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.

- 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

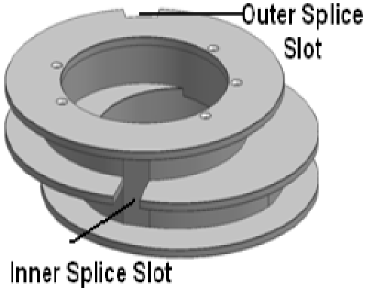
Advanced Technologies in accelerator R&D, design & construction

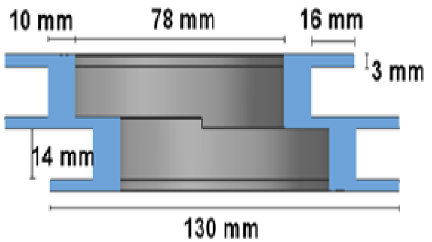
Muons, Inc.

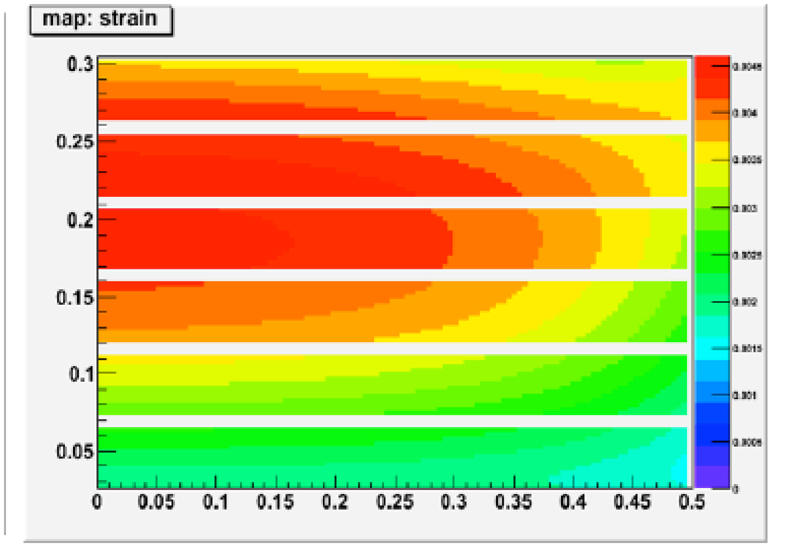
- Sources and Beams: p, μ, e, γ, H−, polarized ions
- NCRF fast-tunable, dielectric-loaded, RF loads
- SRF cavities, magnetrons, couplers, HOM dampers
- Magnets: HTS High-Field, Helical, High Radiation, Quench Detection/Protection (YBCO and Bi2212)
- Simulations: G4beamline, ACE3P, MuSim (MCNP6), etc.
- 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.

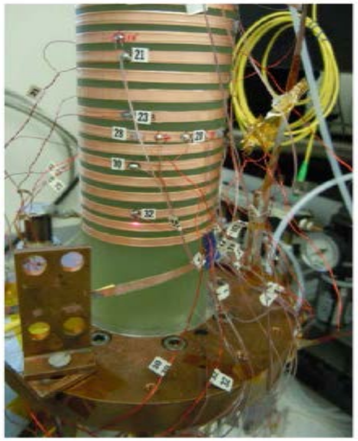
Magnet Technology

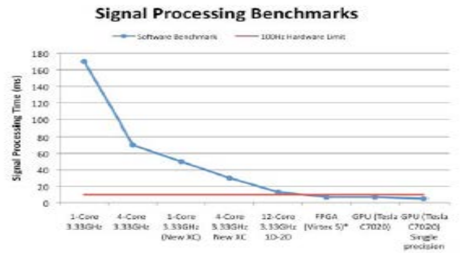
- Demonstrated technology to wind NbTi and YBCO coils for a helical solenoid to be used for muon beam cooling
- High field solenoid design using YBCO and Bi-2212 conductor for the ambitious goal of achieving fields greater than 30 T
- Fiber Optics for quench protection.
  - National Instruments Big Physics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

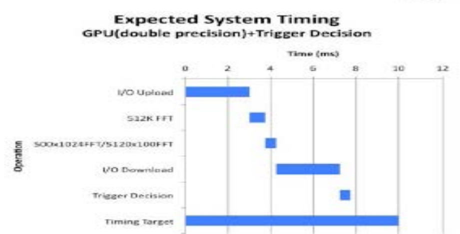












Magnet Commercialization

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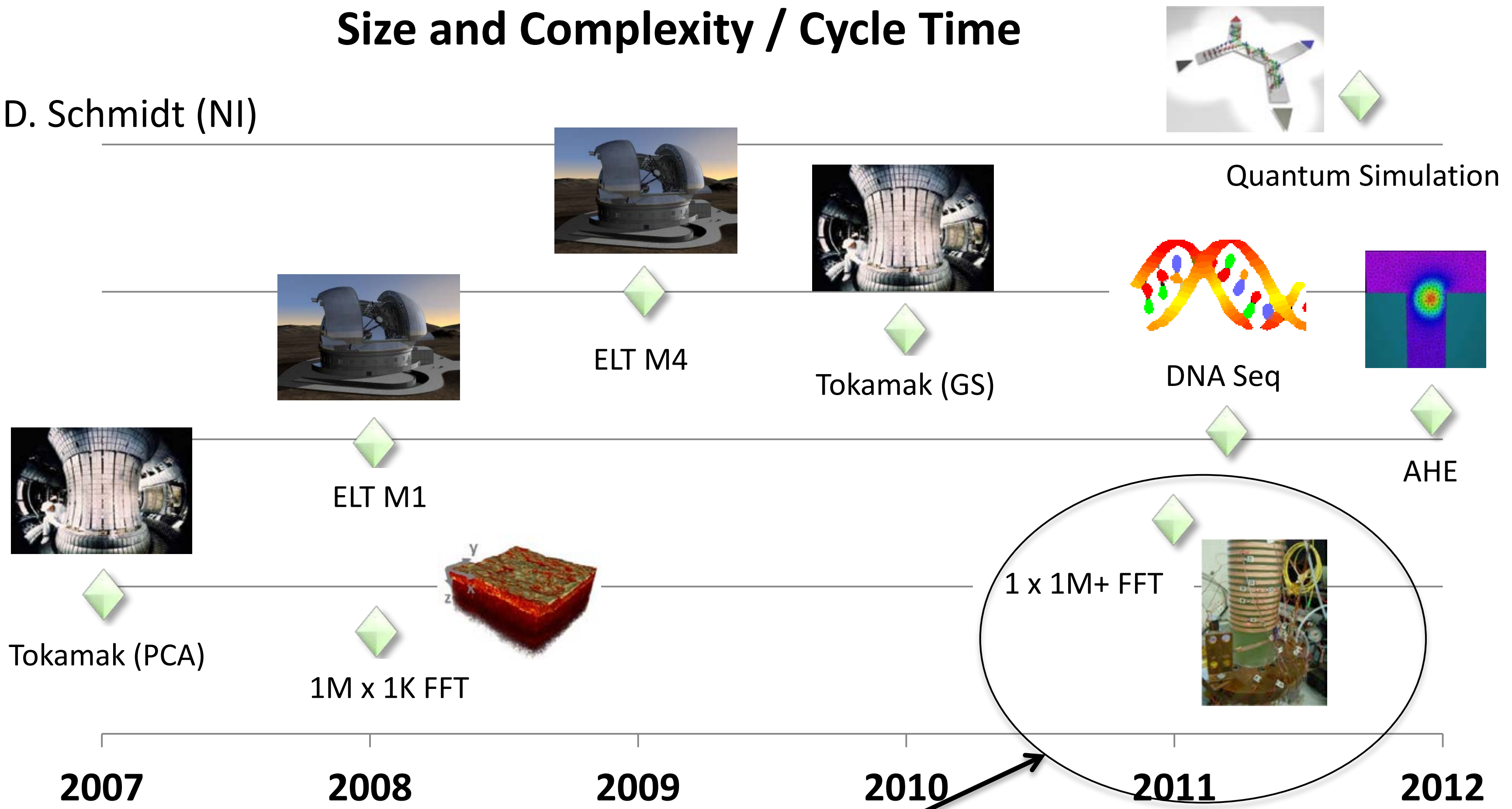
Partners

- LANSCE-R Wire-Sanner System
  Bill Biswell, *BiRa*
- Fiber Optic Based Quench Protection for High Temperature Superconducting Magnets
  Gene Flanagan, *Muons Inc.*
- Flex MOSTAB
  Junichi Hatano, *Chuo Electric Works*
- Partnerships with Big Physics
  Richard Layne, *Tessella*
- LabVIEW Bootcamp
  Terry Stratoudakis, *ALE System Integration*
- Development of cRIO-based Control for Beam Emission Spectroscopy Plasma Diagnostic System for Tokamaks
  Tamás Winkler, *evopro*
- High Energy Application's Signal Conditioning for National Instruments
  Sheilon Wunder, *Verivolt*

BiRa Systems
Muons, Inc. Innovation in Research
CEW CHUO ELECTRIC WORKS LTD.
Tessella Technology & Consulting
ale System Integration
it's possible! evopro
Verivolt
NATIONAL INSTRUMENTS™

Real-Time HPC Trend



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)

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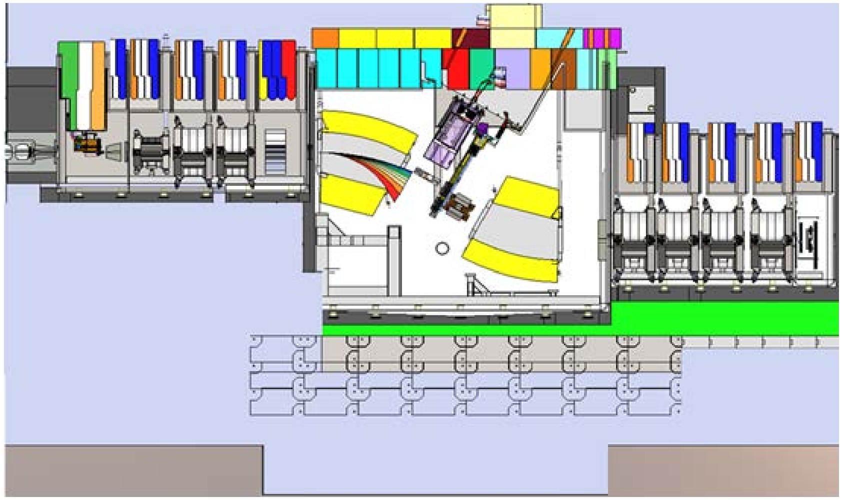
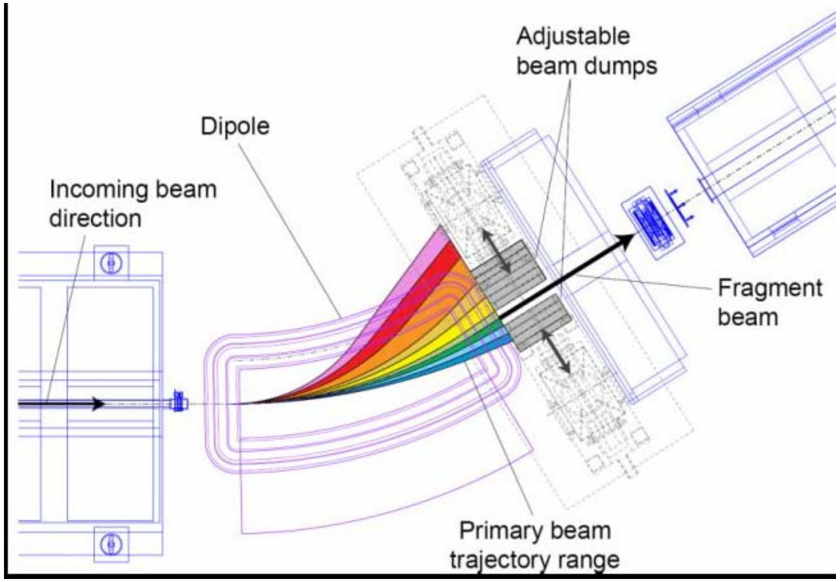
FRIB Dipole Project Description

- 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 2.5×10^{14} neutrons/cm^2/year (10 MGy/ year). This is ~1 kw/m.





Unique Approach

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- 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.

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

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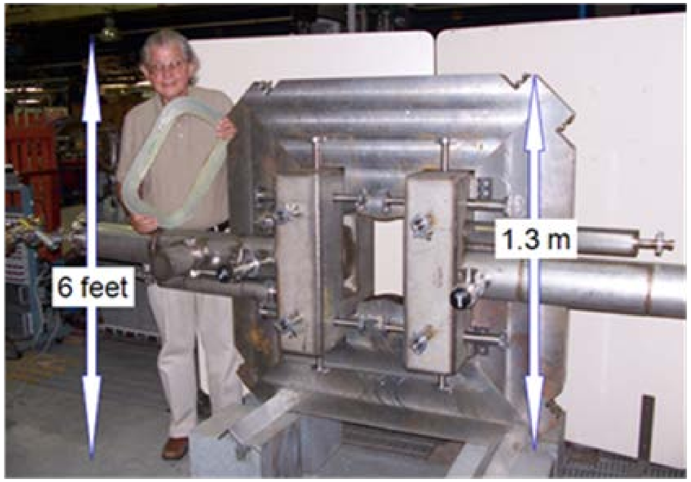
BNL Experience is Important

- 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

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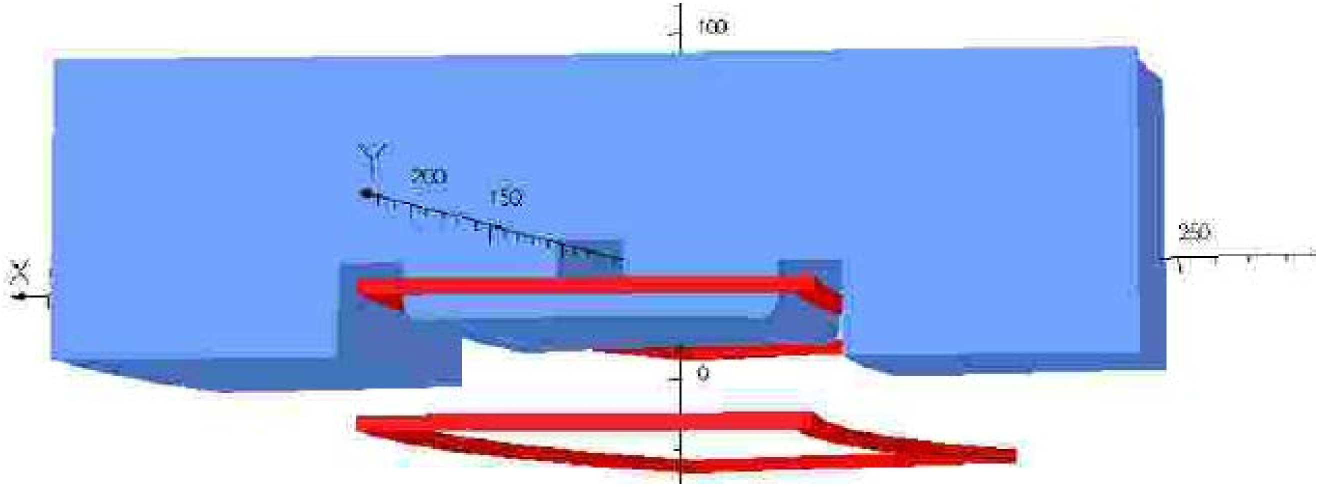

- Each fragment separator magnet:
  - bends the beam 30° with a field of 2 T and 2m magnetic length
  - provides a uniform field to $\Delta B/B<0.007$ over the beam aperture
  - is a superferric design where HTS coils magnetize the iron
  - is large/expensive: 80 Tonnes of iron/8km of YBCO now at $92/m
  - 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

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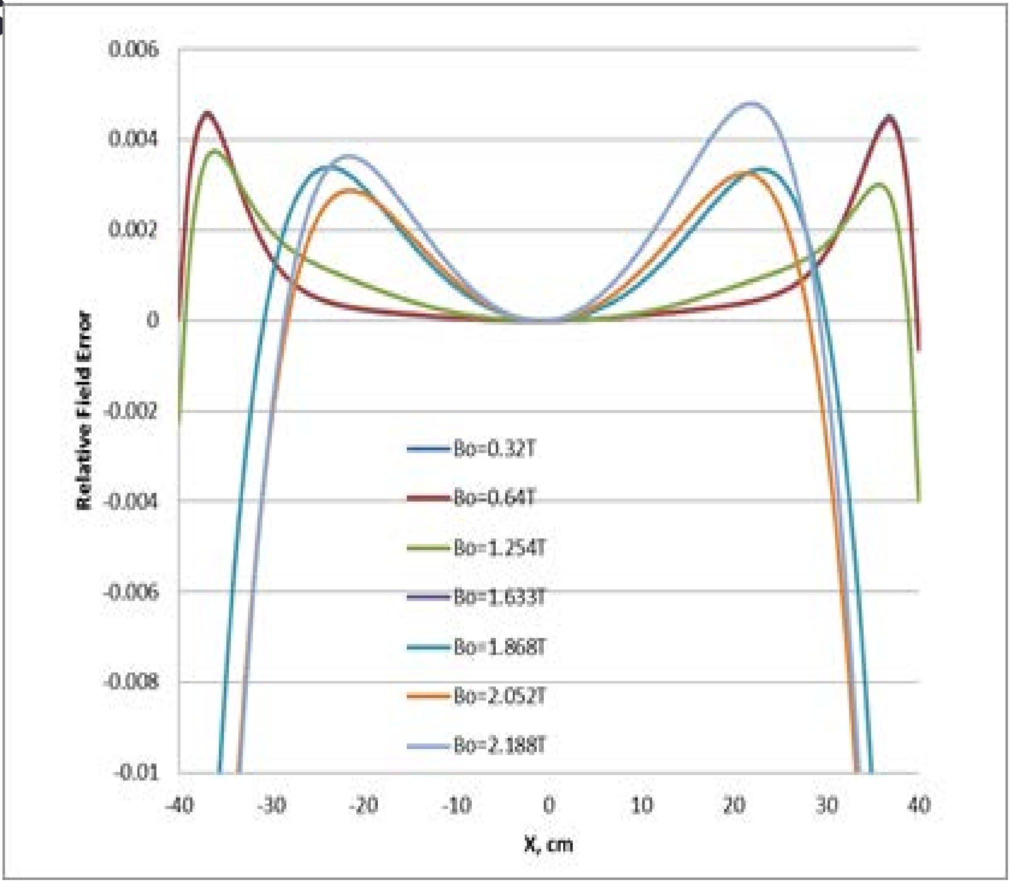
- The FRIB dipole needs to operate with a field range of $0.5<B_0<2.2$ T.
- with field error of $\Delta B/B<0.007$ over the useful field aperture of ± 30 cm from the aperture center.



Goals of the Phase II Project

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- 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

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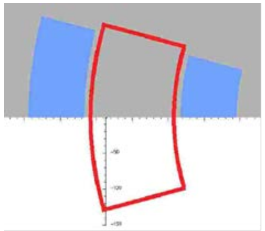
Coil Winding Issues

- 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.



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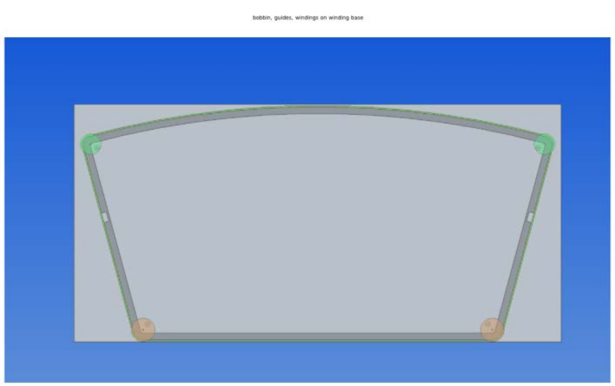
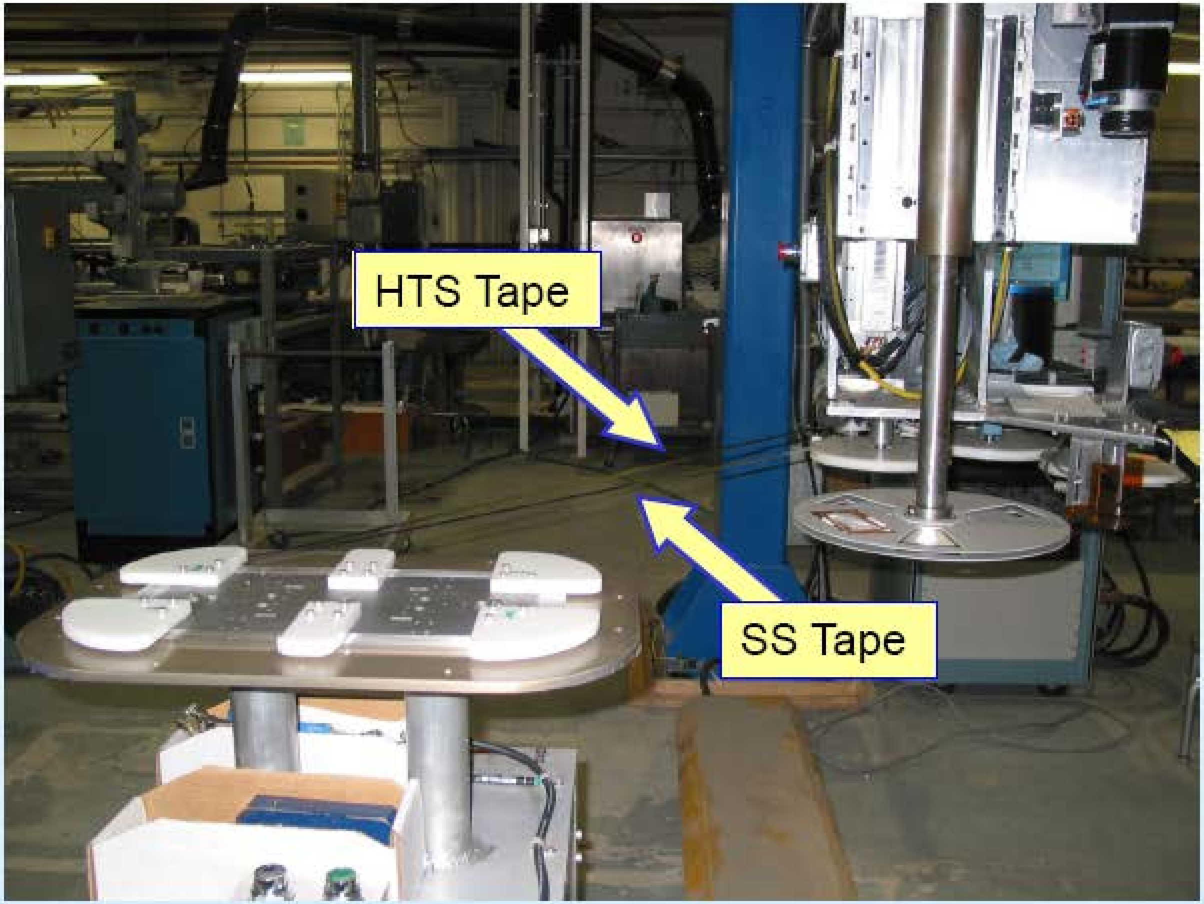


BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

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.)

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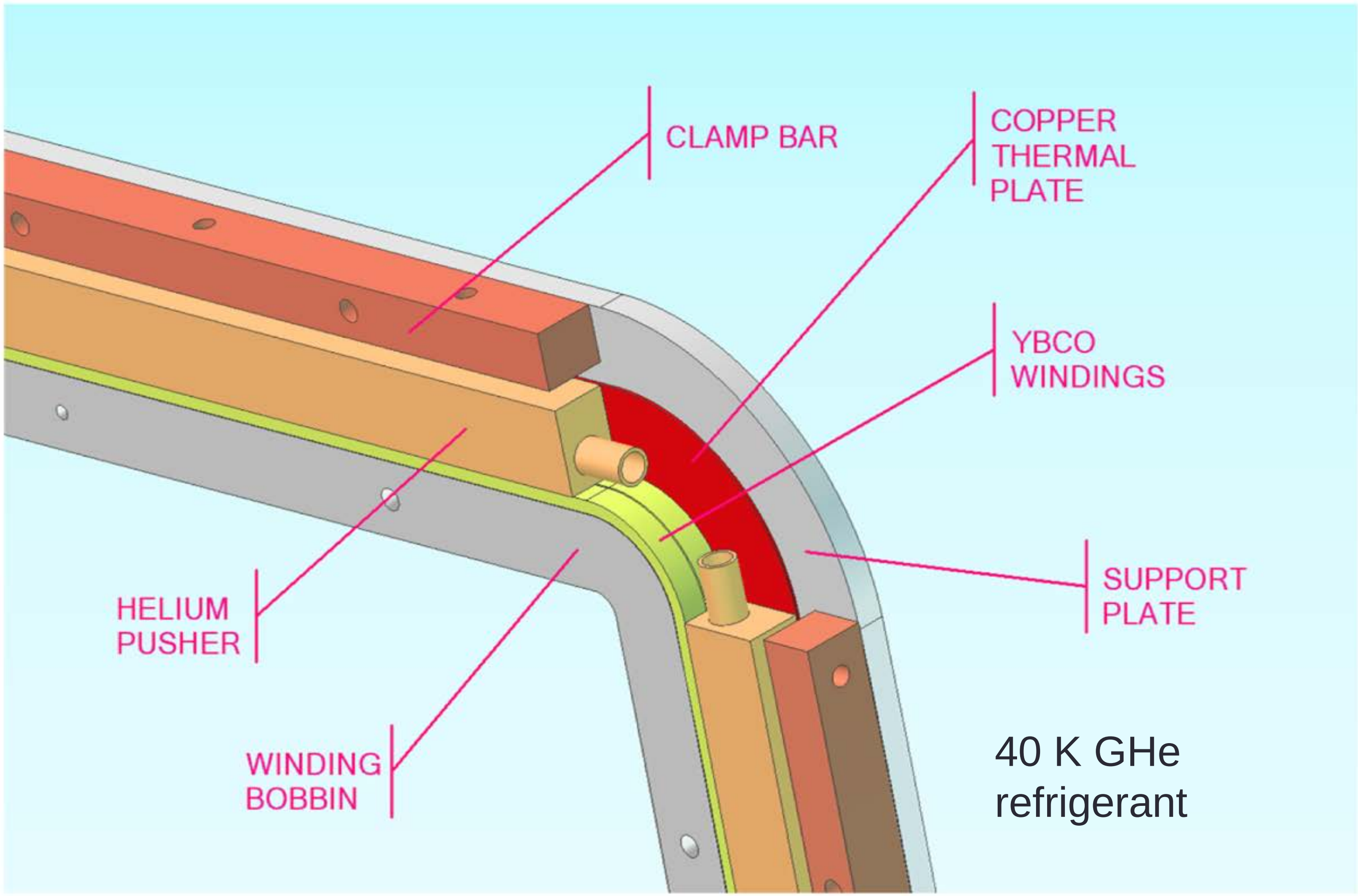

40 K GHe refrigerant

Illustration of Placement of Voltage Taps for Diagnostic Purposes

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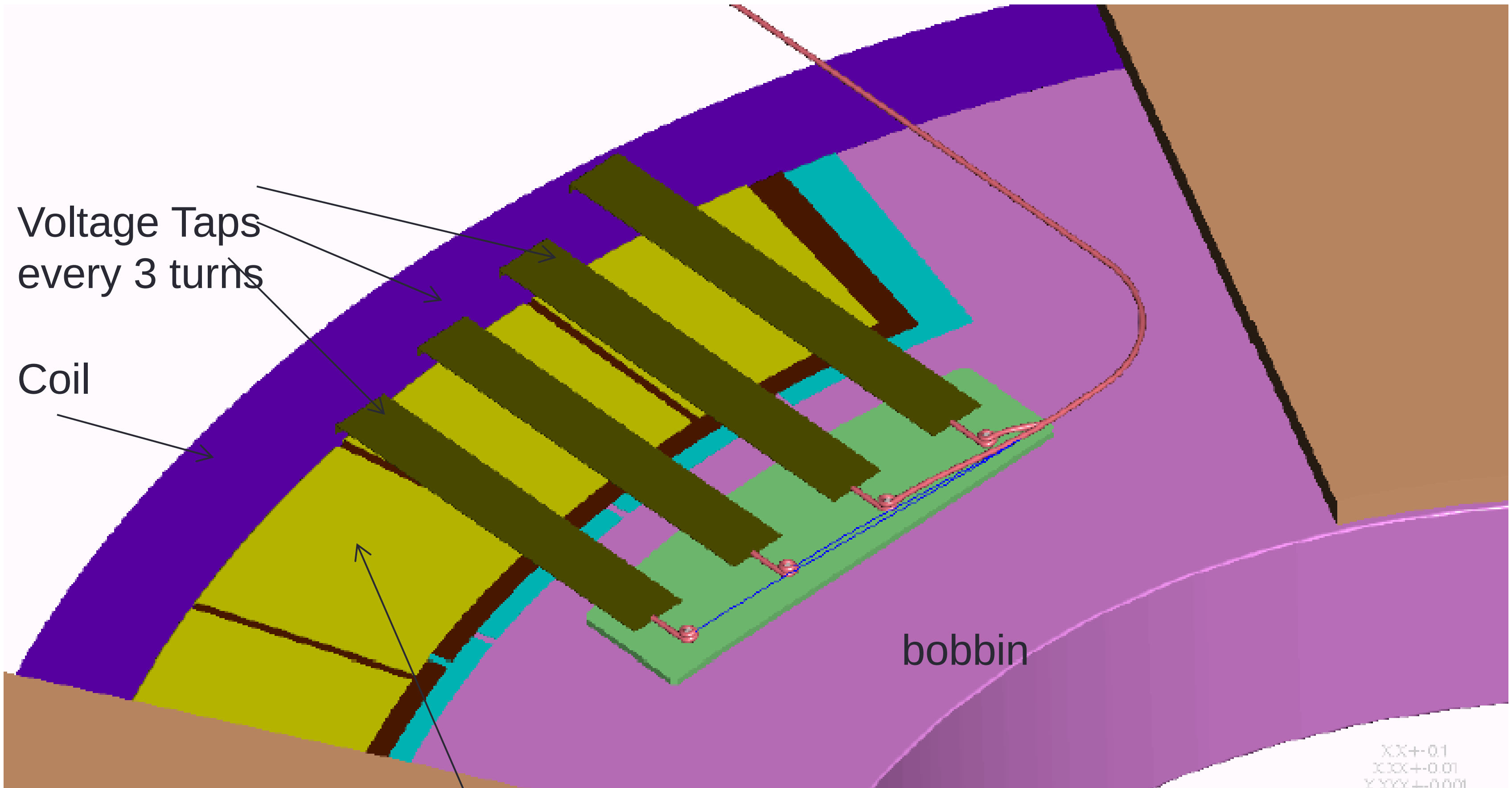

Large Forces Influence the Prototype Design

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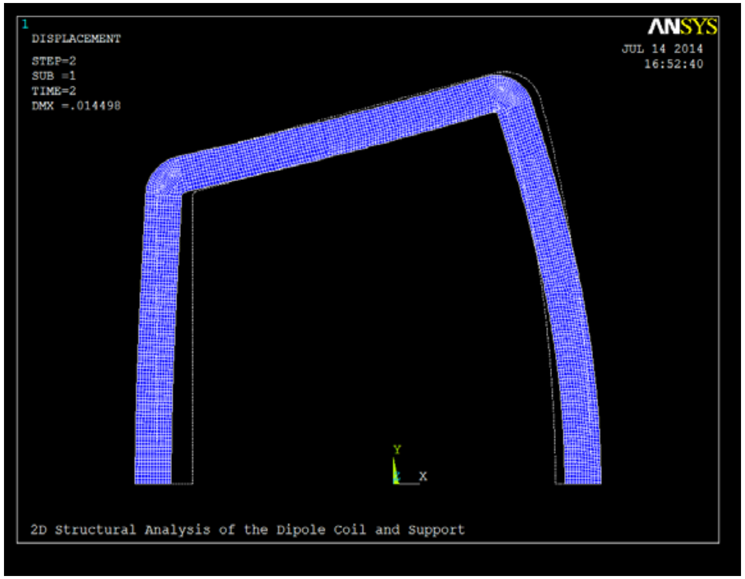
- Coils carrying 256 kA in a magnetic field will be subjected to large Lorentz forces.
  - These forces will deform the coils and potentially place large strain on the conductor.
- Placing SS inside the coil cryostat can control the conductor strain, but adding significant material will increase the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

TABLE II
LORENTZ FORCES PER UNIT LENGTH ON THE COIL

Field	Coil	F_{radial}/Length	$F_{vertical}$/Length
Tesla		N/m	N/m
2.0	Outer	120735	105252
	Inner	-108828	108512
2.2	Outer	167079	112226
	Inner	-146093	117935



Next Milestones

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- 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