HTS Magnets for Accelerator and Other Applications

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HTS Magnet Projects at BNL With Significant Funding

- Medium field Quad for FRIB/RIA at MSU (DOE/NP funded)
- 20^+ T HTS solenoid for Muon Collider (PBL/BNL SBIR)
- ~25 T large aperture HTS solenoid for SMES (ARPA-E funded)

BNL has been active in HTS magnet R&D for well over a decade

HTS magnet R&D has increased substantially in recent years!

HTS Magnet Programs at BNL

- The level of involvement may be gauged by the amount of HTS coming in. Net total in all programs (normalized to 4 mm tape):
  - Obtained so far: ~20 km
  - Next two years (based on funded programs): ~35 km
- Successfully designed, built & tested a large number of coils & magnets:
  - Number of HTS coils built: ~100
  - Number of HTS magnet structures built and tested: ~10
- HTS Magnet R&D for a wide range of operating conditions:
  - High field (>20 T), low temperature: two funded programs
  - Medium field, medium temperature: three funded programs
  - Low field, High temperature: several in house, built and tested

Very High Field (20-40 T) Solenoids

Made with the Second Generation (2G) HTS

PBL/BNL SBIR for Muon Collider

SBIR proposals from Particle Beam Lasers (PBL), Inc.:

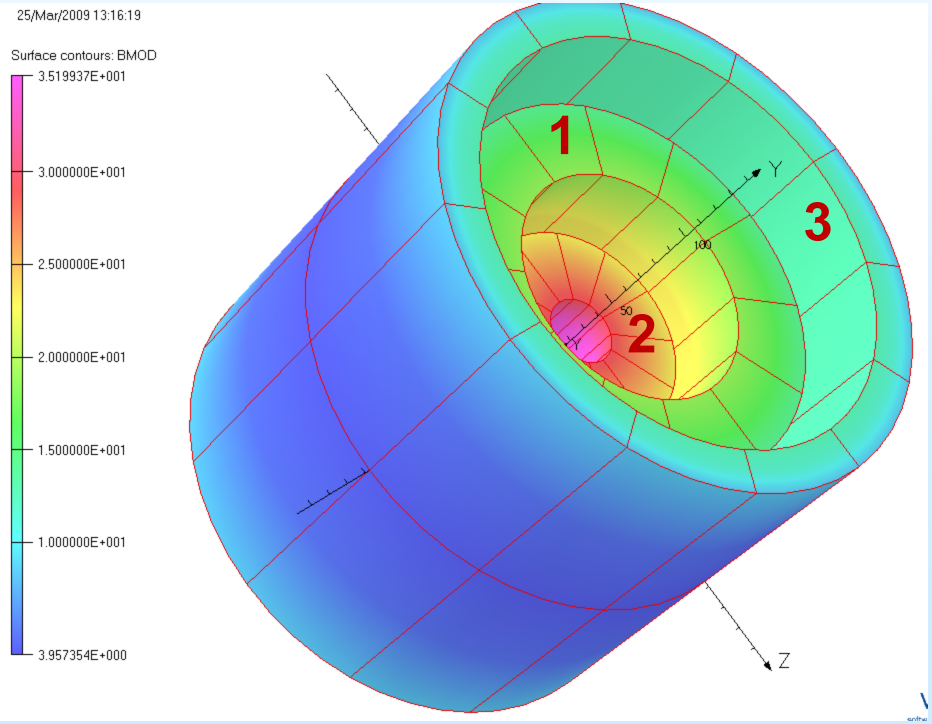
1. Phase II #1 (funded): ~10 T HTS solenoid (middle)
2. Phase II #2 (funded): ~12 T HTS (inner)
3. Phase I (proposal under review): 12-15 T Nb_3Sn (outer)

20⁺ T All HTS Solenoid (1 & 2):

addresses challenges with high field HTS solenoids

35⁺ T All Superconducting Solenoid (all three together):

addresses challenges with high field s.c. solenoids



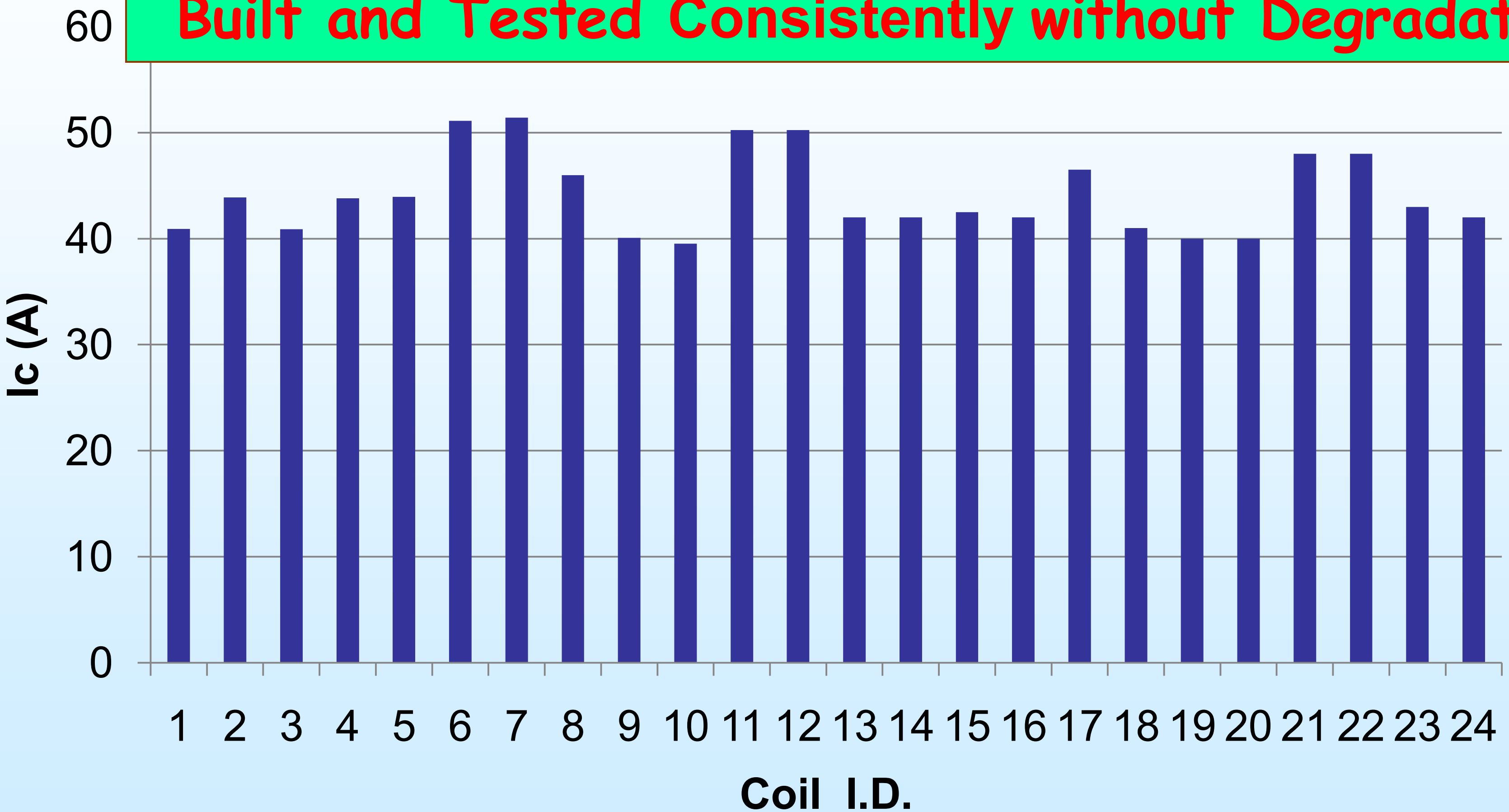
Superconducting
Magnet Division

Status of BNL/PBL SBIR #1 (10 T HTS Outsert)

- 29 coils for 100 mm aperture solenoid have been wound with stainless steel insulation
- Each coil is made with 100 meters of second generation (2G) HTS
- This is a significant HTS R&D program with ~3 km of conductor already consumed
- All coils have been individually tested at 77 K (24 coils needed for the solenoid)
- 24 coils have been selected after they passed all QA requirements, including 77 K test
- We should have the test result of the completed solenoid in about six months

Test Results of 24 Coils at 77K

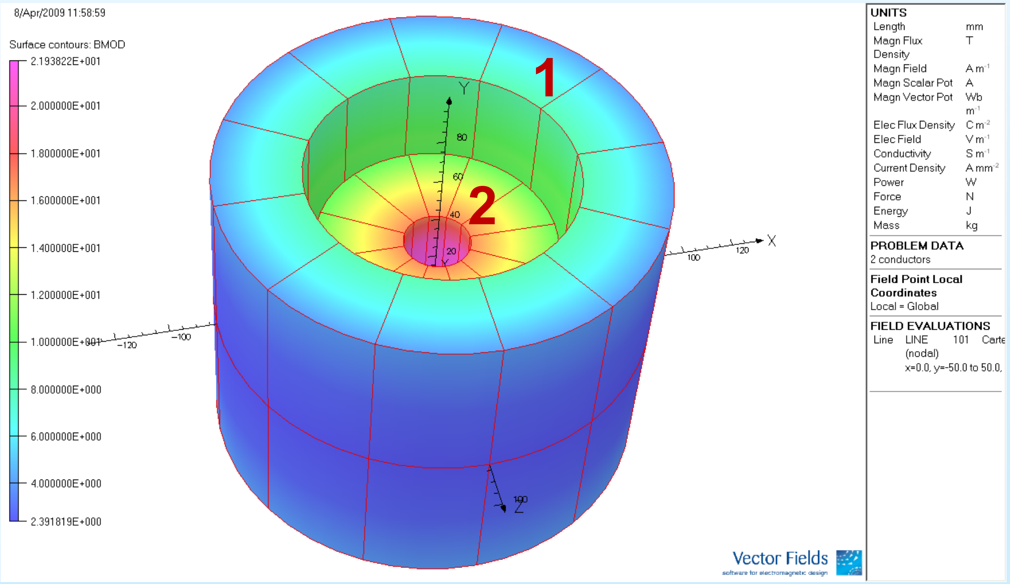
Proof: Coils with the second generation HTS Can be Built and Tested Consistently without Degradation



Field parallel ~0.5 T; field perpendicular ~0.3 T @40 A

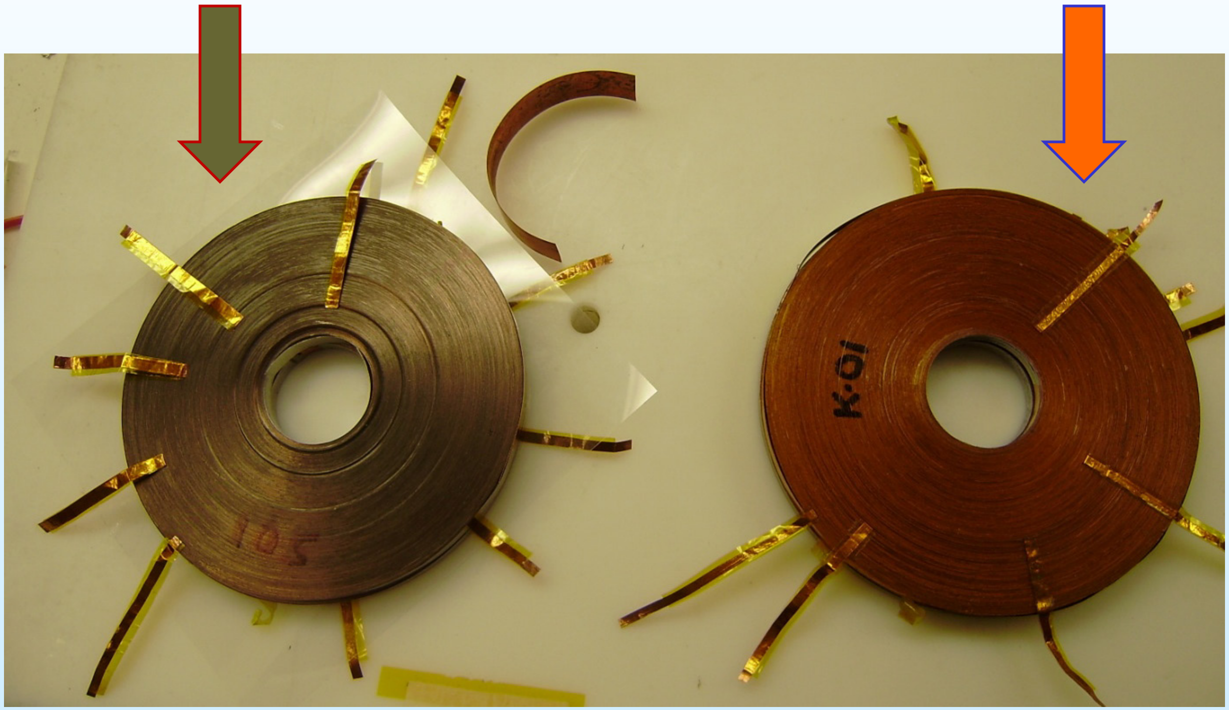
Status of BNL/PBL SBIR #2 (10+ T HTS insert)

- Coil i.d. ~25 mm; o.d. ~95 mm (can go inside 100 mm solenoid)
- Inner Solenoid needs twelve pancake coils
- Each coil is being made with 50 meters of ~4.2 mm wide 2G HTS from SuperPower



Status of BNL/PBL SBIR #2 (contd.)

- 5 coils have been wound, each with 50 m tape from SuperPower
- Two have stainless steel insulation and three kapton insulation



- A solenoid made with above four coils has been recently tested at NHMFL in background field of a ~20T solenoid (total field ~24T)

Results of Insert Coil Test at NHMFL

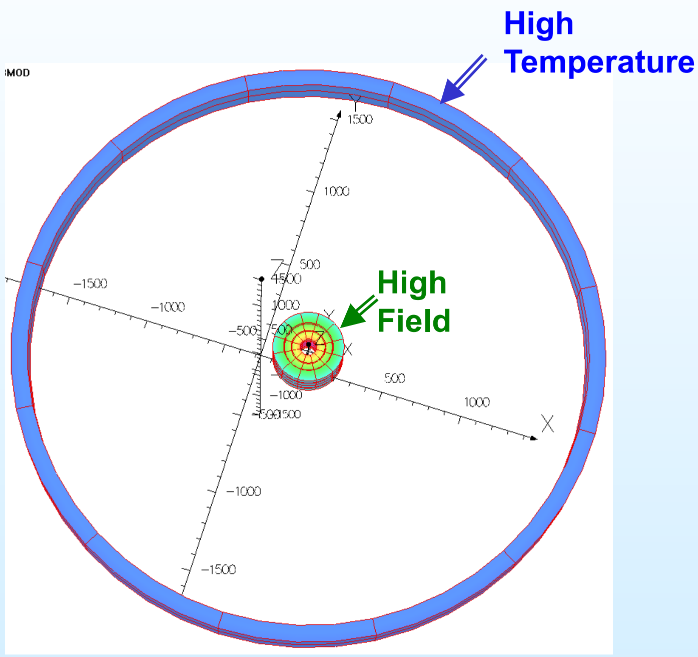
- **Goals of the tests:**
  - Compare stainless steel and Kapton insulation in coils made with HTS tape
  - Examine operation under multiple cycles to ~250 Amp (or so)
  - Examine influence of varying conditions (ramp rate, background field)
- **Test Results:**
  - All four coils reached ~150 A at ~24 T total field (~4 T from HTS coils)
  - Both (with SS & with Kapton) reached ~300 A in self-field (target ~250 A)
  - Coils made with stainless steel insulation were more robust
  - Could not observe significant difference between the coils made with Stainless Steel and Kapton insulation for ramp rate as high as 5 A/sec
- **A dry run for the 20^{+} T HTS solenoid test (in about a year) to fields approaching 35-40 T in the same background field magnet**
- **A positive experience at NHMFL in a friendly atmosphere**

HTS Superconducting Magnetic Energy Storage

- ARPA-E invited proposals on energy storage system under stimulus package
- It required demonstration of certain parameters within the funding limitations

Two options examined for HTS:

1. **High Temperature (>55 K) Option:**
   Saves on cryogenics (Field ~2.5 T)
2. **High Field (>20 T) Option:**
   Saves on Conductor (Temp. ~4 K)



Our analysis of HTS option:

Conductor cost dominates the cryogenic cost by an order of magnitude (both in demo device and in large application

Our proposal:

- **Aggressive design to reduce the amount of conductor needed**
- **Ultra high fields (24 – 30 T): Energy α B^2 ; B α conductor amount**
- **For HTS, ultra high field reduces the system size and *cost***

Superconducting Magnetic Energy Storage (SMES)

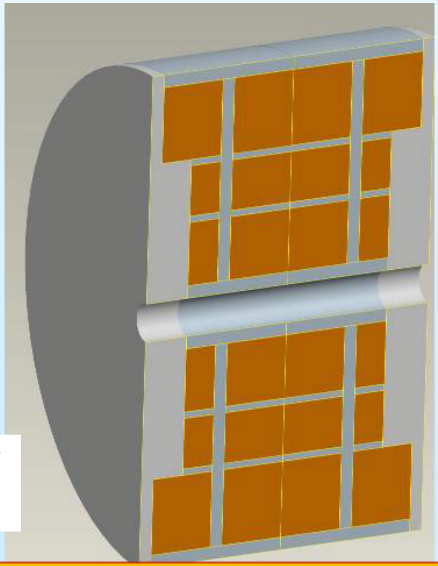
High field, large aperture, HTS solenoid is a highly ambitious goal:

arpa-e specifically asked for "high risk high reward" proposals!

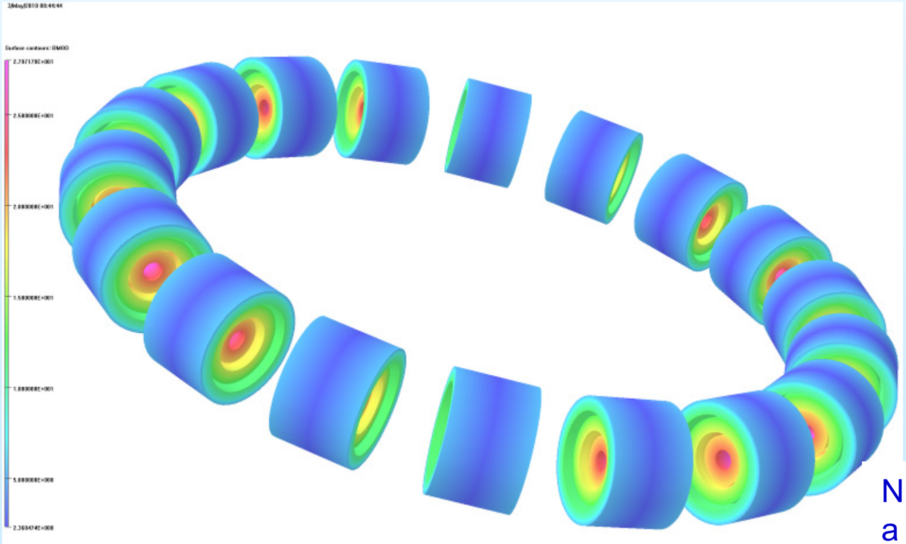
- **37 were selected out of ~3,700 proposals submitted !!!**

this one was the third largest in this announcement with 5.25M$

Participants: ABB, USA (Lead), SuperPower (Schenectady and Houston), and BNL (Material Science and Magnet Division)



Basic structure of a single Unit



Number of units in a SMES system

Key Parameters: ~24 T, 100 mm, 2.5 MJ, 12 mm YBCO

- **Medium field magnets** (high radiation and high heat loads)
- Significant source of funding for HTS magnet R&D at BNL

HTS Quadrupole for

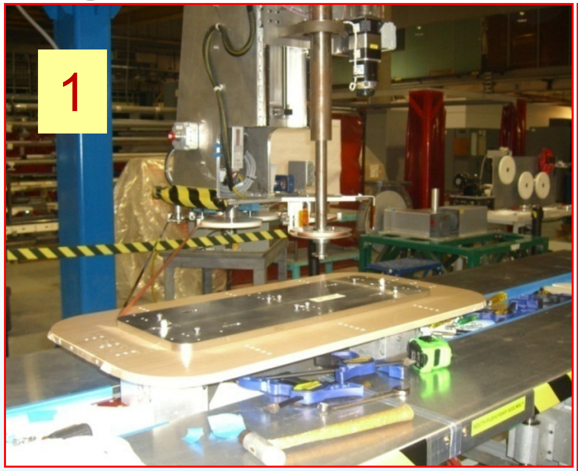
Facility for Rare Isotope Beams (FRIB)

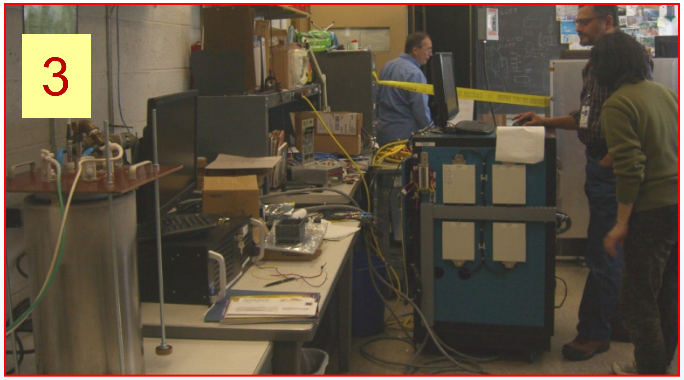
FRIB will create rare isotopes in quantities not available anywhere

- Site: Michigan State University

Activities on the Floor

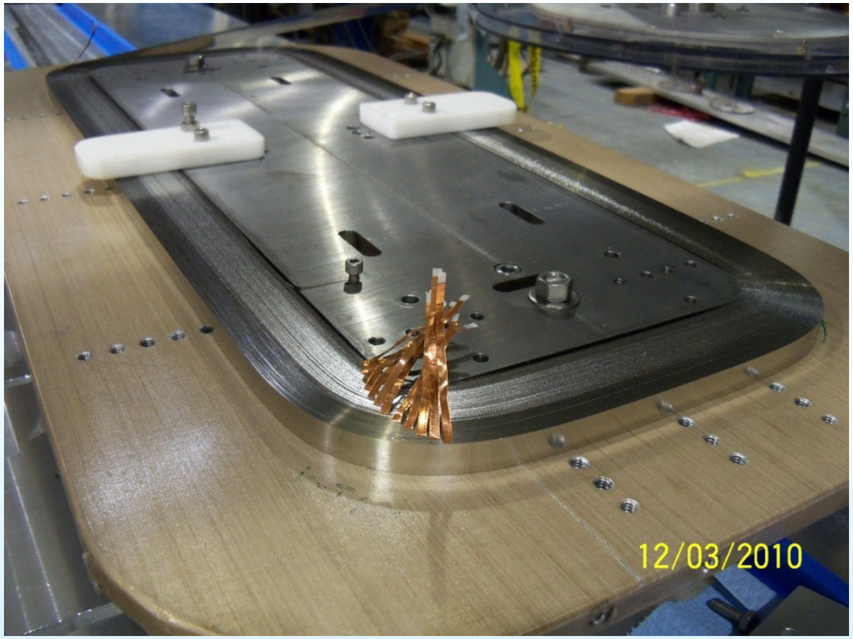
(snapshots around noon hour on January 20, 2010)



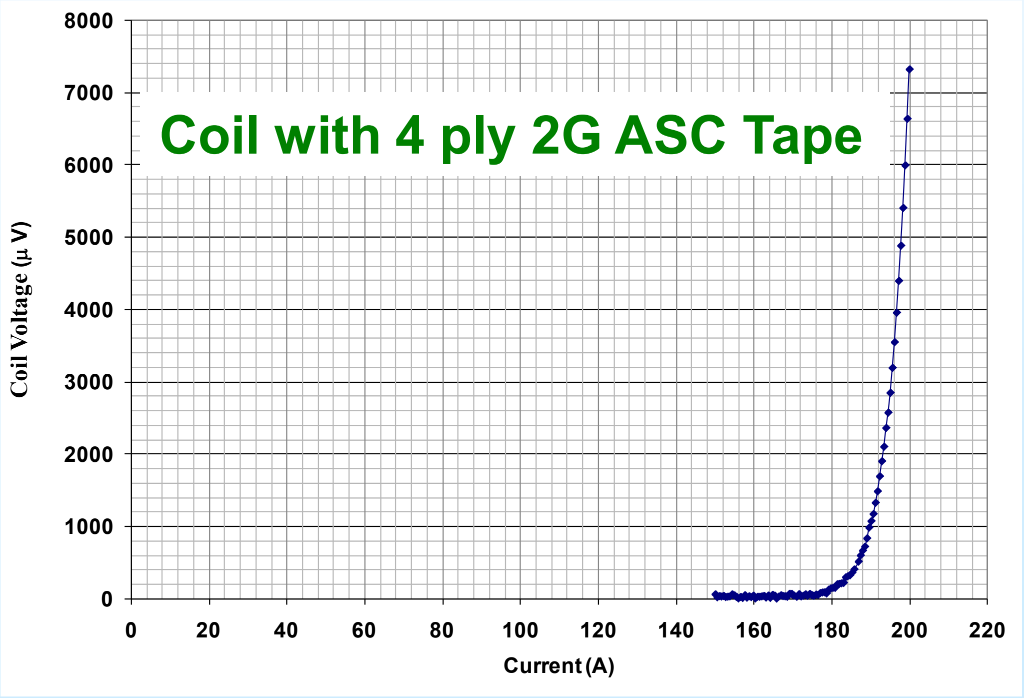


1. An HTS coil being wound on automatic winder
2. Another HTS coil being prepared for test in liquid nitrogen (notice a fancy cryostat!)
3. Advanced magnet protection system being developed
4. Three coils in storage (next best to being in magnet)

Construction and Test Results

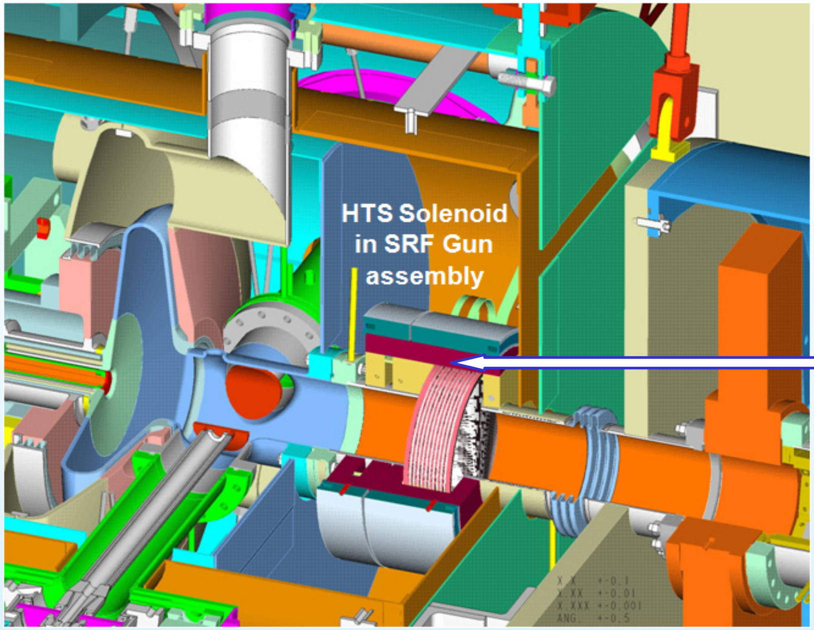


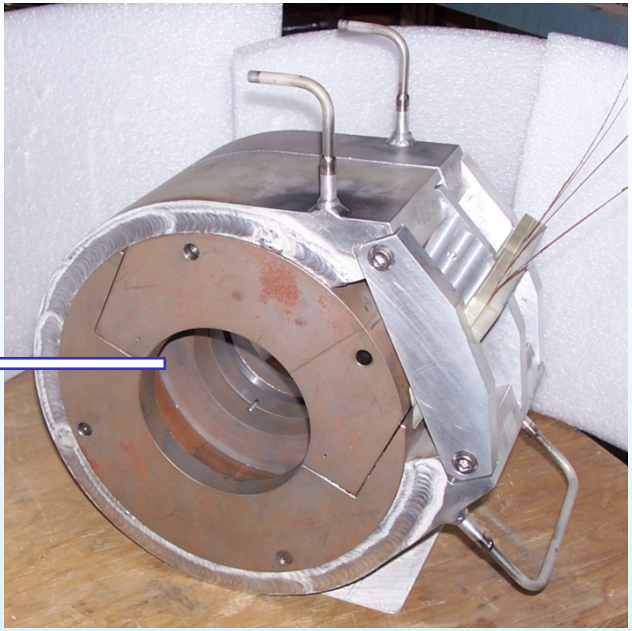
- FRIB coils are being made with significant HTS
  - Each coil uses ***over 1 km*** equivalent of standard 4 mm 2G HTS tape
- Unique opportunity to test large 2G HTS coils
- Need 8 coils (4 with SuperPower, 4 with ASC)
- 6 of eight coils made, 3 tested at 77 K
- One coil is made without any splice

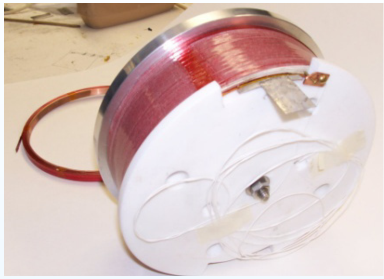


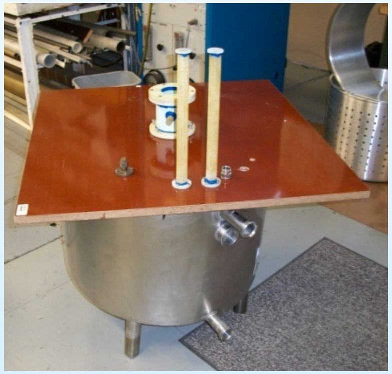
- All three coils performed well @77 K
- SuperPower coil carried ~87 A
- ASC coil (double tape) carried ~195 A
- Computed self-field: ~0.5 T

Low Magnetic Field Application
HTS Solenoid with Superconducting Cavity for the Energy Recovery Linac (ERL) at BNL









HTS solenoid is placed in cold to warm transition region after the superconducting cavity where neither LTS or copper solenoid would work

Early focusing provides a unique and better technical solution

PAC 2011 Papers on HTS from BNL

A wide range of HTS R&D @ BNL presented at this conference:

1. Engineering Design of HTS Quadrupole for FRIB – Cozzolino, et al.
2. Design, Const. and test of Cryogen-free HTS Coil Structure – Hocker, et al.
3. Influence of Proton Irradiation on Second Generation HTS in Presence of Magnetic Field – Shiroyanagi, et al.
4. Novel Quench detection system for HTS Coils – Joshi, et al.
5. Measurements of the Effect of Axial Stress on YBCO Coils – Sampson, et al.
6. Open Midplane Dipole for Muon Collider – Weggel, et al.
7. Design Construction and Test Results of HTS Solenoid for ERL – Gupta, et al.
8. HTS Magnets for Accelerator and Other Applications – Gupta

For More Information
Please Visit BNL Magnet Division this Saturday
and view the following longer presentation

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http://www.bnl.gov/magnets/staff/gupta/

High Temperature Superconducting Magnets

Revolutionizing Next Generation Accelerators and Other Applications

Ramesh Gupta
Superconducting Magnet Division

466th Brookhaven Lecture

February 16th, 2011

http://www.bnl.gov/magnets/staff/gupta/

SUMMARY

- **Progress in HTS magnet technology has been very encouraging**
- **A significant number of coils and magnets (with ~20 km HTS) have been successfully built and tested (more with ~35 km soon)**
- **We are now moving from small size demo coils to large and very challenging magnet applications where HTS offers unique solution**
- **HTS magnets are poised to revolutionize the field the same way the conventional superconducting magnets did a few decades ago**
- **A wide range of HTS magnet R&D is being carried out at BNL**