(1) RF Power Coupler
(2) Piezoelectric Tuner
(3) Cavity tuning during fabrication

October 2011 Project X collaboration meeting

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October 25, 2011

Background: Power Coupler Experience at Argonne National Laboratory

- **ATLAS: World's first superconducting linac for ions (1978-present)**

  Cavities prior to the 2009 109 MHz ATLAS Energy Upgrade used small ***variable position magnetic loop coupler*** (split-ring and 4-gap interdigital QWR) with ~200 Watts forward power

  - provides direct connection of center conductor to outer conductor for easy cooling

- **ATLAS Energy Upgrade 2009**

  109 MHz QWR required a ***large loop inserted far into the rf space*** at the bottom of the cavity

  - One QWR cavity was assembled with a capacitive probe

- **New ATLAS Intensity Upgrade 2010-2013**

  Relatively higher power (4 kW) plus the desire to couple from the bottom makes capacitive coupler a natural choice

Basic Considerations for Power Coupler

1. **Power handling capability**
   - ATLAS, 4 kW at 72 MHz (full reflection, overcoupled/weakly coupled)
   - Project X, 10 kW 162 MHz

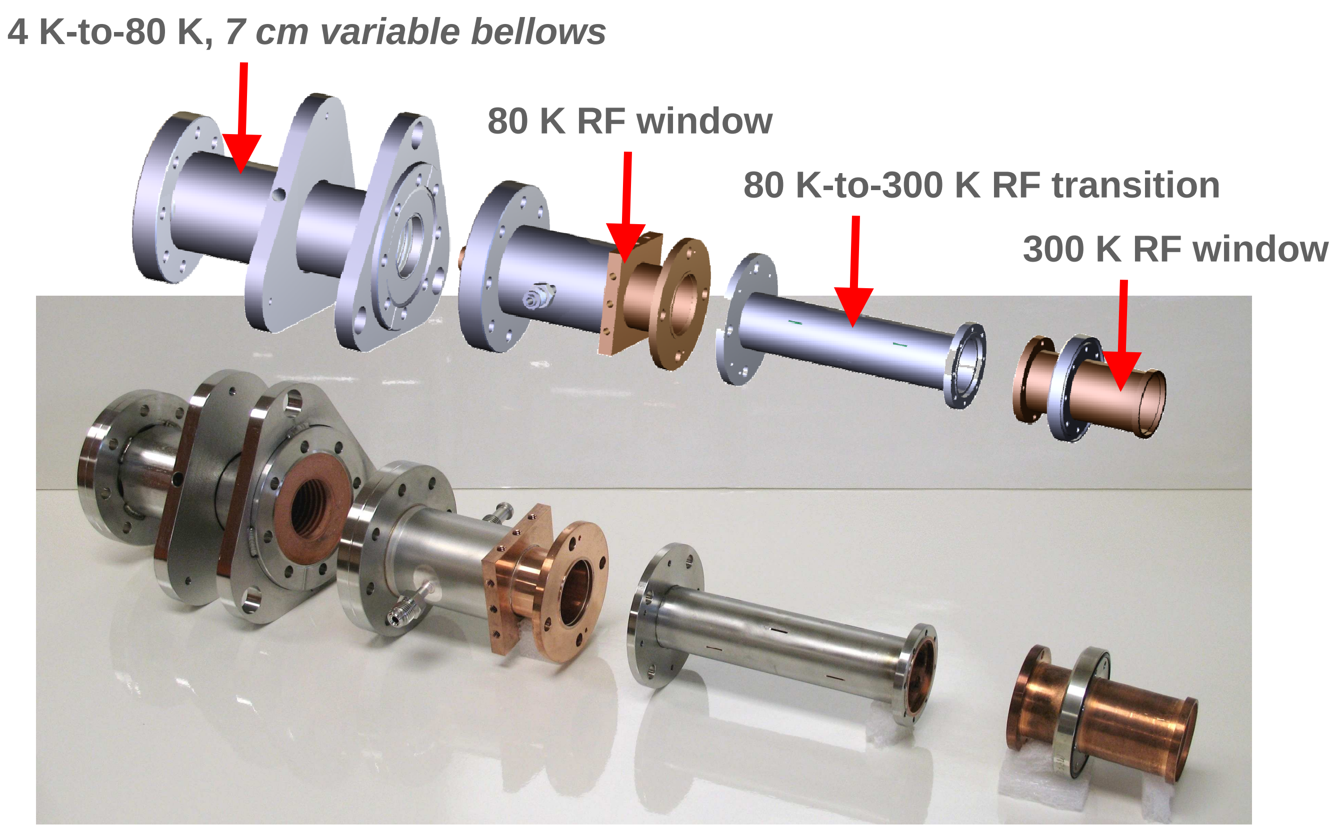
2. **Little/No adverse impact on cavity rf performance**
   - Cleanliness
   - Static/dynamic heat losses to He

3. **Suitability for anticipated linac operating modes**
   - High beam-power, overcoupled, full reflection
   - Low beam-power, ~critically coupled as for beam tuning
   - RF conditioning of SRF cavity, cavity multipacting, high-power pulse conditioning

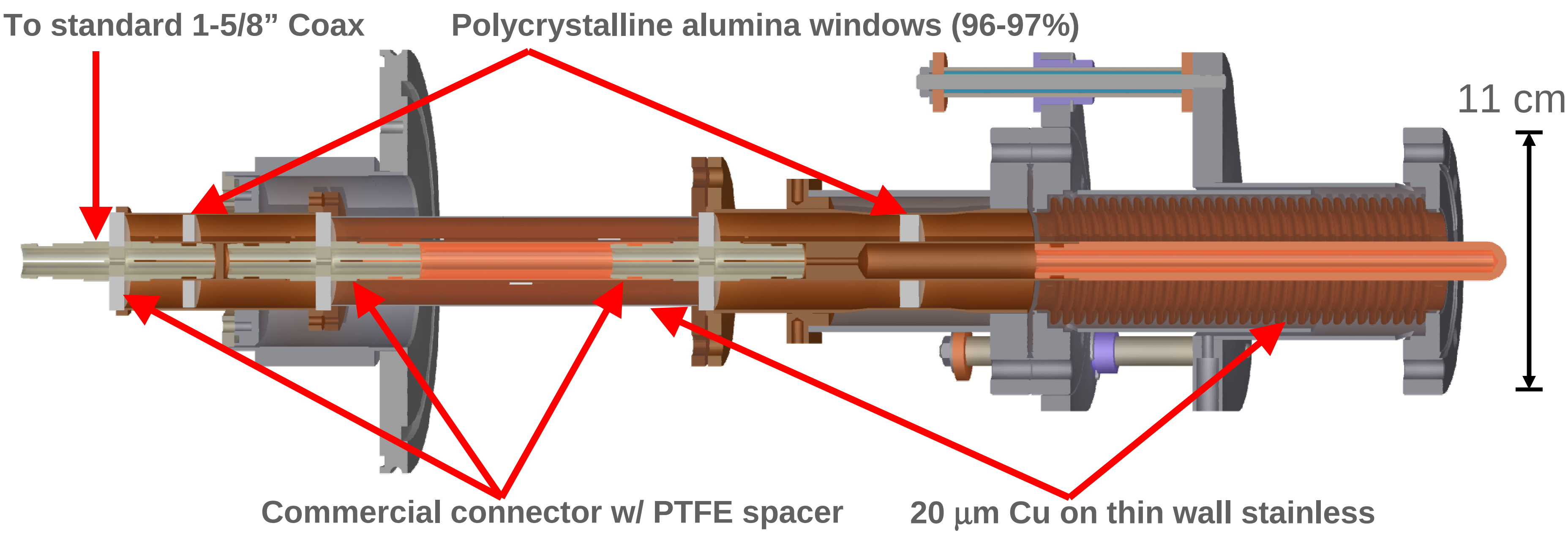
New ANL Power Coupler: 4 kW, 72 MHz (nominal)

ANL has developed an electric field coupler based on a 4 cm (1-5/8”) diameter, 50 Ω coaxial transmission line for:

- Phase and amplitude control
- Power for high intensity beams



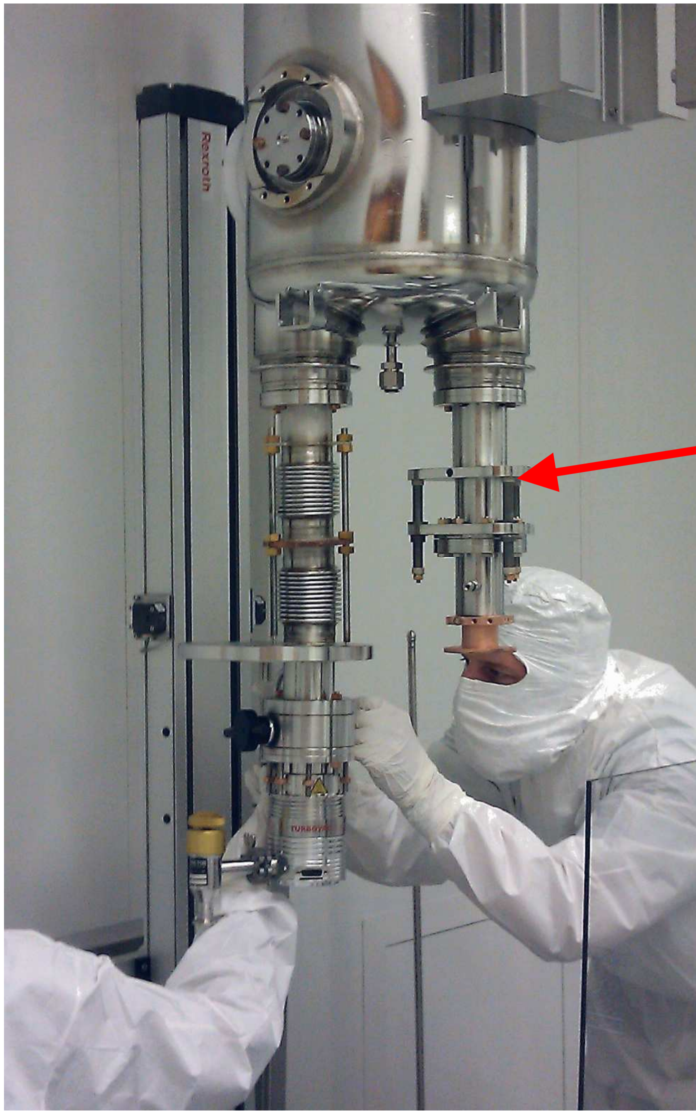
Power Coupler Section View



Power Coupler Parameters

Parameter	Value
Overall length	58.5 cm
Bellows length (4 – 80 Kelvin)	17.8 cm
Cold Window length	14.4 cm
Thermal transition length	15.7 cm
Warm window length	8.9 cm
Line Impedance	50 Ω
Reflection coefficient S11 @ 72 MHz	-22 dB
Static Heat leak to 4 Kelvin	13 mW
Static Heat leak to 80-to-300 Kelvin	2.1 W

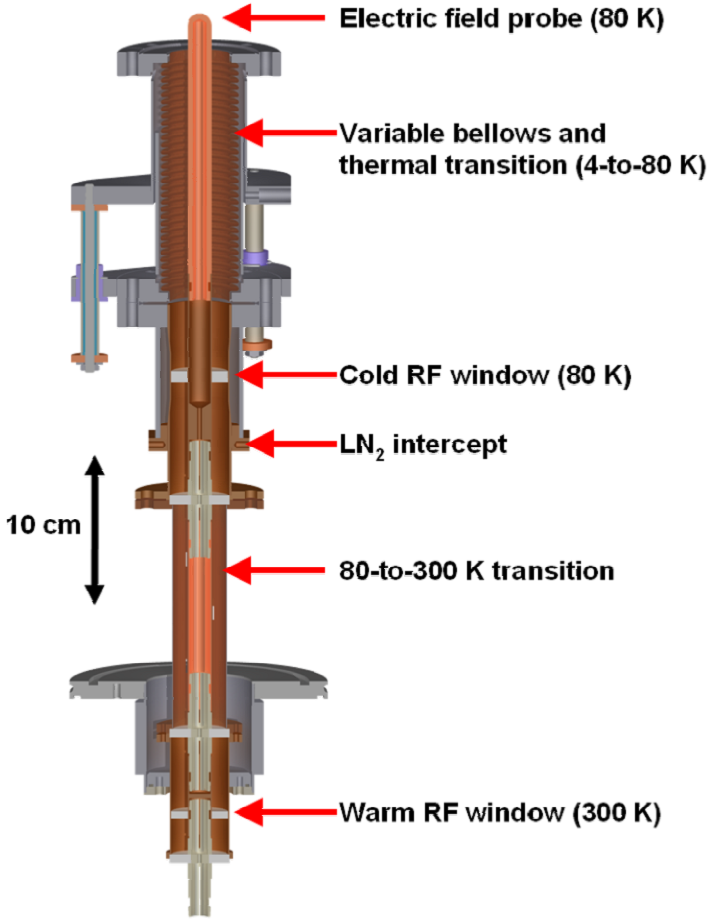
Power Coupler During Cavity Assembly

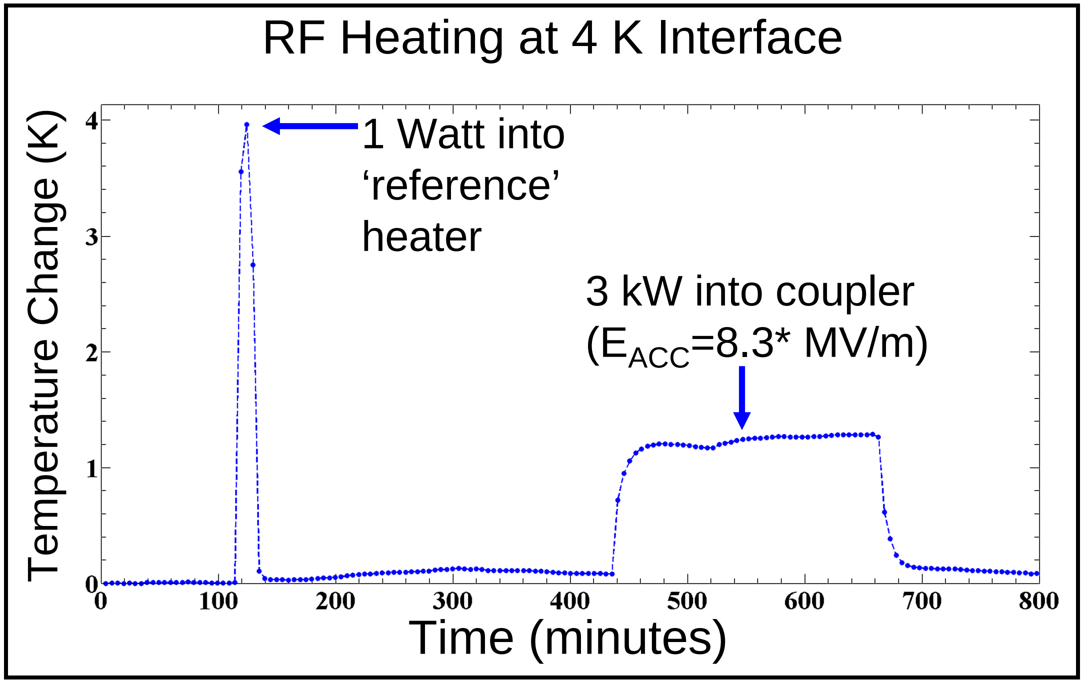


Coupler (bellows and cold window)

Measured Coupler Heating: 4 Kelvin Cavity/Coupler Flange

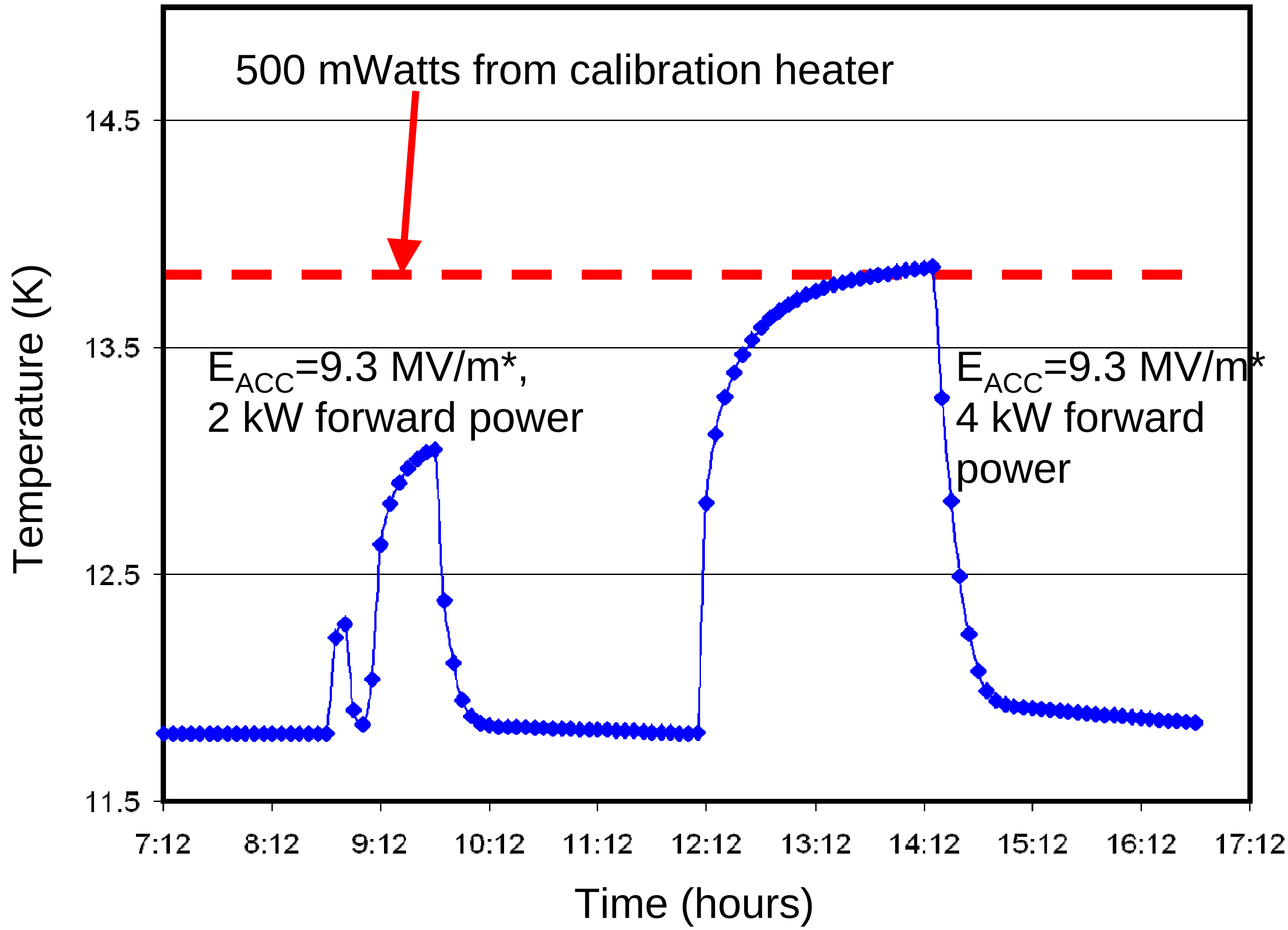
- Completed realistic tests at 3 kW forward power
- ***No unexpected rf heating observed***





*E_{ACC}=8.3 MV/m is planned ATLAS field level ($l_{eff}=\beta\lambda$)

Measured Coupler Heating: 4 Kelvin Cavity/Coupler Flange



*E_{ACC}=9.3 MV/m is ~10% above planned ATLAS field level

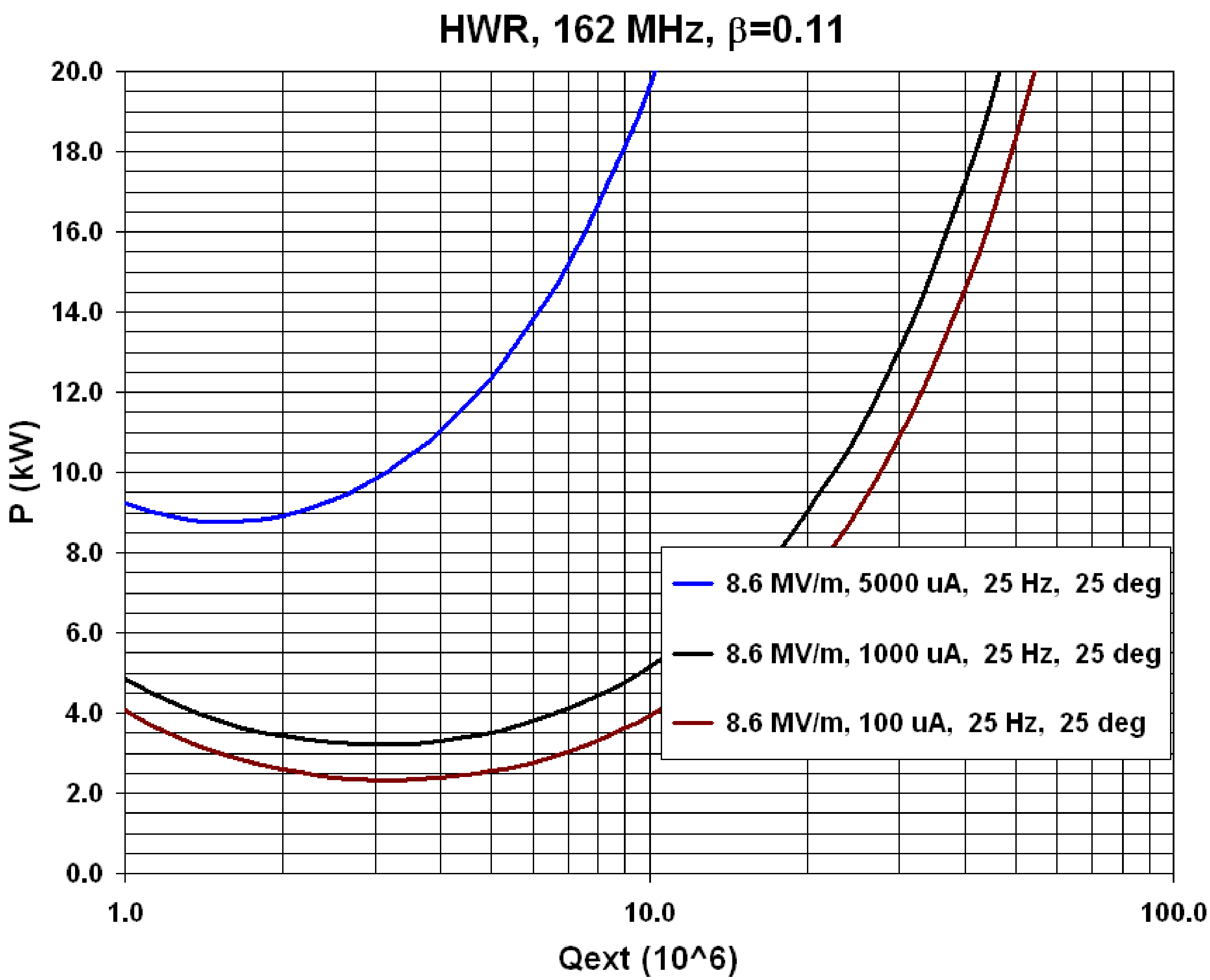
Extension to162 MHz, 10 kW forward power

- **Power handling capability**
  - ATLAS 4 kW at 72 MHz (full reflection, overcoupled/undercoupled) – **demonstrated in many hours of testing**
  - Project X, 10 kW at 162 MHz – **coupler multipacting possible (rf window-to-conductor) in the range 4-10 kW at 162 MHz; ANL will do some study but prototyping much more important**

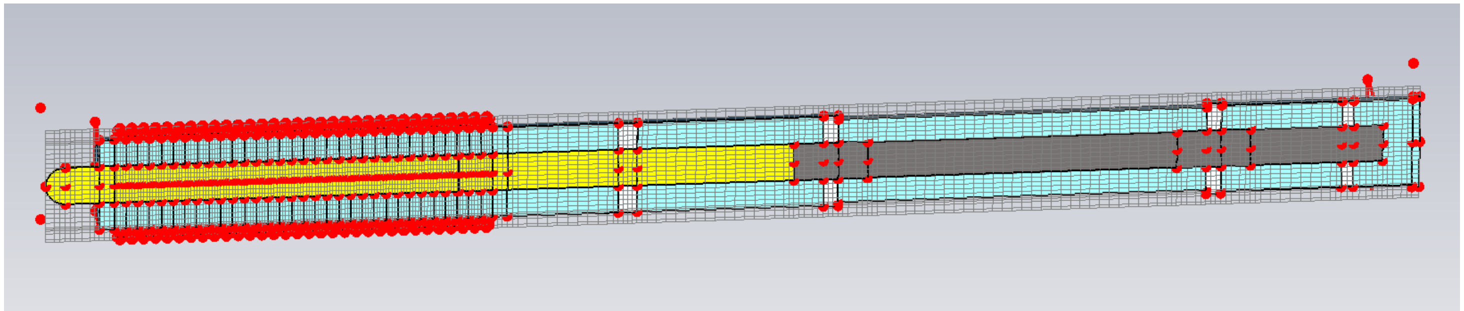
- **Little/No adverse impact on cavity rf performance**
  - Cleanliness
  - Static/dynamic heat losses to He – **scaling from present measurements dynamic heat load to 4 K should be 1 - 1.5 Watts for 10 kW 162 MHz; will be easily reduced by straightforward shortening of the bellows/cold window assembly without creating large static losses (only ~0.013 Watts now)**

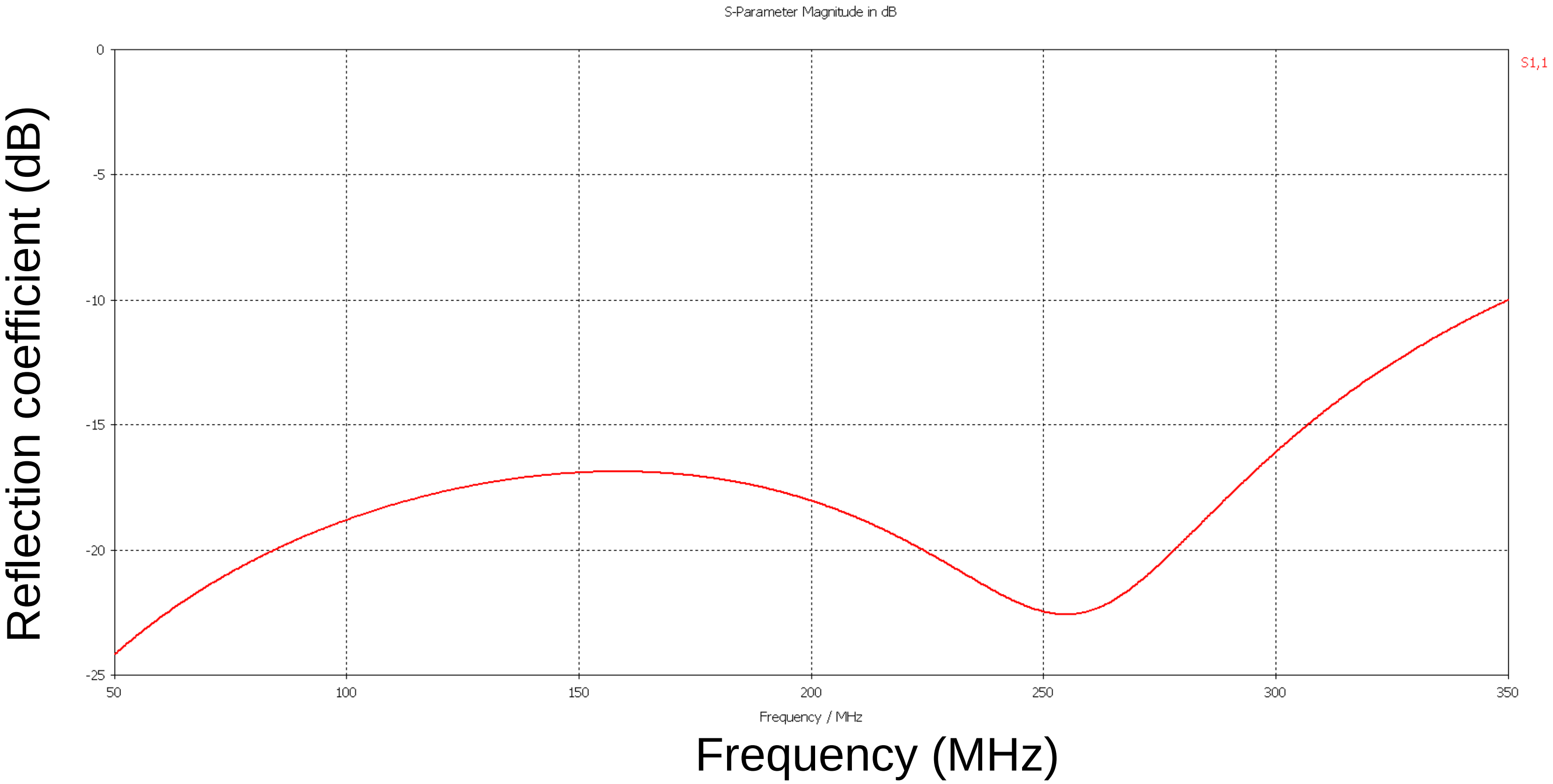
- **Suitability for anticipated linac operating modes – want to maintain variable coupling for same reasons**
  - High beam-power overcoupled, full reflection
  - Low beam-power, ~critically coupled as for beam tuning
  - RF conditioning of SRF cavity, multipacting, high-power pulse conditioning

Coupler RF power requirements



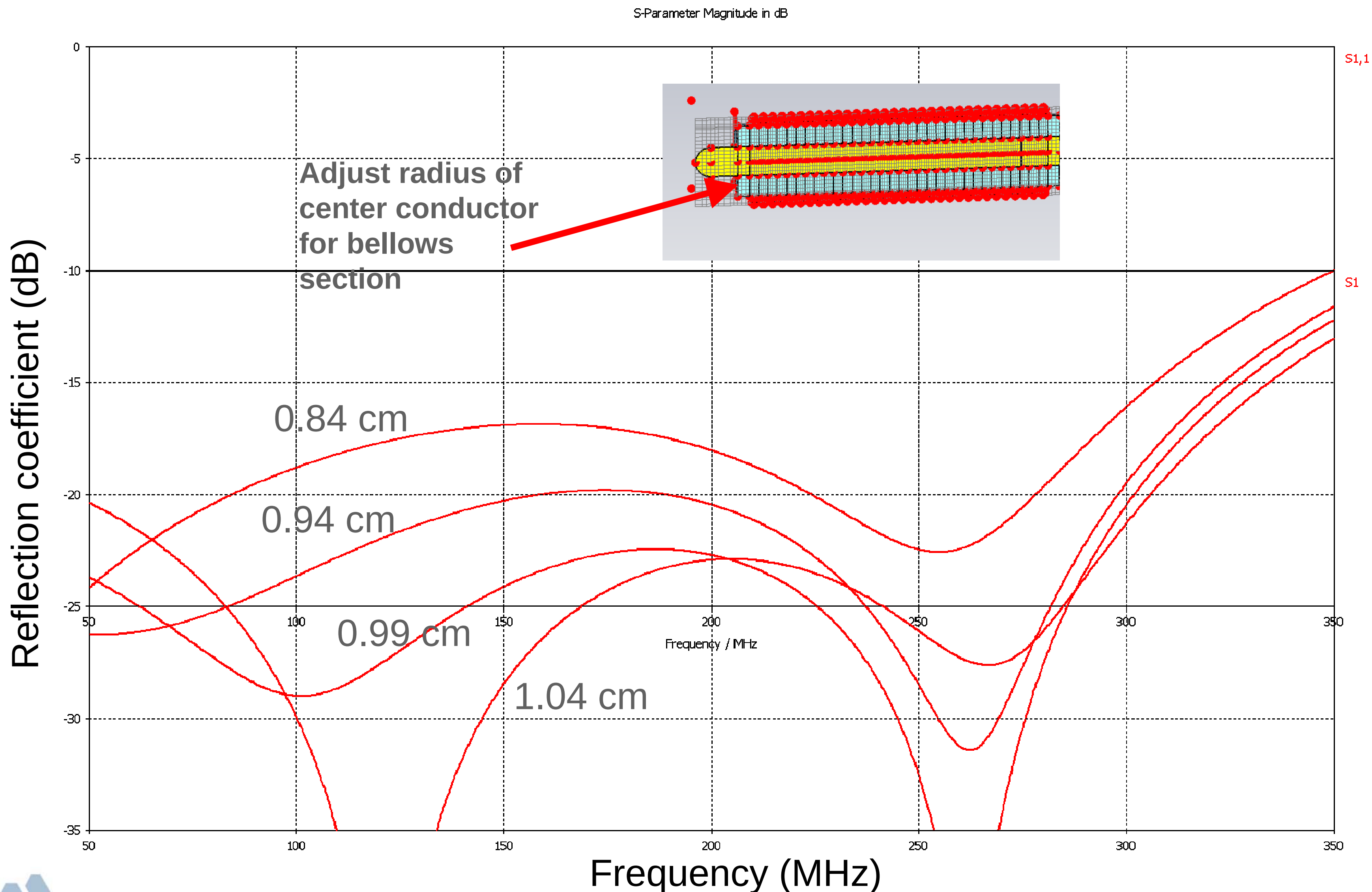
Coupler reflection coefficient vs. frequency





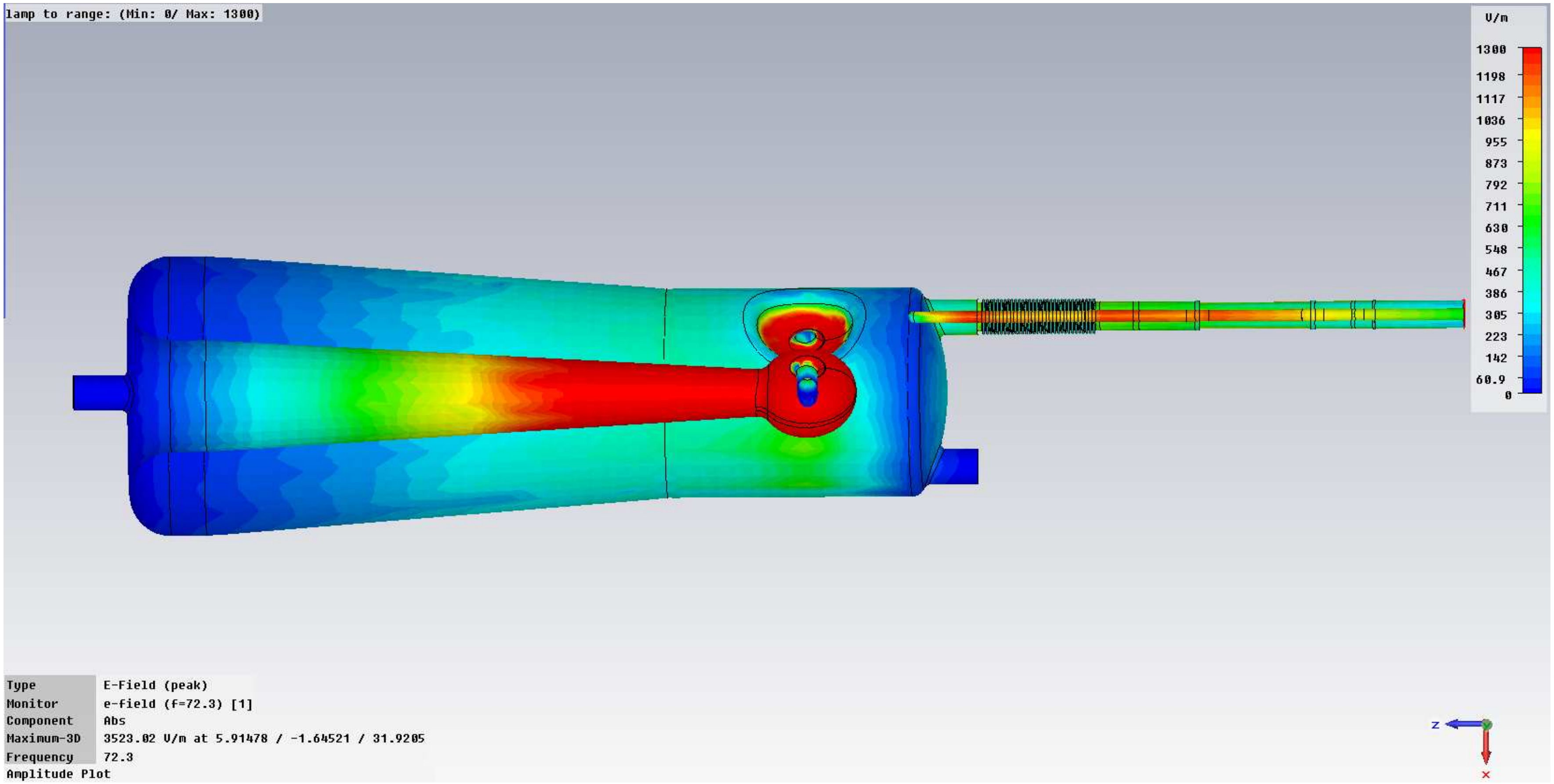
Coupler reflection coefficient – OK already

However, easy to optimize by increasing radius of center conductor inside bellows section



Ongoing Work:

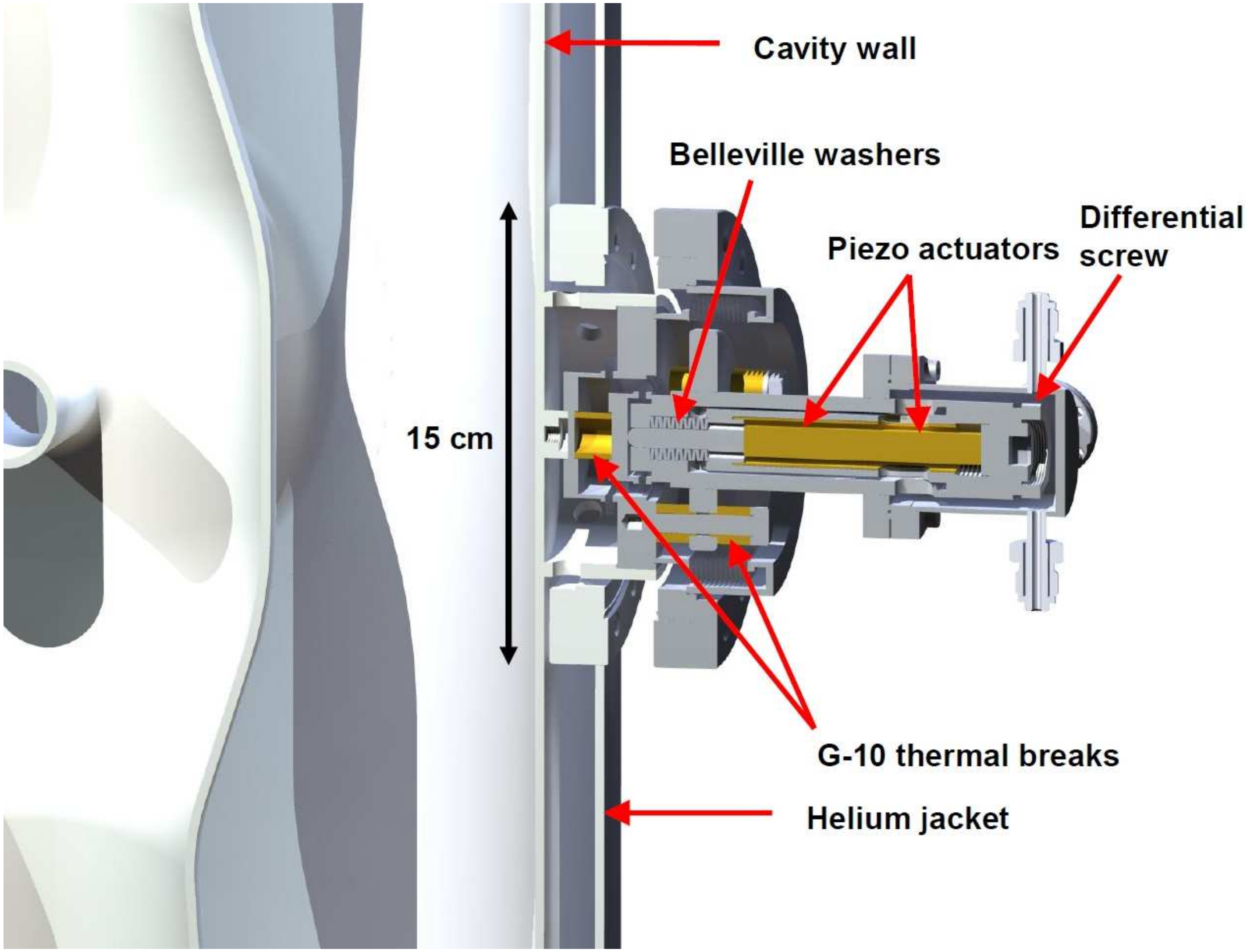
Study field profile and RF losses using CST Microwave Studio



Challenge: A realistic simulation requires accurate losses on each of the components (normal and SC) and calculation at the peak of the cavity resonance; not easy due to mesh effects

(2) Piezoelectric Tuner

Piezoelectric tuner (cut section) on a halfwave cavity wall

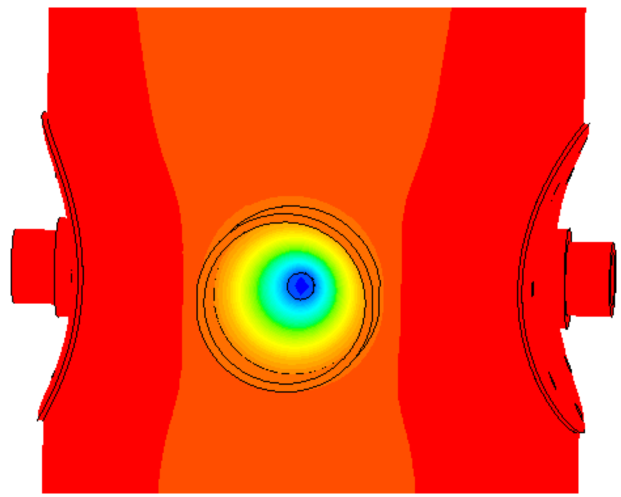


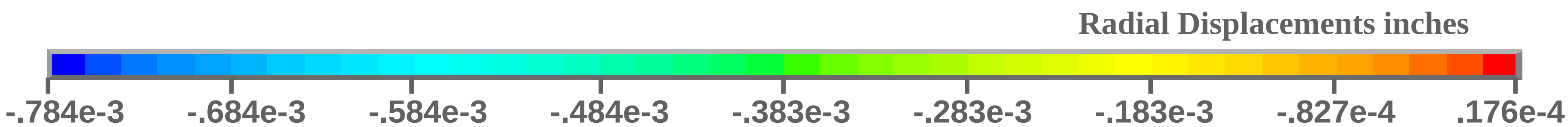
FEA Simulation (72 MHz QWR) of the Effect of Piezoelectric Tuner using only 1 of 2 stacks

20 microns through gap element

df = -46.5 Hz

Tuner Load 42. lbs





Piezoelectric tuner mechanical components

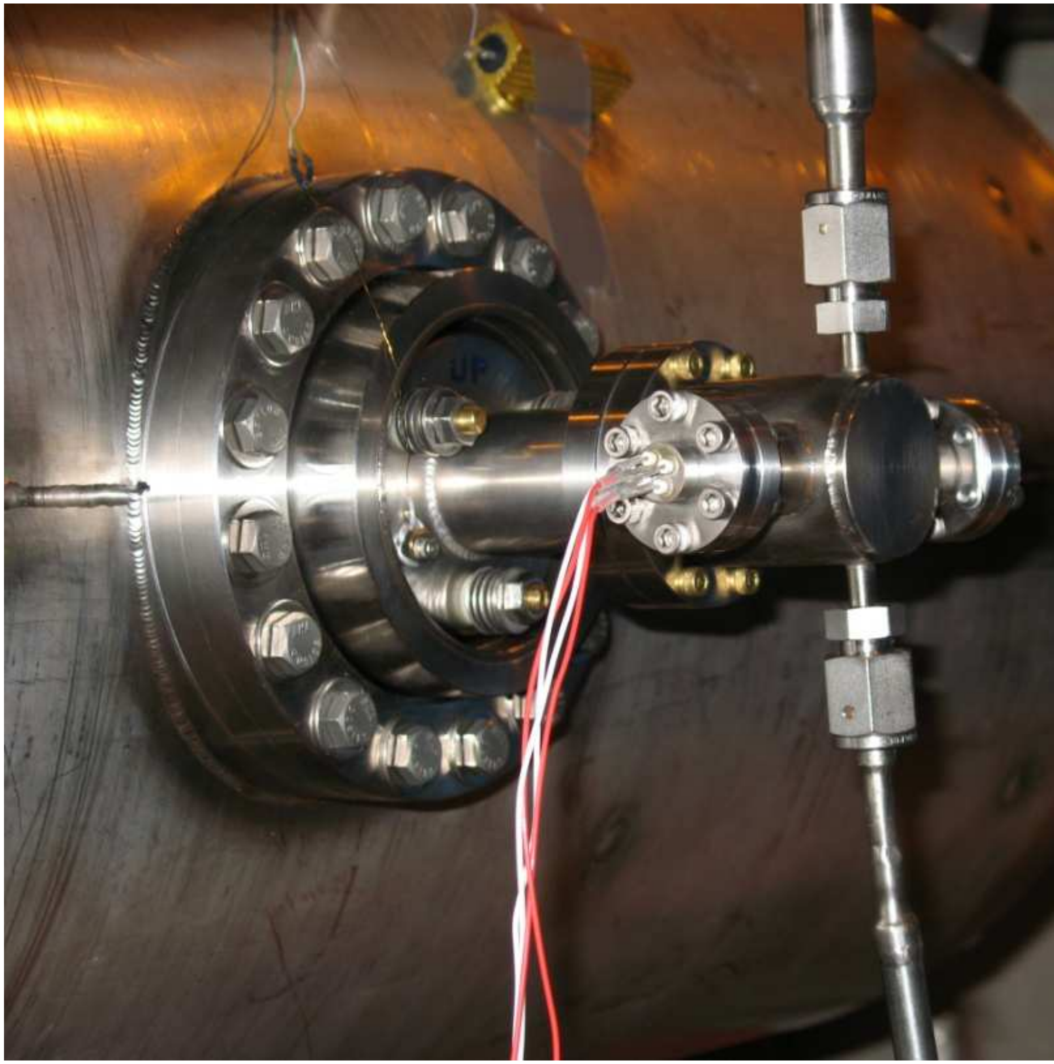
"Compression" of the piezoelectric stack during cooldown

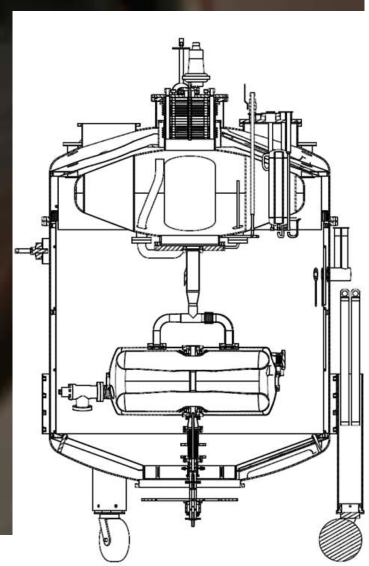
	Compression		
PART	**OPERATING TEMP**	**LENGTH (INCH)**	**ΔL(inches)**
MOUNTING RING (Nb)	4K	1.230	1.75E-03
CARTRIDGE GUIDE TUBE (INVAR-36)	80K	3.880	1.36E-03
WASHER STACK (G-10 NORMAL DIRECTION)	4K	0.313	2.09E-03
SHOULDER WASHER (G-10 FILL DIRECTION)	4K	0.125	3.11E-04
BELLOWS FLANGE (STAINLESS STEEL)	4K	0.250	7.43E-04
DIFFERENTIAL SCREW (SILICON BRONZE)	80k	0.110	3.84E-04
TOTAL			**6.64E-03**

“Shrinkage” of the piezo stack and related components during cooldown

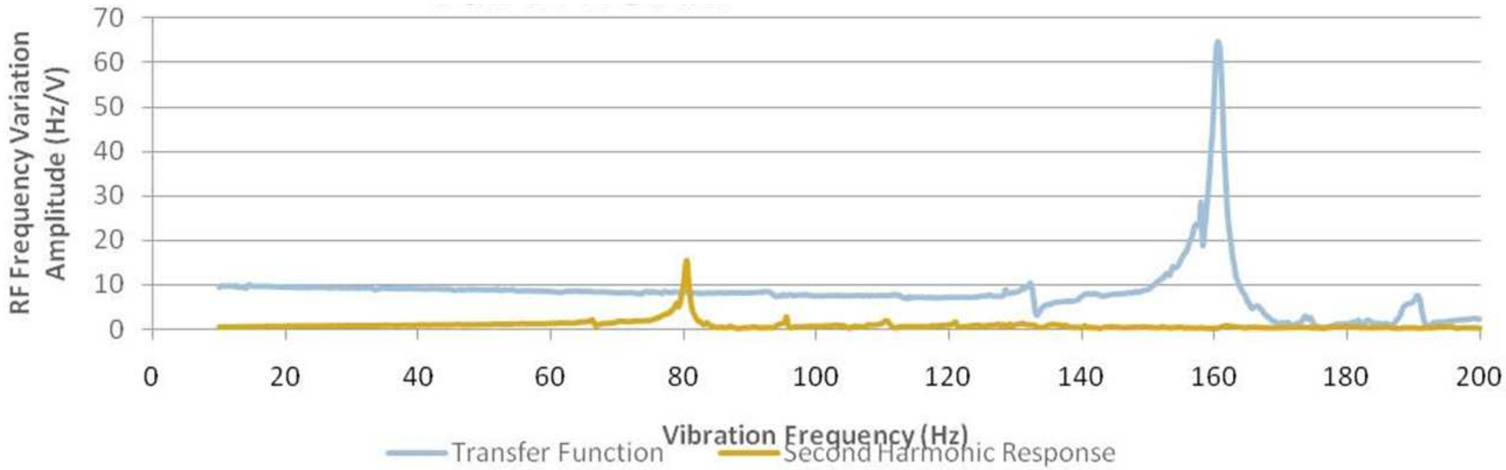
	Decompression		
PART	**OPERATING TEMP**	**LENGTH (INCH)**	**ΔL(inches)**
PIEZO PLUNGER (INVAR-36)	80K	1.538	5.38E-04
SM. BELLOWS DISK (INVAR-36)	80K	0.213	7.44E-05
CYLINDER (G-10 FILL DIRECTION)	4K	0.500	1.25E-03
LG. BELLOWS DISK (INVAR-36)	4K	0.088	3.24E-05
BOSS (Nb)	4K	0.313	4.44E-04
PIEZO STACKS (PZT)	80K	3.150	2.96E-03
PIEZO THRUST PLATE (STAINLESS STEEL)	80K	0.125	3.51E-04
TOTAL			**5.65E-03**
Total effective compression on the piezo stacks			**9.90E-04**

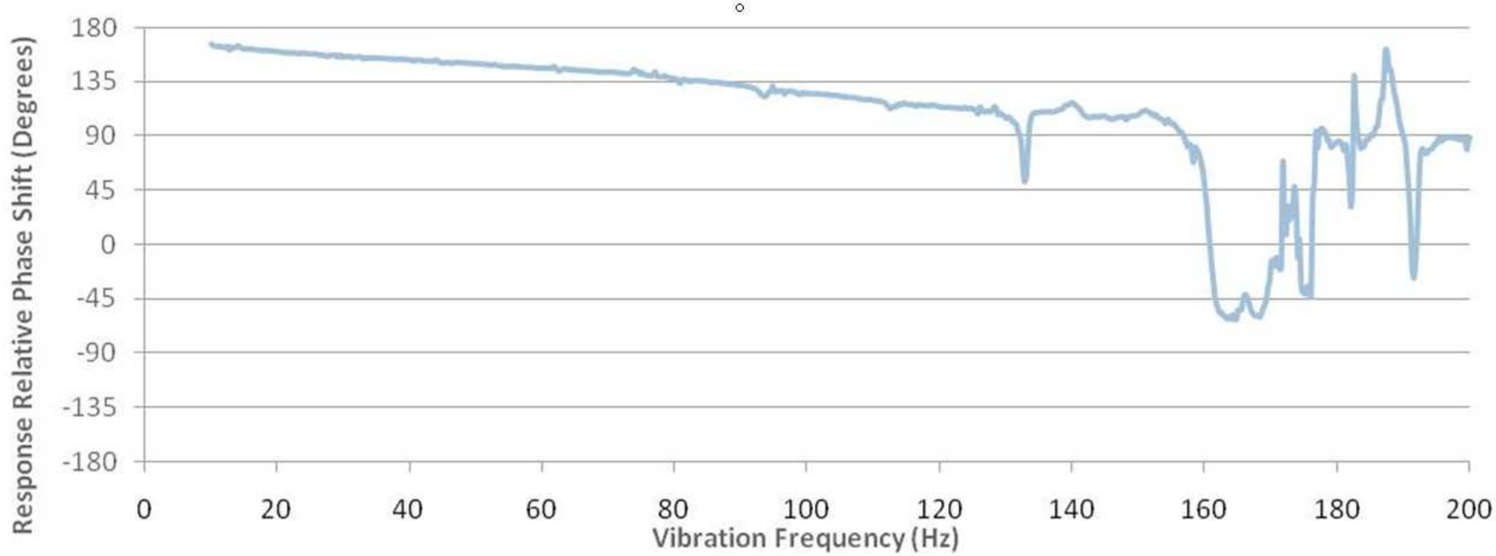
Piezoelectric tuner on the side of the (RIA) 172 MHz half-wave cavity



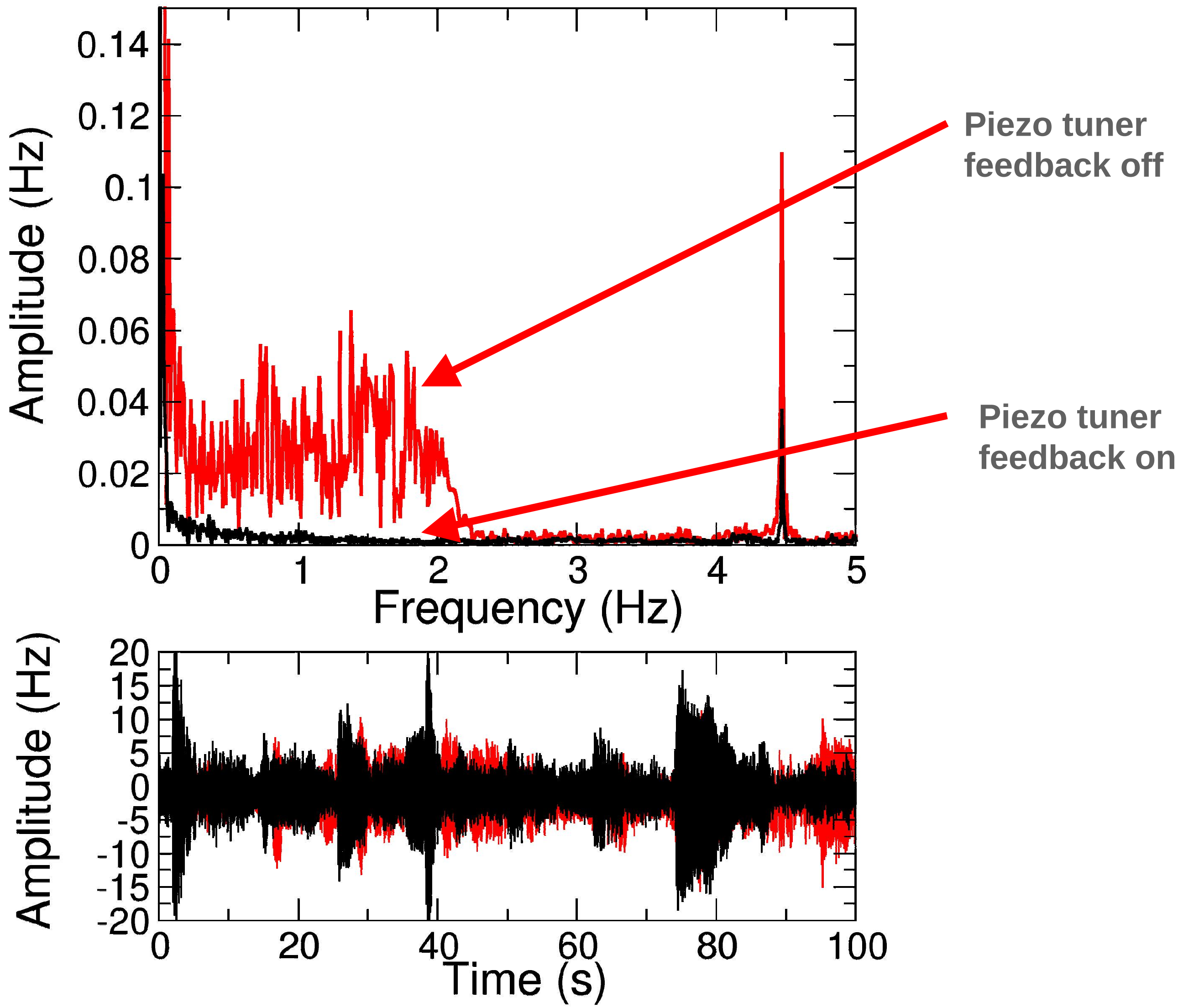


Measured Piezoelectric tuner transfer function with 172 MHz Half-wave cavity



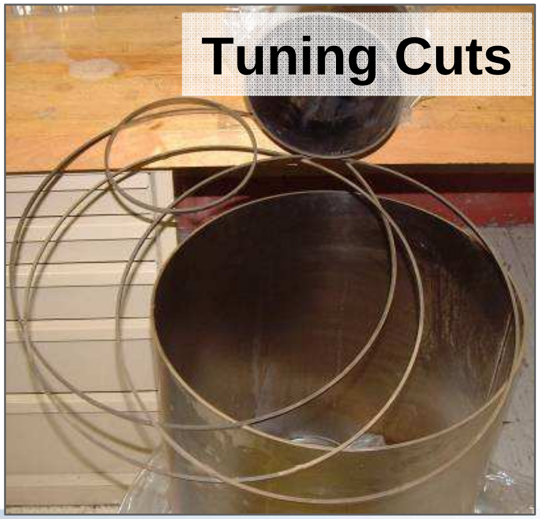


“Low frequency” microphonics damping with the piezo tuner (ANL 72 MHz QWR)



(3) Cavity tuning during fabrication

Cavity Fabrication by Wire EDM



Wire EDM at Adron

Cavity - Tuning

		∆ Frequency	Frequency	
1)	Release 1/2 of Slow Tuner Pressure	14	72,764	kHz
2)	Vent He system to atmosphere -.3 atm	0.4	72,764.4	kHz
3)	Warm cavity up to room temperature	-104.1	72,660.3	kHz
4)	Vent cavity space to air	1.19	72,661.5	kHz
5)	∆freq due to dielectric constant of air	-22.4	72,639.1	kHz
6)	Electropolish cavity	-28.5	72,610.6	kHz
7)	Add Dome Weld shrinkage 28 mil	2.1	72,612.7	kHz
8)	Clamp dome w/ 10mil indium wire	0.8	72,613.5	kHz
8)	Add Dome Cut (nominal 0.635cm overlong)	16.5	72,630.0	kHz
9)	Add Tapered housing weld shrinkage top 28m	4.2	72,634.2	kHz
10)	Add Tapered housing weld shrinkage bott 28m	2.8	72,637.0	kHz
11)	Add tapered housing 10mil indium top	1.5	72,638.5	kHz
12)	Add tapered housing 10mil indium bott	1	72,639.5	kHz
13)	Add Center conductor weld shrinkage 20mil	-30.5	72,609.0	kHz
14)	Add 10 mil indium for center conductor	-15.2	72,593.8	kHz
15)	Add back center conductor/cylinder .4935 in	-690.9	71,902.9	kHz
16)	Add back center conductor/cylinder .4935 in	-690.9	71,212.0	kHz
17)	Add back in 1.25 on bottom of cylinder	53	71,265.0	kHz

Example of tuning steps

Mechanical tuning

TIG welding

E-beam welding

- Mechanical frequency tuning well understood
- Some uncertainty from SS weld deformation (especially with ASME pressure code)
- Solution: Final closure weld now using e-beam weld (valuable prototype lesson)

Summary

- Existing ANL RF power coupler demonstrated at 72 MHz and 4 kW forward power (with full reflection)
  - This coupler should be the starting point for 162 MHz, 10 KW RF coupler for FNAL
- Piezoelectric tuner well suited to inherently stiff half-wave design
  - At ~$12K/unit with all controls this may offer substantial savings compared to rf power
  - Should be kept in the Project X development plan at least through cavity prototyping phase
- Cavity fabrication and tuning is well understood