HIGH RADIATION ENVIRONMENT
NUCLEAR FRAGMENT SEPARATOR
MAGNET

Project PI: Dr. Stephen Kahn
(presented by Rolland Johnson, President of Muons, Inc.)
Muons, Inc.
552 N. Batavia Avenue
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DOE STTR Grant DE-SC0006273
Phase II Grant Project Period 08/07/2012-08/07/2014
NF extended to 08/07/2015
Presentation Outline

• Company Background
  • Selected Projects of Potential Interest
• Project Description and Goals
• Project Status
• Summary and Outlook
Company Description

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:

- National labs
  - ANL, BNL, Fermilab, JLab, LANL, LBNL, ORNL, PNNL, and SLAC
- Universities
  - U of Chicago, Cornell, FSU, IIT, NCSU, NIU, and ODU

To invent new accelerator concepts and to develop the relevant technology for their realization.

Our creative, competent staff and research partners love difficult beam physics and engineering challenges.
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, monoenergetic photons, rare decay experiments, 6d muon beam cooling, solar wind generators, and anything needing creative solutions.
Magnet Technology

- Demonstrated technology to wind NbTi and YBCO coils for a helical solenoid to be used for muon beam cooling.
- High field solenoid design using YBCO and Bi-2212 conductor for the ambitious goal of achieving fields greater than 30 T.
- Fiber Optics for quench protection.
  - National Instruments Big Physics Symposium now in Austin.
Magnet Commercialization

**Partners**

- **BiRa**
  - LANSCE-R Wire-Sanner System
    - Bill Biswell, BiRa
- **Muons, Inc.**
  - Fiber Optic Based Quench Protection for High Temperature Superconducting Magnets
    - Gene Flanagan, Muons Inc.
- **CHUO ELECTRIC WORKS LTD.**
  - Flex MOSTAB
    - Junichi Hatano, Chuo Electric Works
- **Tessella**
  - Partnerships with Big Physics
    - Richard Layne, Tessella
- **ALE System Integration**
  - LabVIEW Bootcamp
    - Terry Stratoudakis, ALE System Integration
- **evopro**
  - Development of cRIO-based Control for Beam Emission Spectroscopy Plasma Diagnostic System for Tokamaks
    - Tamás Winkler, evopro
- **Verivolt**
  - High Energy Application’s Signal Conditioning for National Instruments
    - Sheilon Wunder, Verivolt
Coil instrumented with fibers. (data point reflects early benchmarking targets - reality will push us much higher on plot - note: we are already in fast company)
FRIB Dipole Project Description

• 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 desired isotopes.
• 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 dose is estimated to be $2.5 \times 10^{14}$ neutrons/cm$^2$/year (10 MGy/year). This is ~1 kw/m.
Unique Approach

- Magnets with superconducting coils allow operation with low electric power usage, but the traditional NbTi and Nb₃Sn 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.
Collaborative Effort with BNL Magnet Division

- **Muons Inc. participants:**
  - Stephen Kahn, project PI, physicist
  - Gene Flanagan, physicist
  - Alan Dudas, design engineer
  - Jim Nipper, engineer

- **BNL participants:**
  - Ramesh Gupta, sub-grant PI, physicist
  - Jesse Schmalze, engineer
  - Michael Anerella, engineer

- **Fabrication:**
  - Richard Kunzelman, Device Technologies

- **FRIB**
  - Al Zeller,
  - Earle Burkhardt,
  - Honghai Song
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 makes use of that experience and extends it to the needs of the dipole separator magnet.
Magnet Design Concept

• Each fragment separator magnet:
  • bends the beam 30° with a field of 2 T and 2m magnetic length
  • provides a uniform field to $\Delta B/B < 0.007$ over the beam aperture
  • is a superferric design where HTS coils magnetize the iron
  • is large/expensive: 80 Tonnes of iron/8km of YBCO now at $92/m$
  • bends vertically, so usual assembly/disassembly requires rotation
• Each coil inside its own cryostat which handles radiation energy deposition
• Lorenz forces are large, using yoke for coil support implies more heat load
The Magnet Needs to Operate Over a Wide Range of Fields

- The FRIB dipole needs to operate with a field range of $0.5 < B_0 < 2.2$ T.
- with field error of $\Delta B/B < 0.007$ over the useful field aperture of $\pm 30$ cm from the aperture center.
Goals of the Phase II Project

• Engineering design of the fragment separator dipole magnet:
  • Structural analysis of the coil system
  • Design of the coil support
  • Thermal analysis of the coil system with helium cooling.
  • Quench studies using quench propagation program

• Construct and test a demonstration YBCO coil
  • Design full size coil, purchase material, construct and assemble.
  • 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
Coil Winding Issues

- **Coil Winding:**
  - Design to avoid winding with negative curvature section.
    - Phase I study showed that one could achieve equivalent performance without negative curvature section.
  - Drawing shows winding bobbin on support plate.
    - Bobbin is 2.5 m long. It must revolve on winding machine.
    - Conductor is wound on the edge of bobbin.
HTS Coil Winding

A coil being wound with a computer controlled winding machine

We need a much bigger winding plate, etc. for Dipole
Drawing of Assembled Coil and Support Structure. (Front Support Plate Removed.)

CLAMP BAR

COPPER THERMAL PLATE

YBCO WINDINGS

SUPPORT PLATE

HELIUM PUSHER

WINDING BOBBIN

40 K GHe refrigerant
Illustration of Placement of Voltage Taps for Diagnostic Purposes

Voltage Taps every 3 turns

Coil

Nomex Insulation

bobbin

Muons, Inc.
Large Forces Influence the Prototype Design

- Coils carrying 256 kA in a magnetic field will be subjected to large Lorentz forces.
  - These forces will deform the coils and potentially place large strain on the conductor.
- Placing SS inside the coil cryostat can control the conductor strain, but adding significant material will increase the already large heat load.
  - An optimized solution is needed.

### Table II

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Next Milestones

- Tooling fabricated and delivered, tested with SS tape
- First HTS pancake wound and tested at 77 K
- Second HTS pancake wound and tested at 77 K
- Two successfully tested pancake coils assembled
- Cryostat for testing assembly at 40 K designed and built
- FRIB (H. Song) and BNL staffs help develop and optimize the experiment program to best align with FRIB needs
- Demonstration that the separator magnet temperature can be maintained with the anticipated radiation heat load
Summary

• Muons, Inc. has a large investment in a variety of HTS magnet R&D projects: YBCO, Bi2212, Quench Det/Prot
• This project with large HTS coils in harsh conditions adds experience in new construction and operation techniques
• Operating HTS magnets at a temperature where the conductor carries large currents and where heat can be removed with high efficiency will have wide application
• Commercial interests, besides providing services and magnets (e.g. corrector coils) to FRIB, includes our GEM*STAR Accelerator-Driven Subcritical Reactor, where beamline magnets must operate in the high radiation environment near a reactor