Muons, Inc.

A novel injection-locked amplitude-modulated magnetron at 1497 MHz

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Outline

- Muons, Inc.
- SBIR Program Status Year 1 including Year 2 plans
- Phase III Framework.

Muons, Inc.

- Rolland Johnson, President
  - Founded in 2002
    - From 2002-2010 --- focused on Muon Collider Technology
    - 2010-Present --- focused on product development and ADSR (Accelerator Driven Sub-critical Reactor) Technology
- Individuals within Muons have created exciting teams and networks for doing research and developing products.

Muons, Inc: a few of the projects

- Simulation programs: MuSim and G4beamline (TR)
  - From Muon Collider to ADSR applications
- Gas Filled Cavities (RJ)
  - Muon Cooling Channels to beam monitors in high radiation environments
- ADSR (RJ MAC BA)
- Ion Sources (VD)
  - H- ion sources for SNS and PIP-II Proton Driver
- Magnet R&D (SK)
  - Muon Collider to ADSR applications and magnetrons
- Microtrons for Gamma Ray and Neutron Sources (GK)
- Magnetrons and RF Components (MN)
- www.muonsinc.com

SBIR Program Status

- Program Overview
  - How we got here
- The Magnetron System
  - Injection Locking and Phase Stability
  - Amplitude Modulation of the magnetron
    - Magnetics Design Optimization
  - Magnetron Prototype
    - Commercialization
  - Year 2 Plans
- Phase III Framework

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Power Sources for NP Programs

- Muons, Inc. and JLab have been working on this problem for a number of years. We had a Phase I study that did not go to Phase II in 2013.
- The study evaluated various options for sources: Klystron, IOT, CFA, magnetron(s) and produced a table showing a "scoring" for the best options

Proceedings of PAC2013, Pasadena, CA USA

AN EFFICIENT RF SOURCE FOR JLAB*

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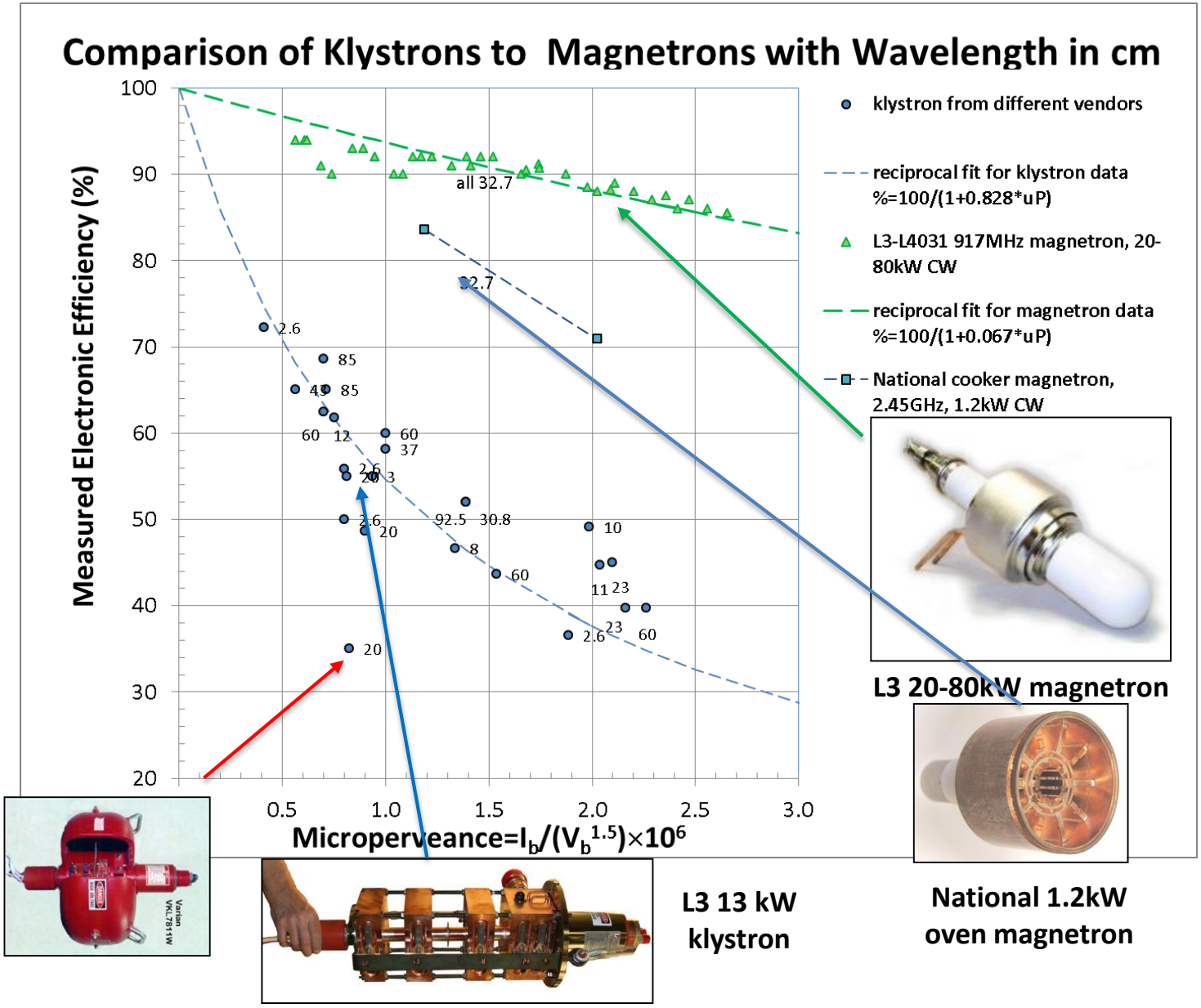
	Sum	Total Tube Cost	# of tubes	Eff	Tube Cost (each)	Gun	Interaction Region	Collector	Total System Cost	RF Driver	waveguide system	Feedback System	Power Supply
Klystron	19	15	1	0.4	6	1	3	2	4	1	1	1	1
IOT	14	8.57	1	0.7	6	2	2	2	5	2	1	1	1
2 Magnetrons													
master slave	19	8	2	0.5	2	1	1		11	3	3	3	2
peer to peer	19	8	2	0.5	2	1	1		11	3	3	3	2
2 CFAs	16	8	2	0.5	2	1	1		8	3	2	1	2
1 Magnetron													
Anode V Modulated	12	2.5	1	0.8	2	1	1		9	2	1	3	3
B-Field Modulated	11	2.5	1	0.8	2	1	1		8	2	1	3	2
Gridded	9.8	3.75	1	0.8	3	2	1		6	1	1	1	3

JLab R&D on magnetron RF source

H. Wang



Magnetron RF source, the potential impact

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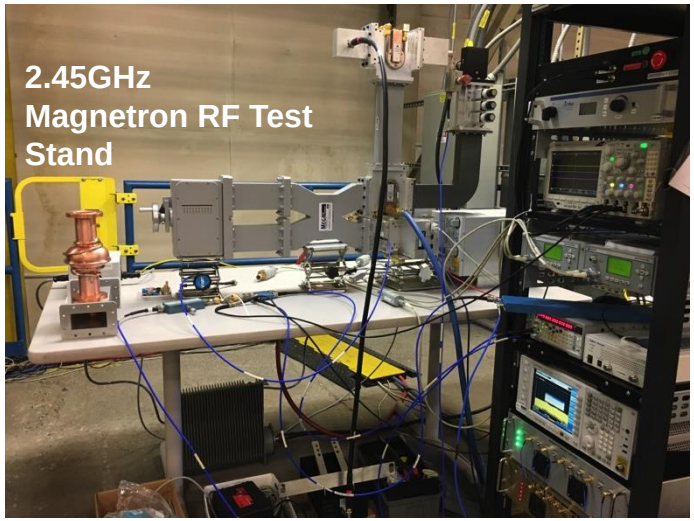
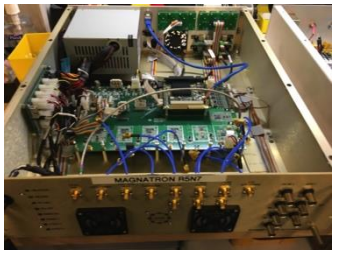
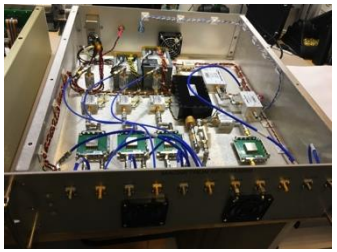
Capital and operation cost saving for CEBAF in RF power

- Low cost of magnetron device
- DC-to-RF efficiency from klystron to magnetron improves from ~35% to ~90%
- 2.22MW of DC power saving
- **$2.8 million saving in power bill, if 41 weeks/year of CEBAF in 6-12GeV operation**

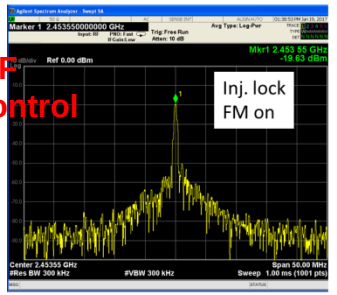
Technology demonstration for all SRF accelerators in the DOE complex

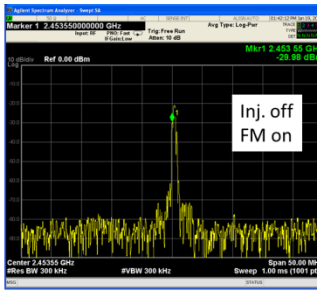




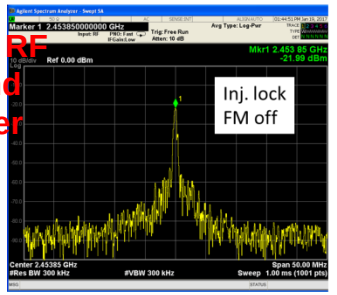


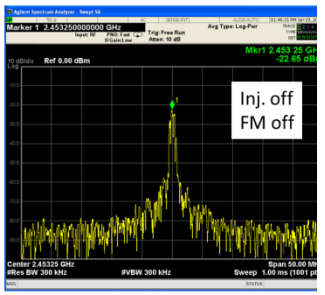
Digital RF FPGA Control Chassis





2.45GHz RF Front End Controller





References:

[1] A. C. Dexter, G. Burt, R. G. Carter, I. Tahir, H. Wang, K. Davis and R. Rimmer, PRST-AB, 14, 032001 (2011).

[2] M. Nuebauer, A.Dudas, R, Rimmer, H. Wang, An Efficient RF Source for JLab, PAC 2013, Pasadena, CA, USA.

[3] H. Wang, T. Plawski, R. Rimmer, Simulation Study Using Injection Phase Locked Magnetron as an Alternative Source for SRF Accelerators , IPAC 2015, May 3-8, 2015, Richmond, VA, USA .

[4] H. Wang, T. Plawski, R. Rimmer, M. Neubauser, A. Dulas, Simulation and Experimental Studies of a 2.45GHz Magnetron Source for an SRF Cavity with Field Amplitude and Phase Controls, IPAC 2016, May 8-13, 2016, Busan, Korea

Phase II Magnetron System

- There are three critical areas for building a prototype System
  - 1. Injection-locking: a prototype system has been built for a 2.45 Ghz magnetron and tested by JLAB
  - 2. Amplitude Modulation by adjusting the magnetic field of the magnetron at low audio frequencies requires a coil design with a matching impedance to a programmable AC power supply
  - 3. Magnetron anode needs a design and a manufacturing process to minimize eddy currents

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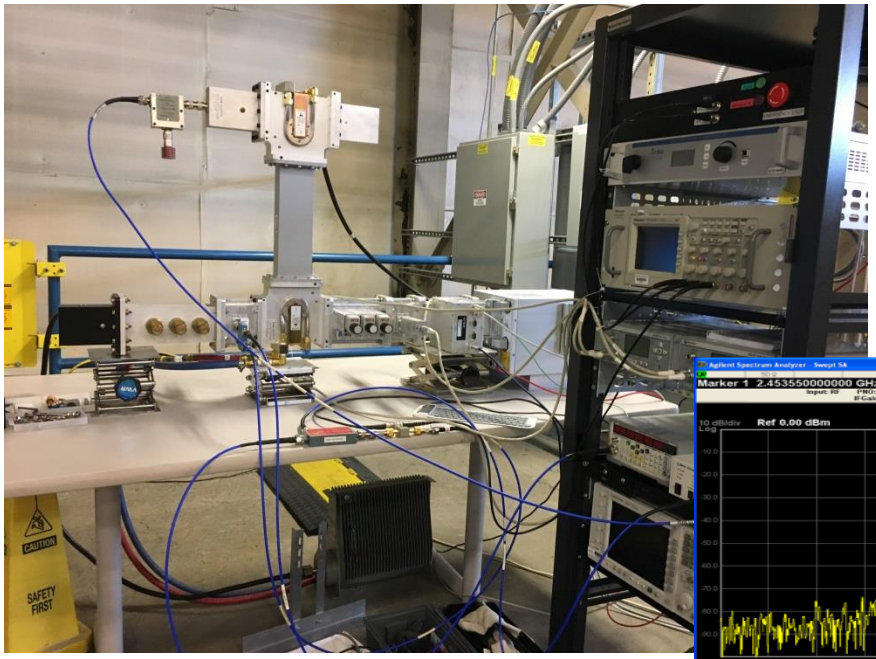
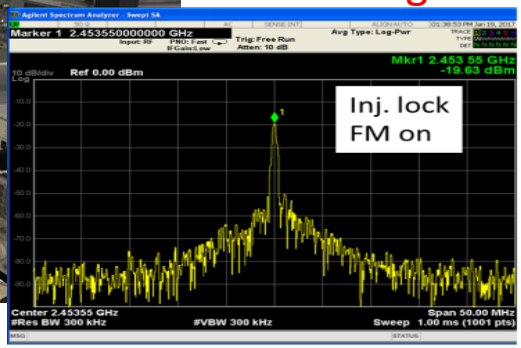
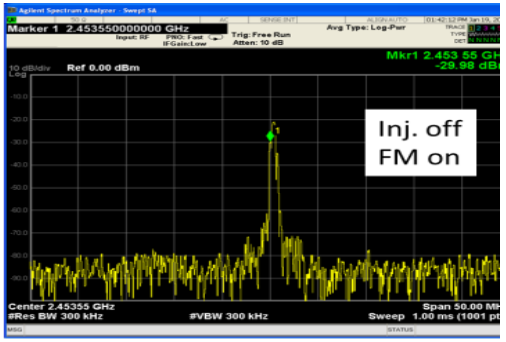
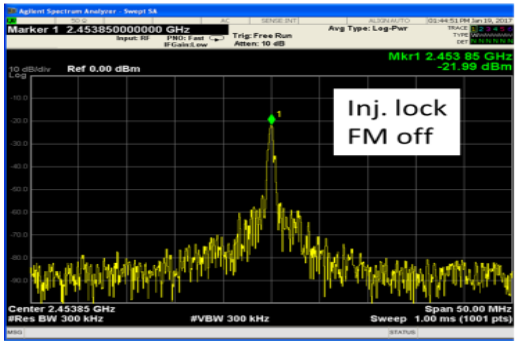
Phase Locked Magnetron (JLAB)

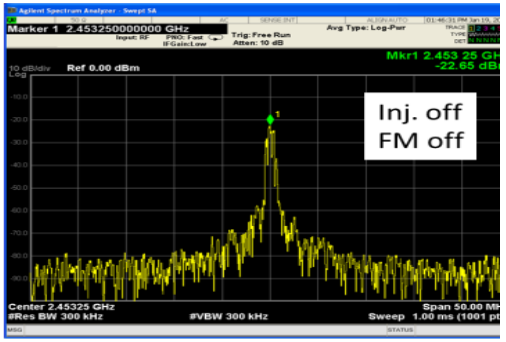


- Using FM from SG384 signal generator with low noise 1W RF amplifier as the LO and a clean RF injection seeding source
- Magnetron output power up to 1.2kW
- Noise level -40dB down from peak power
- ~30 db gain







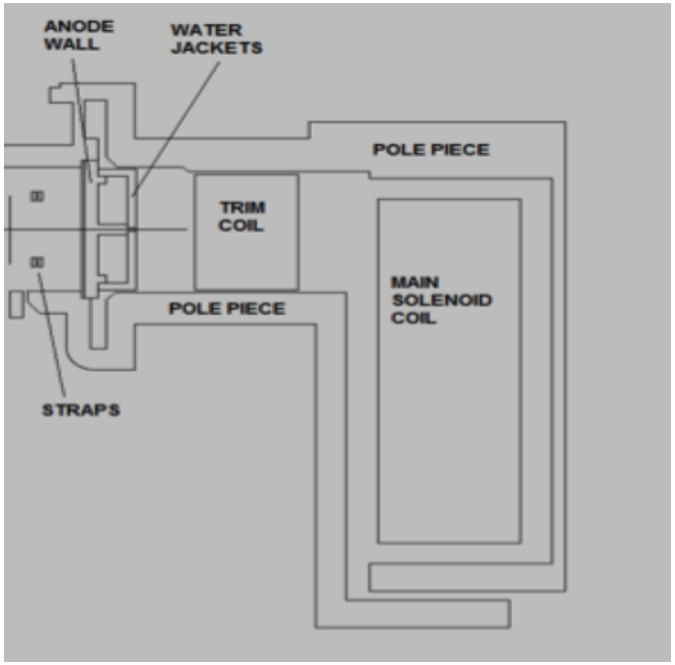


Injection Locking

- JLAB has performed locking tests on a 1kw 2.54 GHz “cooker” magnetron. The 1497 MHz magnetron is planned for completion by Dec 2017 and testing will begin.
- Digital controller algorithms that were designed for “cooker” magnetron will be tested on the 1497 MHz magnetron and modified as required.
- On schedule

Magnetic Field Variation

- Coil Design and placement in the prototype configuration



- The trim coil design is being evaluated for optimum inductance to match a programmable power supply. (It maybe similar to California Instruments CS Series (3kVA-18kVA) programmable AC supply)
- We will be doing more experiments this year to evaluate power supply options and trim coil design
- On Schedule

Magnetron Production of the 13 kW tube

- All parts are on order and being delivered for assembly at Altair Technologies in Fremont, CA.
- Plan to build a standard 1497 MHz magnetron so that injection locking system can be evaluated first.
  - This will include the optimization of the Q_{ext} which controls the bandwidth of injection-locking and the gain of the system.
- A second magnetron will be built to have a special anode for minimizing eddy currents also by Dec 2017.

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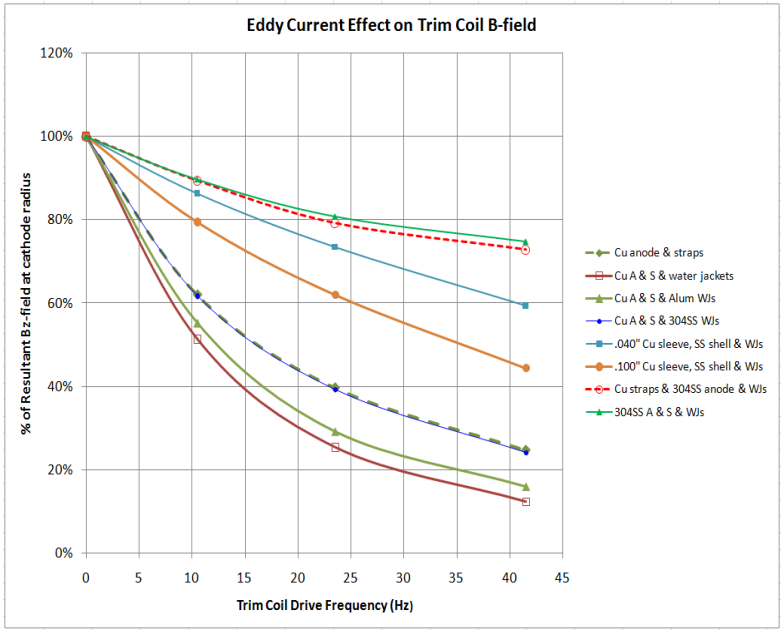
Eddy Current

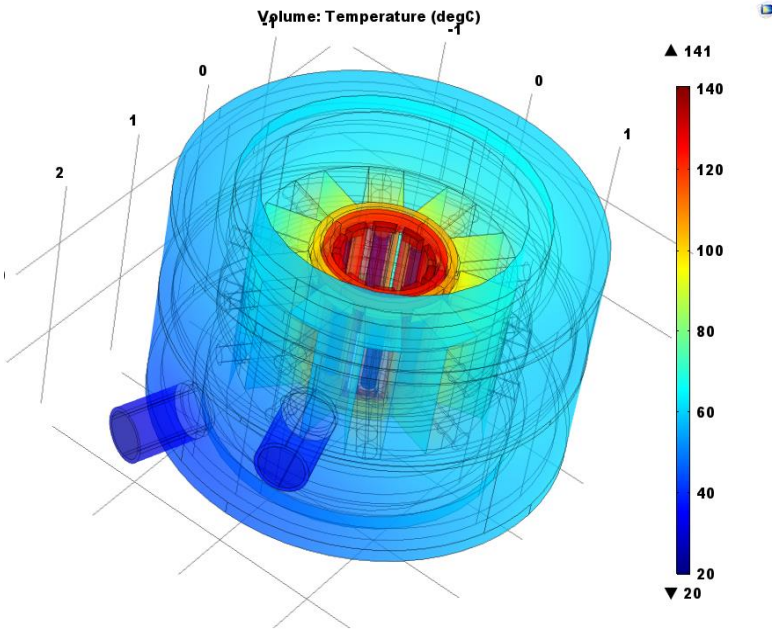
- A varying the magnetic field in a conductor (copper) creates opposing magnetic fields



- Changing the material to stainless steel reduces the effect, but does not eliminate it.
- Manufacturing a magnetron anode with stainless steel has never been done before because of the obvious heating problems
- We have studied the problem extensively and have a solution.

Anode design

- Several Comsol runs to evaluate the thermal issues.



- We will be using a manufacturing process to create a bi-metallic anode.
- The tips of the vanes receiving most of the intercepted power will be copper.
- The method for manufacturing the anode is being worked out and will be incorporation in the second magnetron we will be building in December of this year.
- On Schedule

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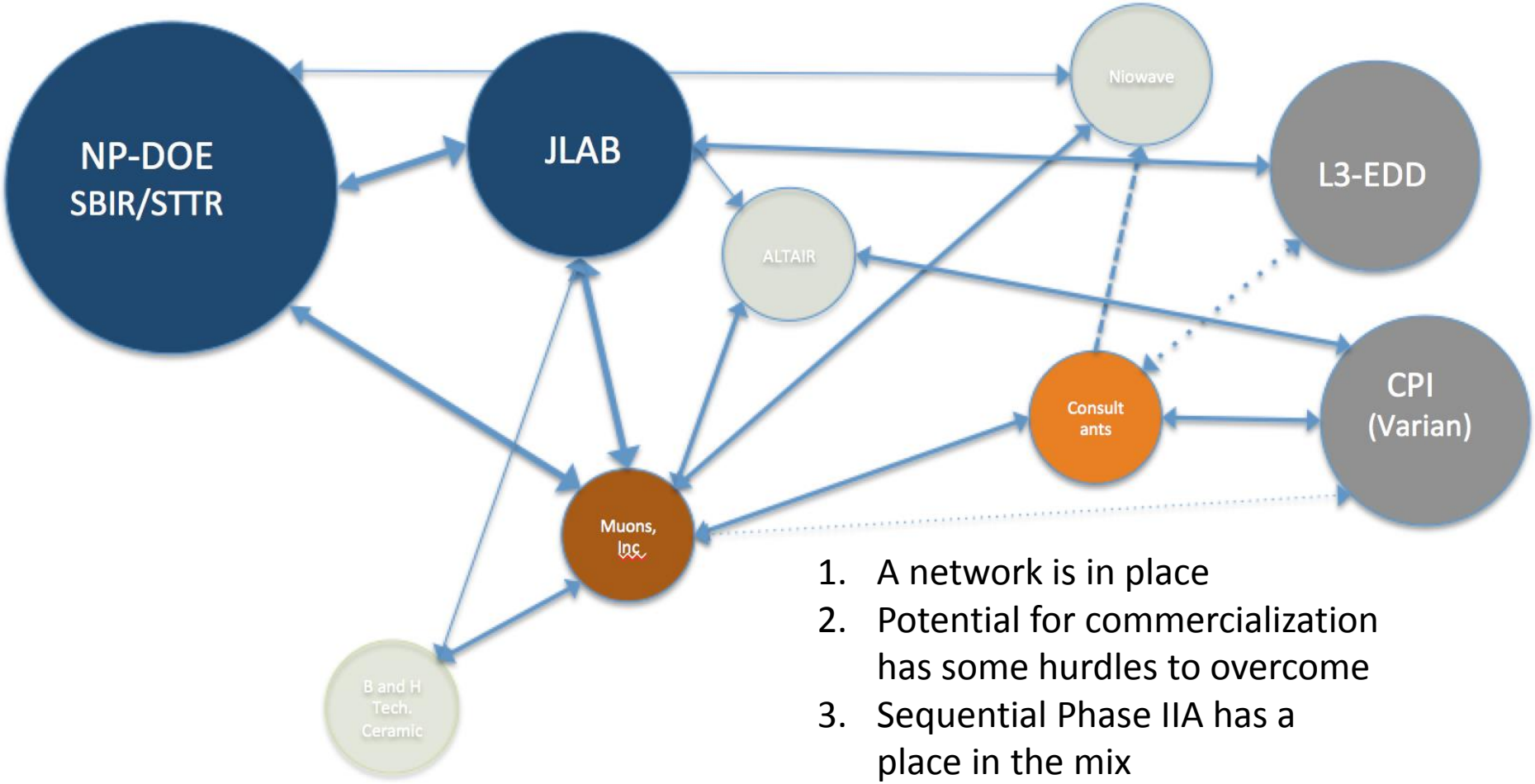
Phase III Framework
(Sequential Phase IIA)

- The Magnetron will need to be licensed by Muons, Inc. to be manufactured by an established tube facility
  - (The least likely option is for Muons, Inc to build a manufacturing plant.)
  - Two US options for tube facilities: L3 Electron Devices and CPI Econco Division
- Manufacturability needs to be established during a Sequential Phase IIA
  - Do processes match a tube manufacturing plant?
  - Life-testing the prototype system with additional design changes as required.
    - For example: Permanent magnet biasing field with a trim coil for AM
- Some Initial investigations and actions have already been taken to establish the parameters for Phase III.

Phase III- background

- CTL (California Tube Lab) was bought by L3 and commercial magnetrons transferred to Williamsport, PA (2012)
  - Two senior magnetron engineers stayed in California and were hired by Muons, Inc as consultants (350 MHz magnetron for Niowave).
    - Knowledge of transfer issues from prototype to manufacturing
    - Knowledge of tube facilities and best practices.
      - CPI Econco Division and Williamsport (L3)
- Consultants will play an important role in establishing the manufacturability of the unique magnetron prototype being designed and built by Muons, Inc.

Phase III --- Summary



1. A network is in place
2. Potential for commercialization has some hurdles to overcome
3. Sequential Phase IIA has a place in the mix

Summary

- The program is on schedule to construct a prototype system.
- No new technical hurdles to overcome.
- Additional funding will be required to ensure a commercially viable product.