Muons, Inc.

Magnetron design, development, and manufacturing by Muons, Inc. (including update on NFE of DE-SC0013203)

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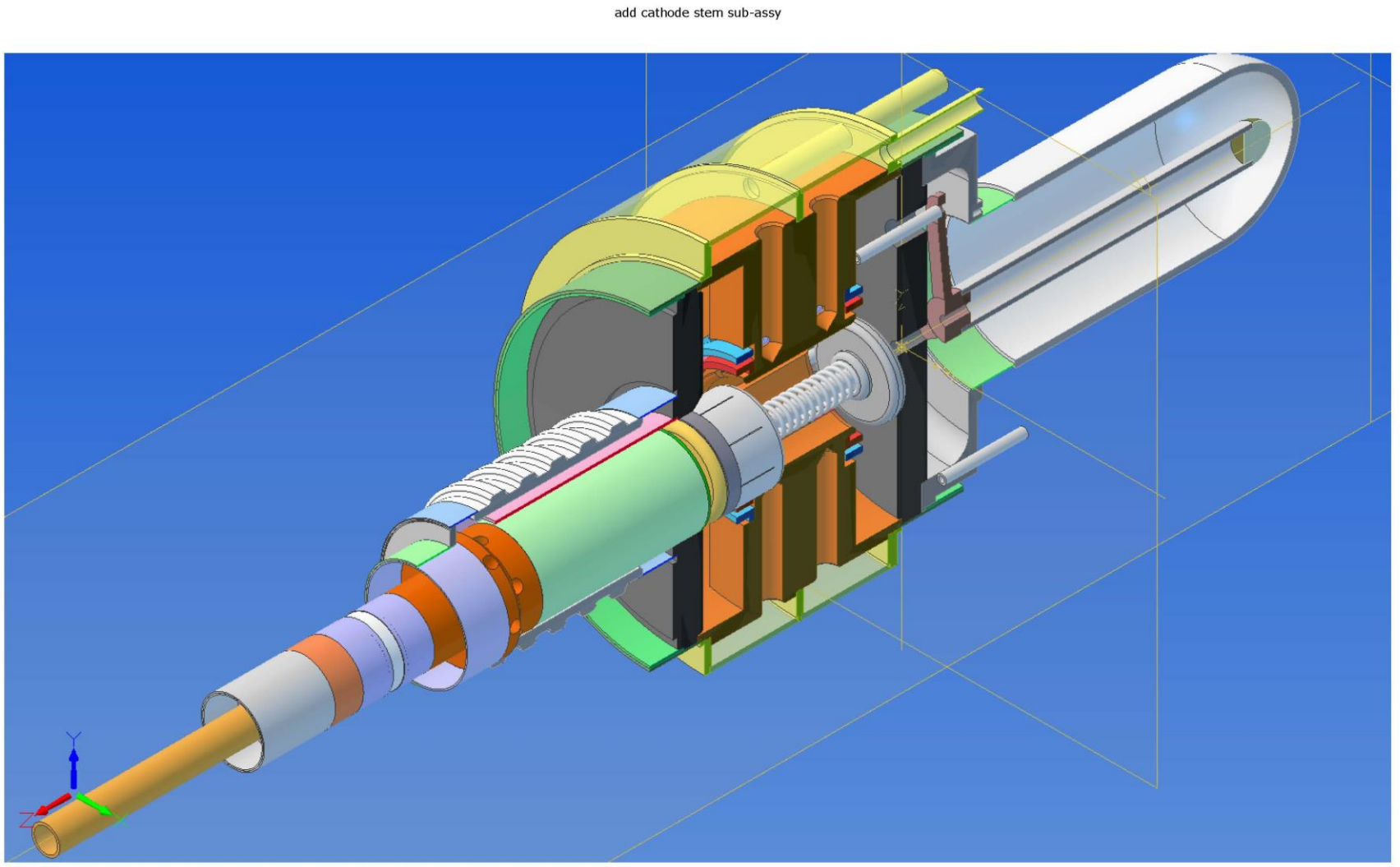
Outline

- Introduction
  - Commercialization BHAG
- Magnetron RF Power Sources
  - 350 MHz (self funded)
  - 1497 MHz (NP STTR Phase I and II: DE-SC00013203 w JLab)
  - 2450 MHz testing new ideas
- Distributed Manufacturing
  - machine shops, magnets, brazing, welding, test facilities
- New Ideas
  - Sub-critical voltage operation
- Next Steps

Introduction

- Muons, Inc. is a leading proponent of Superconducting RF (SRF) Accelerator-Driven Subcritical Reactors (ADSR) with Mu*STAR
- https://www.youtube.com/watch?v=dS2dq13fTMk
- High-power, efficient power sources needed to drive SRF cavities are major capital and operating expenses for such systems.
- Magnetron power sources, invented a century ago, can be the most cost-effective solution for ADSR if some limitations can be overcome.
- Efforts to address these limitations are discussed, including the 1497 MHz magnetron development project supported by an NP STTR grant to replace CEBAF klystrons.

Assembly – 1497 MHz



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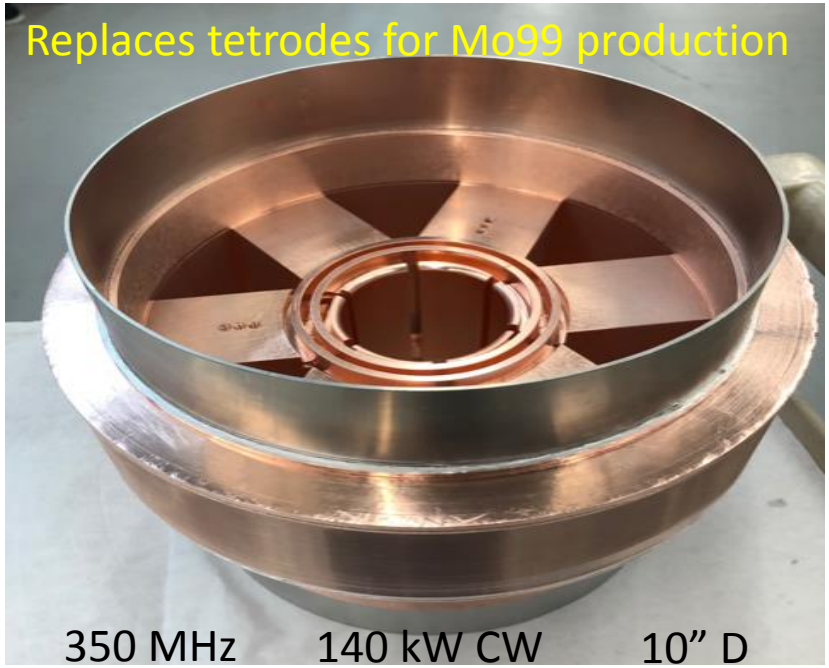
SRF Linacs need efficient microwave power

Muons, Inc. is developing power sources for Superconducting Radio Frequency Linacs
First tests of two magnetrons underway now. Magnetrons are up to 90% efficient vs klystrons 50%. Capital cost 1/5 of klystrons

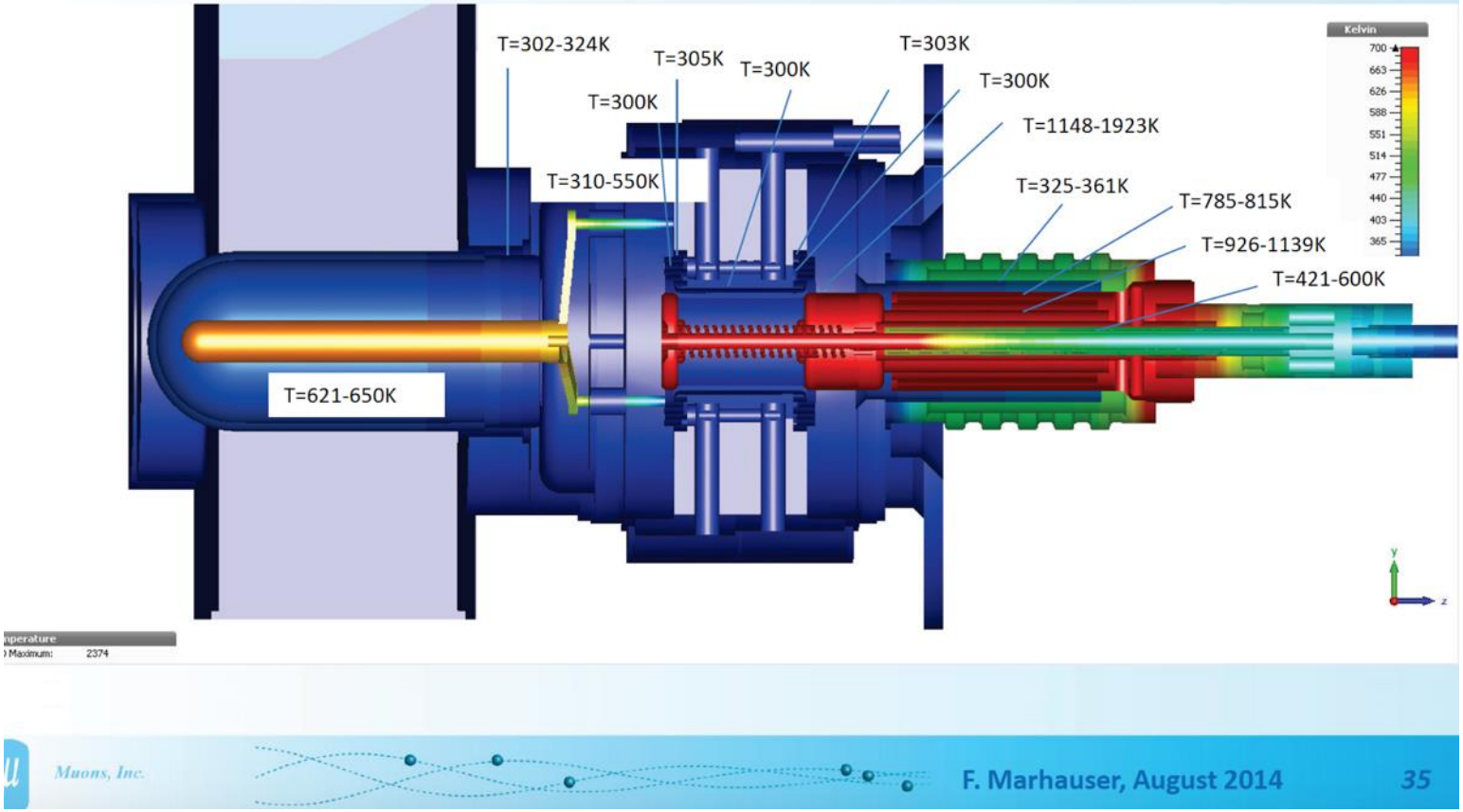


350 MHz 120 kW

- Replacement for Niowave's 30 kW tetrode
  - Injection locked with high-power circulator
- Industrial Applications
  - Indonesia: Kenneth Tan, Dawnyx Technologies

Modeling 350 MHz

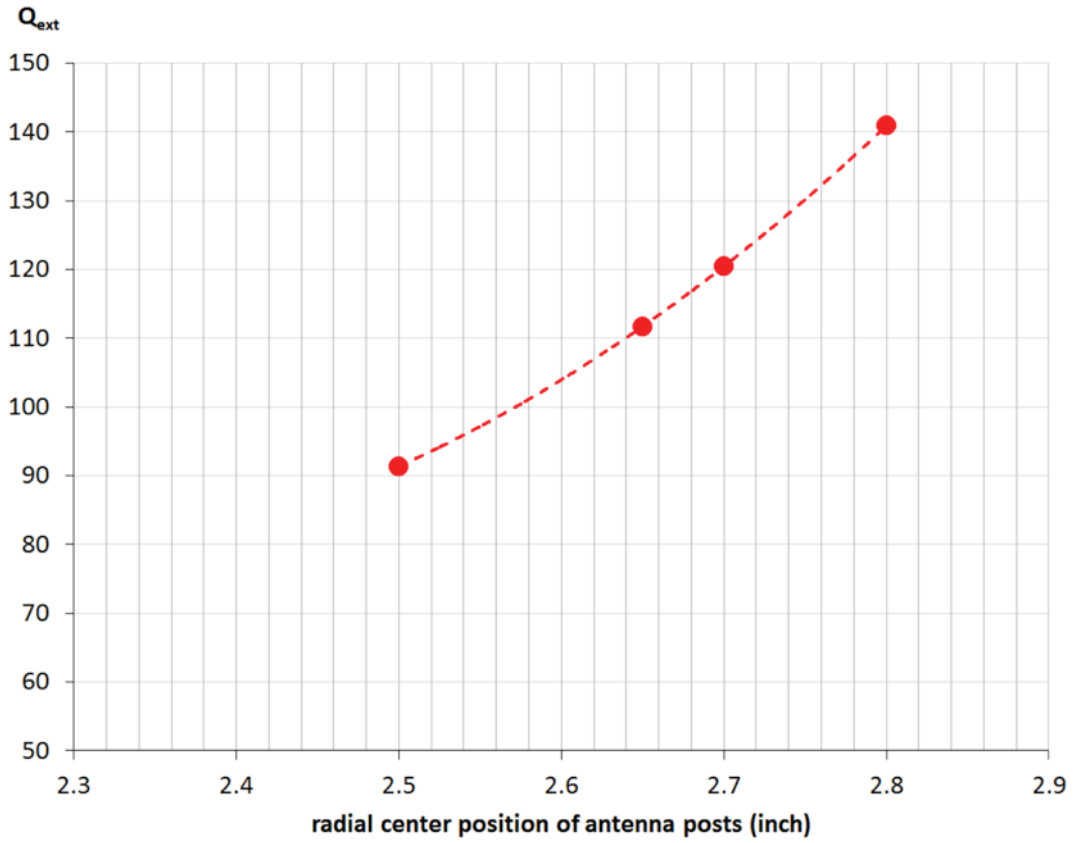
- P_{out} = 100 kW

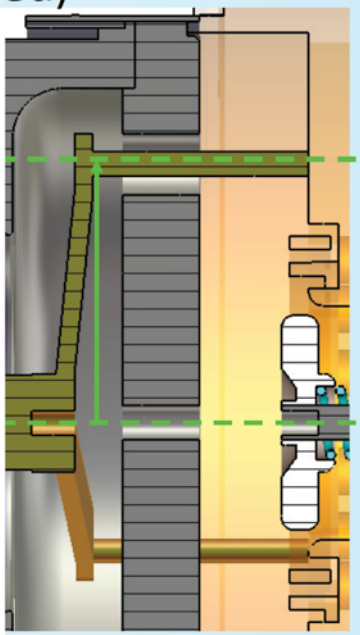


Modeling 350 MHz (continued)

Q_{ext} Simulations

- 3 posts and through-holes shifted (rest unchanged)





Parts Status 350 MHz

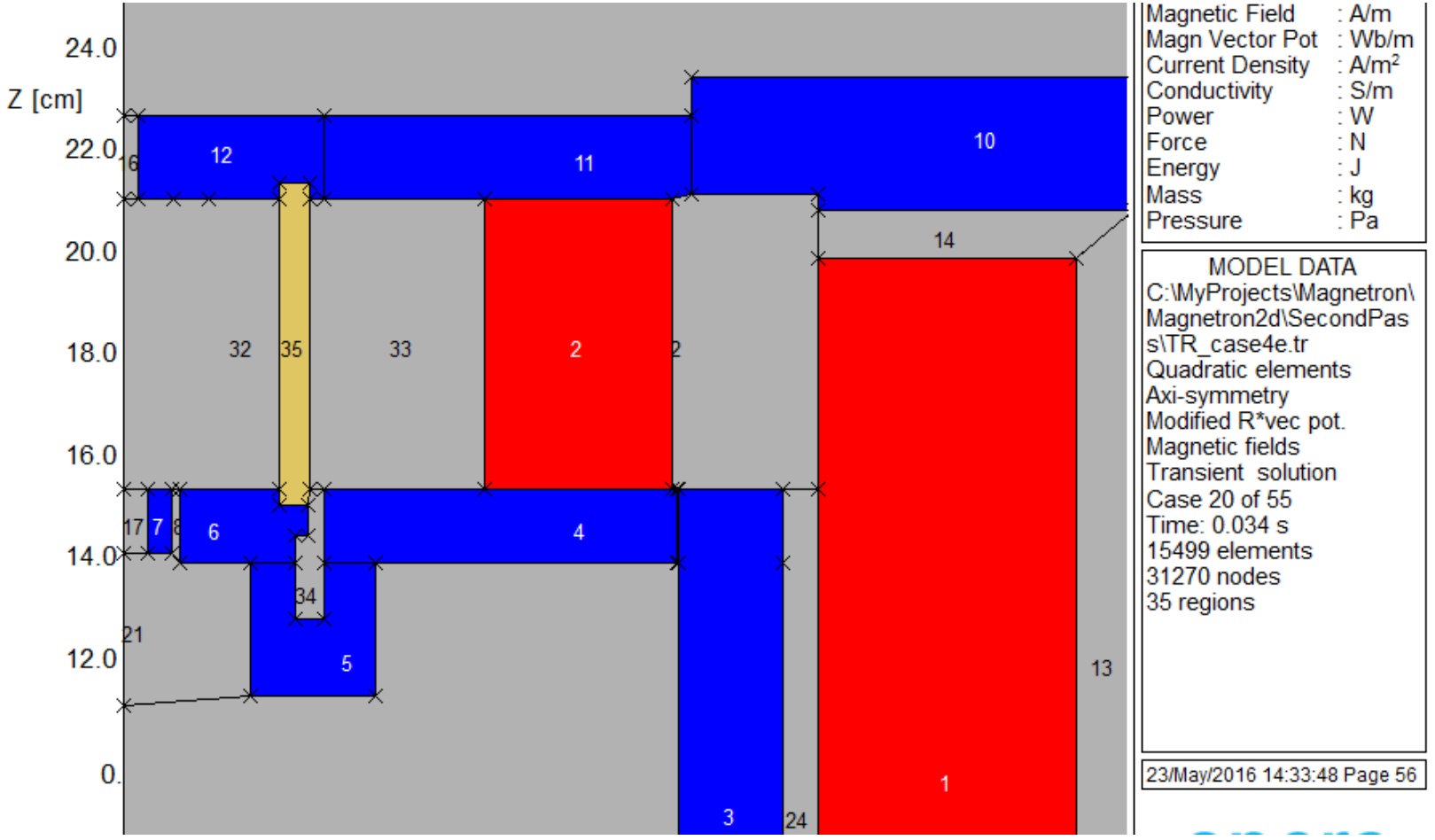
Program Status 350 MHz

- Anode complete awaiting Qext measurements
  - Reduced height coax to waveguide coax adapter delivered for single port calibration
  - May need additional hardware for two port calibration.
  - Deliver parts and assemblies to FIARC for Qext measurement by Milorad and/or Grigory?
    - Test facilities large enough for 350 waveguide parts
    - May need a lift to maneuver the anode carefully with antenna and components.
    - Assembly available for viewing.
- Cathode stalk is brazed needs filament welds.

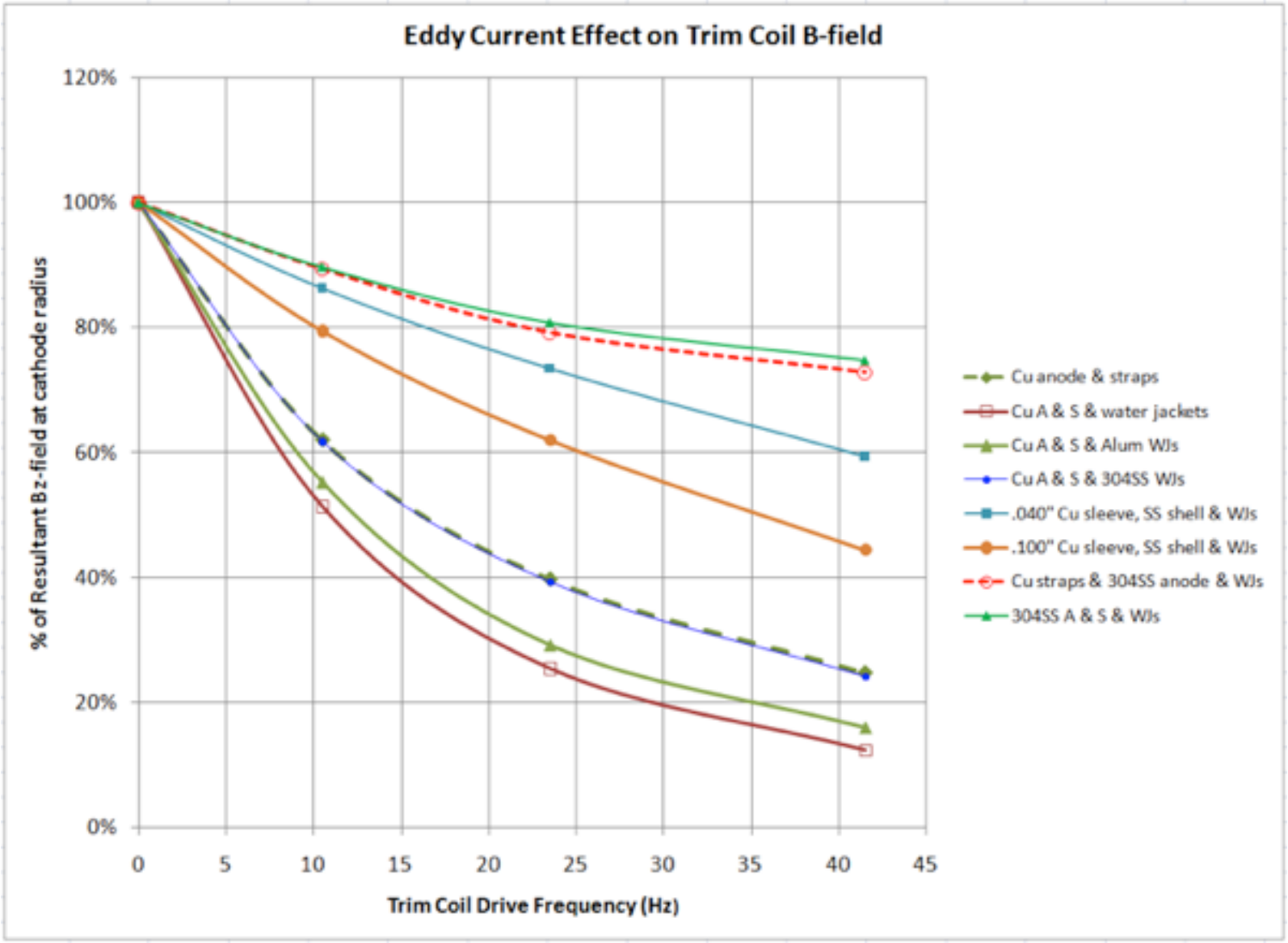
1497 MHz AM magnetron for JLAB

- AMing the magnetron with magnetic field
- Modeling the eddy currents identified a need for a bi-metallic anode.
- Bi-metallic anode completed along with standard anode.
- Two magnetrons being built, soon to JLab
- Feed-back electronics developed by JLab
  - Bob Rimmer, Haipeng Wang

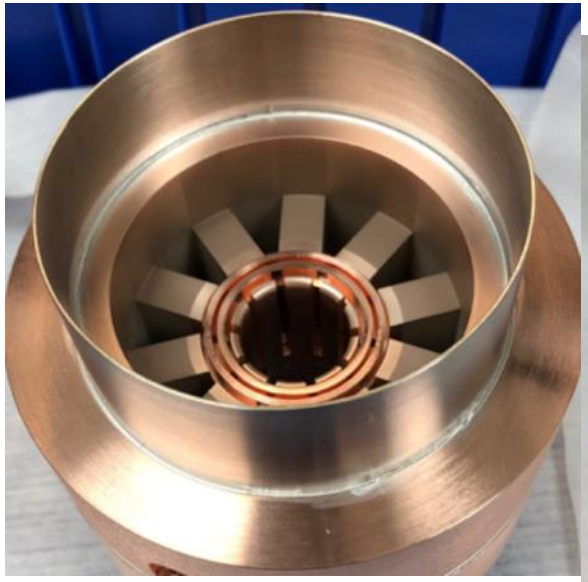
Eddy Current Calculations (Opera and Comsol)

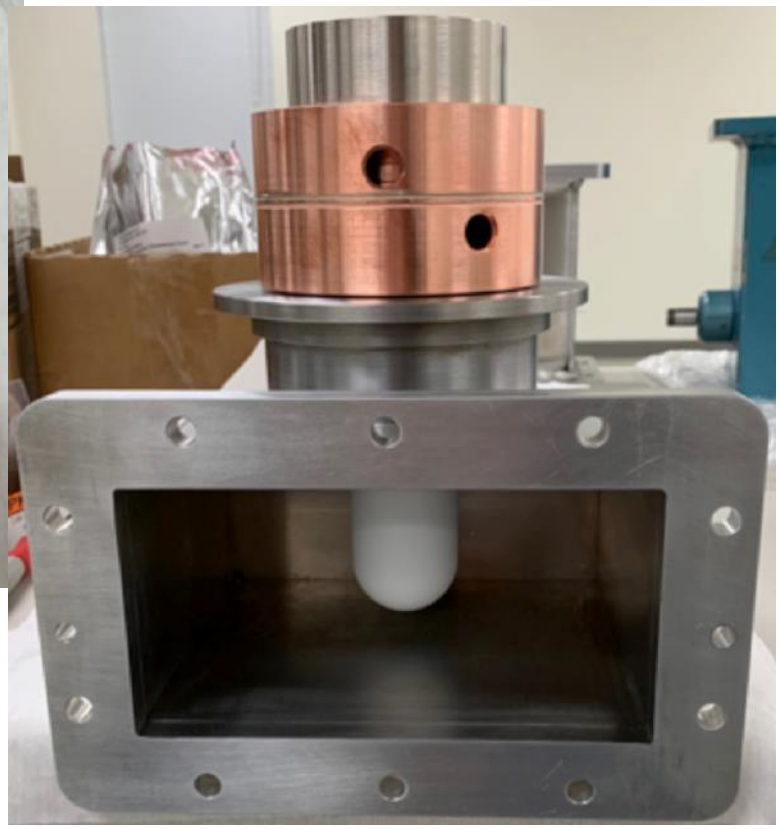


Eddy Current Calculations (Opera and Comsol)



Parts Status – 1497 MHz





Program Status-1497 MHz

- Standard and Bi-metallic anodes
  - completed awaiting last brazes
- Two Cathode Stalks at Heatwave for filament welding:
  - Jan: new moly parts needed to be made
  - Feb: prototype parts delivered to Heatwave
  - Mar: final parts delivered to Heatwave and test parts for moly-to-iron weld
  - April: final SOW completed and PO delivered to Heatwave
  - June: Heatwave status parts being procured for test fixtures.
  - July: projected completion date 7/19

Cathode Stalk Completed

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Cycle Testing and Inspection

Date, Time	Voltage VAC	Amps	Power	Press. Torr	Pyro Temp. Filament
7/16/19					
10:50	1.08	30.9			
11:00	1.190	29.2	34.748		
11:15	2.010	39.7	79.797		
11:55	3.070	46.9	143.983		
12:30	4.040	57.6	232.704		
12:35	3.030	45.1	136.592		1460
1:00	4.100	53.6	162.408		1604
1:04	4.530	55.6	227.755		1657
1:08	5.010	59.9	271.528		1742
1:20	5.510	63.0	315.530		1772
1:30	6.690	66.1	364.211		1834
1:35	6.510	68.9	460.941		1920
1:45	6.990	71.6	466.116		1993
1:49	7.540	74.4	520.056		2033
1:56	8.050	77.3	582.842		2110
1:59	7.990	76.5	615.825		2098
	0.000	0.0			

7/17/19 thermal cycling to test Ni braze joint

Cycle details:
4V, hold for 1 minute
6V, hold for 1 minute
8V, hold for 15 minutes
power off, hold for 30 minutes
repeat

10 cycles completed

no visible cracks in the Ni braze on the CRS/Mo joint

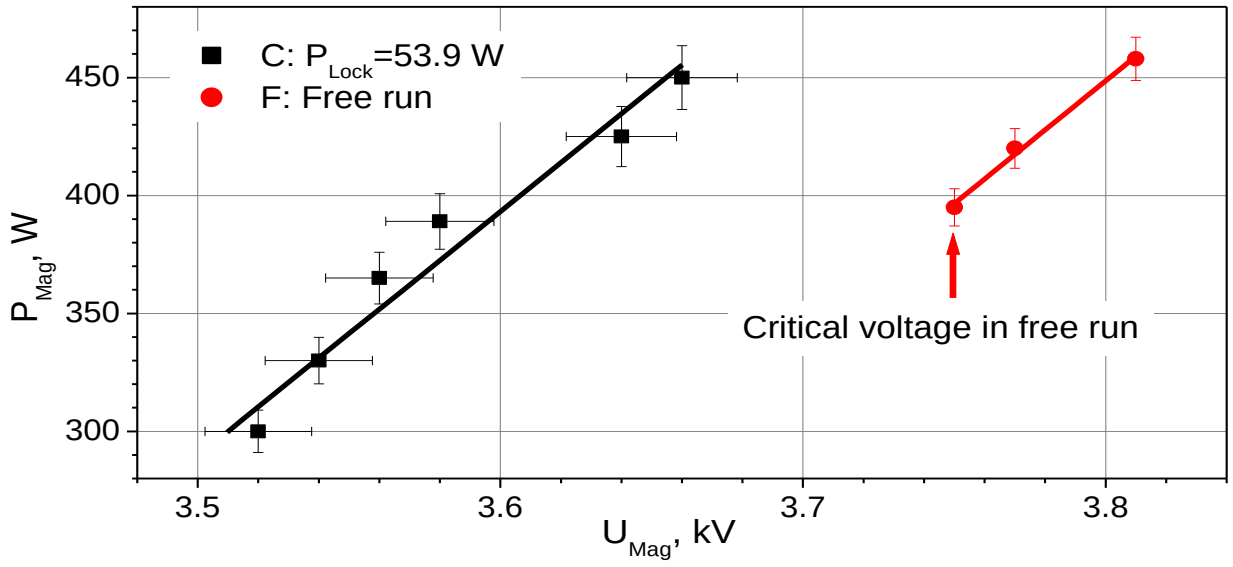
measured pitch after thermal cycling from cathode end hat end:
.109, .112, .112, .112, .112, .112, .110, .109, .109

Distributed Manufacturing

- Piece parts from various suppliers
  - Machine shops primarily Grand Island Machining
  - Ceramics
    - Coorstek
    - B and H Technical Ceramics
  - Explosion bonding: high energy metals
- Brazing, bakeout, general assembly – Altair
- Welding – Heatwave
- Magnets – Device Technologies
- Testing – FIARC?

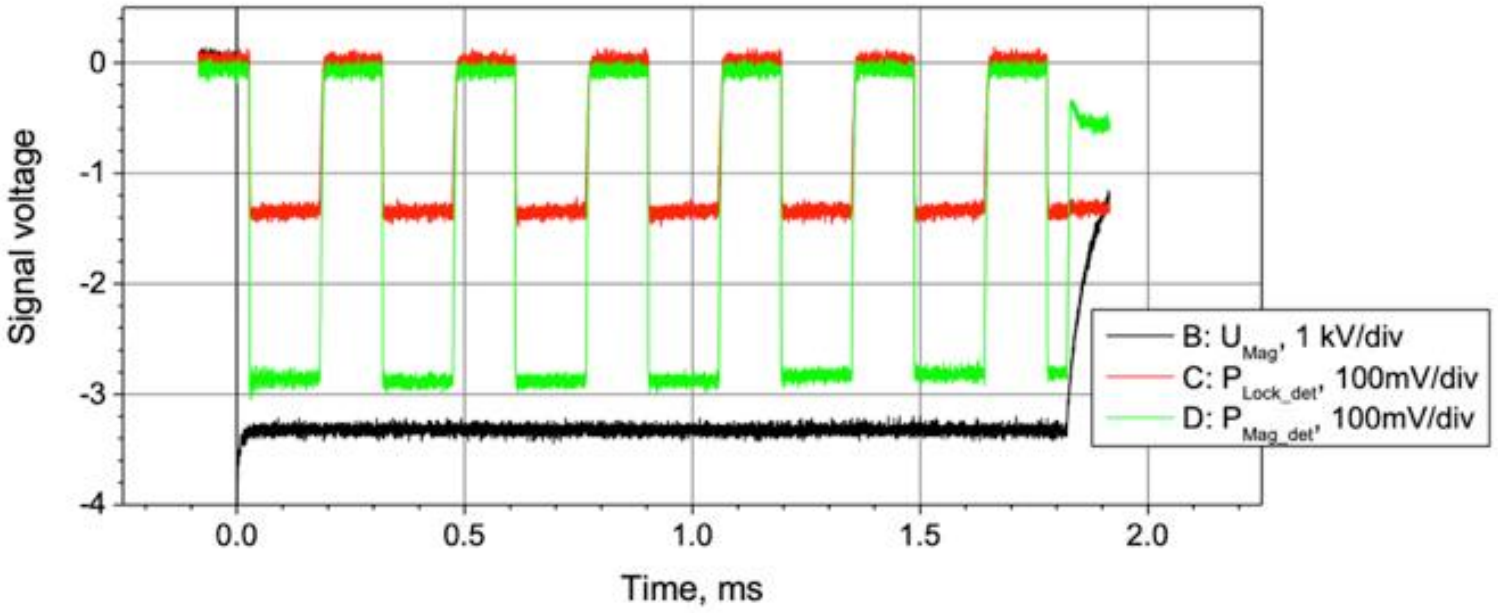
New Ideas - tests at 2450 MHz

- Subcritical voltage operation
  - cathode voltage less than needed for self-excitation
  - Locking/control voltage sent in through antenna
  - adds to cathode voltage to control rf phase and power
  - Allows magnetron to act more like an amplifier



New Ideas - tests at 2450 MHz

- Subcritical voltage operation
  - Useful for pulsed operation



The black trace shows the magnetron voltage (1 kV/div),
The red trace shows the detected locking signal of ≈100 W,
The green trace shows the magnetron output detected signal of ≈330 W.

Next Steps
shipping 1497 MHz parts to JLab

Test setup ready at JLab.
Haipeng ready to test feedback system needed for microphonics control.
If successful, replacement of klystrons could lead to 5-year payback in power savings.

Thanks to Michelle and Manouchehr for support