift		0.263	0.264

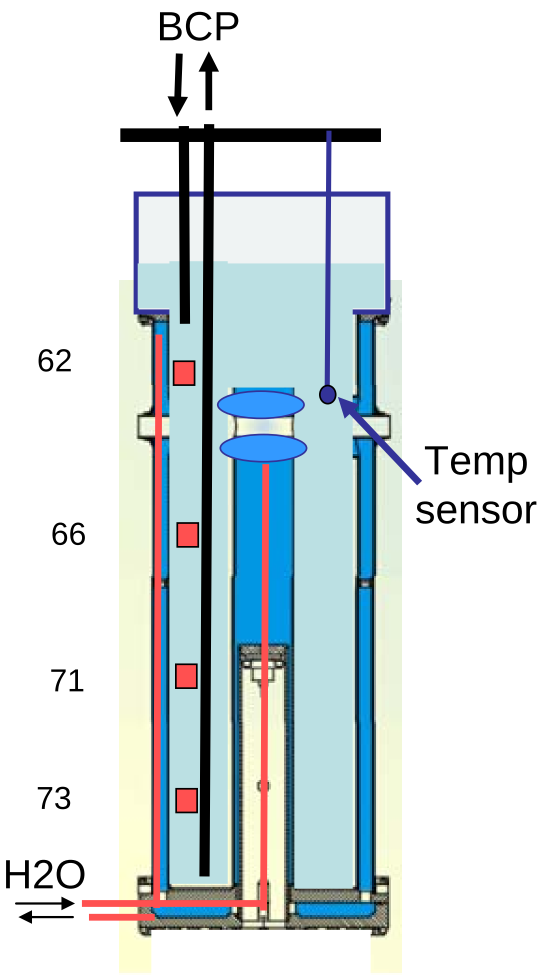


Cuts

Etching before weld

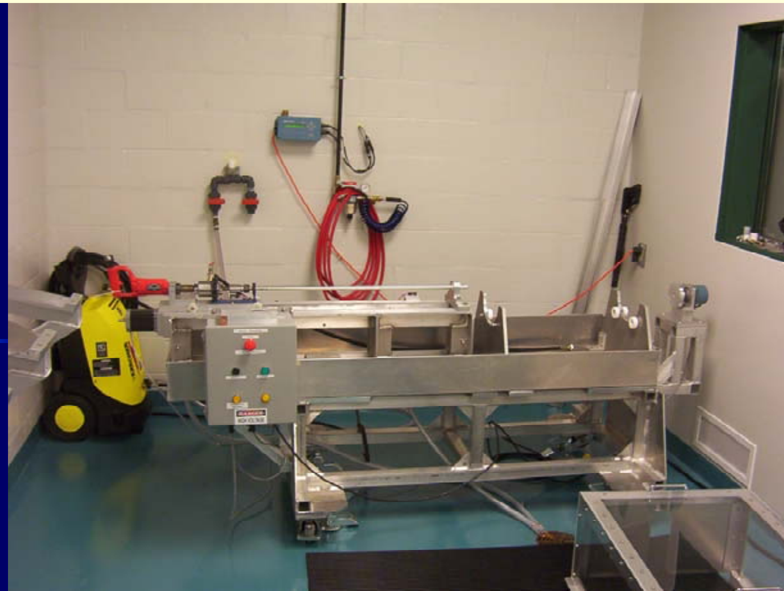
Gap adjustment before beam ports welding

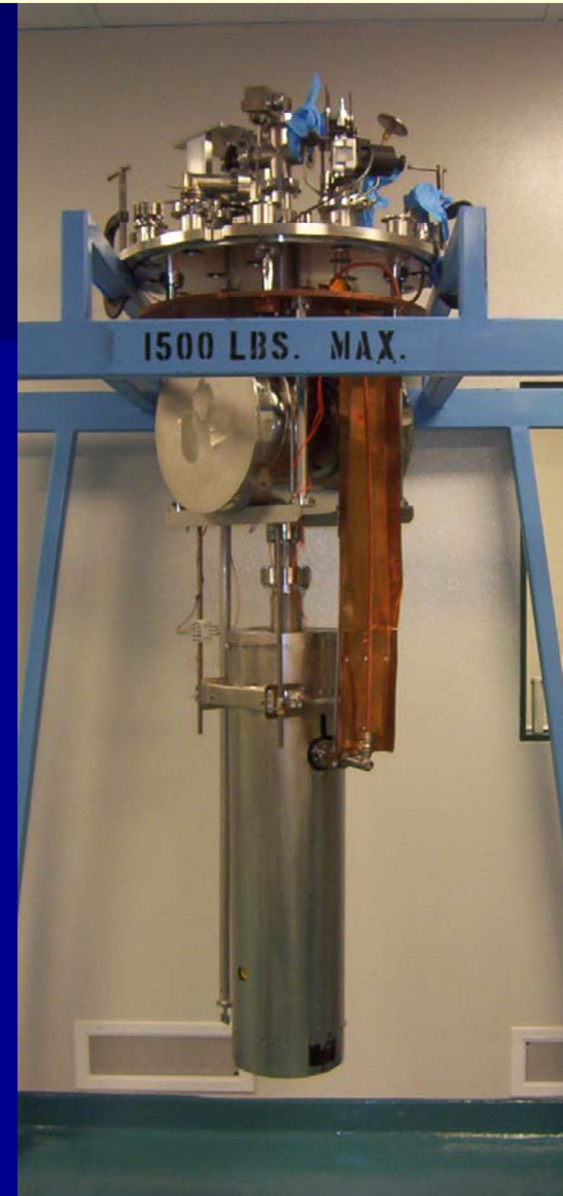
Etching Cavity 4



BCP 1:1:2
HF,HNO3,H3PO4

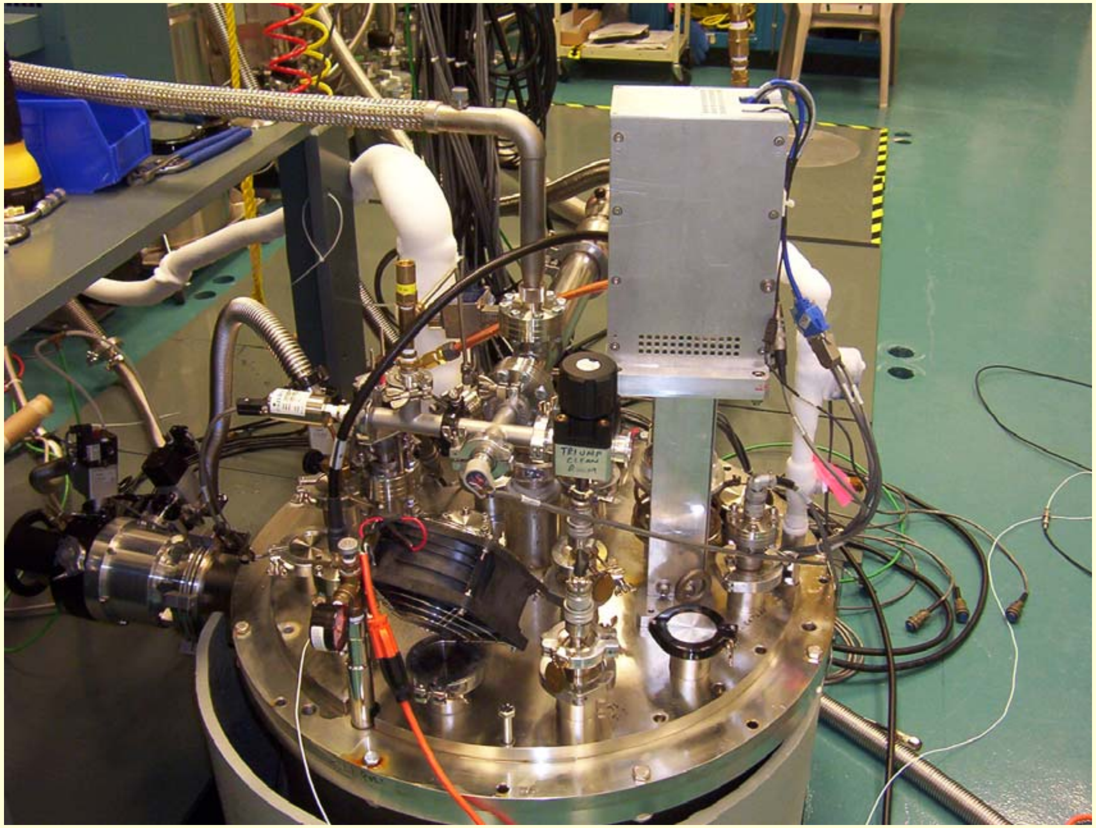
- etching of Cavity 4
  - Degrease cavities as per pre-weld etch
  - Start with acid at 9gm/ltr
  - Cavity and acid pre-chilled
  - Attach teflon extension tube, place in fume hood and pump acid into cavity
    - Pump chilled water into cavity jacket and center conductor during etch
    - Acid thermalized at ~6.5C
    - Recirculate acid (from bottom to top) for 1 minute every 5 minutes
    - Fill cavity with DI water and flush then fill
  - Etched for 100 minutes at an average etch rate of 0.72micron/minute
  - Cavity weight changed by 120gm

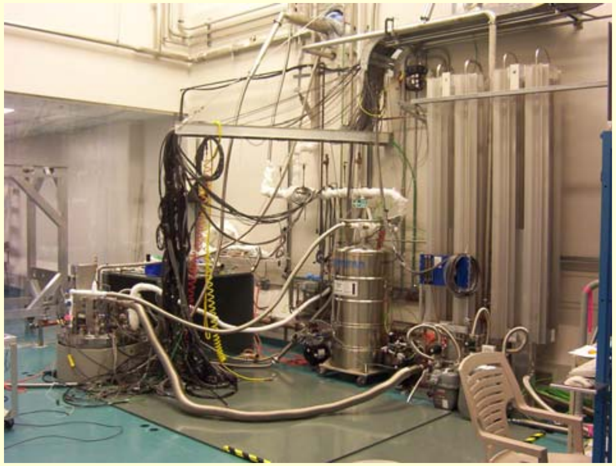




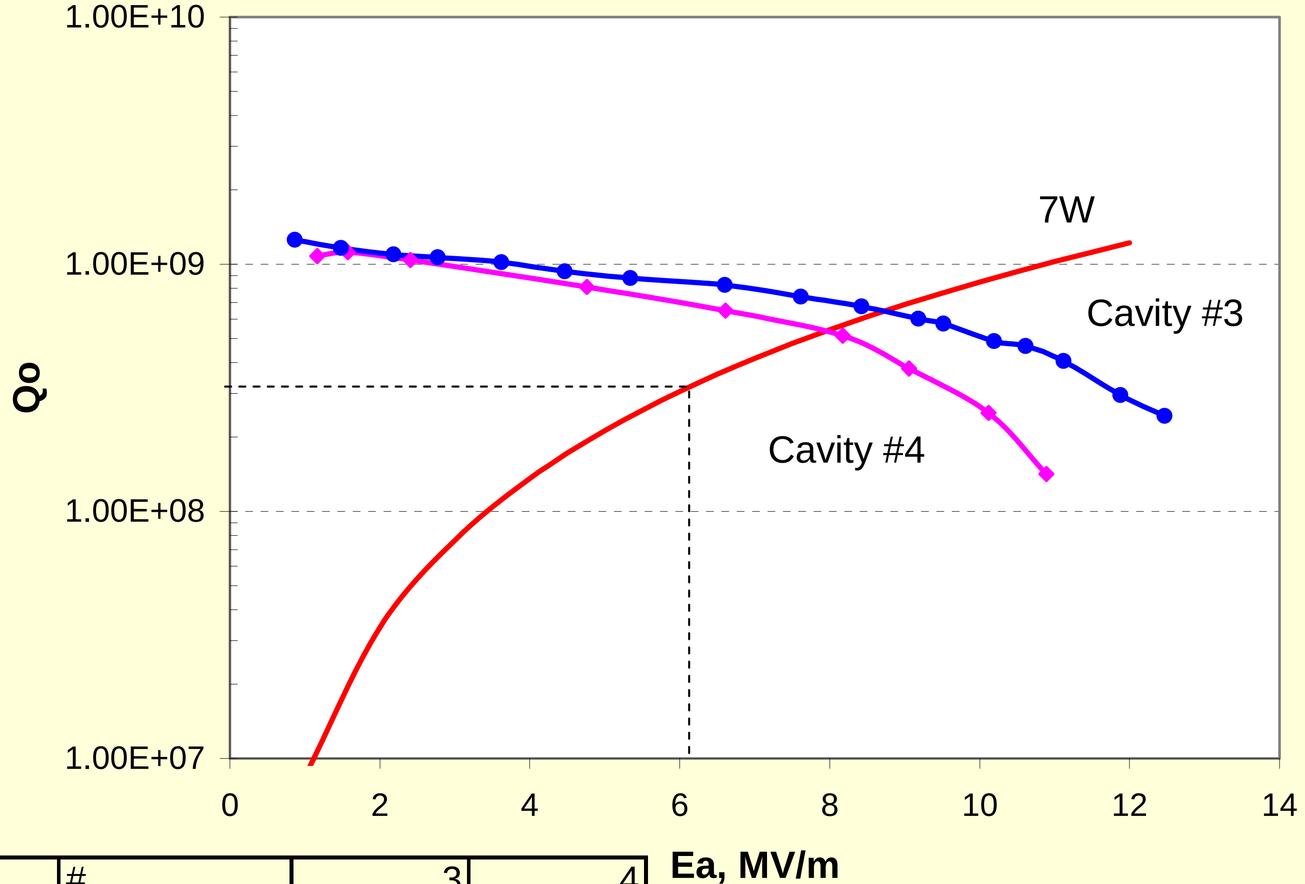
Typical treatment involves 30-40 minute high pressure water rinse and twenty four hour air dry in a clean room, followed by vacuum pumping and bake out at 95C for 48 hours.

SC Tests





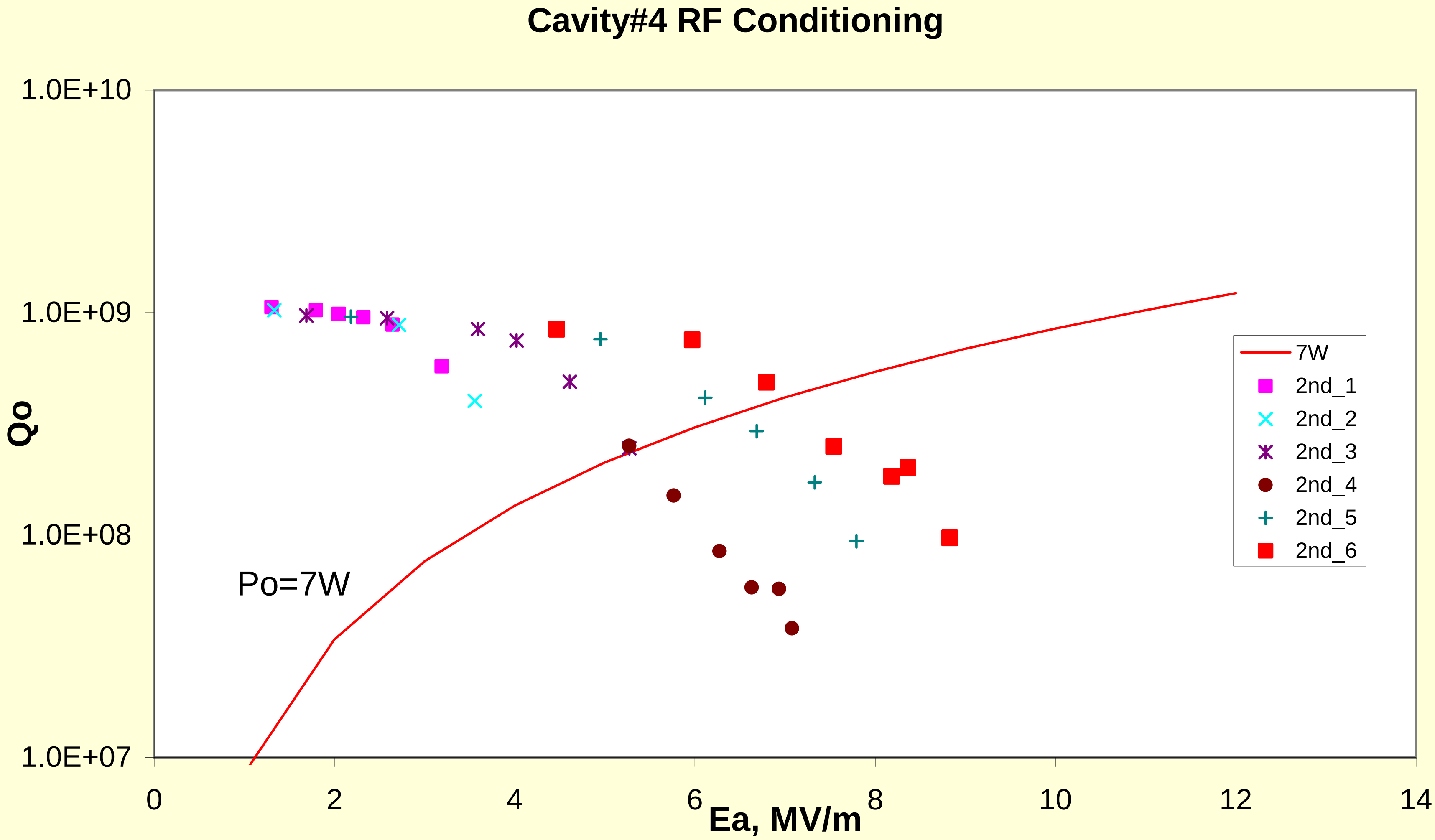
Single cavity cryostat and superconducting test area



Cavity	#	3	4
fo	MHz	141.423	141.456
Qo		1.10E+09	1.20E+09
Ea@7W	MV/m	8.1	8.8
EaMax	MV/m	10.9	12.5
Df/Dp	Hz/Torr	-3.3	-1.7
Df/DEa^2	Hz/(MV/m)^2	-0.8	-0.9
Df300-4K	kHz	263	265

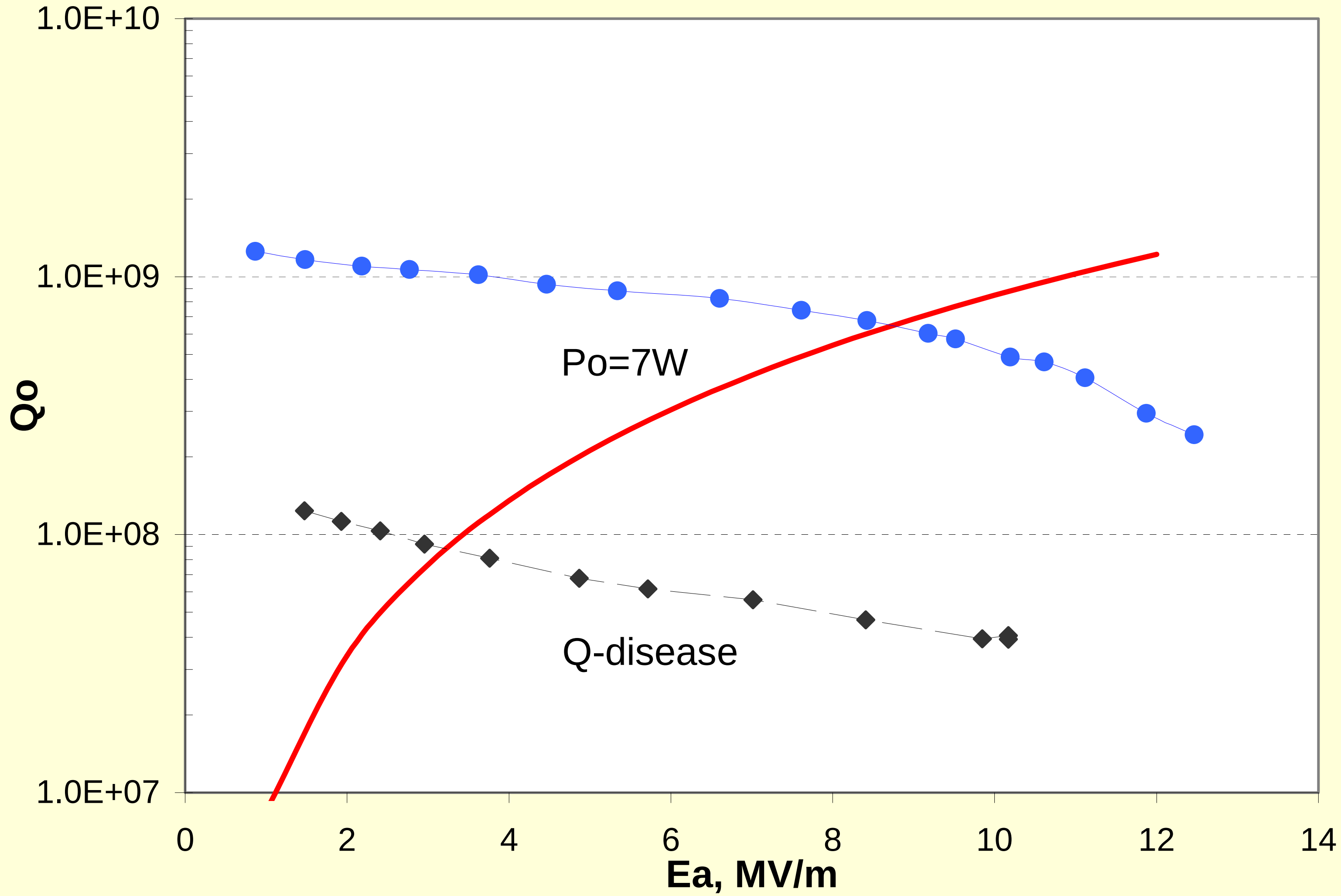
Prototype Test Results

At 7W Ea~8.5 MV/m, Va~1.5 MV
(design goal 6MV/m and 1.08 MV)



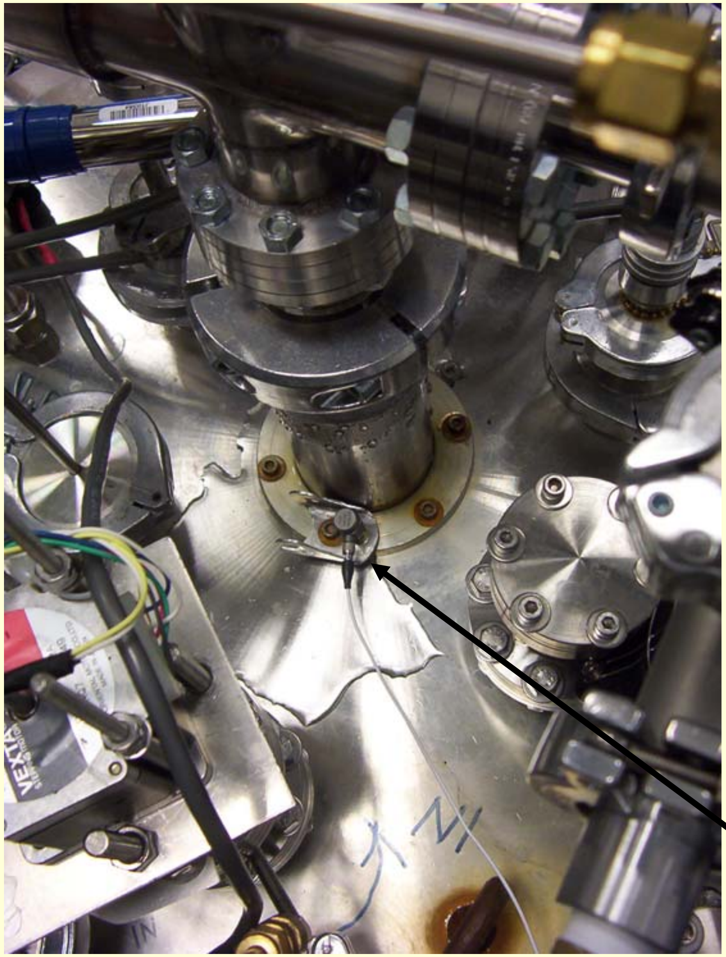
Q-curves measured after cavity RF conditioning cycles.

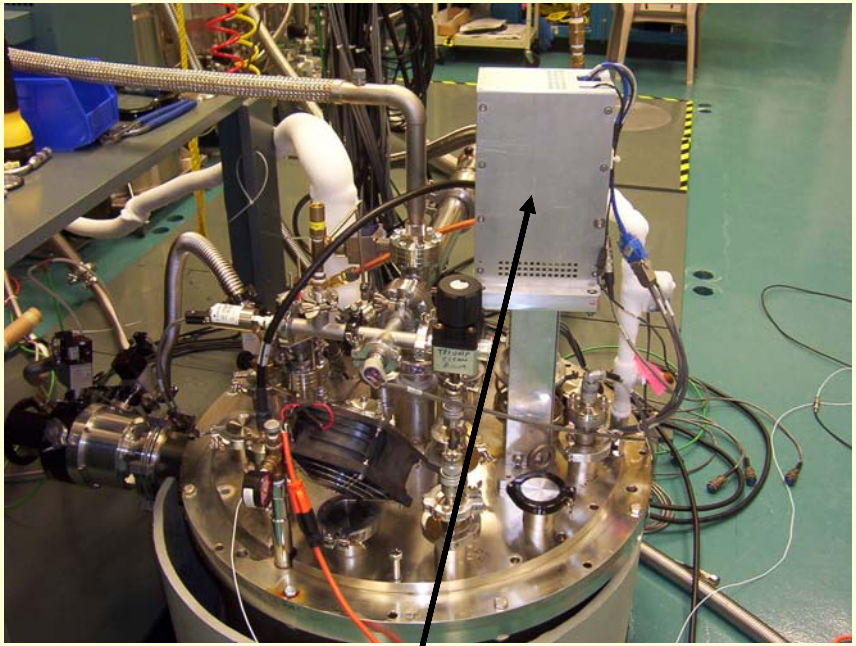
RF pulsing (0.5s/1s) of overcoupled cavity with Pf~200-400W. For better efficiency we put ~10^{-5} Torr of He in the cavity volume.



Cavity#4 after stay in the range of temperature 50-100K got Q-disease
10 times Q-drop, very much helium boiling at high fields
Q-curve shape changed – knee to concave

Tuner Motor and Accelerometer Setup for Vibration Test



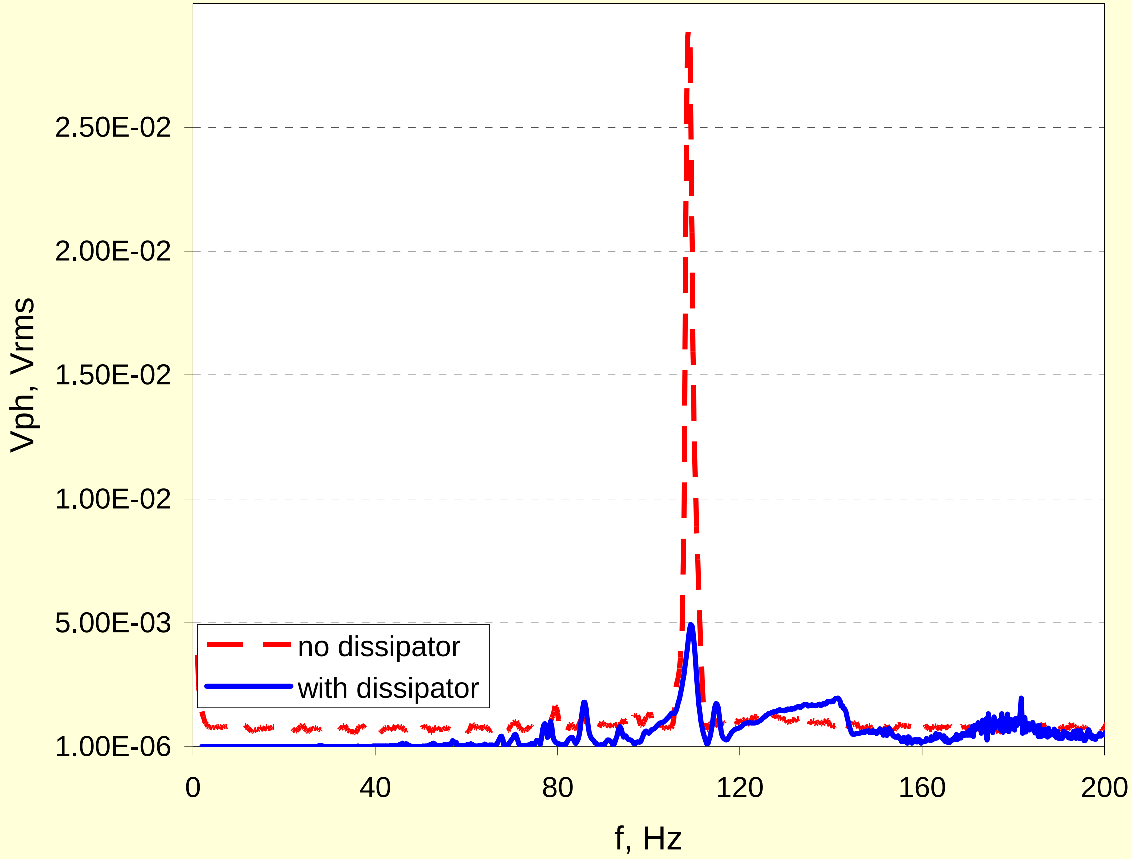


Tuner Motor

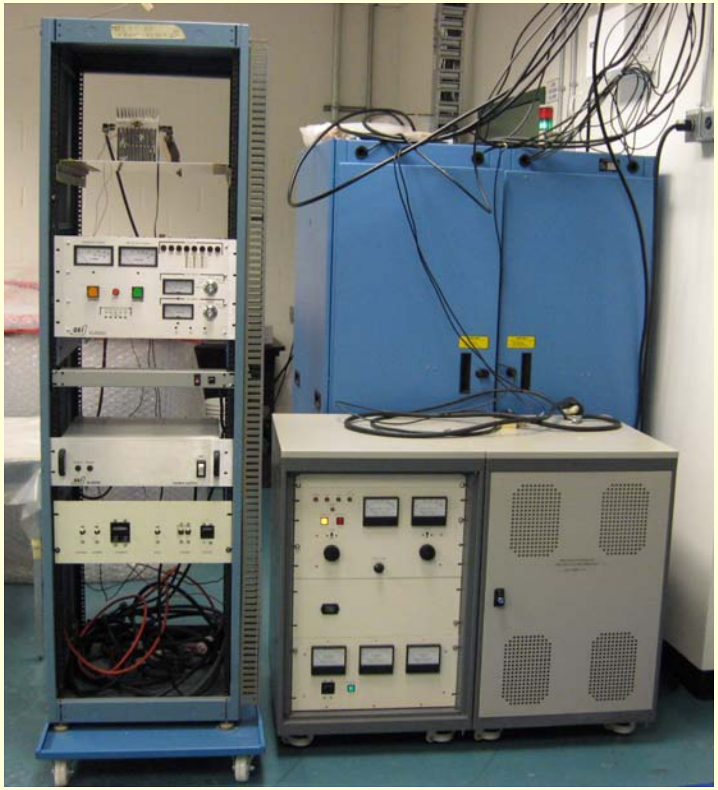
Accelerometer

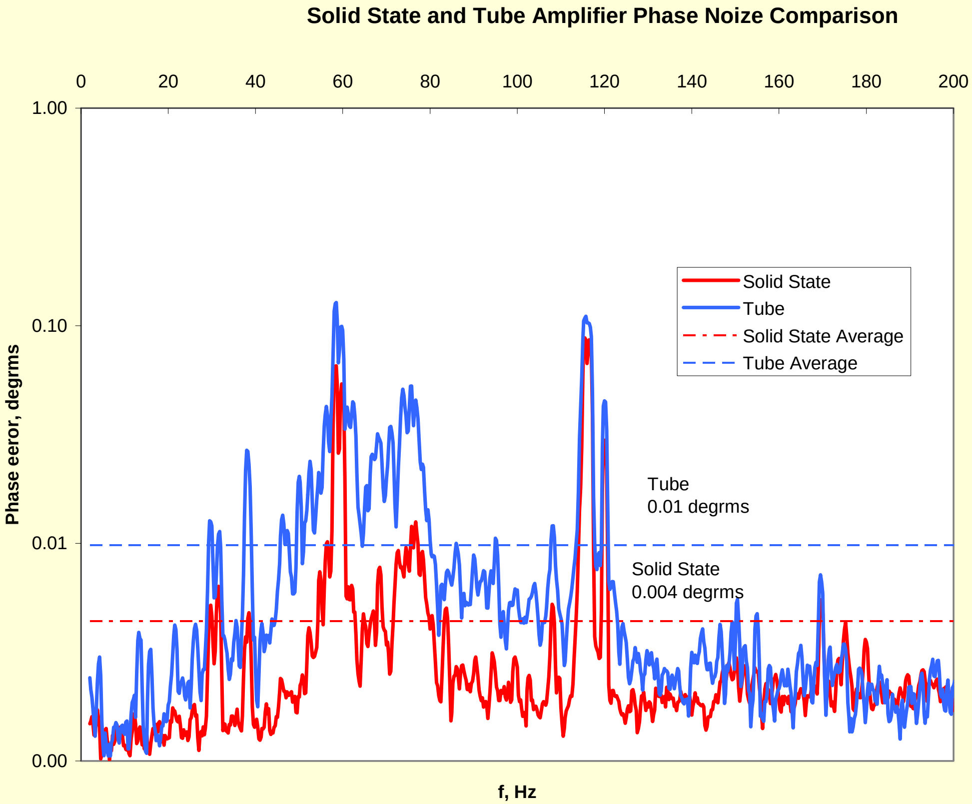
Mechanical Dissipator Performance

Cavity lowest mechanical resonance ~110 Hz which is from inner conductor
Frequency deviation with dissipator is ~6 times less than without
With dissipator we could use less overcoupling, then ~6 times less Pf



Solid State and Tube Amplifier

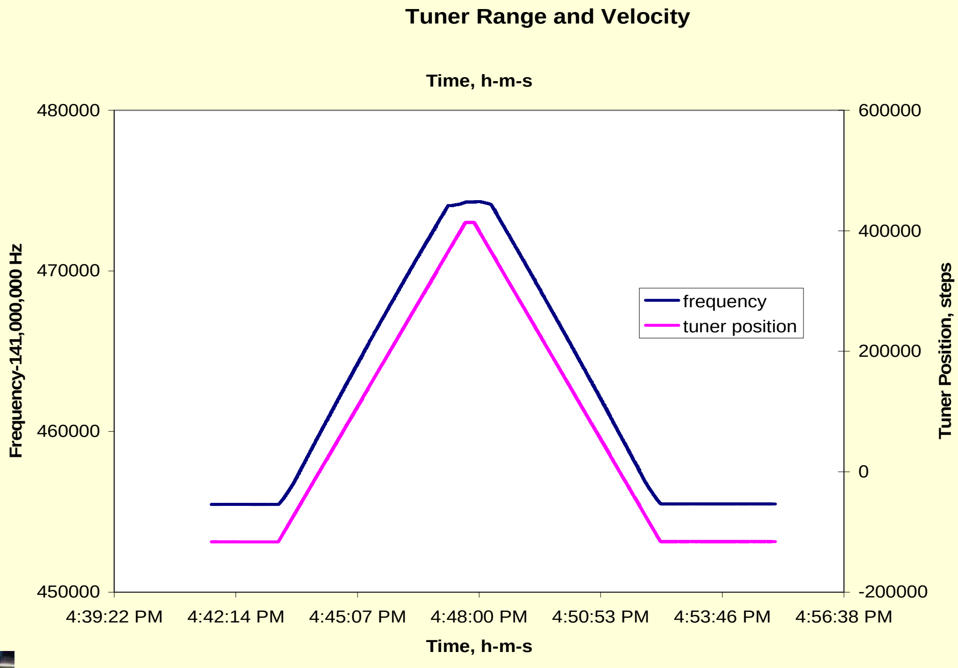


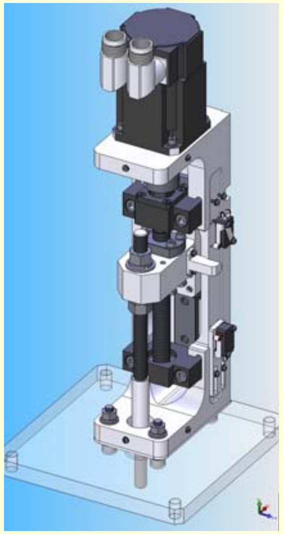


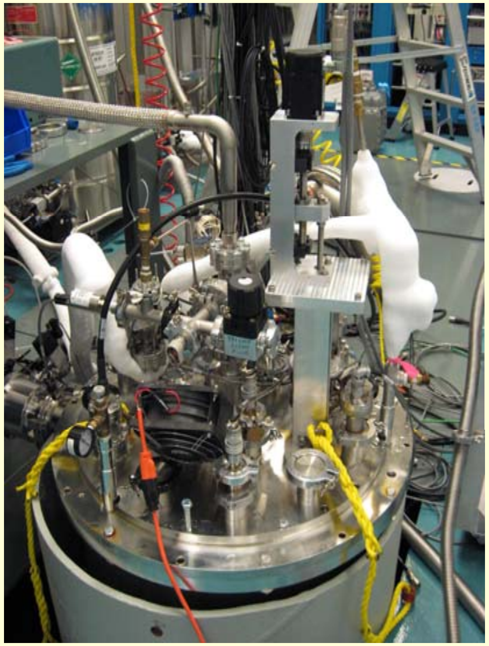
Solid State Amplifier designed for High Beta ISAC-II Cavities at QEI during the test shown very good performance and twice less noise level in RF System of the cavity in comparison with tube amplifier

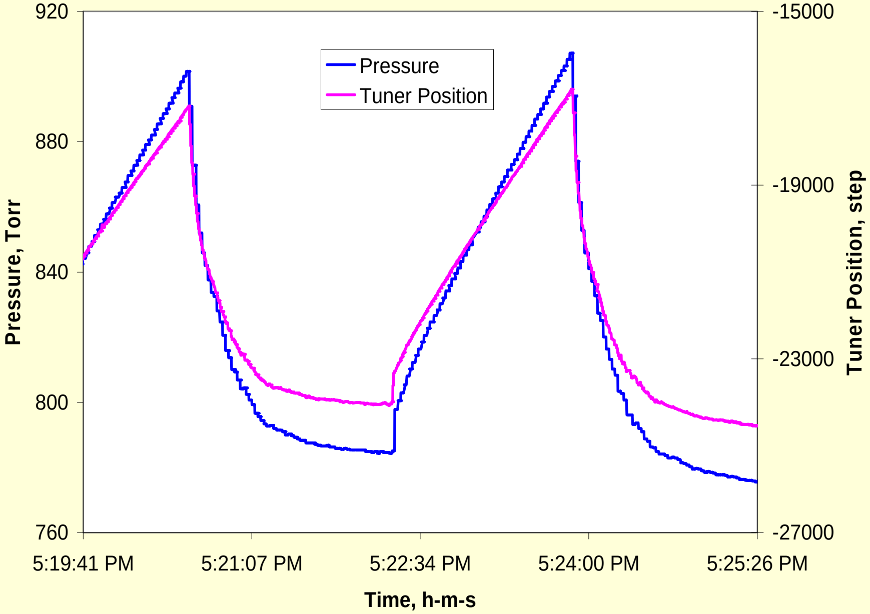
New Tuner

Static Test:
Range ~18.5 kHz, Velocity 76 Hz/s,
Resolution 0.04 Hz/step
Dynamic tests:
•He pressure variations
Ea= 6.4MV/m,Pf=166W, Df~40 Hz
Pressure variation 137 T ->Dfo~330 Hz
Velocity ~5.5T/s=13Hz/s
•Reference signal variations
1 Hz FM up to 10Hz deviation

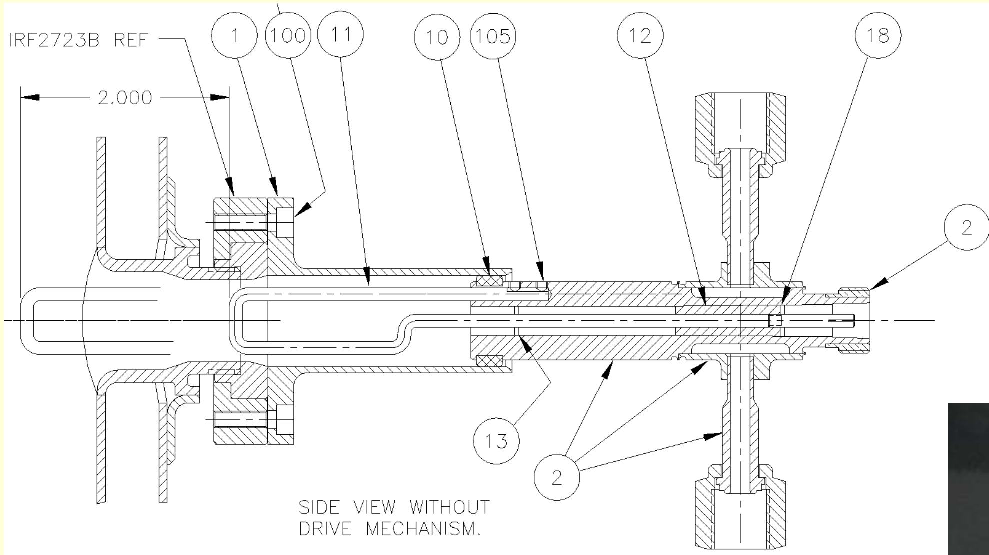




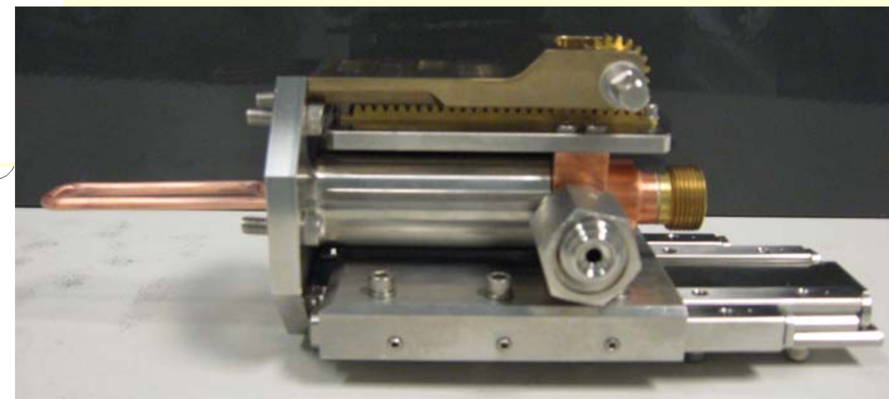


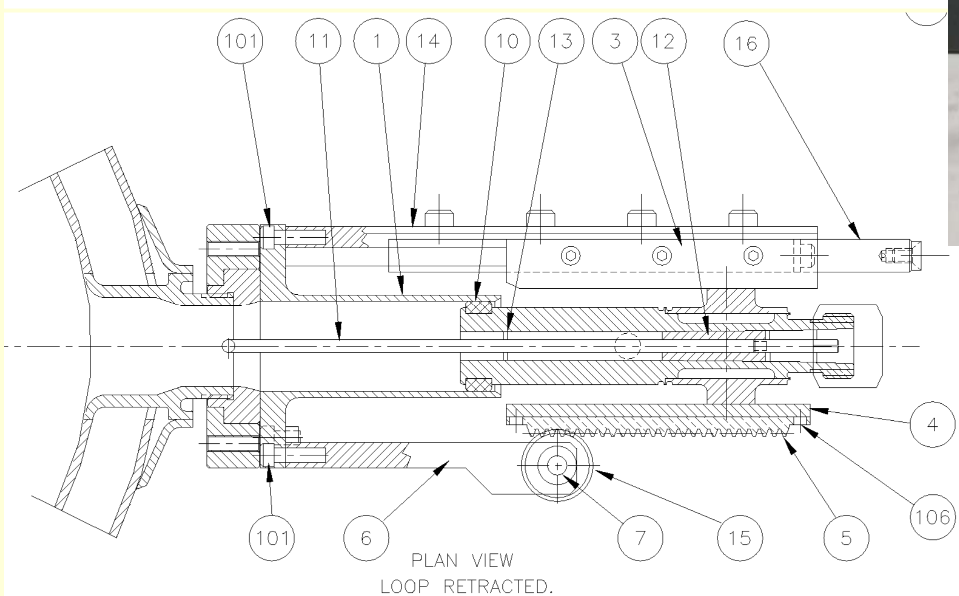


New Coupler Design



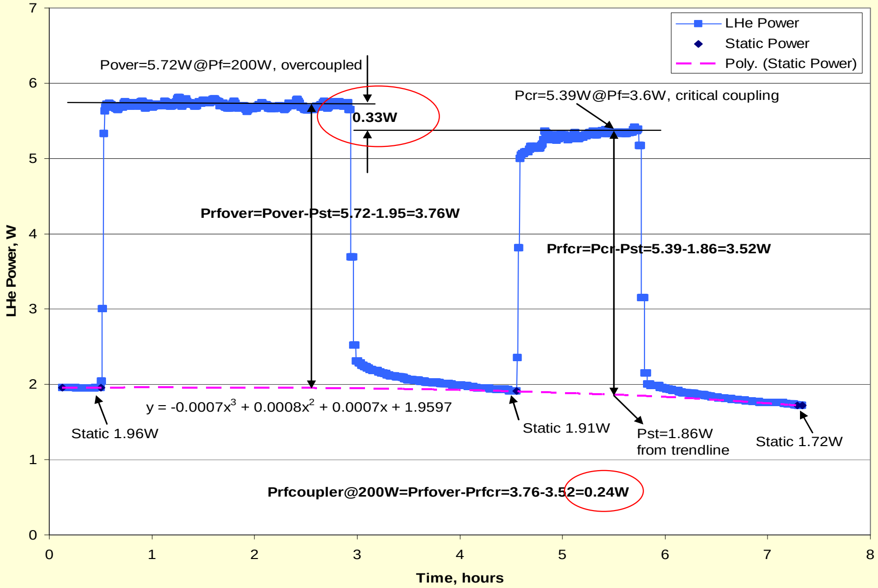
Heat sink for liquid nitrogen flux
Shapal RF window is thermal drain for inner conductor

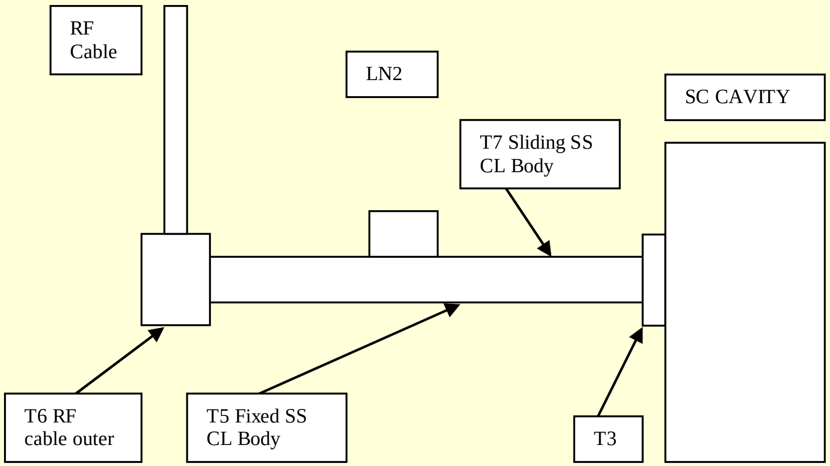


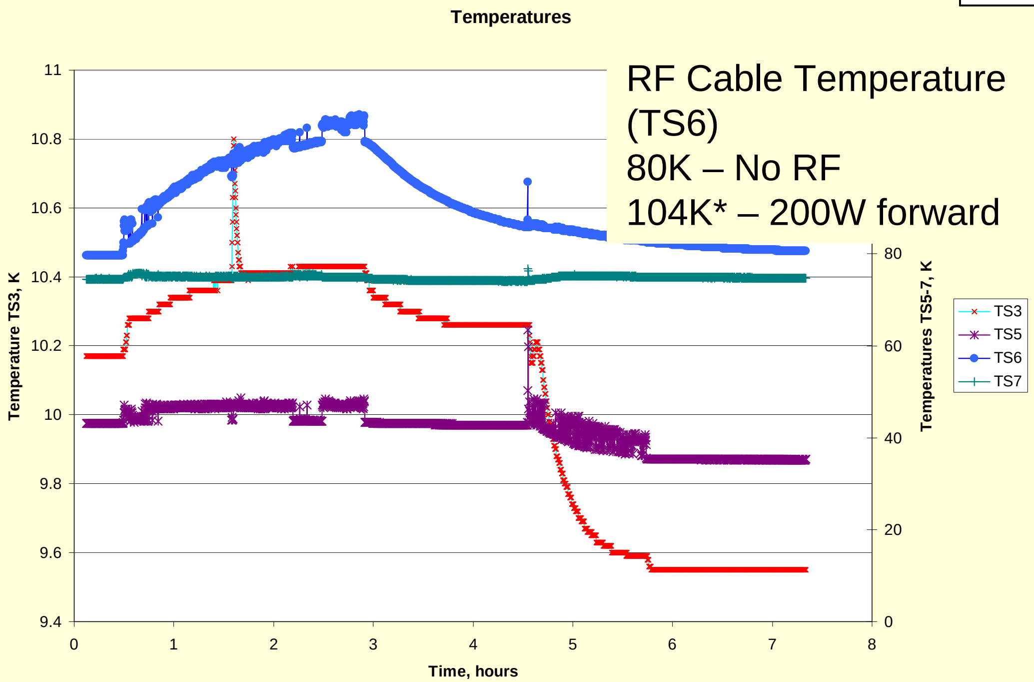


Trolley plate with cross-roller bearings provides smooth movement and holds load from rf cable and bellows with nitrogen

Coupler Design Test

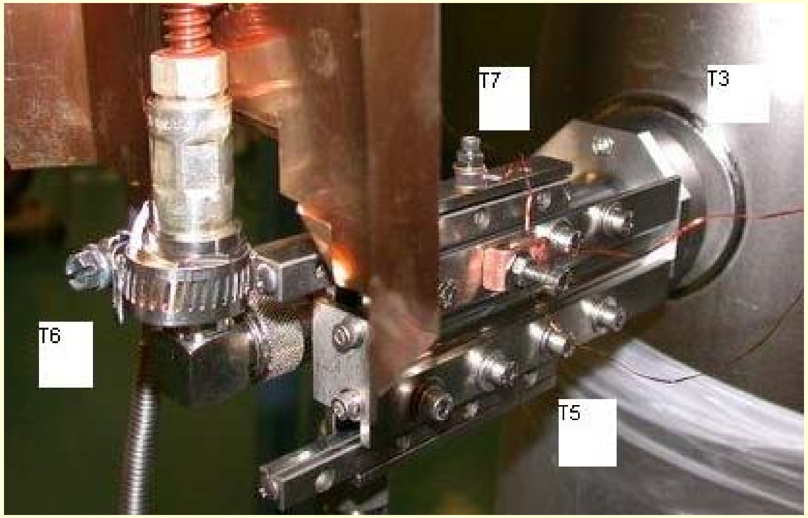






RF Cable Temperature (TS6)
80K – No RF
104K* – 200W forward

Coupler Loop Power Dissipation for He System
~0.25 W at Pf=200W



CONCLUSIONS

Two superconducting bulk niobium ISAC-II high beta prototype cavities have been developed, produced and successfully tested. The acceleration gradient at nominal power dissipation 7W is more than 8 MV/m. The fabrication of twenty cavities are underway with the first six expected in October 2008.

$t := \frac{-1.4}{1000}$ m - shift of the beam relatively aperture center

$$Ey := \frac{Ey2 - Ey1}{0.002} \cdot t + Ey2 - 0.001 \cdot \frac{Ey2 - Ey1}{0.002}$$

$$Bx := \frac{Bx2 - Bx1}{0.002} \cdot t + Bx2 - 0.001 \cdot \frac{Bx2 - Bx1}{0.002}$$

linearly interpolated field values along shifted beam

Scaling of the fields for Ea=6 MV/m

$Ez := sc \cdot Ez$ $Ey := sc \cdot Ey$ $Bx := sc \cdot Bx$ $Ex1 := sc \cdot Ex1$ $Ex2 := sc \cdot Ex2$

$Ey0 := sc \cdot Ey0$ $Bx0 := sc \cdot Bx0$

Calculation of the variation of the transverse momentum at Ea=6MV/m

$$\Delta\theta e(\beta) := \frac{q}{A} \cdot \frac{\sqrt{1-\beta^2}}{mo \cdot \frac{c^2}{qe}} \cdot \frac{\sum_{n=0}^{N} \left(Ey_n \cdot \sin\left(\frac{2 \cdot \pi \cdot f \cdot z_n}{\beta \cdot c} + \phi s + \pi \right) \right)}{\beta^2} \cdot \frac{Length}{N} \cdot 10^3$$ mrad - electric component

$$\Delta\theta m(\beta) := \frac{q}{A} \cdot \frac{\sqrt{1-\beta^2}}{mo \cdot \frac{c^2}{qe}} \cdot \frac{\sum_{n=0}^{N} \left[\beta \cdot c \cdot Bx_n \cdot \cos\left[\left(\left(\frac{2 \cdot \pi \cdot f \cdot z_n}{\beta \cdot c} + \phi s + \pi \right)\right)\right] \right]}{\beta^2} \cdot \frac{Length}{N} \cdot 10^3$$ mrad - magnetic component

$\Delta\theta s(\beta) := \Delta\theta e(\beta) + \Delta\theta m(\beta)$ mrad - trajectory angle at resonator output