High Radiation Environment Nuclear Fragment Separator Magnet

Project PI: Dr. Stephen Kahn
Muons, Inc.
552 N. Batavia Avenue
Batavia, IL 60510

DOE STTR Grant DE-SC0006273
Phase II Grant Project Period 08/07/2012-08/07/2014
Non-Funded extension to 09/07/2015

Muons, Inc. μ

Presentation Outline

- Company Background
  - Primary R&D interests
- Project Description and Goals
- Project Status
- Summary and Outlook

Company Description

Muons, Inc.

- Muons, Inc. is a firm of experienced scientists and engineers specializing in accelerator physics with offices in Batavia, IL and Newport News, VA
- Muons, Inc. has grant and contract partnerships with various National Laboratories and Universities.
  - Labs include ANL, BNL, FNAL, Jlab, LANL, LBNL, ORNL, PNNL, and SLAC.
  - Universities include U of Chicago, Cornell, FSU, IIT, NCSU, NIU and ODU.
- Our goal is to invent accelerator concepts and to develop the relevant technology for their implementation.

Muons, Inc.

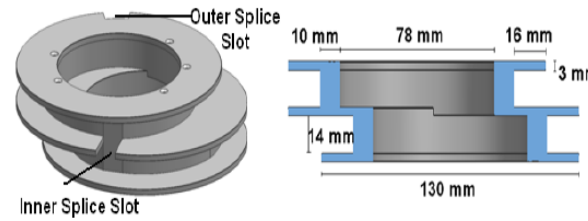
Advanced Technologies in accelerator R&D, design & construction

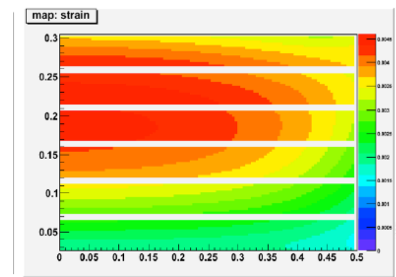
- Sources and Beams: p, μ, e, γ, H−, polarized ions
- NCRF fast-tunable, dielectric-loaded, RF loads
- SRF cavities, magnetrons, couplers, HOM dampers
- Magnets: HTS High-Field, Helical, High Radiation, Quench Detection/Protection (YBCO and Bi2212)
- Simulations: G4beamline, ACE3P, MuSim (MCNP6), etc.
- Detectors: profile monitors, fast TOF
- Applications: Colliders, Factories, ADS Reactors, SNM detection, SMES, mono-energetic photons, rare decay experiments, 6d muon beam cooling, solar wind generators, and anything needing creative solutions.

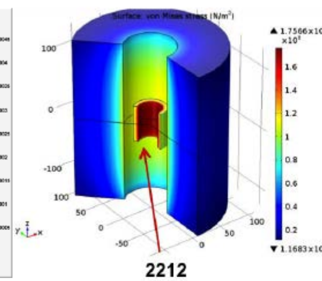
Muons, Inc.

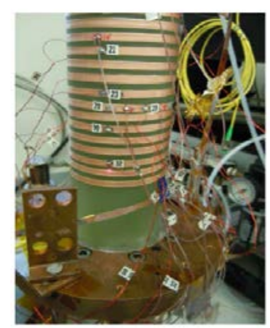
Magnet Technology

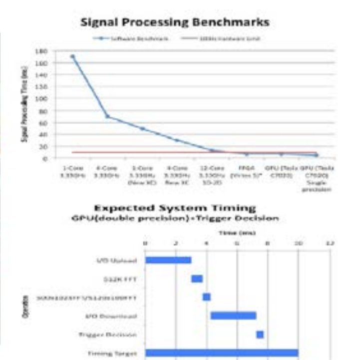
- Developed and demonstrated technology to wind NbTi and YBCO coils for a helical solenoid to be used for muon beam cooling for use in a muon collider
- High field solenoid design using YBCO and Bi-2212 conductor for the ambitious goal of achieving fields greater than 30 T
- Fiber Optics quench detection system. This was based on Rayleigh scattering to detect strain and temperature variations







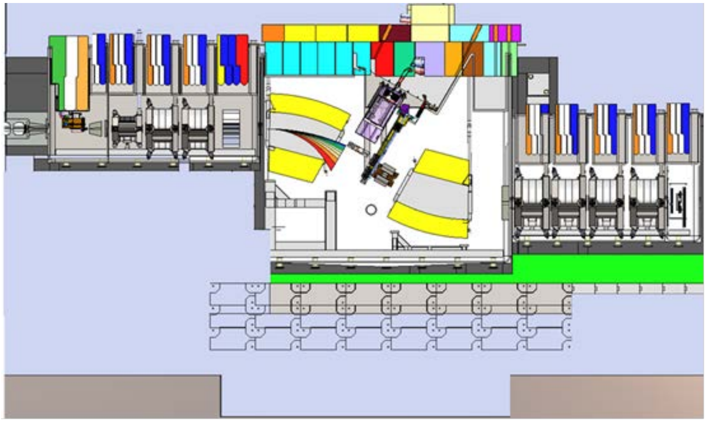


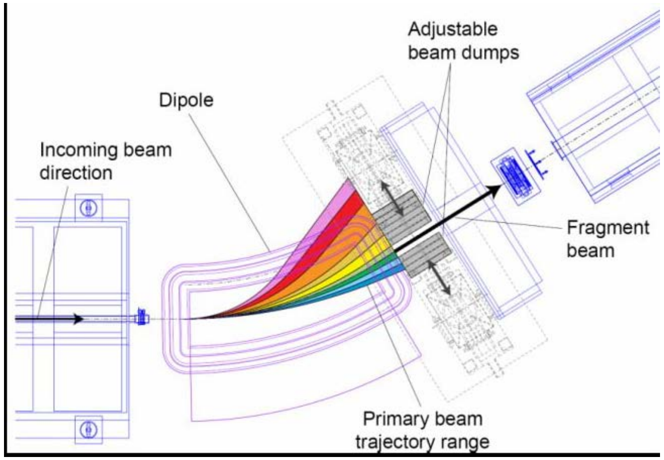


FRIB Dipole Project Description

Muons, Inc.

- Design of a dipole magnet to be used for the fragment separator for the FRIB project.
- This magnet will be situated in a high radiation environment and is used to select the desired isotope.
- The magnet design must accommodate the high heat load from the radiation and cannot use materials that can't withstand the radiation.
    - At the separator magnet the does is estimated to be 2.5×10^{14} neutrons/cm^2/year (10 MGy/ year). This is ~1 kw/m.





Unique Approach

Muons, Inc.

- Magnets with superconducting coils, allow operation with low electric power usage, but the traditional NbTi and Nb_3Sn superconductors are sensitive to quenches from beam loss and must operate near 4.5 K.
  - Carnot principles tell us that heat removal at 4.5 K is inefficient.
- HTS conductor offers a unique solution for the high radiation and high heat load environment.
  - HTS conductor can operate at 40 K where heat removal is an order of magnitude more efficient than at 4.5 K.

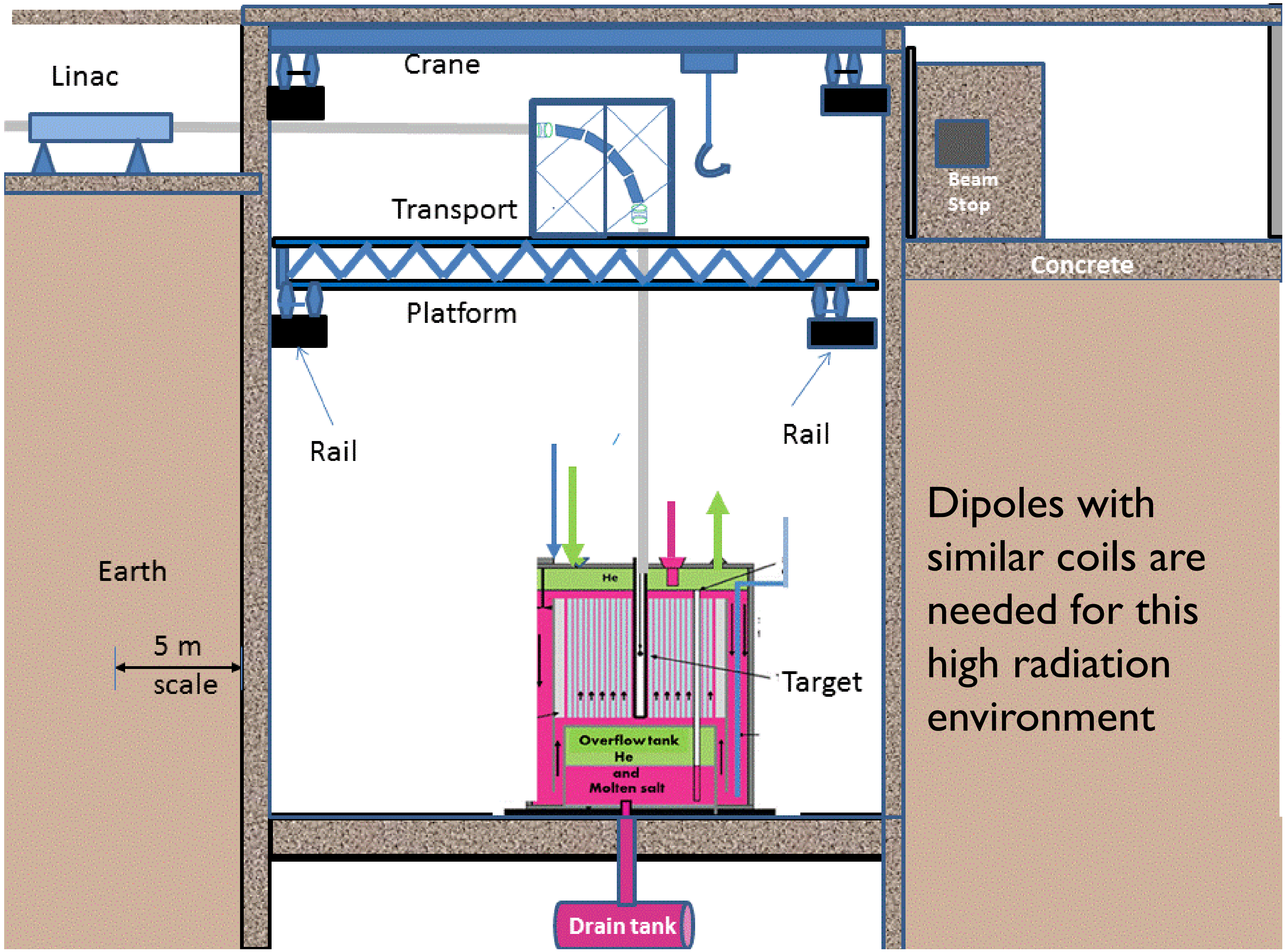
FRIB Decision

Muons, Inc.

- MSU has decided that an HTS magnet was too risky and will build the fragment separator magnet with conventional warm conductor. This precludes MSU as a potential customer.
- We still feel that magnets with HTS conductor will have important applications in the future.
  - The Future Circular Collider (FCC) will likely want 16 to 20 T magnets in a synchrotron radiation environment.
  - A beam transport line for ADSR. This is a project with great interest at Muons, Inc.

Muons, Inc.

Our Commercial Application: GEM*STAR Subcritical Accelerator-Driven Reactor



Collaborative Effort with BNL Magnet Division

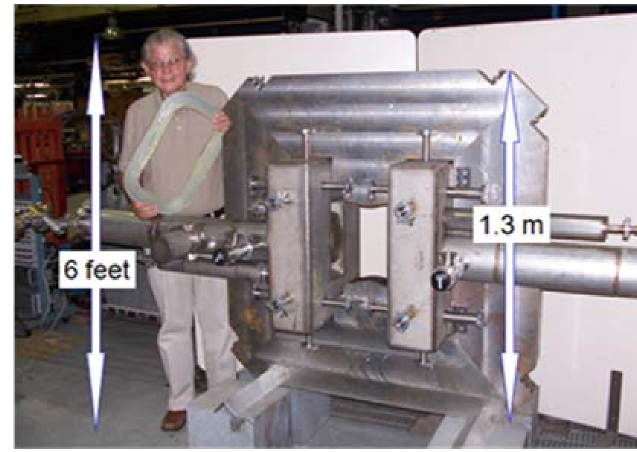
Muons, Inc.

- Muons Inc. participants:
  - Stephen Kahn, project PI, physicist
  - Gene Flanagan, physicist
  - Alan Dudas, design engineer
- BNL participants:
  - Ramesh Gupta, sub-grant PI, physicist
  - Jesse Schmalze, engineer
  - Michael Anerella, engineer
  - Bill Sampson, physicist
- Fabrication:
  - Richard Kunzelman, Device Technologies

Muons, Inc.

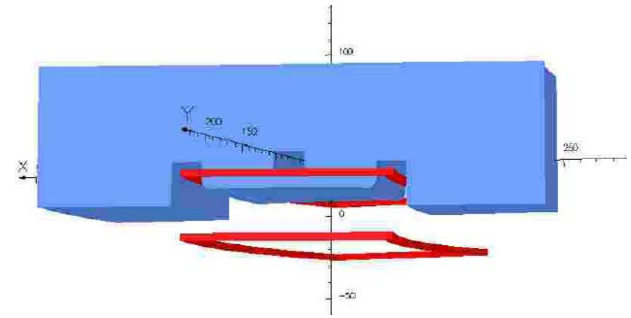
BNL Experience is Important

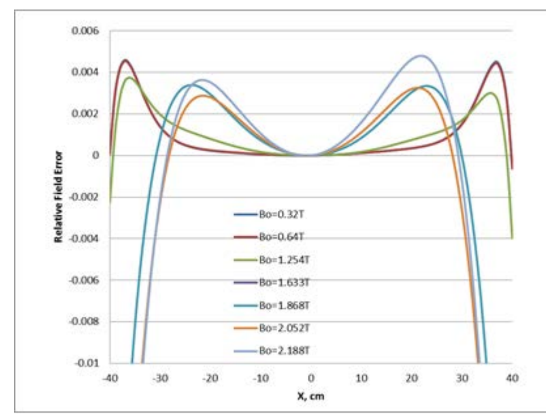
- BNL has a program to use YBCO conductor for accelerator magnets.
  - They built an R&D quadrupole magnet for FRIB (shown.) using HTS coils.
  - Our project will make use of that experience and adapt it to the needs of the dipole separator magnet.



Magnet Design

- Each fragment separator magnet bends the beam 30° with a field of 2 T.
- To achieve this field requires 256 Kamp-turns in each coil.
- The magnetic length is 2 m.
- The magnet is a superferric design where HTS coils magnetize the iron to produce the desired field.
- Each coil is inside its own cryostat which must handle the energy deposited from the radiation. Any mass inside the cryostat generates heat.
- The field must be uniform with an error $\Delta B/B<0.007$ within the useful field aperture ± 30 cm from the center for 0.5 to 2 T.
- Because the coil is in high radiation we cannot use organic materials for either insulation or support. This is an important issue for the design.





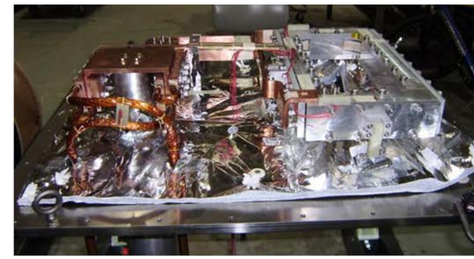
Goals of the Phase II Project

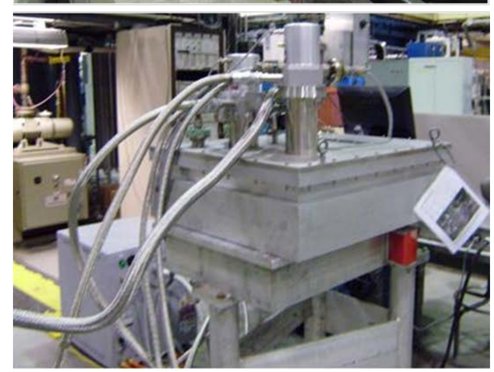
Muons, Inc.

- Engineering design of the fragment separator dipole magnet:
  - Structural analysis of the coil system
    - HTS conductor can be degraded by excess strain.
  - Design of the coil support
    - Large forces need to be supported to reduce coil strain.
  - Thermal analysis of the coil system with helium cooling.
    - Must minimize heat leaks.
  - Quench studies using quench propagation program
- Construct and test a demonstration YBCO coil
  - Design full size coil, purchase material, construct and assemble.
    - Handling the full size coil has unique problems associated with mechanical strain
  - Test at 40 K operating temperature. Use heater coils to simulate heat deposition.
- Analyze test coil results and prepare design report
  - finalize design based on test results
  - evaluate cost of magnet
  - prepare design report

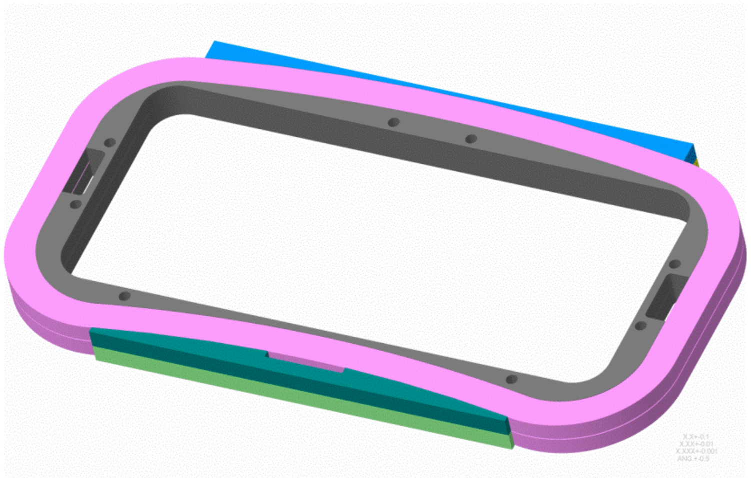
Modifications to the Project

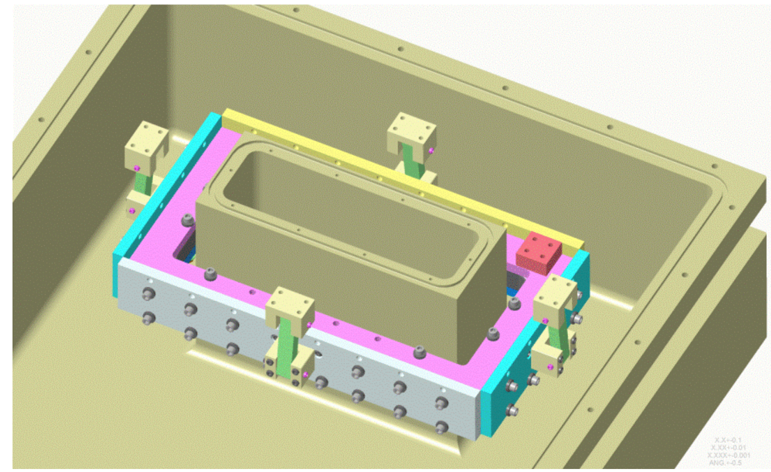
- Manufacturing a full size coil along with a cryostat is not needed for FRIB.
- Our new approach is to use an existing cryostat and scale the dimensions to fit the cryostat. We can wind a realistically large number of turns.
- The coil will be curved at both the inner and outer radius. The inner radius will have negative curvature which is more difficult to wind.
- This cryostat has a cryo-cooler to cool it to 40 K. This can reduce the need for helium as a coolant.

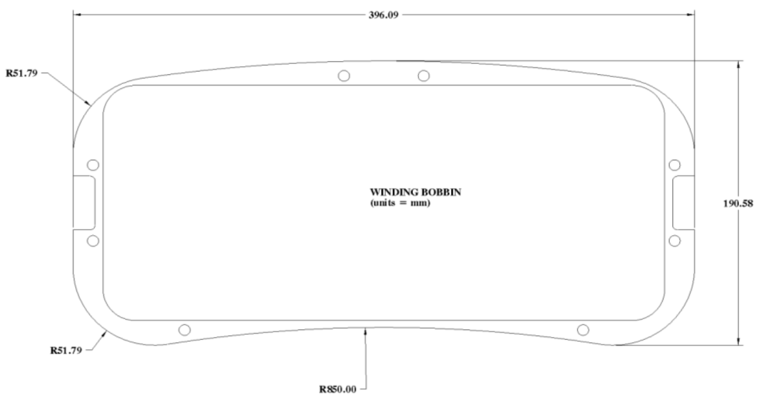


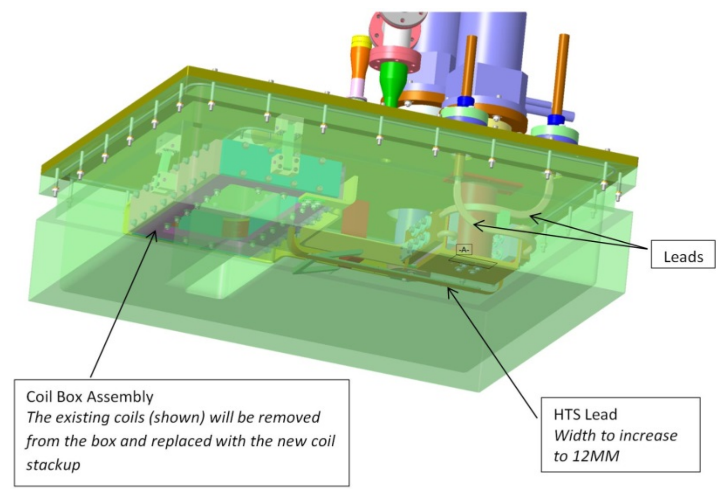


Test Winding Bobbin and Cryostat



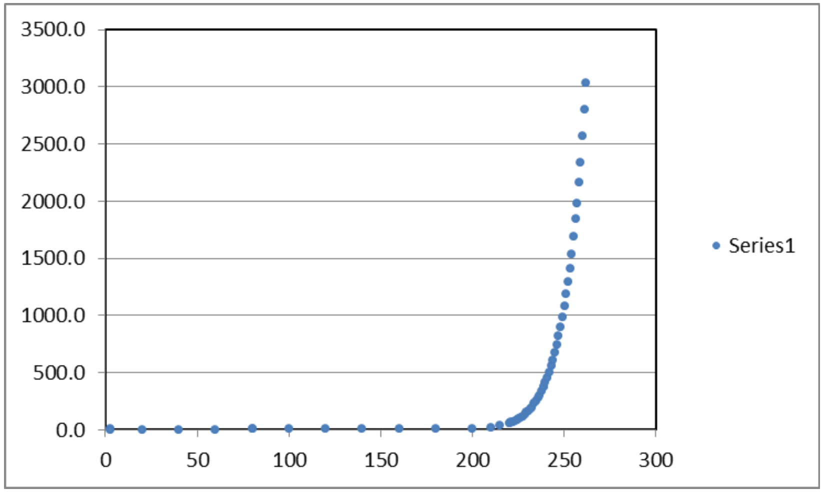




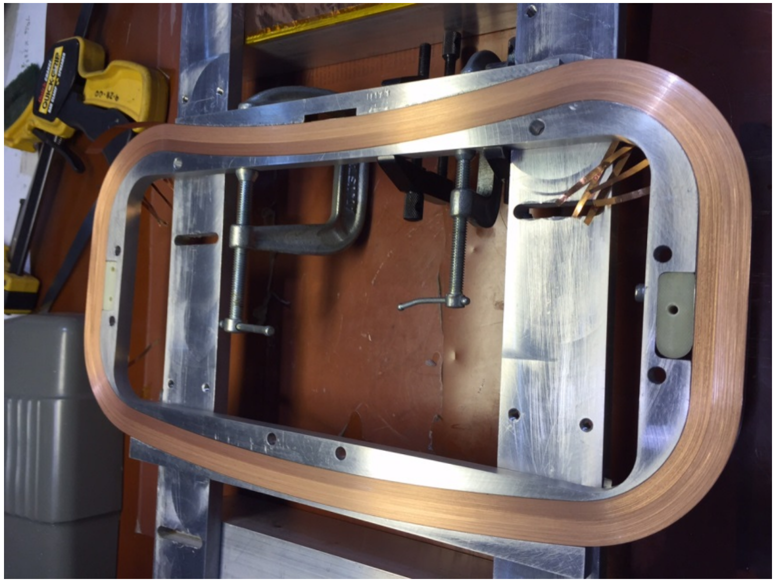


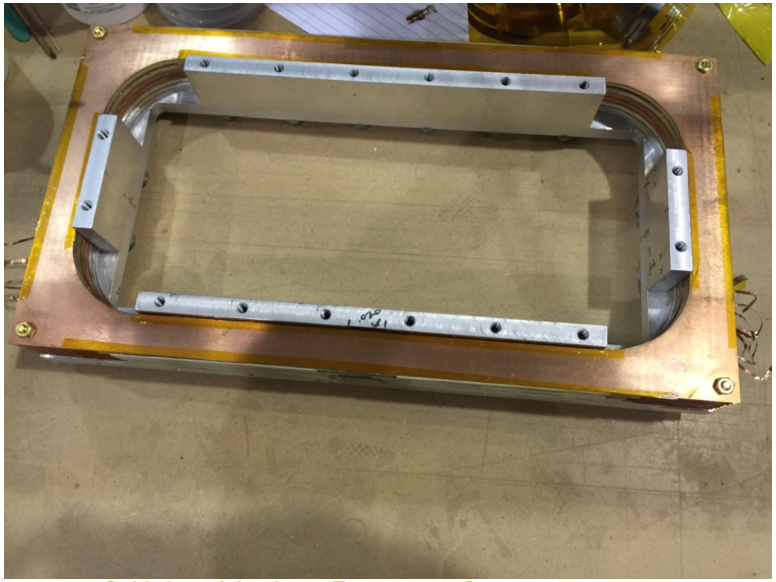
Current Status

- A five turn test coil has been wound and successfully tested at 77 K. The coil carried 250 A.
- A coil with a full number of turns has been wound but not yet tested.



Quench curve for 5 turn test coil





Tasks Ahead

- The first "pancake" coil will be tested at 77 K.
- Wind and test second coil "pancake" at 77 K.
- Assemble two successfully tested pancake coils and insert into the cryostat.
- The double pancake is tested at 40 K.
- Experimental program demonstrating that the coils can be maintained at 40 K under the anticipated radiation heat load.

Summary

Muons, Inc.

- Muons, Inc. has a strong interest in a variety of HTS magnet projects
- Operating HTS magnets at a unique temperature where the conductor can carry significant current and where heat can be removed with significant efficiency will have wider application
- Commercial interests, besides providing services and magnets to the accelerator community, is in our GEM*STAR Accelerator-Driven Subcritical Reactor, where beam transport magnets near the reactor must operate in the high radiation environment