Phase and Frequency Locked Magnetrons for SRF Sources

SBIR/STTR NP Exchange Meeting

Oct 24-25, 2011

Mike Neubauer, Chief Engineer, Muons, Inc.

Richard Sah and Al Dudas, Muons, Inc

Milorad Popovich, Fermilab PI

Muons, Inc.

Outline of Presentation

- Introduction to Muons, Inc.
- Phase and Frequency Locked Magnetrons for SRF Sources (Fermilab subcontractor). This project is funded by a Phase II STTR grant from NP (DOE). Currently in our second year.
  - Description of Problem
  - Technical Approach
  - Current Status
  - Commercialization Plan

History of Muons, Inc.

- Muons, Inc. was founded in 2002 to participate in SBIR and STTR programs which fund research on muon beam cooling and on applications such as neutrino factories, muon colliders, and stopping muon beams.
- Muons, Inc. collaborates with labs (ANL, BNL, Fermilab, JLab, SLAC, LBNL) and universities (Cornell, FSU, Hampton U, IIT, NIU, ODU, U of Chicago)
- Muons, Inc. and its collaborators have been responsible for a number of key inventions and innovations for muon colliders, and muon colliders have now become a very active field of research for future energy-frontier facilities for high-energy physics.

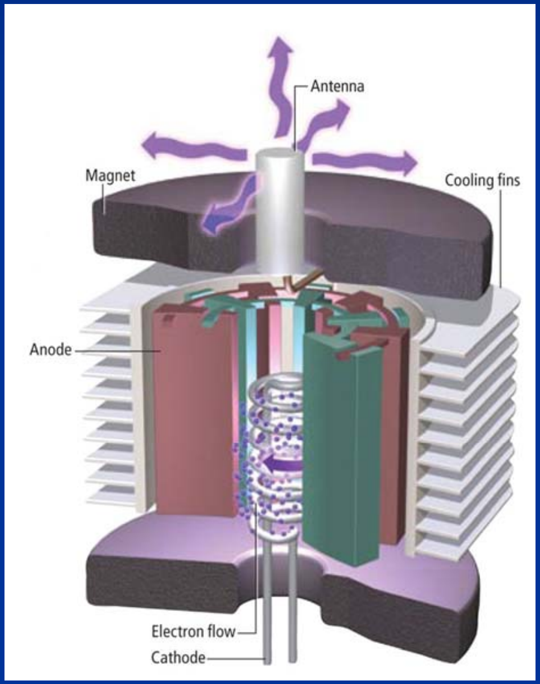
High-Power RF Hardware Development at Muons, Inc.

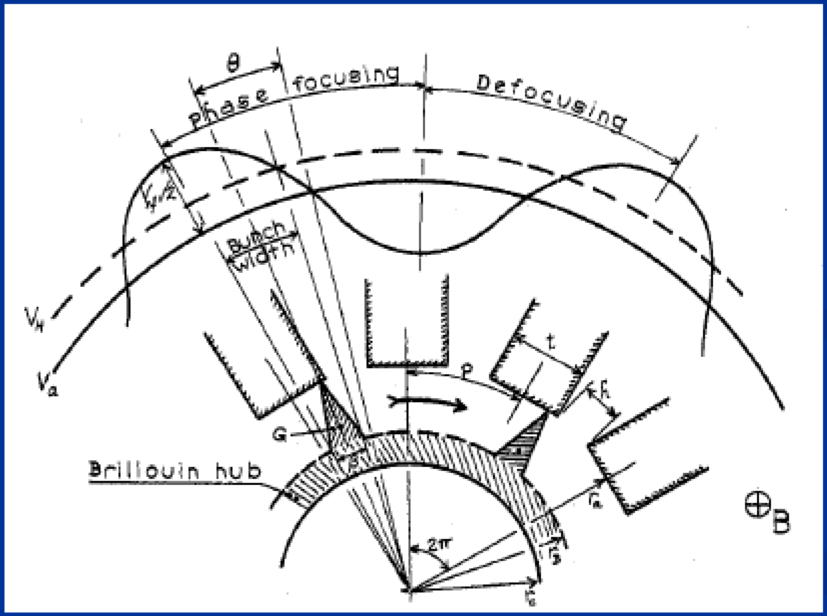
- Three years ago, we hired two RF engineers and initiated a program to develop high-power RF hardware.
- This initiative has been very successful in terms of grant awards, and four ongoing Phase II awards now account for an important fraction of the company income.
- One of these funded projects is "Phase and Frequency Locked Magnetrons for SRF Sources."

The opportunity and the problem

- The opportunity is that magnetrons produce RF power for the lowest cost and operate at >90% efficiency.
- The problem is they are noisy, low Q sources:
  - Frequency pushing from power supply ripple and current fluctuation
  - Frequency pulling from load variations
  - Phase instability due to a cylindrically symmetrical resonant structure
- Great for a microwave oven and terrible for operating as a source for a high Q SRF cavity

Magnetron Operation Basics





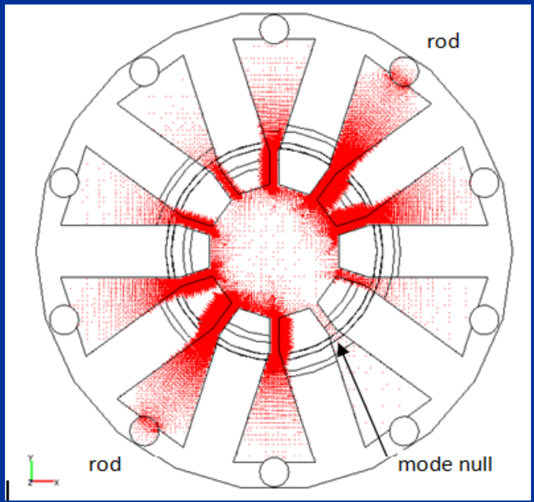
Vaughn, J.R.M., "A Model for Calculating Magnetron Performance," IEEE Transactions on Electron Devices, Vol. ED-20, No. 9, September 1973.

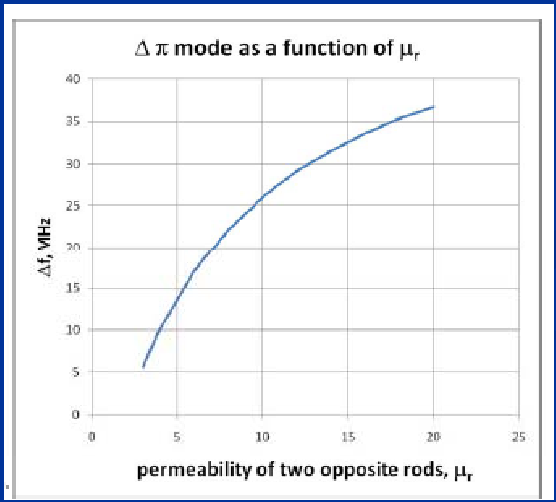
Technical Approach

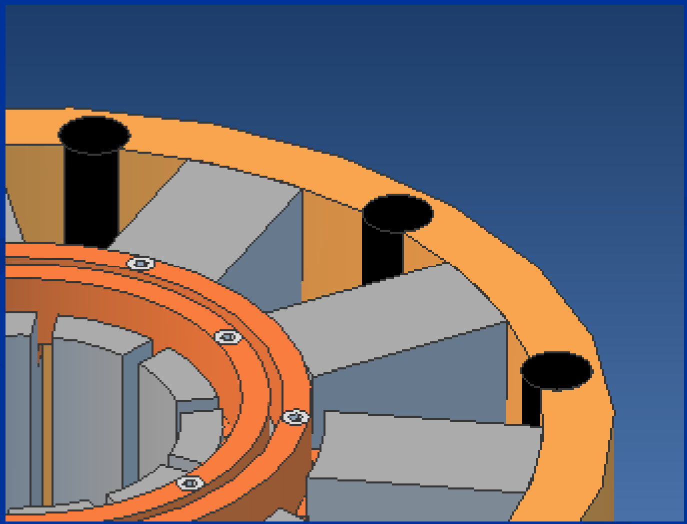
- Break the symmetry of the resonant structure for phase stability
- Provide for reasonably fast (ms level) and easy frequency adjustability.
- Partner early on with a commercial manufacturer of magnetrons
- Dual use application
  - Accelerators require frequency and phase locked operation
  - Phased array radar system requires only frequency adjustability of greater than 10% bandwidth.

Technical Approach

- Two or more cells loaded with ferrite/garnet material breaks the symmetry and locks the “free-wheeling” modes in place. This will reduce phase noise.







Next nearest mode

Technical Issues

- Find a suitable material that is vacuum compatible with bakeout temperatures of 500C
- Determine a magnetic field operating point for the chosen material that
  - Minimizes losses and
  - Does not interfere with the magnetic field which operates the magnetron
  - And is not saturated by the magnetron magnetic field
- Design an electronic feedback circuit to vary the ferrite/garnet magnetic field to control the magnetron frequency relative to a standard. Straightforward task once the operating points are established

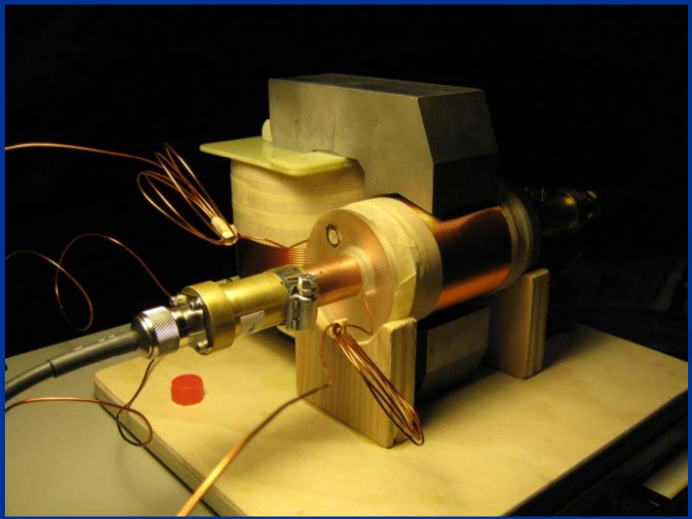
Phase II

- Finding the right material
- Shielding the ferrite/garnet from the magnetron magnetic field
- Build a test-fixture to measure the magnetic fields and magnetron resonant circuit characteristics
  - Test the magnetic shielding design
  - Determine the operating range for the ferrite/garnet that does not adversely impact the magnetron performance
  - Measure resonant circuit Q
- Build a prototype magnetron

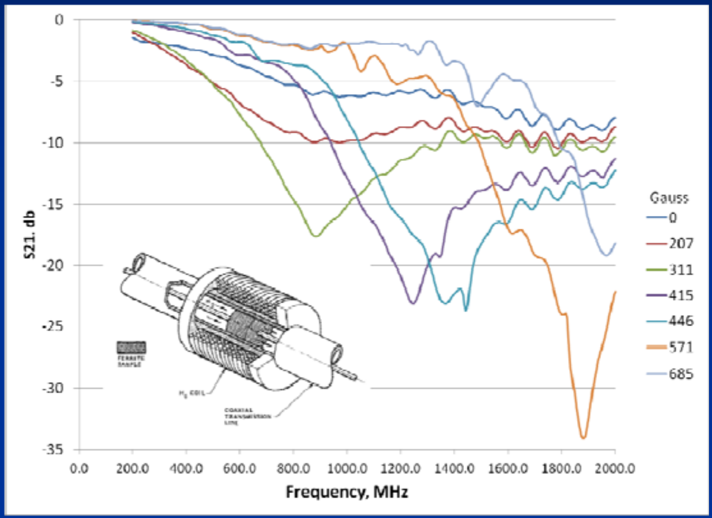
Finding the right material

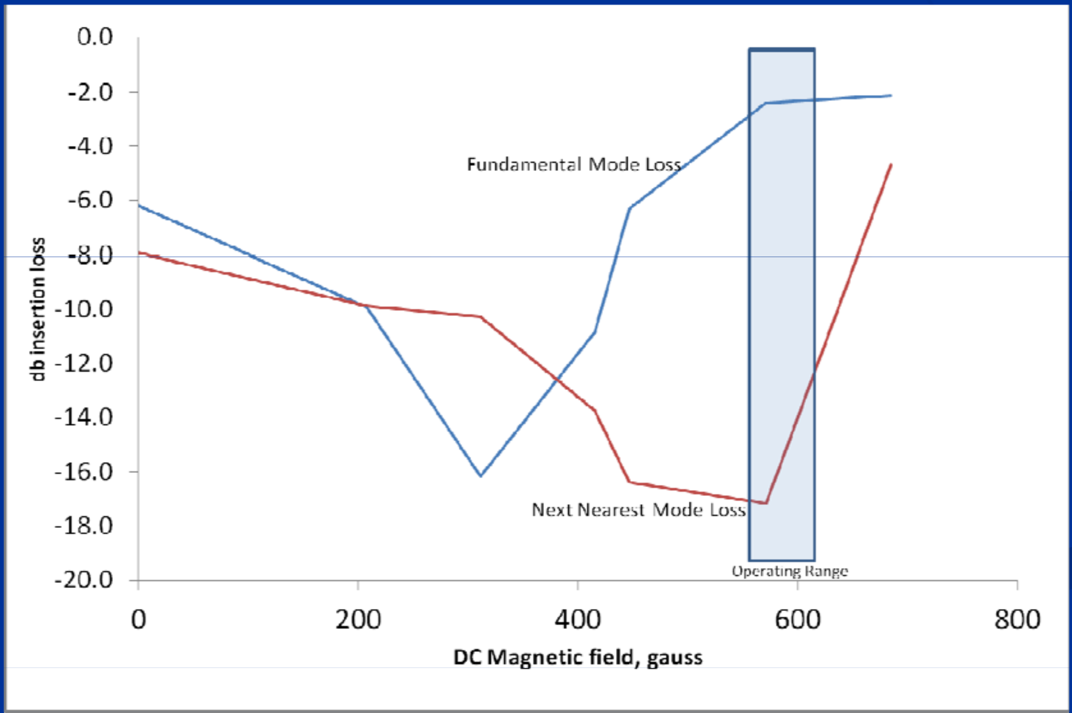
- Many samples purchased for coaxial measurements
  - TEM RF fields
  - DC Magnetic field orthogonal to TEM fields
  - DC Magnetic field parallel to TEM fields
- Not the exact field configuration found in the magnetron, but a cost effective method to sort through many materials and find the best candidates

Finding the right material



Finding the right material





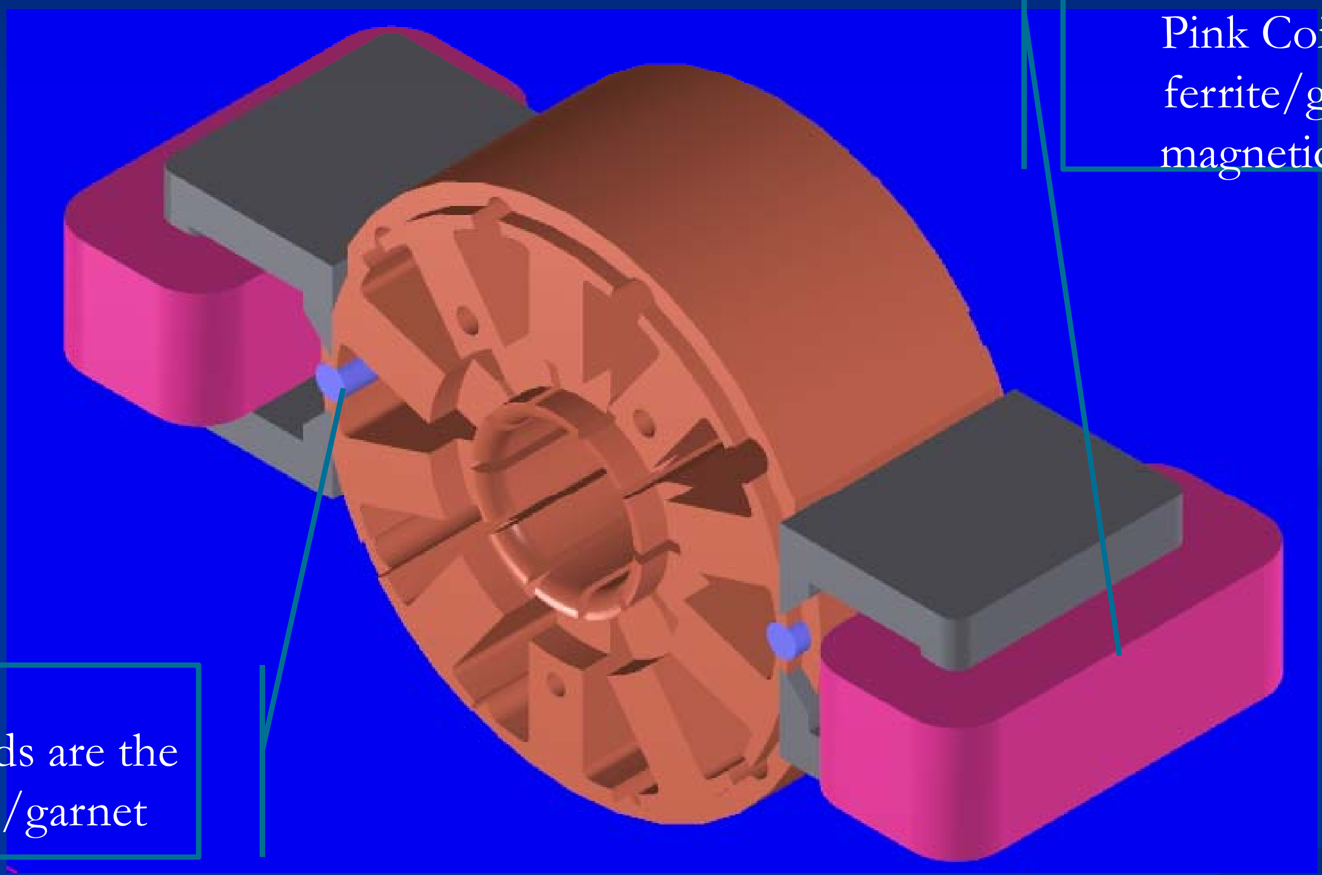
Muons, Inc.

We found the right material

- The magnetic field required for the ferrite/garnet is known
- It passed the 500 C bakeout test without outgassing

Muons, Inc.

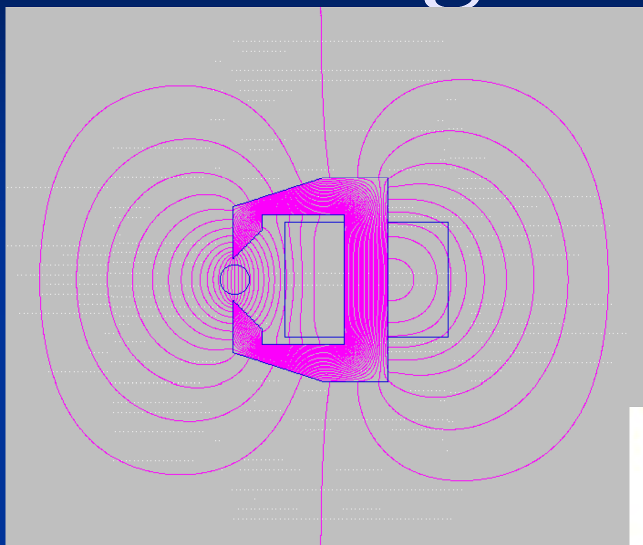
Magnetic Shielding Design

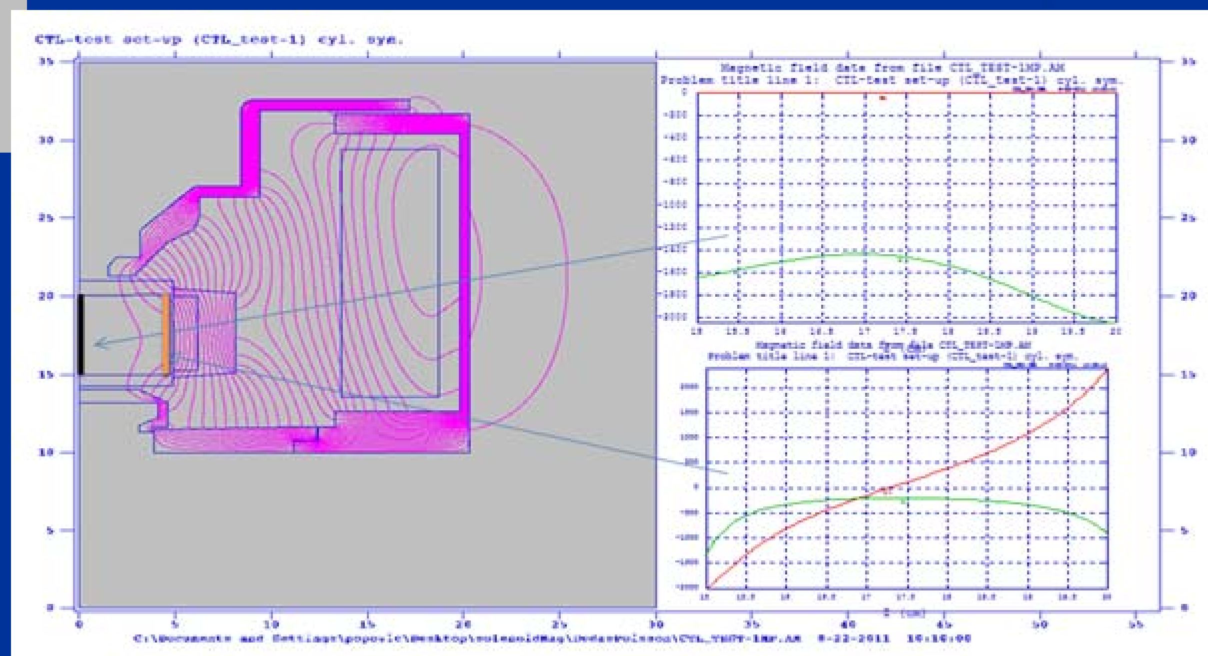


Pink Coils for ferrite/garnet magnetic field

Blue rods are the ferrite/garnet

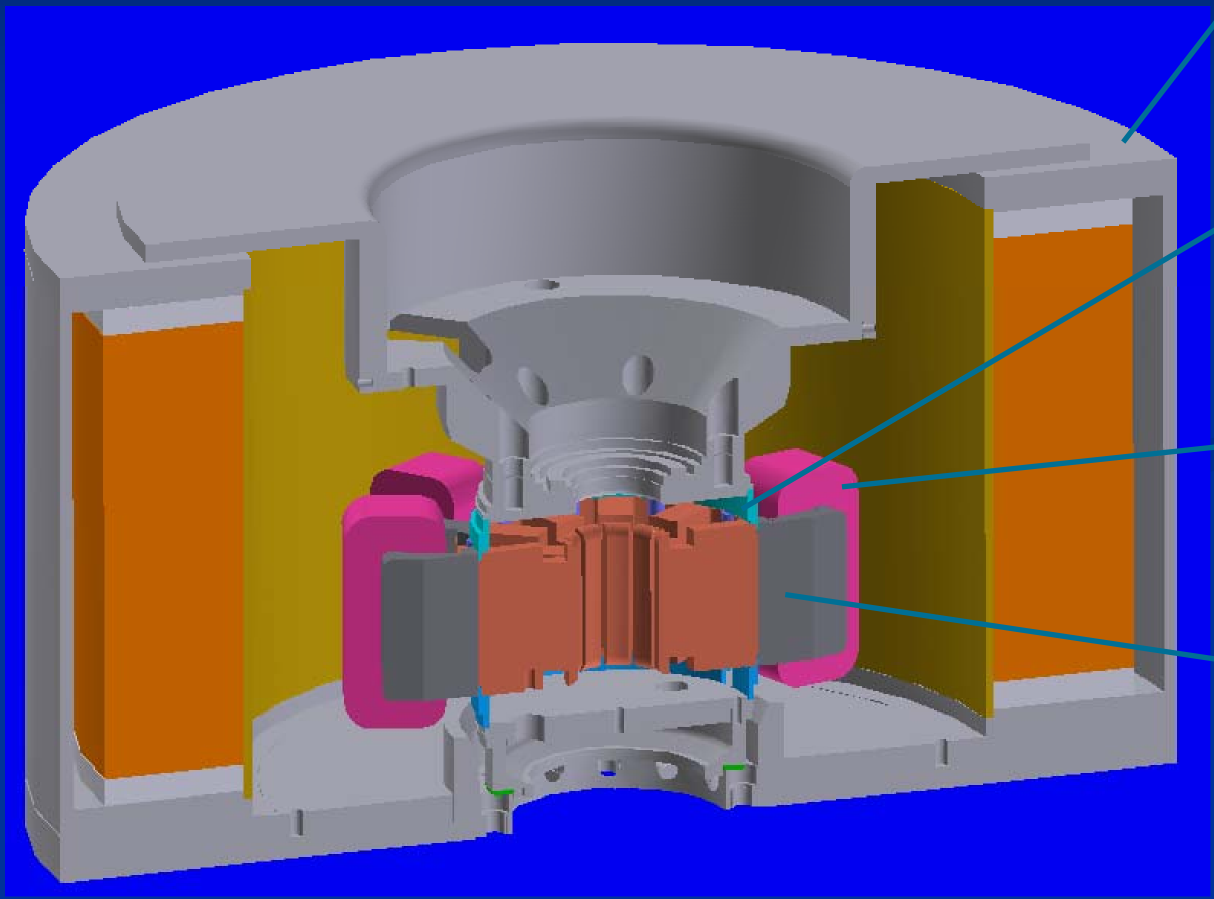
Magnetic shielding design





magnetic field for the ferrite/garnet

Magnetic Shielding Design



All gray areas are iron in the existing magnetron

Blue rods are the ferrite/garnet

Pink Coils for ferrite/garnet magnetic field

Iron yoke for ferrite/garnet magnetic field

Summary of Phase II status

- Material chosen
  - Ferrite/garnet at about 600 gauss
- Magnetic shielding designed
  - Variation of B_z in interaction region is minimized
  - Shielded ferrite/garnet from magnetron field
- Building a mock-up of the magnetics
  - To test magnetron anode/resonator performance with the material in place
  - Final test of quantity of the material that can be used

Commercialization Plan

The DOE has increased its emphasis on the Commercialization of technologies developed under the SBIR and STTR programs, and Muons, Inc. has made great strides in meeting this goal.

- Commercialization Process
- Manufacturing Partner
- Agreement
- Status

Commercialization Process

- For research projects in the area of high-power RF hardware, the completion of the SBIR or STTR research project consists of the construction and testing of a proof-of-principle prototype. The results will be published and reported to the DOE.
- Successful commercialization require additional steps:
  - Engineering design of a commercial product
  - Manufacturing and Sales

Manufacturing Partner

- Muons, Inc. is a research firm, not a manufacturing firm, so we must partner with a Manufacturing Partner to complete the commercialization process.
- For "Phase and Frequency Locked Magnetrons for SRF Sources," we have signed a contract with our Manufacturing partner. CTL is a business unit in the Electron Devices Division of L-3 Communications, and it is a major U.S. manufacturer of magnetrons. (~$10M in sales)
- <u>For all new proposals</u> in the area of RF hardware, we have signed MOUs with highly-qualified Manufacturing Partners.

Status of Collaboration with CTL

- During Phase I, CTL provided magnetron know-how and magnetron parts, in support of the research effort. This successful research led to a Phase II award.
- As discussed earlier, CTL is providing crucial technical support during the current Phase II research.
- Our Manufacturing Partner will take the lead in developing a fully-commercialized design, and in sales and manufacturing.