LCLS-II Couplers and Related R&D

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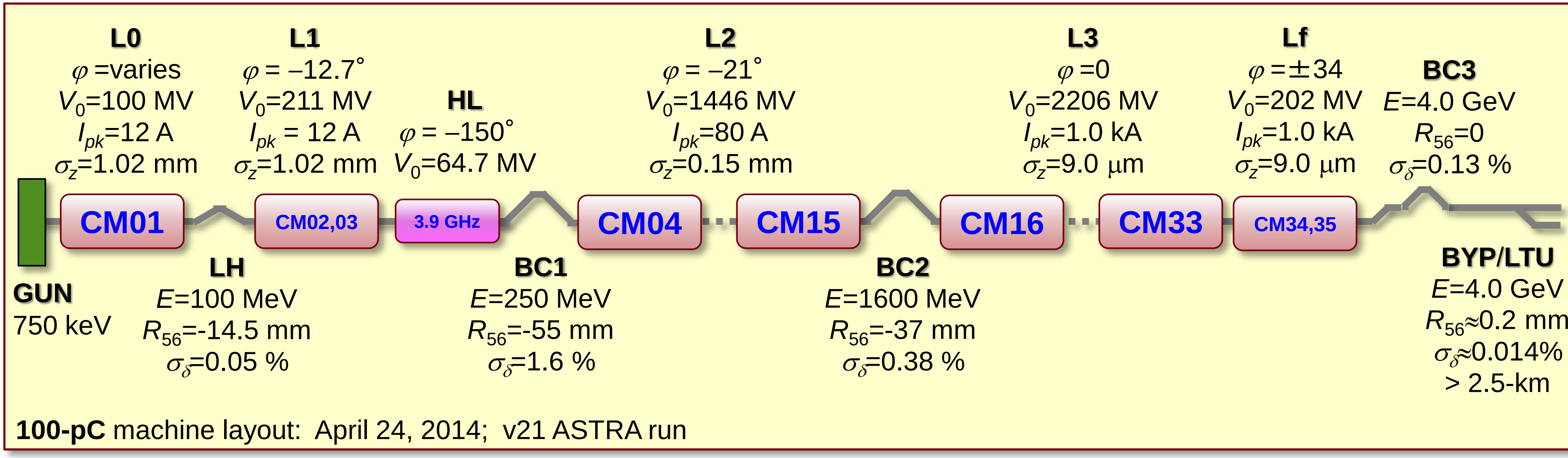
June 23, 2015

Linac Layout, Gradients, Spares and Cavities per Source



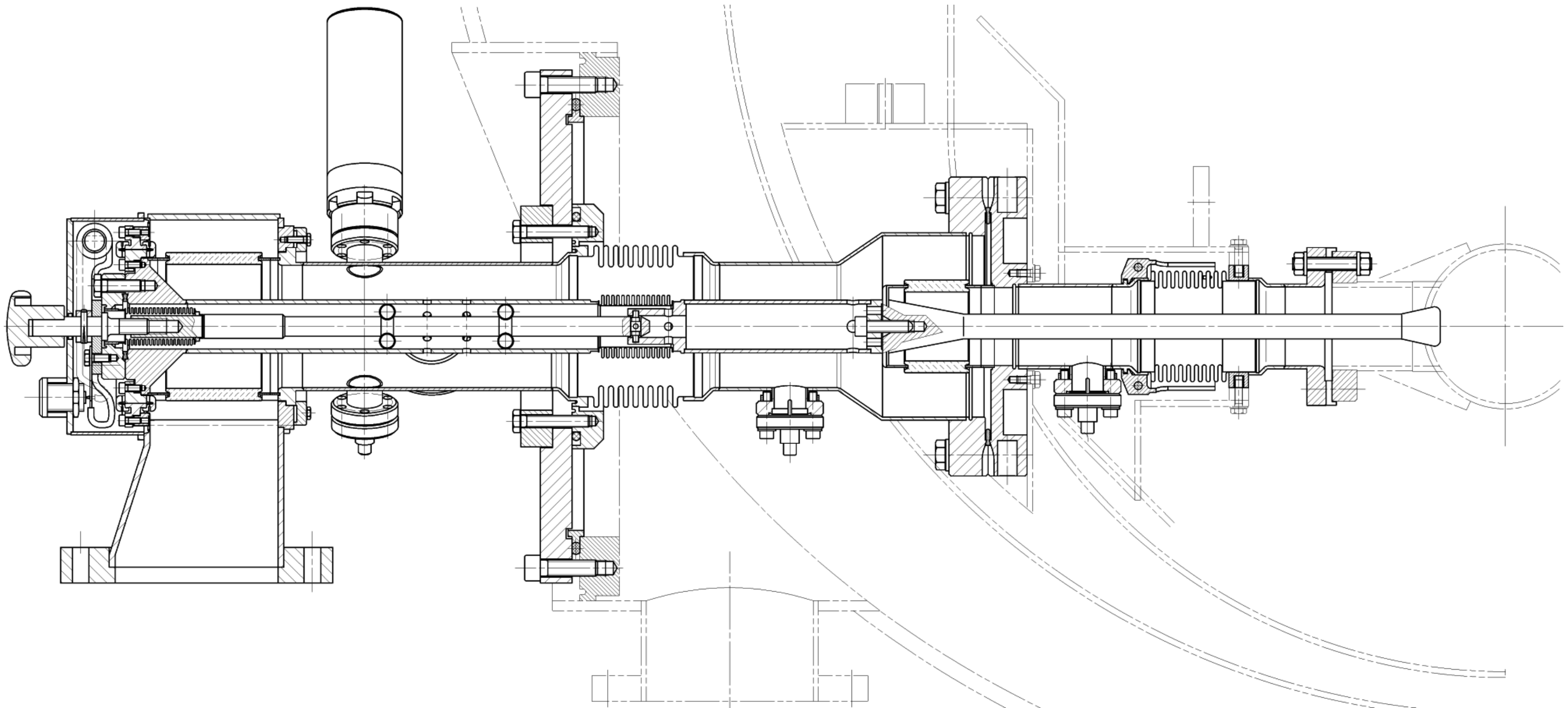
Linac Sec.	V_0 (MV)	φ (deg)	Acc. Grad.* (MV/m)	No. Cryo Mod's	No. Avail. Cav's	Spare Cav's	Cav's per Amp.
L0	100	varies	16.3	1	8	1	1
L1	211	-12.7	13.6	2	16	1	1
HL	-64.7	-150	12.5	2	16	1	1
L2	1446	-21.0	15.5	12	96	6	1
L3	2206	0	15.7	18	144	9	1
Lf	202	±34	15.7	2	16	1	1

In total need 280, 1.3 GHz variable couplers (~ 7 kW max input) and 16, 3.9 GHz fixed couplers (~ 1 kW max input)

1.3 GHz Cavity Power Coupler

Use basic DESY 2006 TTF3 design with EuXFEL modifications, but

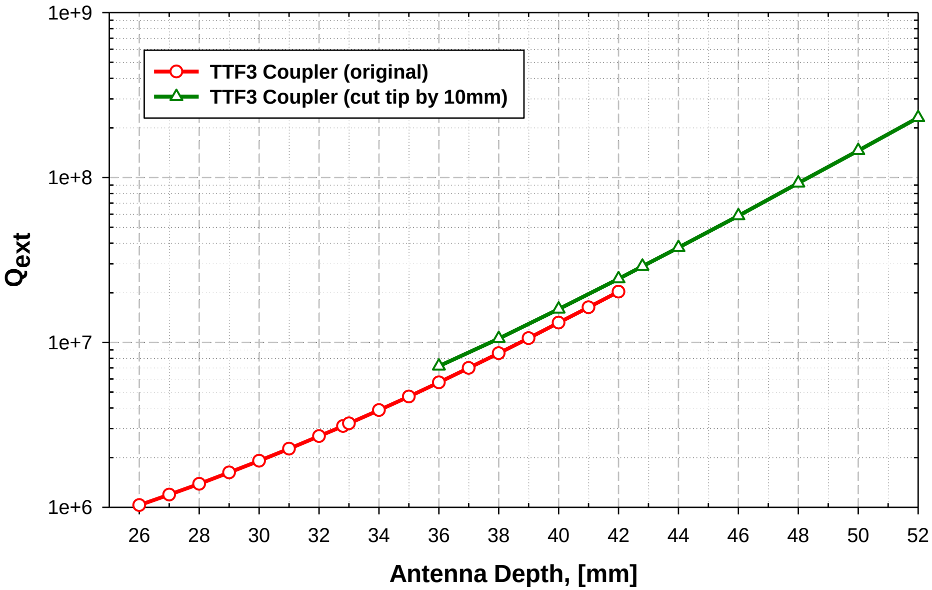
- Shift Qext range higher
- Improve cooling of warm section so can run at 7 kW with full reflection
- Modify waveguide assembly (use flex ring and aluminum WG box) but retain original manual knob antenna positioner



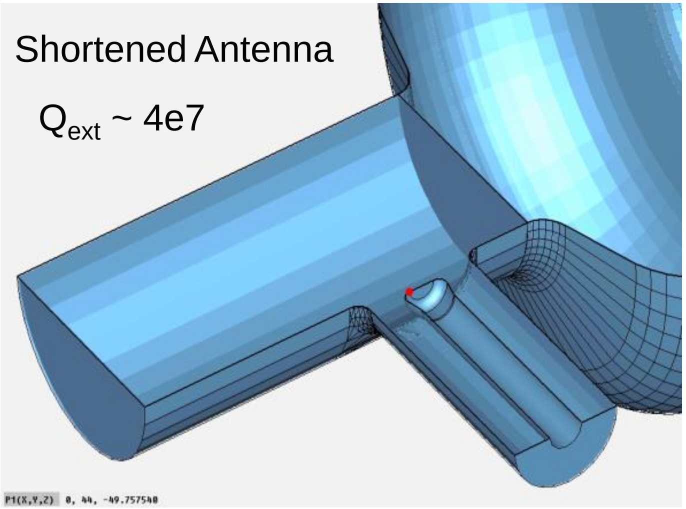
LCLS-II Coupler Technical Specs

Item	Spec	Comment
Design	DESY TTF3	With additional modifications
Max Input Power	7 kW CW	
Max Reflected Power from Cavity	7 kW CW	Assume would be able to run with full reflection
Minimum Qext Foreseen	1e7	Allows 16 MV/m with no beam and 6.8 kW input
Matched Qext	5e7	Match for 0.3 mA beams at 16 MV/m, 26 Hz BW
Reduction in Antenna Length	8.5 mm	Maintain 3 mm rounding
Range of Antenna Travel	+/- 7.5 mm	Nominal defined by bellows
Predicted Qext Min	3.6e6 - 7.5e6	Includes +/- 5 mm transverse offsets
Predicted Qext Max	1.0e8 - 1.5e8	Includes +/- 5 mm transverse offsets
Warm Section Outer Cond Plating	10 um +/- 5 um, RRR = 10-100	Nominal EuXFEL
Warm Section Inner Cond Plating	150 um +/- 30 um, RRR = 10-100	Increase to limit temp rise < 150 degC
Cold Section Outer Cond Plating	10 um +/- 5 um, RRR = 30-80	Nominal EuXFEL
Center Conductor HV Bias	Optional	Use flex copper rings that can be replaced with existing capacitor rings if HV bias needed
Warm and Cold e-Probe Ports	Yes	Will not instrument – do not expect multipacting
Warm Light Port	Yes	Will not instrument – do not expect arcs
Motorized Antenna	No	Adjust manually
Cold Test and RF Processing	No	Given low fields and no multipacting bands up to 7kW, will only process in-situ

Shorter Coupler Antenna

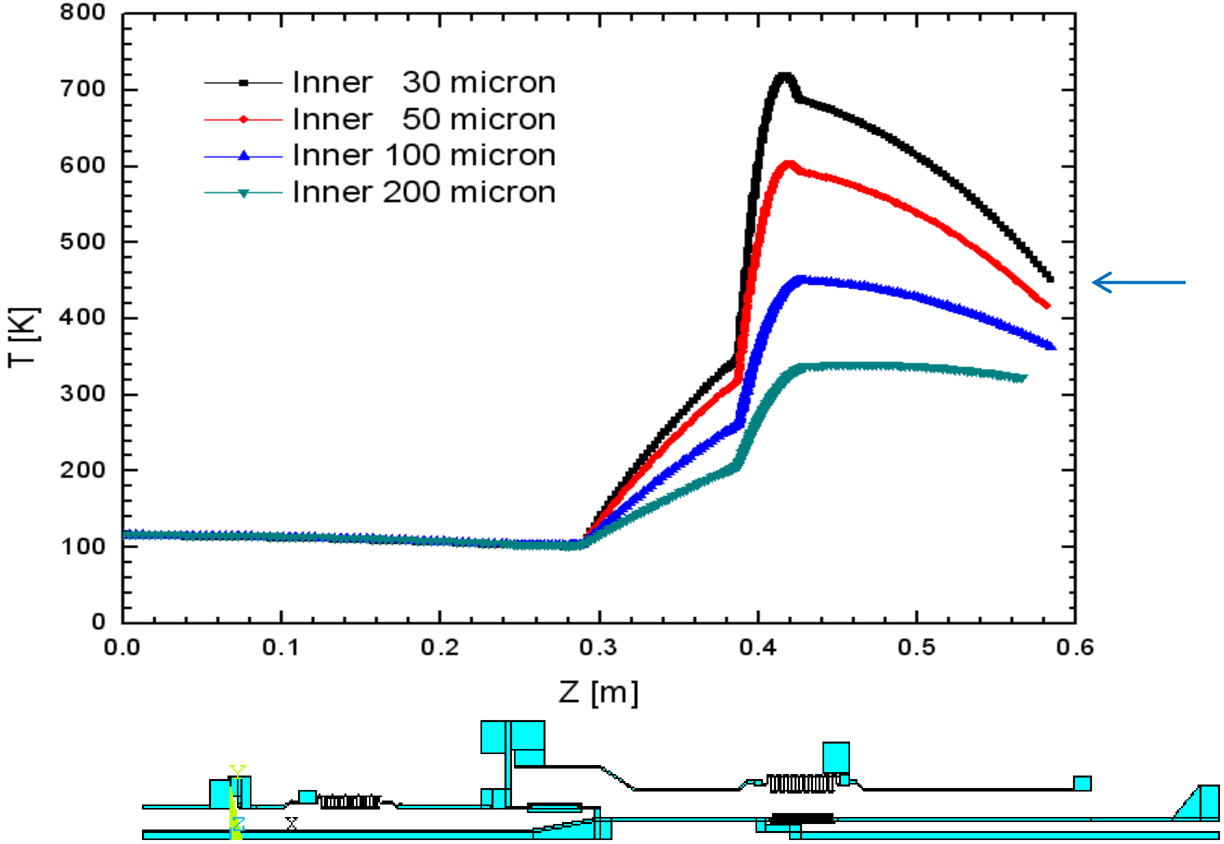


	Q_{min}	Q_{mid}	Q_{max}
Original coupler*	1E6	4.0E6	2.0E7
Tip cut by 10 mm	8E6	4.0E7	2.0E8
Tip cut by 8.5 mm	6E6	2.5E7	1.4E8



Coupler Heating

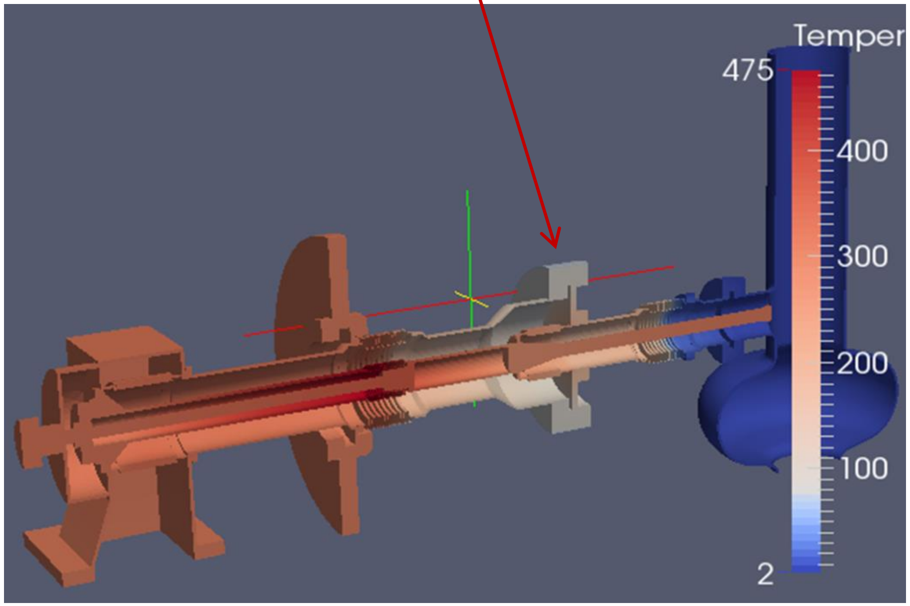
Inner conductor temperature for 15 kW TW operation for various thicknesses of the warm section inner conductor copper plating

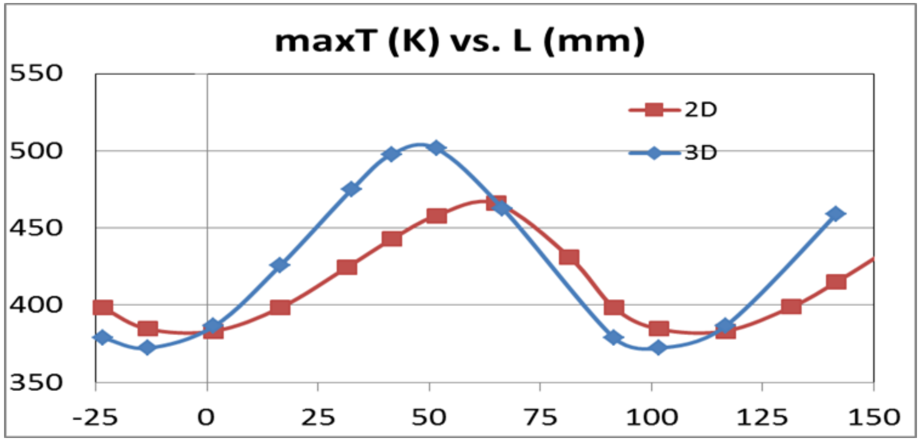


Limit to 450 K (bake temp)

7 kW Full Reflection Simulations

- Simulations assume 100 um inner conductor plating and no resistivity increase with plating roughness
- 3D case includes heating in the warm window
- Assume CF100 flange held at 70 K



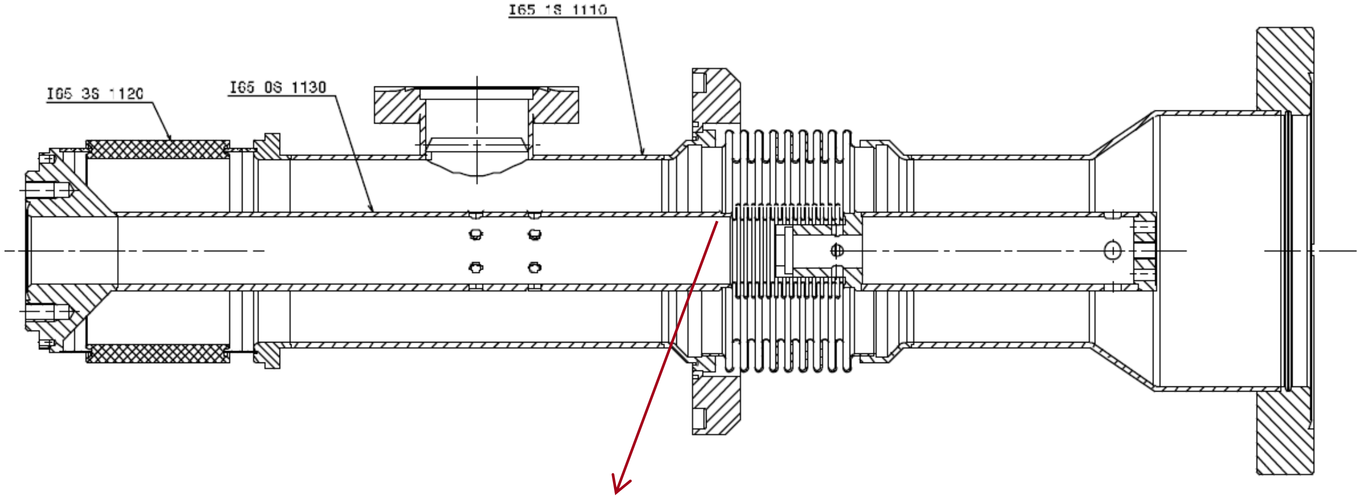


Location of a rf short (mm) used to simulate reflection from cavity for various frequency detuning

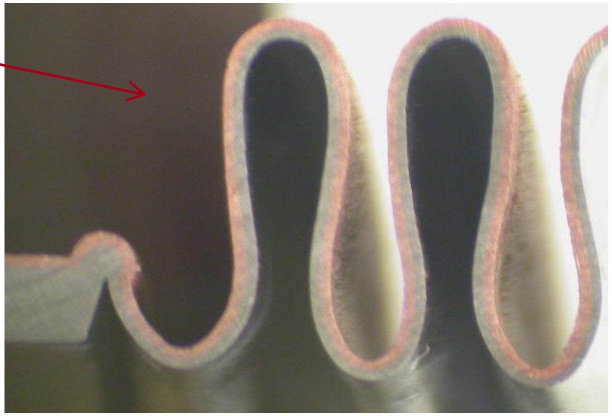
Thicker Copper Plating Qualification

Increase copper plating thickness on warm section inner conductor from 30 um to 150 um

Had 5 ILC sections modified in this way – use for metrology and HTS tests

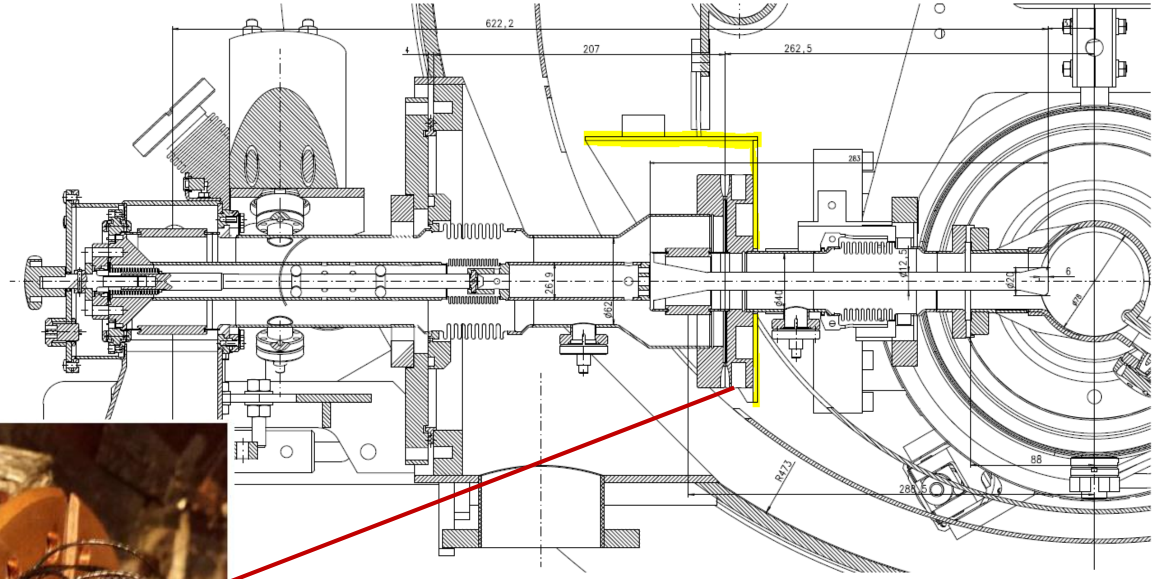


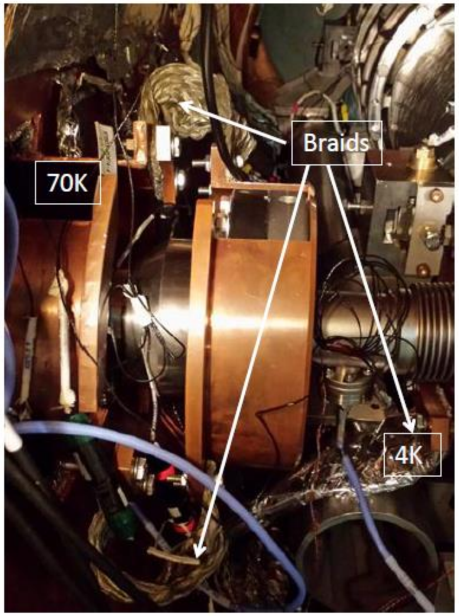
Cross section of inner conductor bellow in a test section: measure 120-180 um copper thickness variation

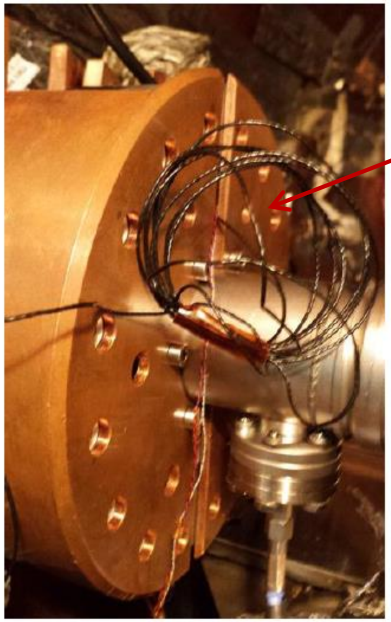


First 6 kW CW Operation at FNAL HTS

- Used shorter antenna and warm section with 150 um plating
- Found coupler temp higher than expected due to poor thermal tie-down



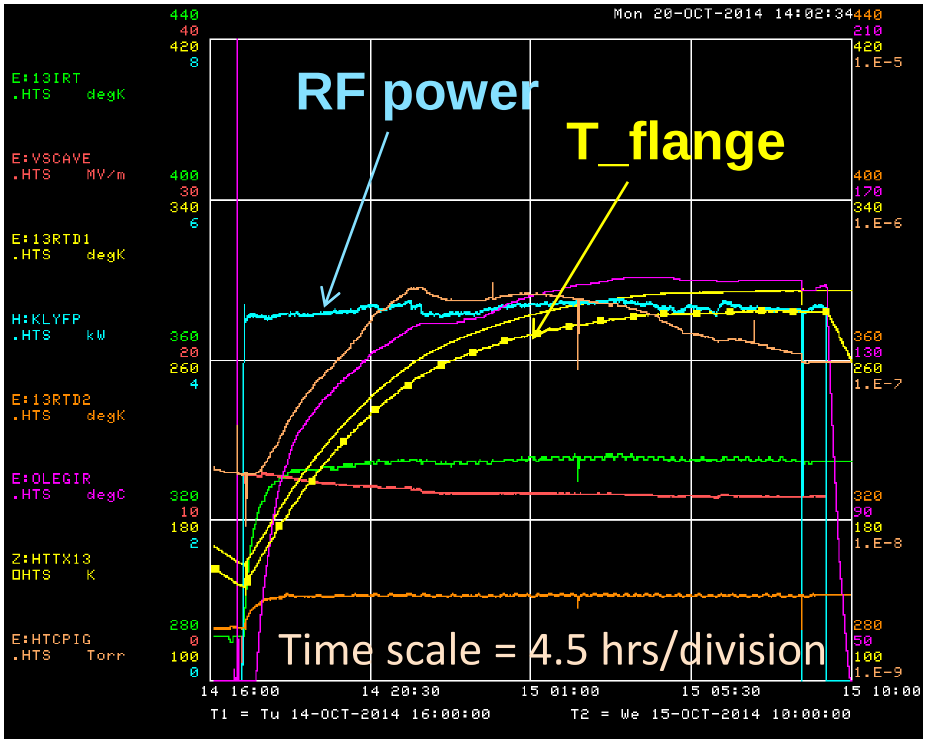


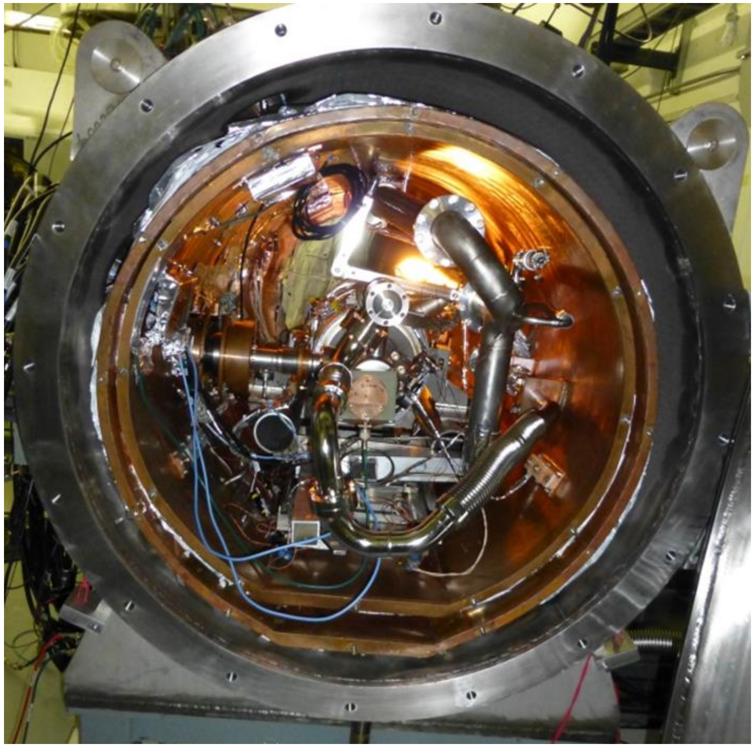


- Will add a SS split-ring washer (a la XFEL) to make the thermal contract between the copper plate and 70 K flange better - also increase the number of braids

First Test (cont)

Coupler +JLAB modified HOM feedthroughs assembled on RI026 cavity (good cavity tested for CM3) –DV program



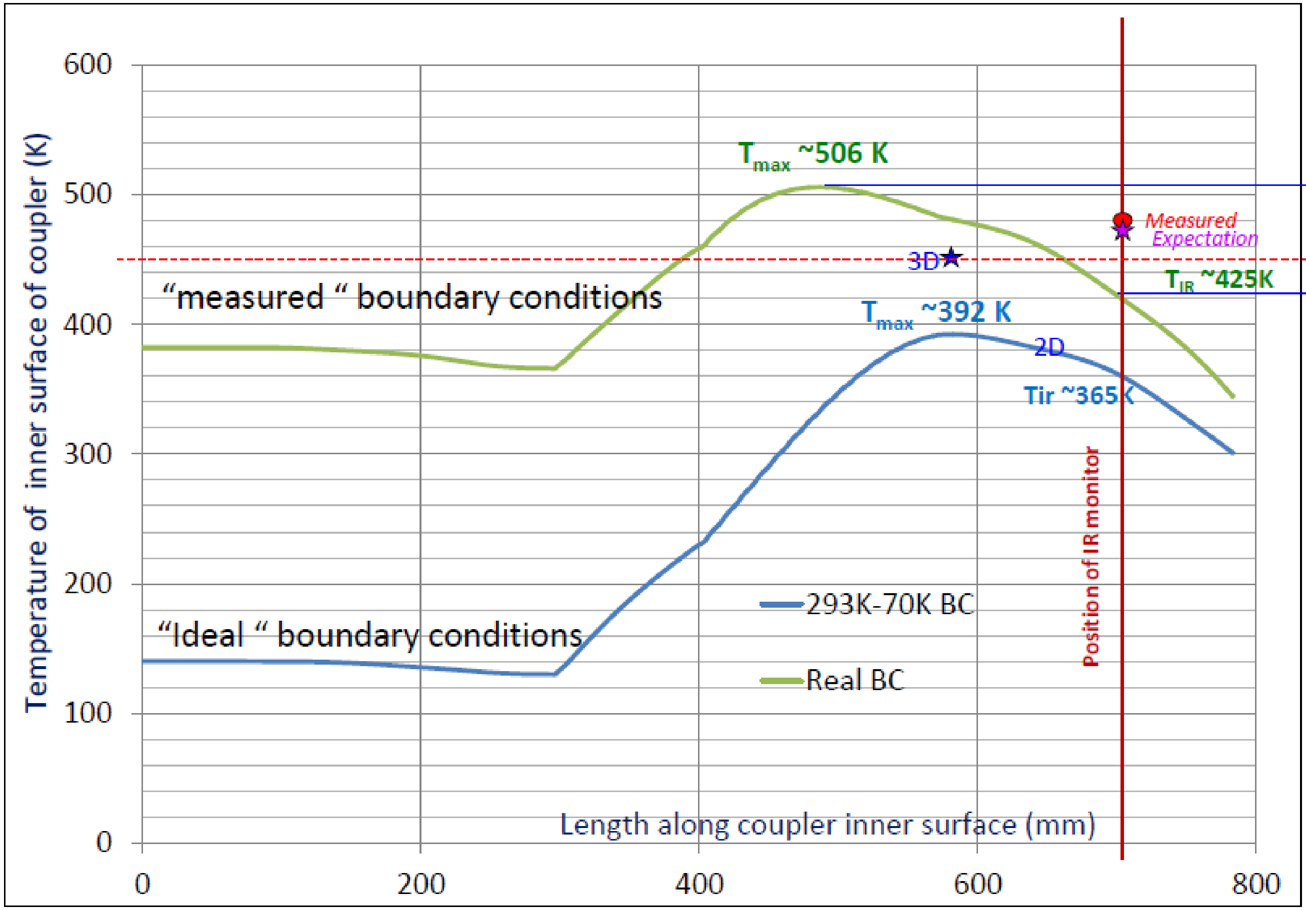


RF processing (max 6kW cw): RT; cold-cavity OFF-resonance; cold, cavity ON-resonance

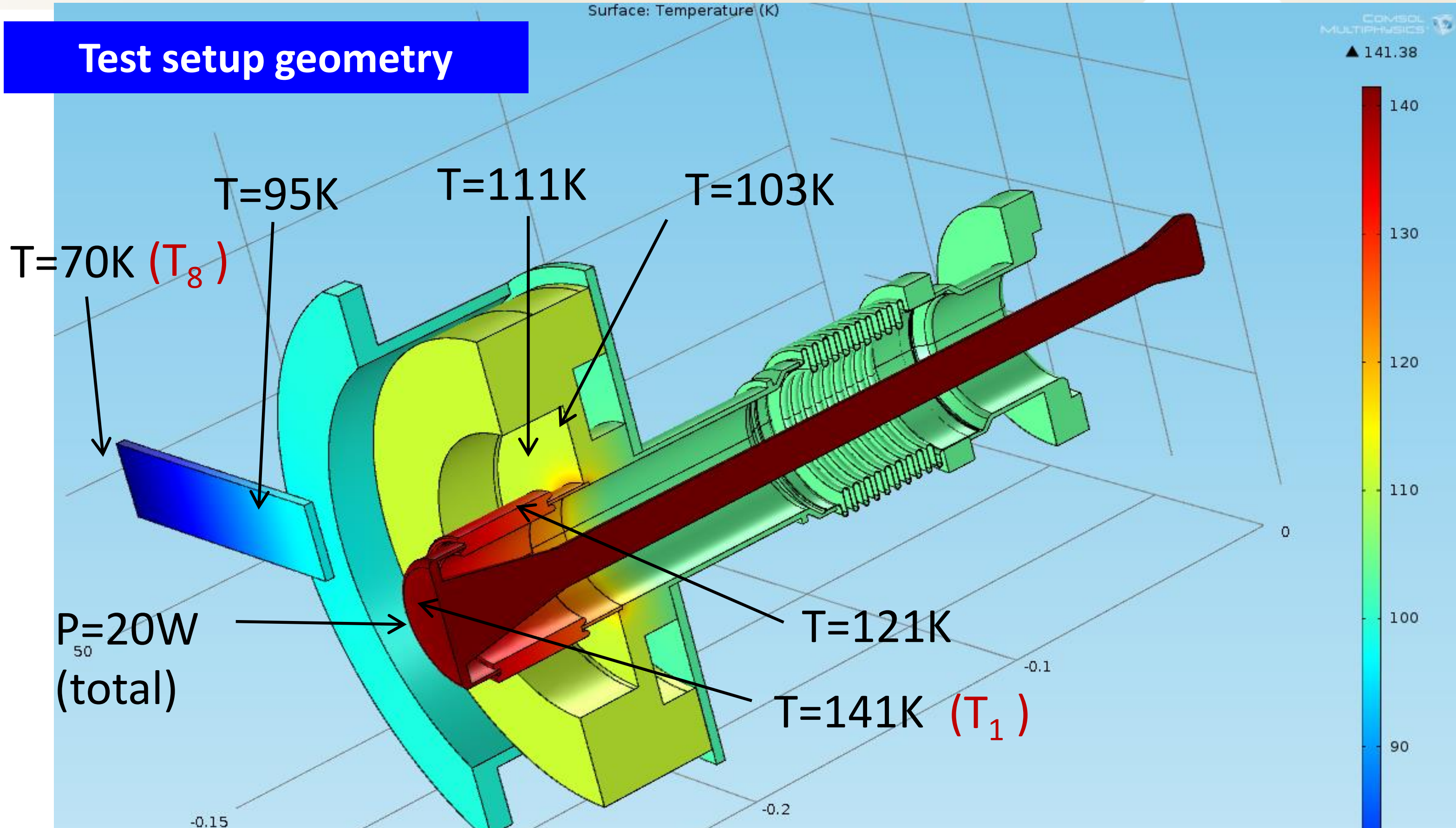
- Smooth processing, no sparks or breakdowns, no MP. Vacuum interlock.
- No effect on Q0 from FPC (Cornell test, HTC)
- Thermal time constant ~10 hrs

Ideal and Measured Temperatures

2D Simulations (blue and green lines) and IR measurement (red dot) with 3D Prediction (purple star)



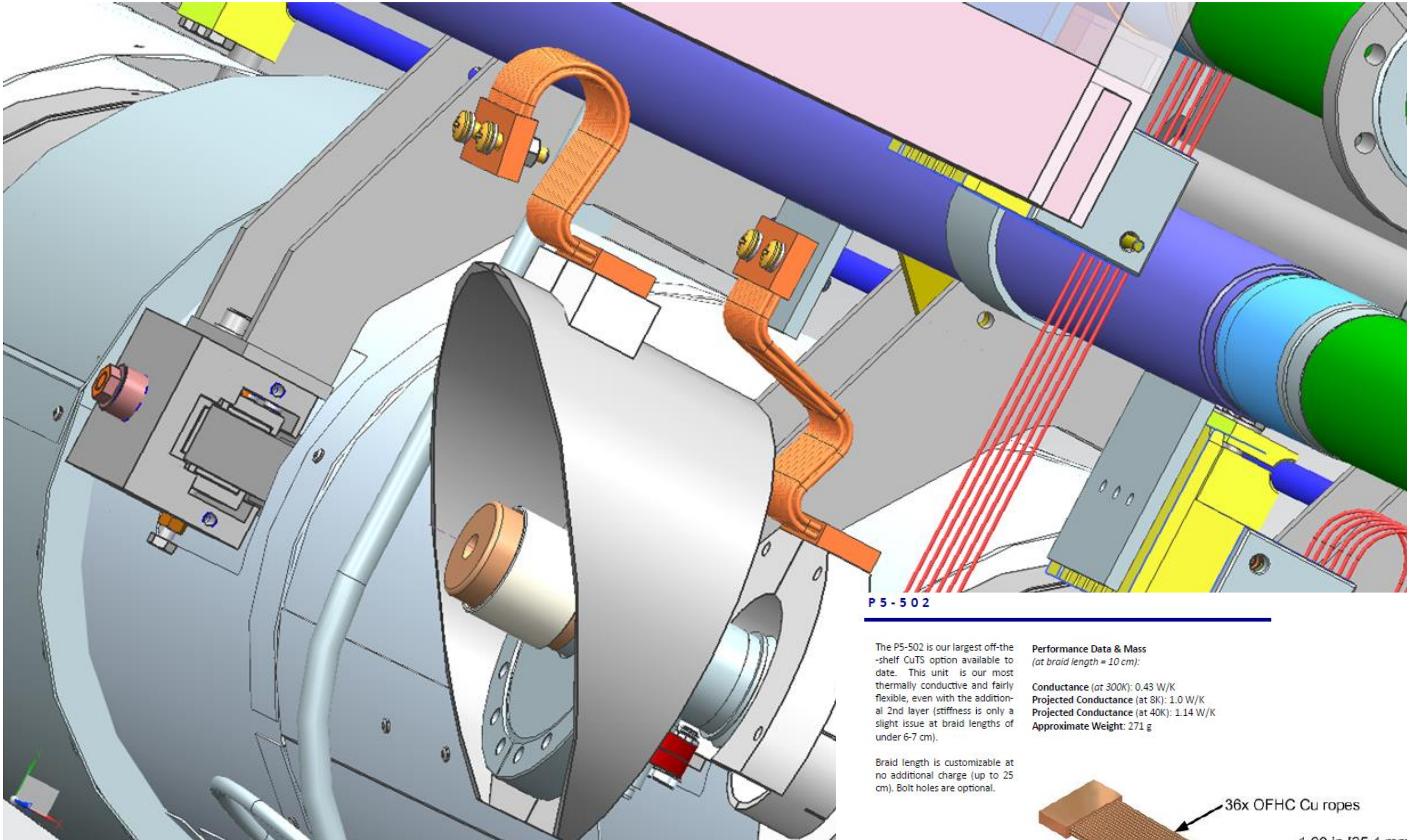
Thermal Simulations vs Measurements (2 Straps)



Simulation result is consistent with measurements at test setup:

- **Simulation: T_1-T_8 = 71 K; Ceramics dT = 20K**
- **Measured: T_1-T_8 = 84 K; Ceramics dT = 21K**
- **Note: contribution from contacts are ~10-15 K**

Current Design with Two Straps



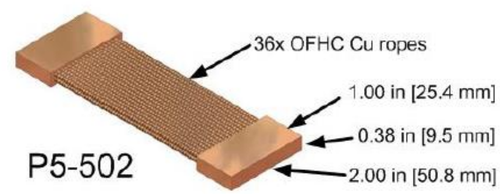
P5-502

The P5-502 is our largest off-the-shelf CuTS option available to date. This unit is our most thermally conductive and fairly flexible, even with the additional 2nd layer (stiffness is only a slight issue at braid lengths of under 6-7 cm).

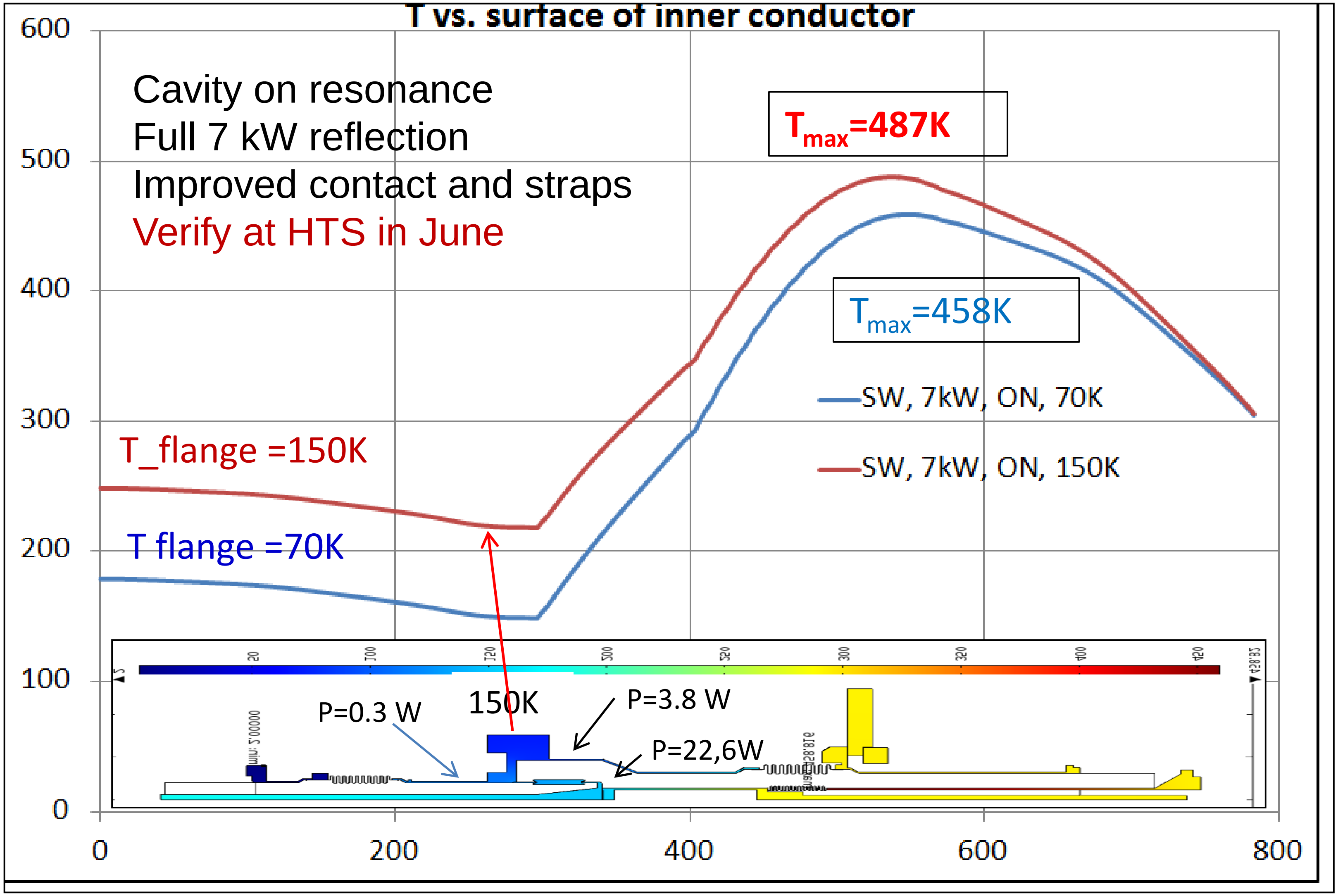
Braid length is customizable at no additional charge (up to 25 cm). Bolt holes are optional.

Performance Data & Mass
(at braid length = 10 cm):

Conductance (*at 300K*): 0.43 W/K
Projected Conductance (at 8K): 1.0 W/K
Projected Conductance (at 40K): 1.14 W/K
Approximate Weight: 271 g



Simulations with 70 K and 150 K Flange Temps



Vacuum Grease or Indium for Better Thermal Anchoring in CMs ?

APIEZON

Cryogenic High Vacuum Grease

Introduction

Apiezon N grease is one of the most widely used vacuum greases within the field of cryogenics, where its ability to improve heat transfer and craze-free performance characteristics at low temperatures are especially important. The product is also widely used at ambient temperatures, information on which is in the data sheet "Apiezon L, M & N Greases."

Thermal coupling medium

Apiezon N grease is important for the coupling of cooling systems to superconducting magnets, cryostats, temperature sensors or any system which is required to reach cryogenic temperatures as quickly as possible.

Apiezon N Grease

- Thermal coupling medium
- Sensor mounting medium
- Sample mounting medium
- Cryogenic vacuum seal
- Silicone & halogen free
- Easily removed

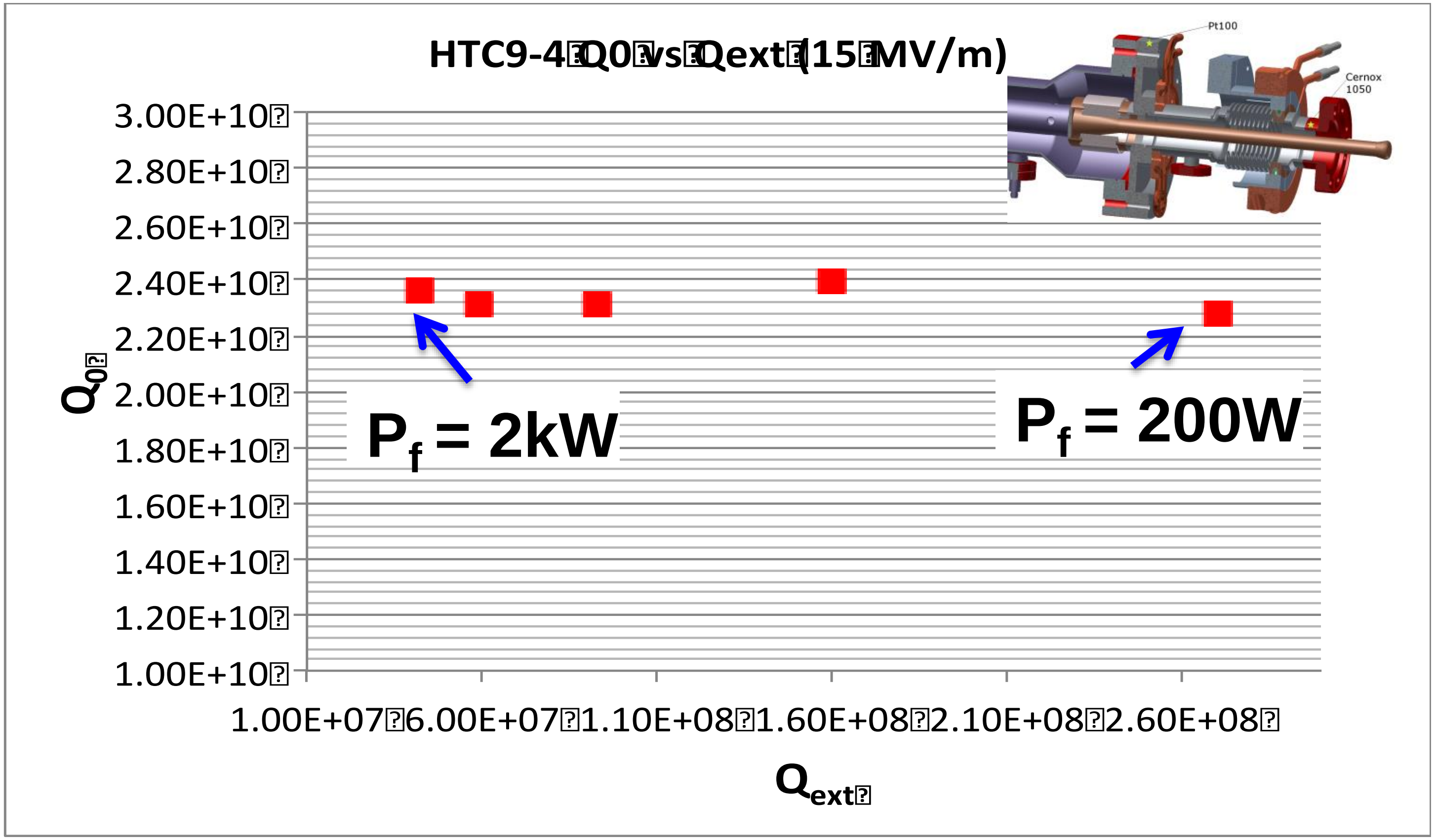
RF and Beam Dynamic Loads (per Cavity and CM)

Loss Origin		Cavity [8]	HOM Coupler [16]				Bellow [9]	Flange [22]	Power Coupler [8]				Σ [n] [W/CM]		
			Rad	Loss											
Fundamental Mode[1,2,3,4,5] (15 MV/m)	Max	8.9 W [71 W]	5 W	0.02 W	0.07 W	0.2 W	2 mW [0.02 W]	50 mW [1.2 W]	0.05 W [0.4 W]	0.8 W [6 W]		7 W [56 W]	73 W	6.3 W	57 W
	Mean		0.8 W [13 W]	5 mW [0.1 W]	12 mW [0.3 W]	30 mW [0.5 W]									
HOM Monopole Resonance[6] (< 10GHz)									BPM [1]	Gate Valve [2]	End Pipe [1]	HOM Absorb [1]			
	Max	0.03 W	3 W	0.02 W	0.05 W	0.15 W	0.03 W	3 mW					0.03 W	0.02 W	0.03 W
	Mean	-	7 mW [0.1 W]	-	1 mW [.02 W]	2 mW [.03 W]	3 mW [0.03 W]	-							
Beam Wake	Radiated[7]	[4.5 W]	[0.15 W]				[0.15 W]	-	-	-	-	-	4.8 W		
	Transient Loss[8]	[0.3 W]		[3 mW]	[7 mW]	[10 mW]	10 mW [0.1 W]	7 mW [0.1 W]	-	75 mW [0.15 W]	30 mW [0.03 W]	4 W [4 W]	0.7 W	0.01 W	4 W
	Resistive[9] Loss (ASA)	-	-	-			7 mW [0.03 W]	-	-	9 mW [0.03 W]	30 W [0.03 W]	-	0.1 W	-	-
Total Loss [W/CM]		71.3 W	13 W	0.1 W	0.3 W	0.5 W	0.2 W	1.3 W	0.4 W	0.2 W	0.05 W	60 W	74 W	6.3 W	61 W
													2K	5K	70K

[n] – number of components in cryomodule

Recent Cornell Coupler Test

Recent results from Cornell HTC tests with modified couplers showed no decrease in Qo when varying the on-resonance input power up to a level comparable to that at LCLS-II for a fixed gradient of 15 MV/m



Cooled flanges with He gas lines

TTF3 Couplers Are Robust RF-Wise:

Breakdown limits at ~ 2 MW
Designed for 300-400 kW pulsed operation at ~ 1% duty
Multipacting starts above 40-50 kW, but is benign (processes out)
CW operation at several kW is more of a heat issue:

2kW Industrial Magnetron air cooled (MSM259M12) £310.00

Industrial Grade Microwave Magnetron 2kW air cooled (MSM259M12) {2M278 TYPE}

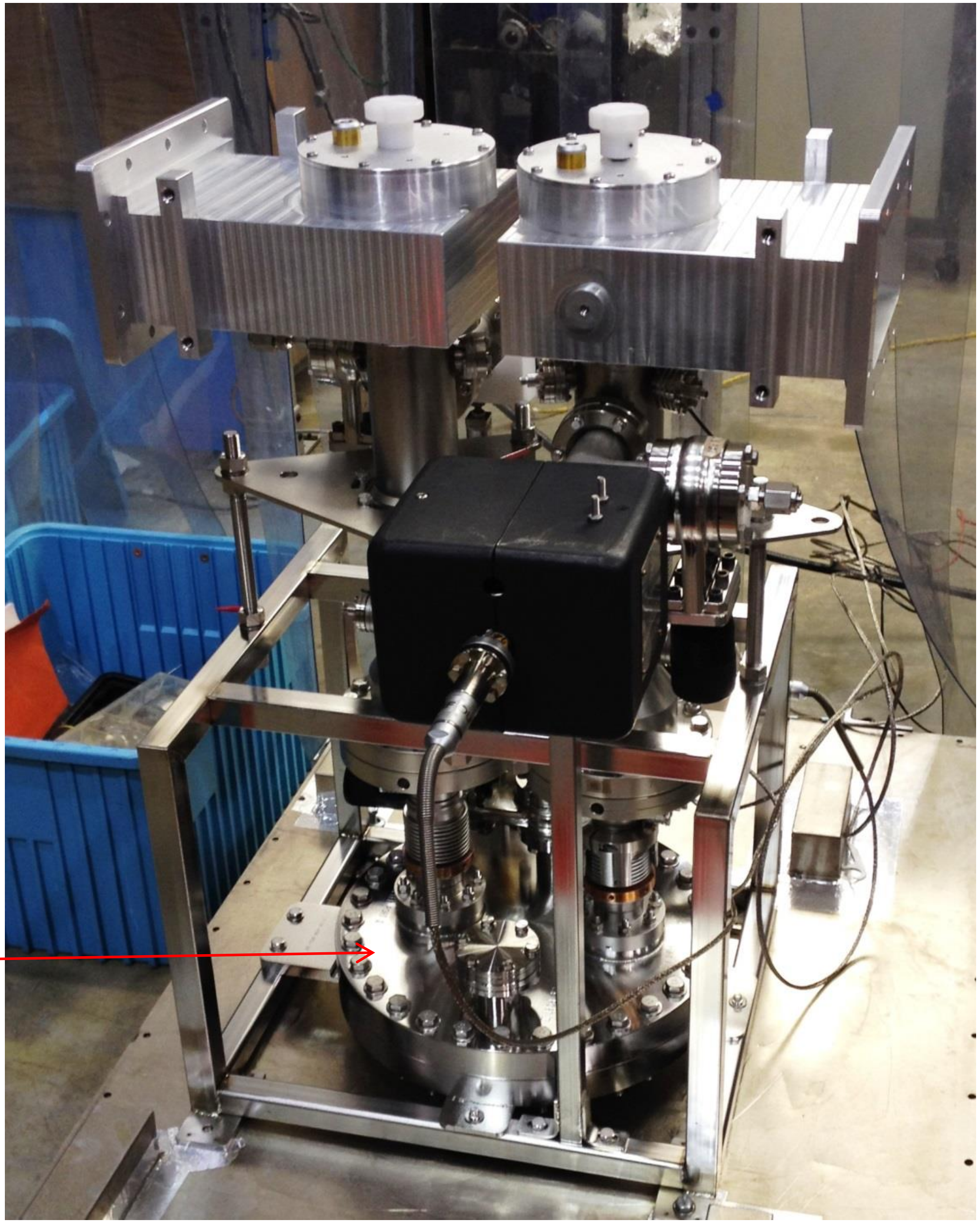
Magnetrons for industrial applications are housed in metallic and ceramic shields for superior performance even under high-temperature and other harsh conditions

FREQUENCY 2455MHz
FILAMENT VOLTAGE stand-by 4.6V
FILAMENT CURRENT 20A
PEAK ANODE VOLTAGE 4.0kV
MEAN ANODE CURRENT 725mAdc
MEAN OUTPUT POWER 2030W
FORCED AIR COOLING 1000L /1min
HEIGHT 116mm
COOLING VENT WIDTH 123mm

'RF Process' Button ?

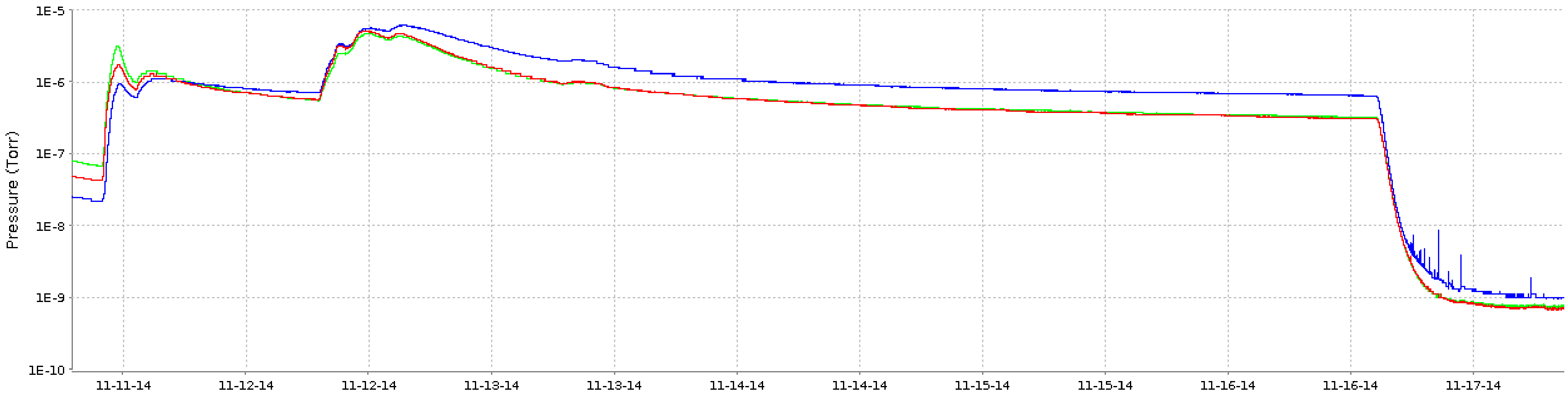
Coupler Prep

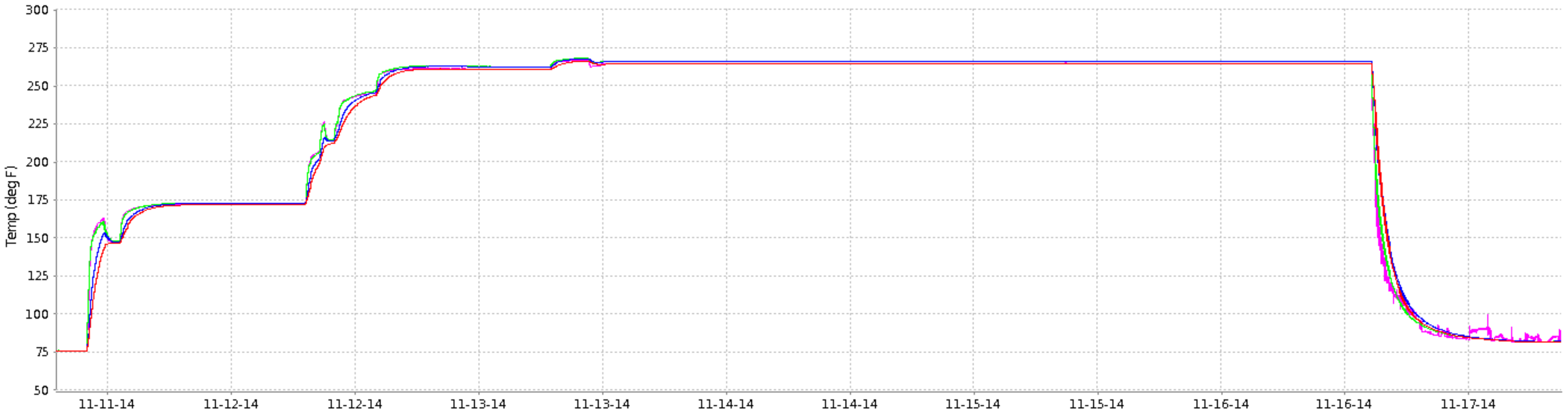
Couplers are assembled, baked and rf processed in pairs, connected through a Coupler Processing Cavity (CPC)



Example of Bake Out: Pressure Drops to 1e-9 Torr

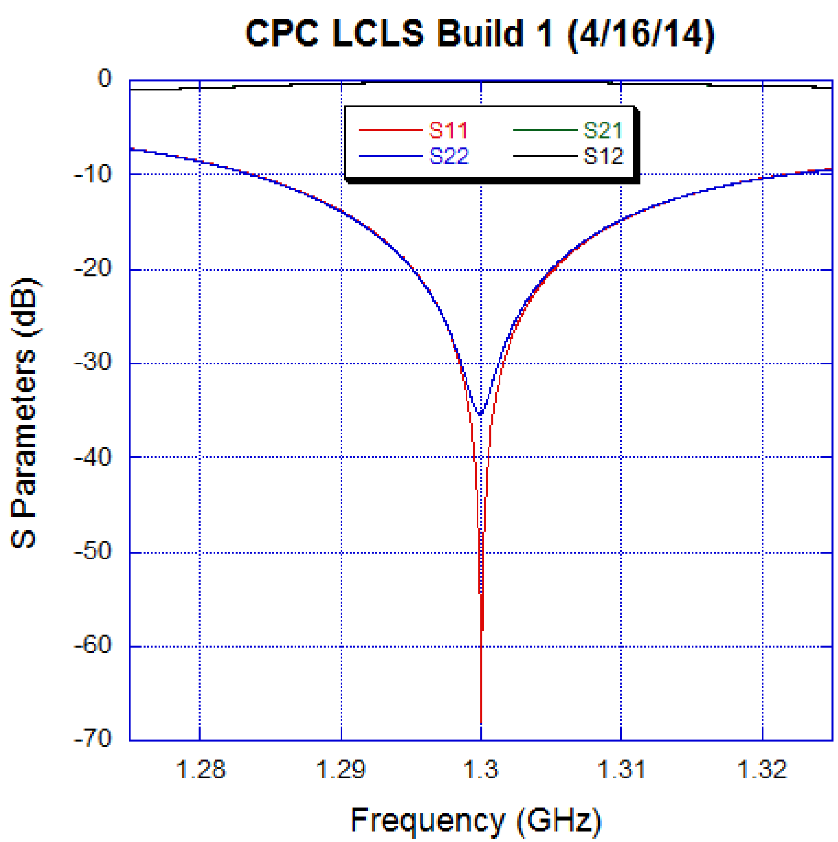
Will be done by the coupler vendors, including hot RGA scans

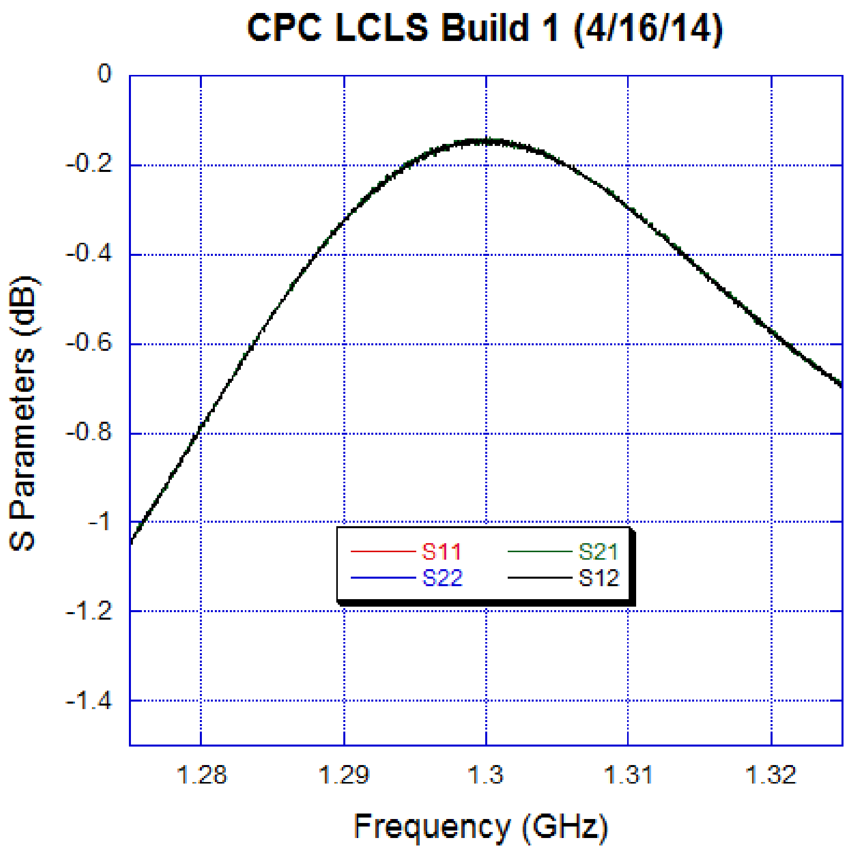




Example of a Typical Cold Test after Antennas Tuned

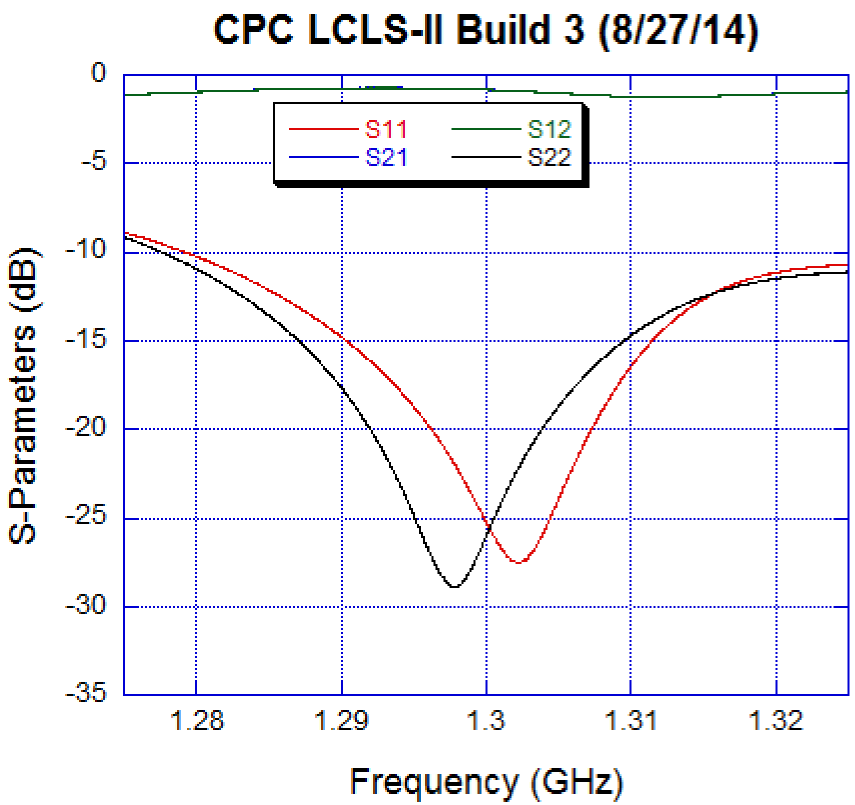
Will not be done by the coupler vendors

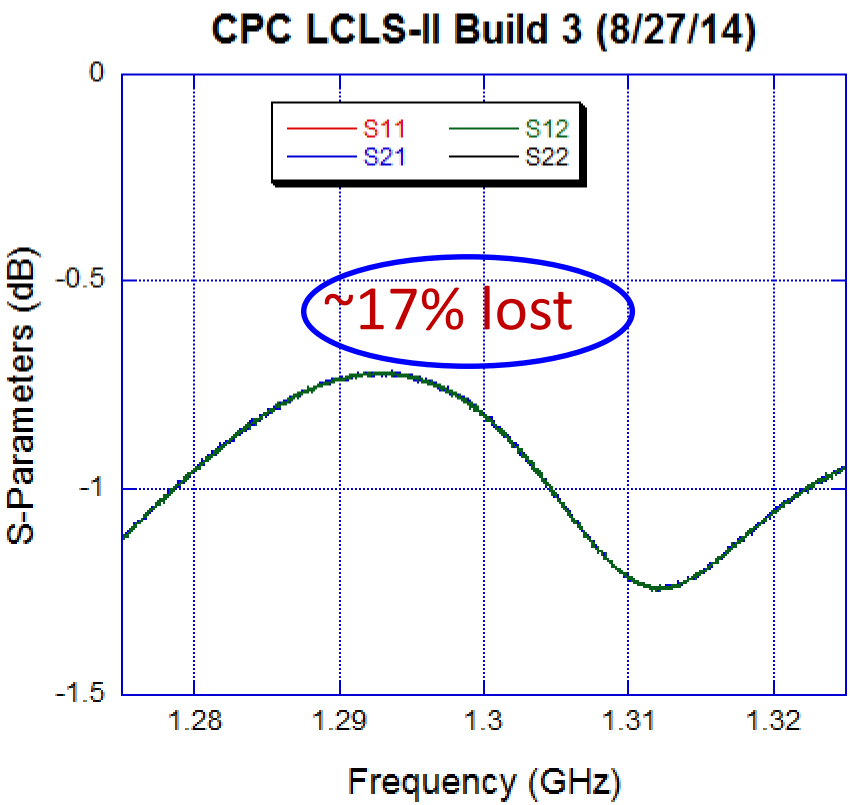




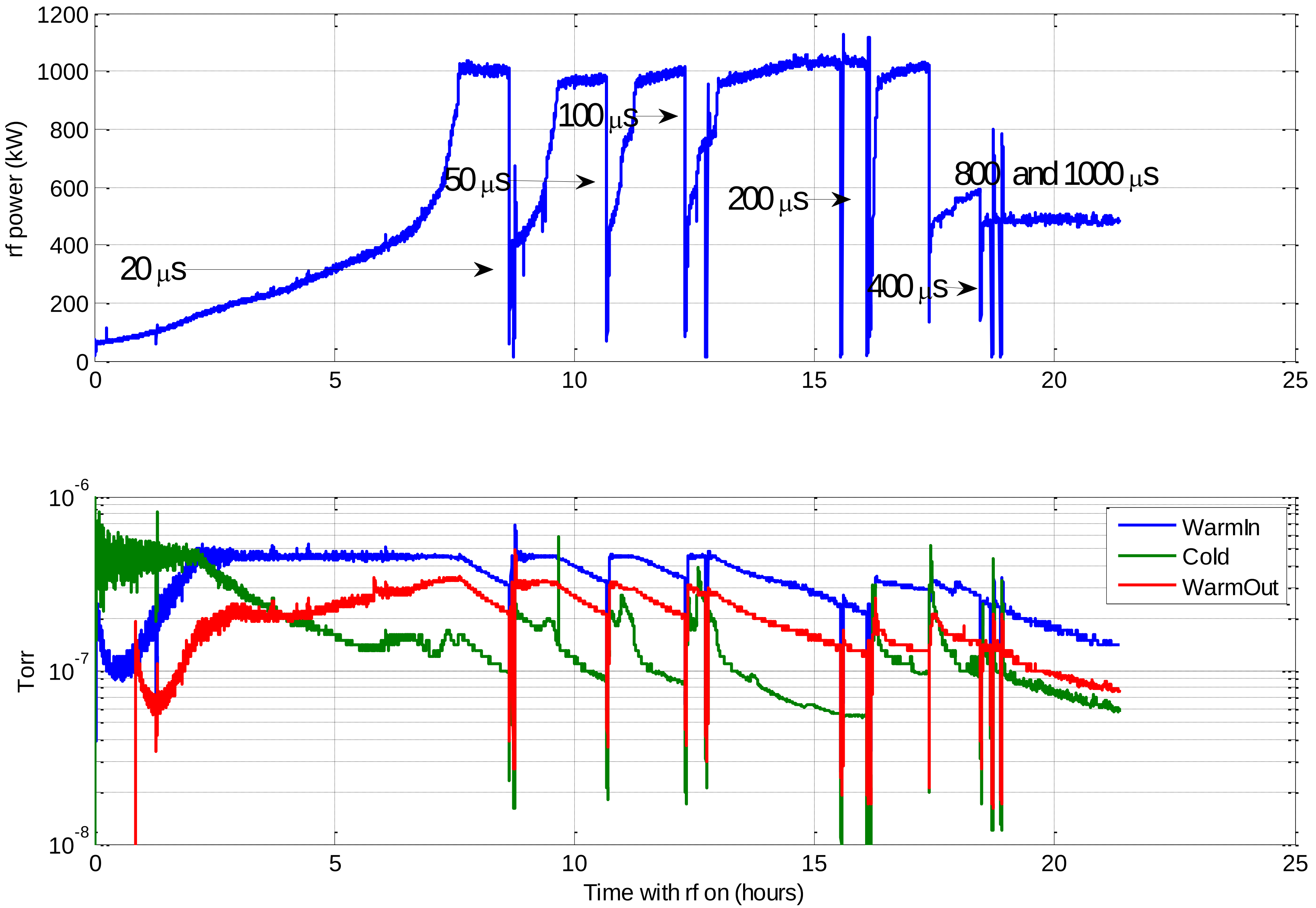
Example of a 'Bad Tune'

Due to WG assembly not being properly attached

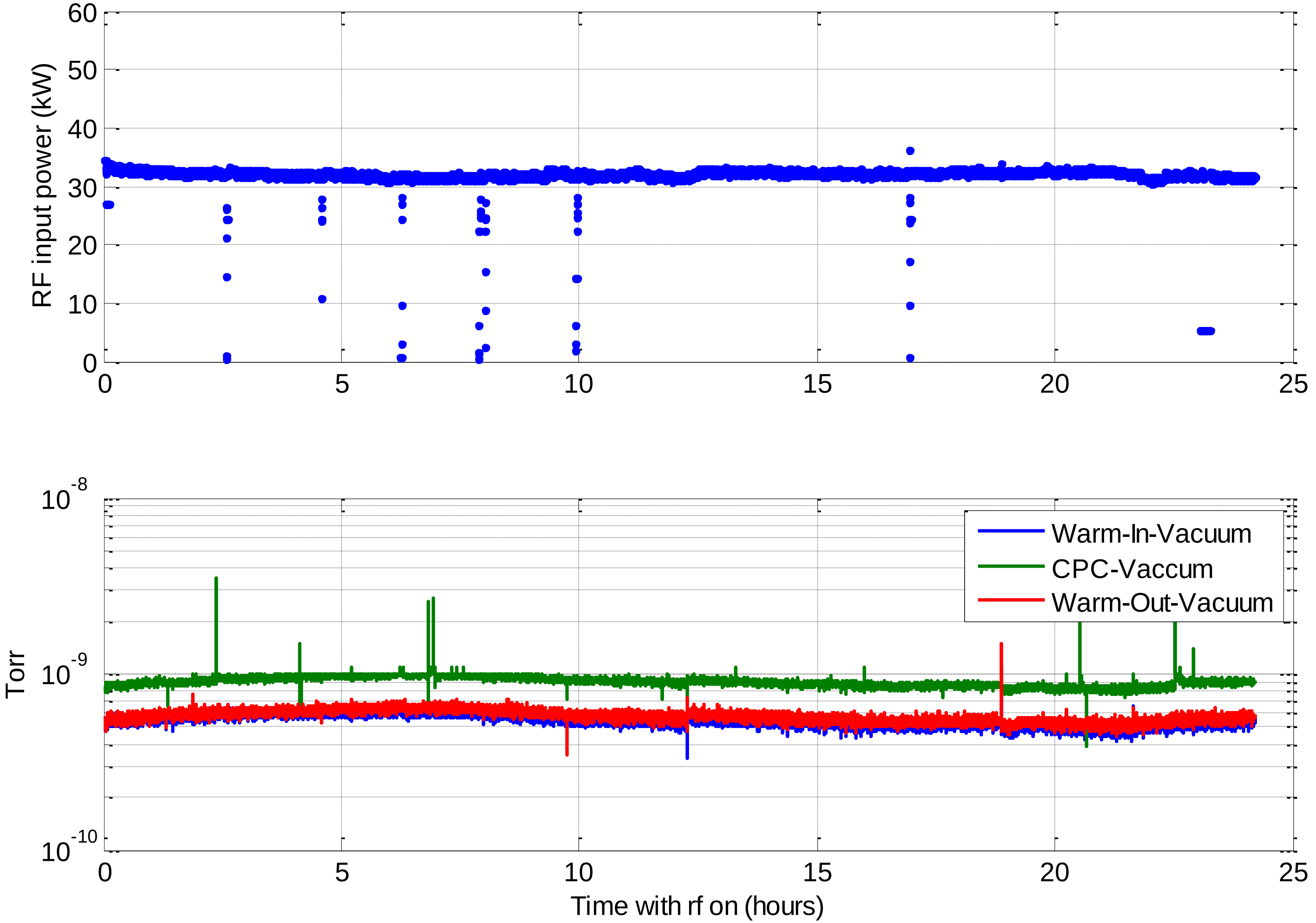




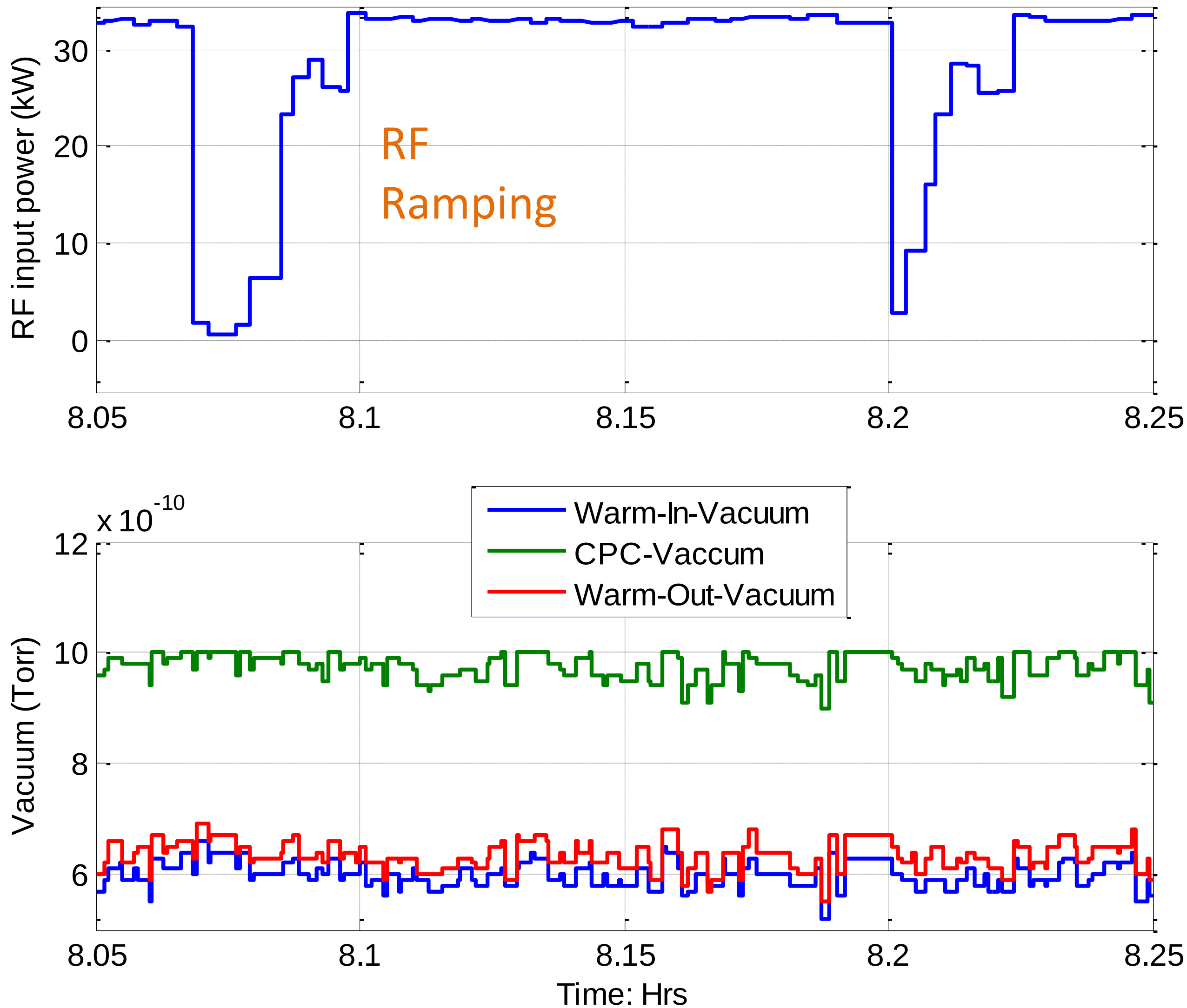
Example of High Power, Pulsed Processing



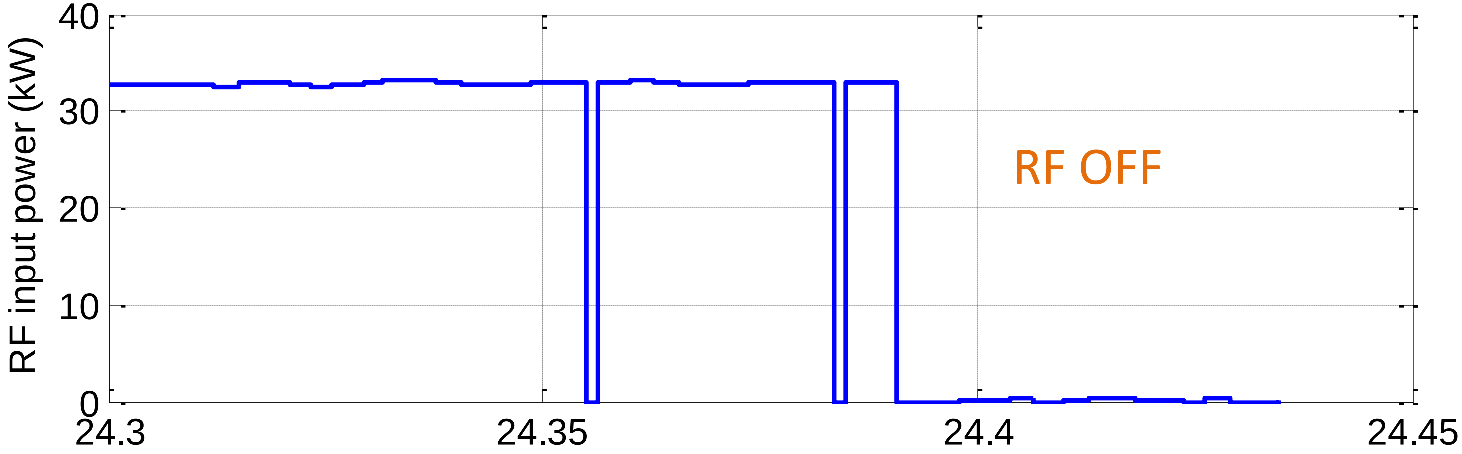
Example of Low Power, Pulsed Processing for LCLS-II

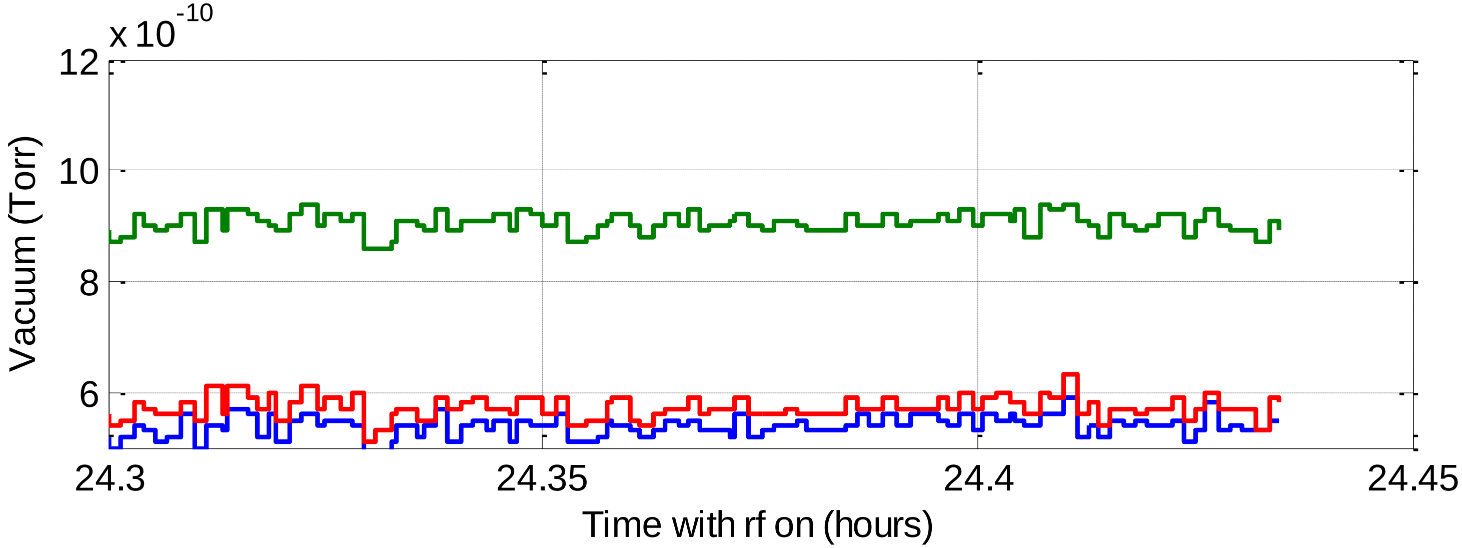


Example Showing No Discernable Impact on the Vacuum due to the RF

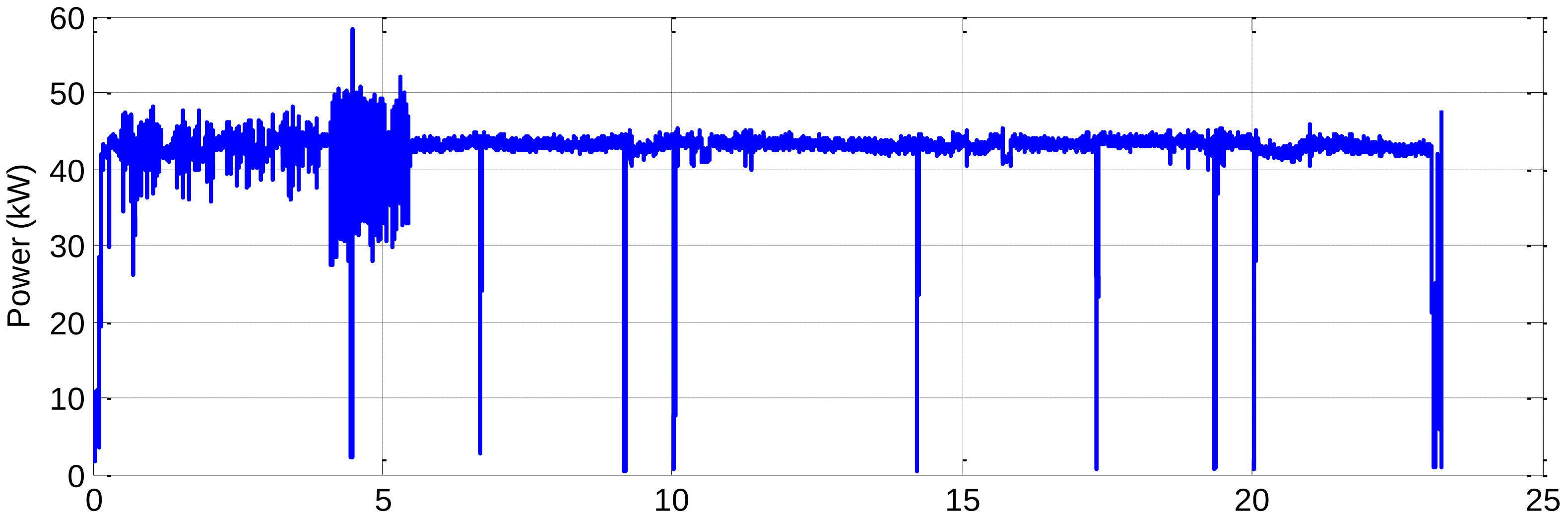


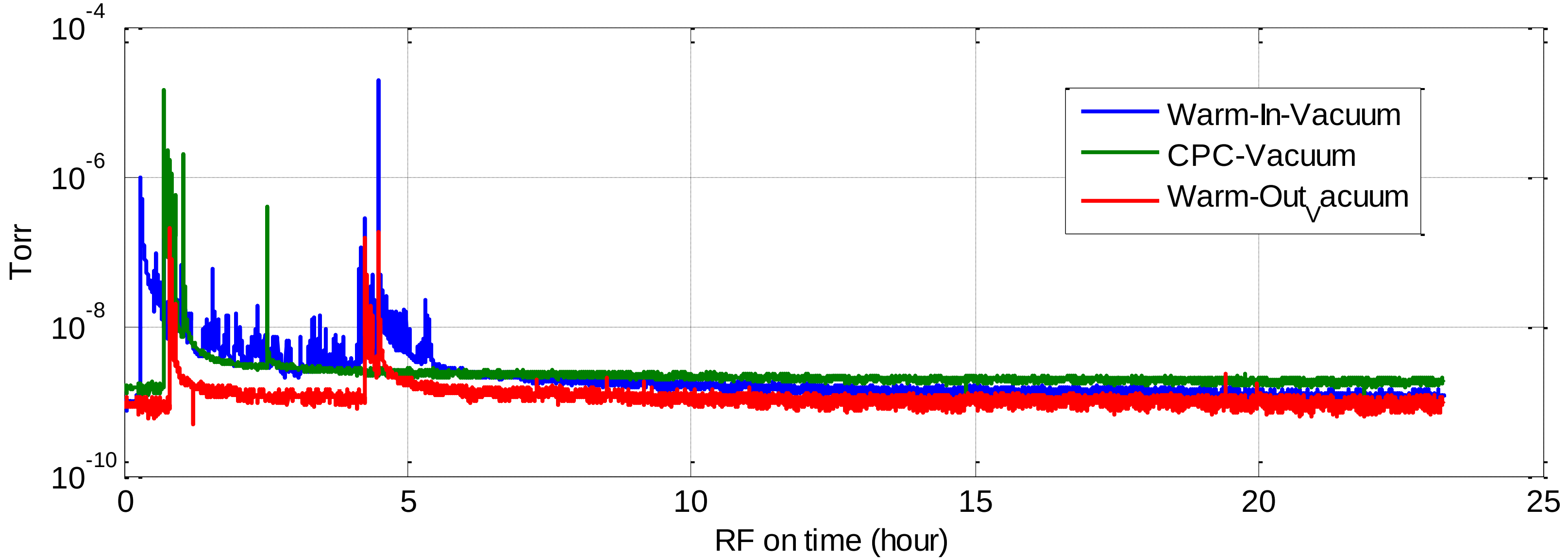
Another Example



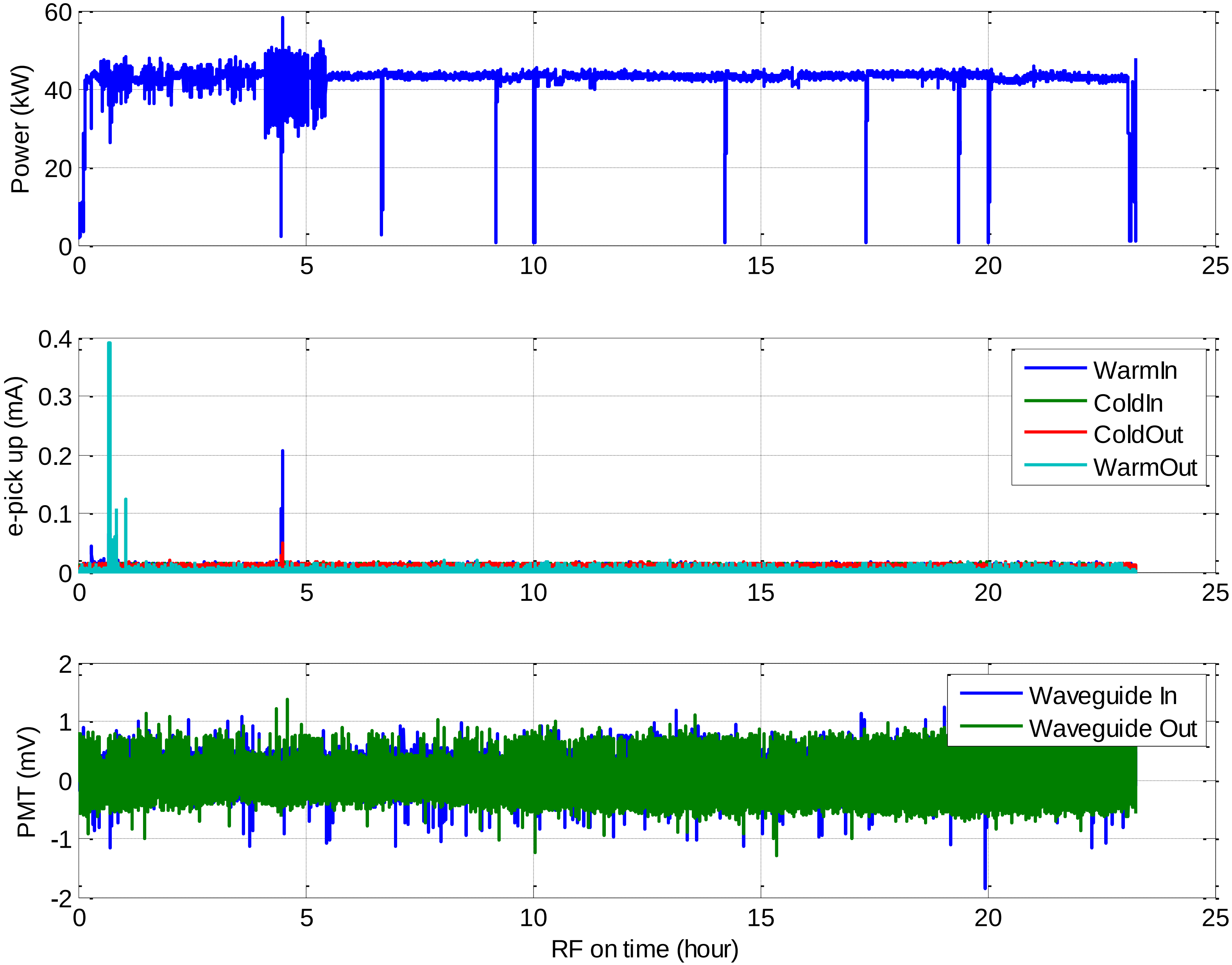


Recent Test Done at Higher Power





Corresponding e-probe and Light Signals



Coupler Status

- Two prototype CM
  - Using shortened cold sections from ILC program – nearly finished providing 8 each to FNAL and FNAL – processed as described above
  - Modified five warm ILC sections (increased plating thickness) – used for HTS at FNAL, Cornell and JLAB – processed as described above
  - Coupler ESD reviewed and used to solicit bids for 8 couplers – two vendors have been awarded contracts. They also provided cost estimates for production couplers. These warm sections will be used for the two prototypes (visited Thales yesterday, and will visit RI tomorrow) – expect delivery in Sept-Oct. 2015
- Production CMs (33)
  - Current plan is not to cold or hot test couplers from vendors, however, submitted an RFI to various labs to estimate cost of processing the couplers. Scope of work described in following slide

Scope of ‘RF Processing’

- Receive assembled couplers from vendor w/o WG – inspect, connect ion pumps and do leak check
- Attach WG and adjust the antennas (cold test)
- Do hot test and record rf, temps, e-probe, light data
  - Operate either 30 kW TW at 25 % duty or
  - 7 kW SW with adjustable short at 50% duty
  - Continue until no vacuum spikes during a > 3 hour period (want to achieve nominal temps and do thermal cycling)
- Take to clean room, clean outer surfaces, do He leak check, RGA scan ?, disassemble and pack warm parts in N2, pack cold assembly under vacuum
- Ship to FNAL or JLAB along with documentation and photos of the cold-warm mating surfaces

Pro's, Con's, Alternative

- Pro's
  - Check quality (warm sections) and vacuum integrity
  - Discover rf contact issues and anomalous heating early
- Con's
  - Added handling (risk of damage)
  - Schedule delays
- Alternative
  - Have vendors do the cold tests
  - Rely on in-situ processing (actually baking using rf to heat coupler). Most problems likely in the warm sections, which are easier to replace). Will have to be done anyway, as both warm and cold sections exposed to air.