HTS Magnet Technology at BNL

Advancements and Capabilities

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Overview

- Brief overview of the HTS magnet program at BNL
- Recent advancements and technological capabilities
  - Areas where we can possibly contribute towards HTS bearing
- Initial ideas/questions/discussion

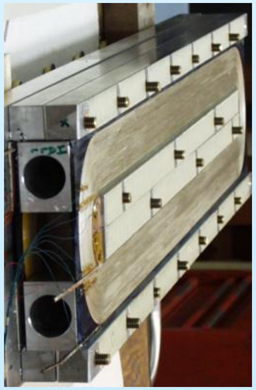
HTS Magnet R&D at Brookhaven Lab

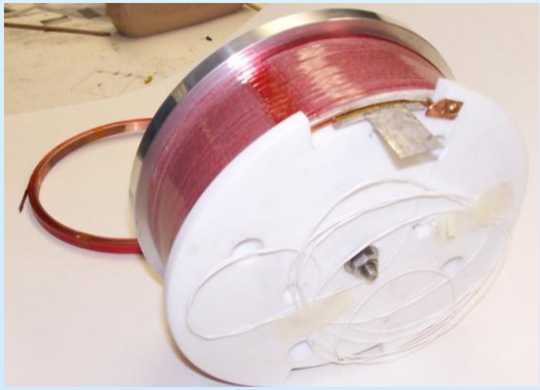
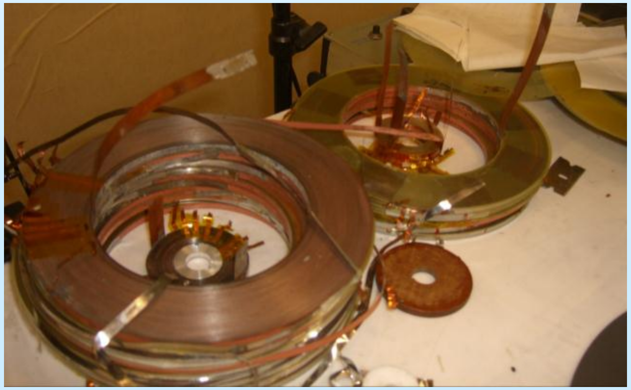
- **BNL has made devices with all varieties of HTS**
  - **BSCCO2212, BSCCO2223, YBCO, MgB_2**
- **Major HTS R&D program at BNL**

  Amount of wire procured (normalized to common 4 mm tape):
  - **~40 km obtained so far**
- **Successfully designed, built and tested a large number of HTS coils and magnets:**
  - **Number of HTS coils built: well over 100**
  - **Number of magnet structures built and tested: well over 10**
- **Support facilities with conductor test facility**
- **Cryogenic engineering for a variety of applications**

HTS Magnet Programs at BNL

- **BNL has been the world leader on HTS accelerator magnet R&D for a decade**
  - **First national lab to design, build and test HTS coils & R&D magnets**
- **BNL has funding from a variety of sources (DOE, partnership with small businesses, universities and now to start with foreign institutions).**
- **We are developing HTS magnets operating over a large range of temperature and field and having a variety of geometries**
- **Variety is the strength of our program. It helps us in fostering a wider understanding and makes the overall development more cost effective**
- **Next few slides – selected examples (not a compilations of all programs)**



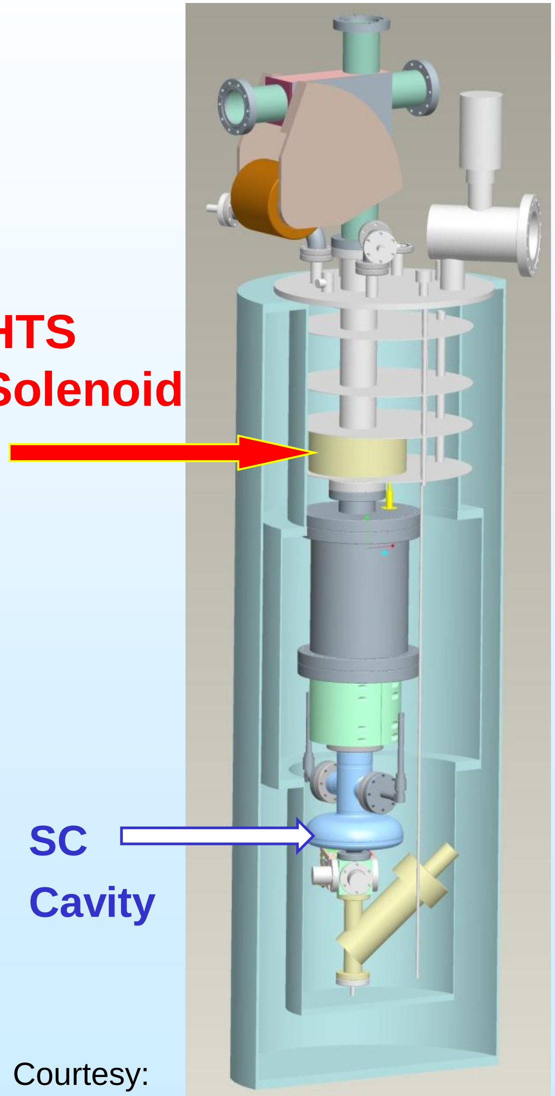
Low Field HTS R&D Magnets

(operating at high temperatures)

HTS Solenoid for Superconducting Electron Gun

Produces intense electron beams with focusing from HTS solenoid

HTS Solenoid

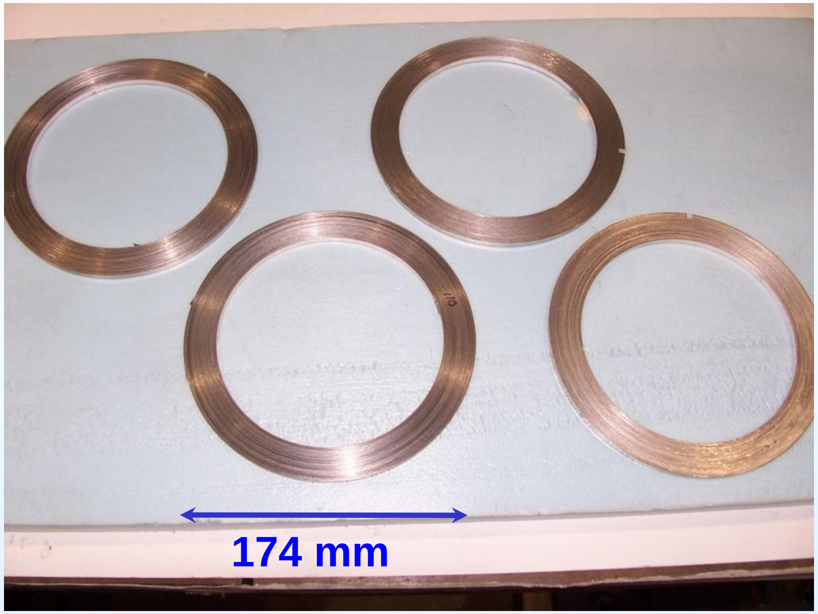


SC Cavity

- No room for LTS solenoid in Liquid Helium
- Copper solenoid would generate ~500 W heat as against the ~5 W heat load of the entire cryostat
- Temperature between baffles ~20 K ***– NO LTS***
- **HTS solenoid provides a unique solution**

Courtesy:
Ben-Zvi, Kewisch

Economical Low Field HTS Solenoid (operating at higher temperature)



- Conductor cost: ~ a few k$
- Compact size
- Low current (<20 A) operation with household wiring

- Testing at ~77 K in LN_2 is much cheaper than testing at ~4 K in LHe
- **HTS provided an economically better (design + build + test) and technically superior solution**

Courtesy/Contributions: Dilgen, Ince

Medium Field HTS Magnet Programs (operating at medium temperature)

1. General Purpose (for accelerators & medical applications)

- Must compete with two established technologies:
  - Magnets powered with water-cooled copper coils
  - Super-ferric magnets with conventional superconductors (NbTi)

2. Special Purpose Magnets:

- **HTS magnets provide unique solution to critical technical problems**

HTS Dipoles for Energy Efficiency

- Room temperature Cu coil magnets: Cheaper to build, expensive to operate (2M$/y)
- Cryo-cooled HTS magnets: Expensive to build, cheaper to operate

Compare the cost of ownership (capital + operation):

➢ ***GOAL: Cost-effective technology to offer saving in cost of ownership after a number of years. Also take advantage of unique situation (upgrade?)***

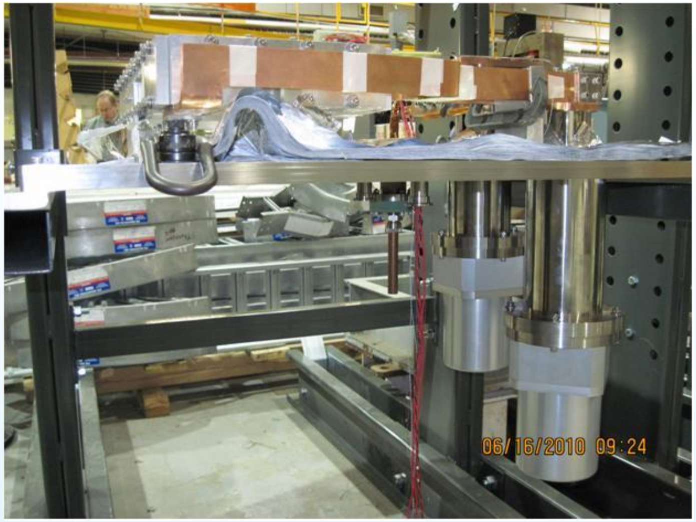
Technology for accelerators, medical facilities and energy storage

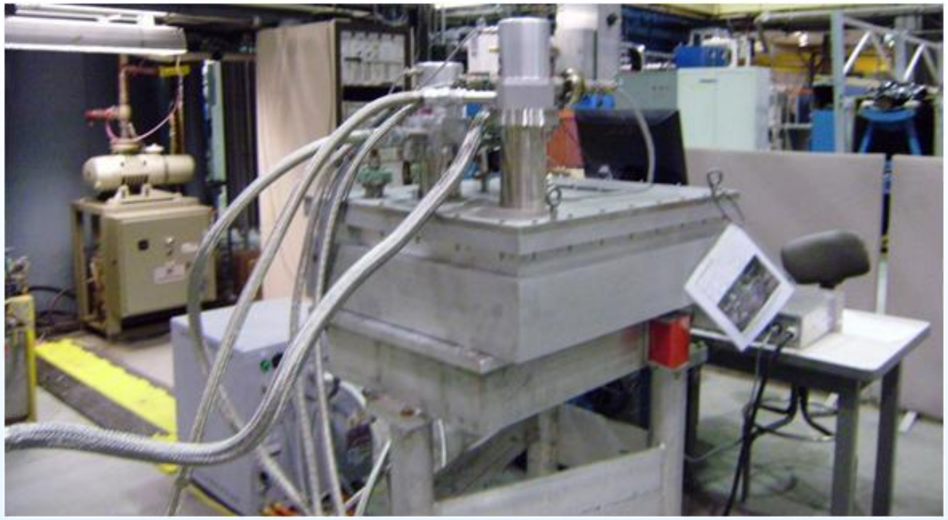
Original BNL 1.55 T Dipoles with Copper Coils (~3 MW)

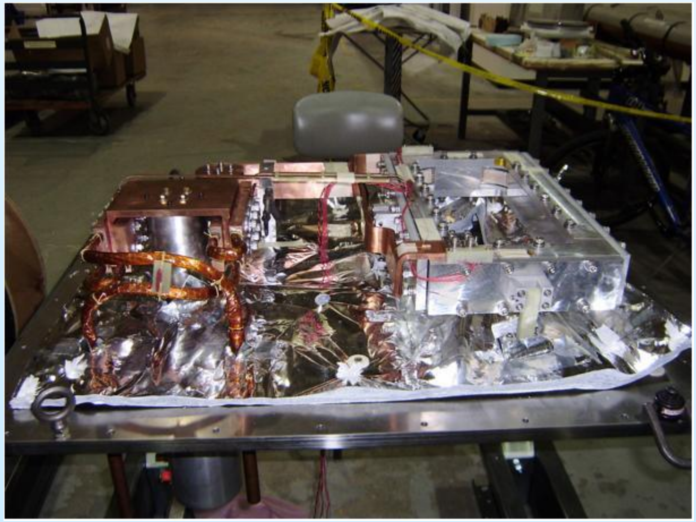
Cu coils replaced by cryo-cooled HTS coils by HTS-110

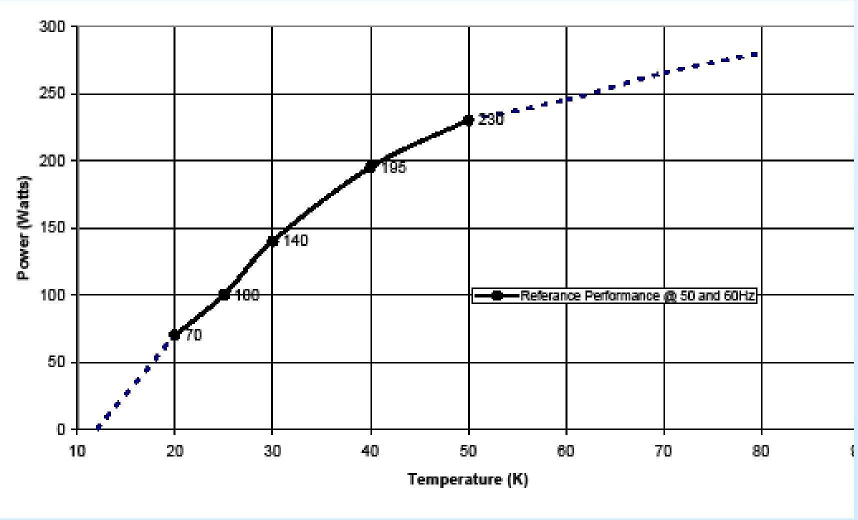
Cryo-cooled HTS coils with technology developed at BNL

HTS and Cryo-coolers (made for each other)



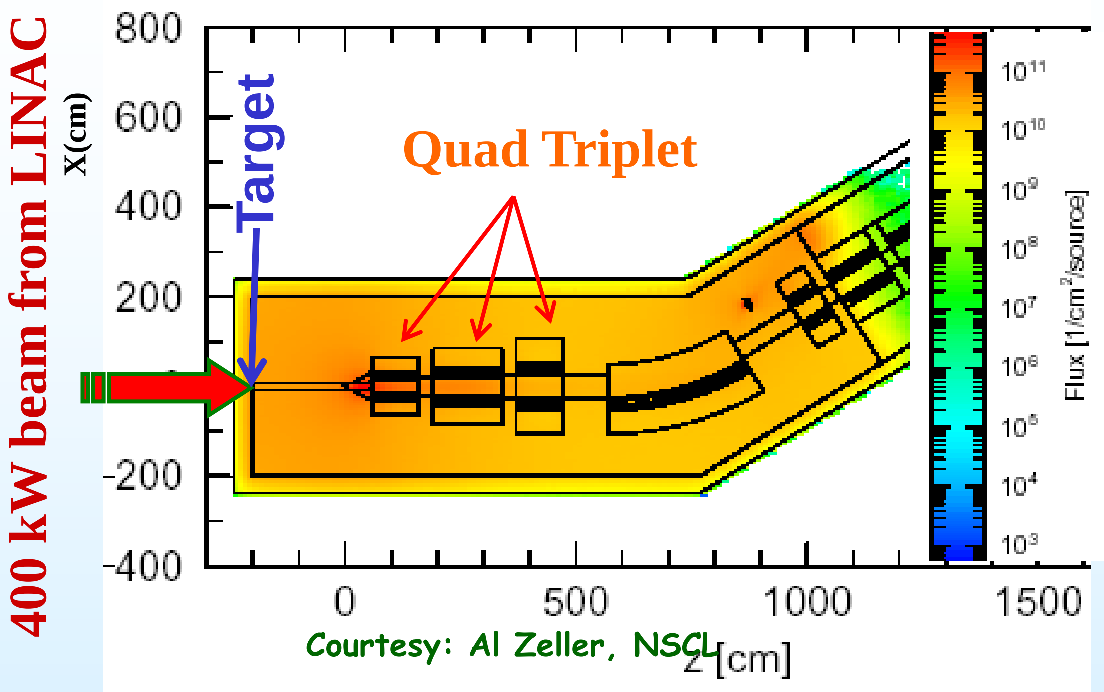






Evening: Switch ON; Morning: Fully COLD

Technical Advantage of Medium Field HTS Magnets in Certain Applications



Medium Field HTS Magnets for FRIB: Facility for Rare Isotope Beams

- High power beam (~400 kW) hits the target to create intense rare isotope beams
- Magnets are exposed to very high radiation and heat loads (~15 kW in the first)
- HTS magnets remove this heat more efficiently at 30-50 K than LTS at ~4 K
- HTS magnets have a large temperature margin, can tolerate a large local increase in temperature and allow a robust cryogenic operation in presence of large heat loads

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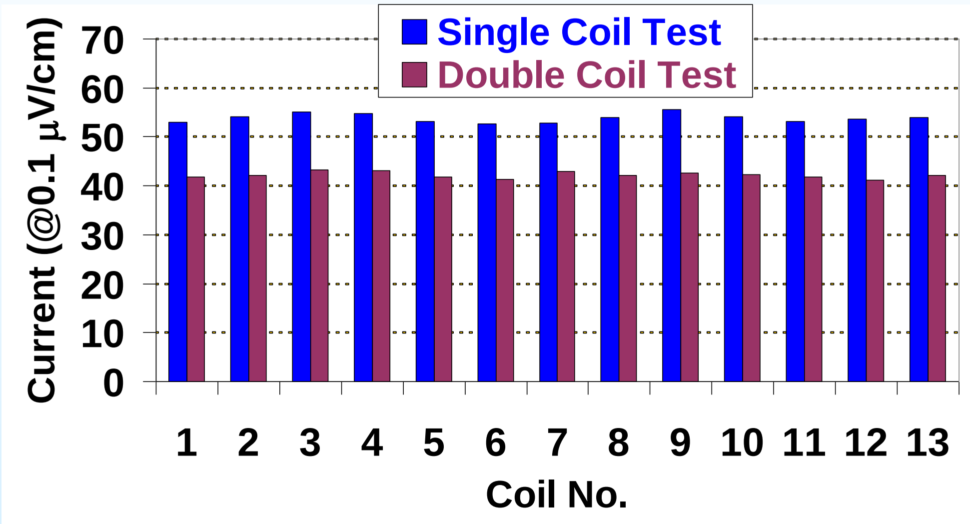
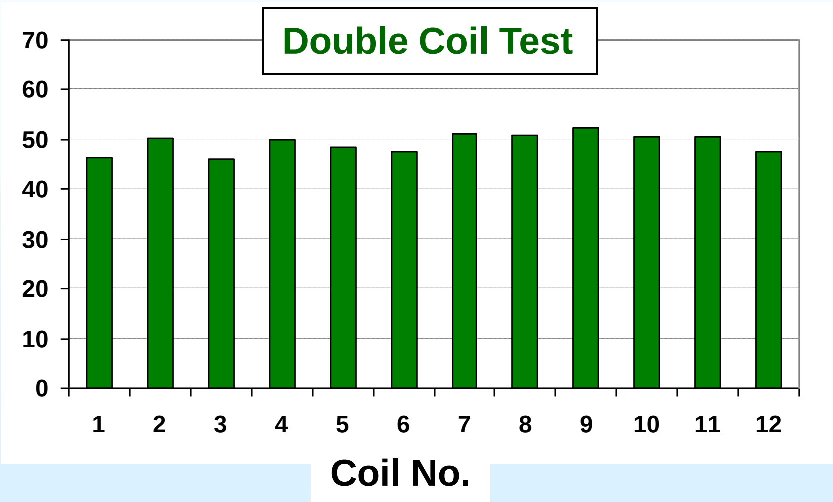
Performance of a Large Number of HTS Coils with LN_2

13 Coils made with earlier tape (HTS ~220 meters)



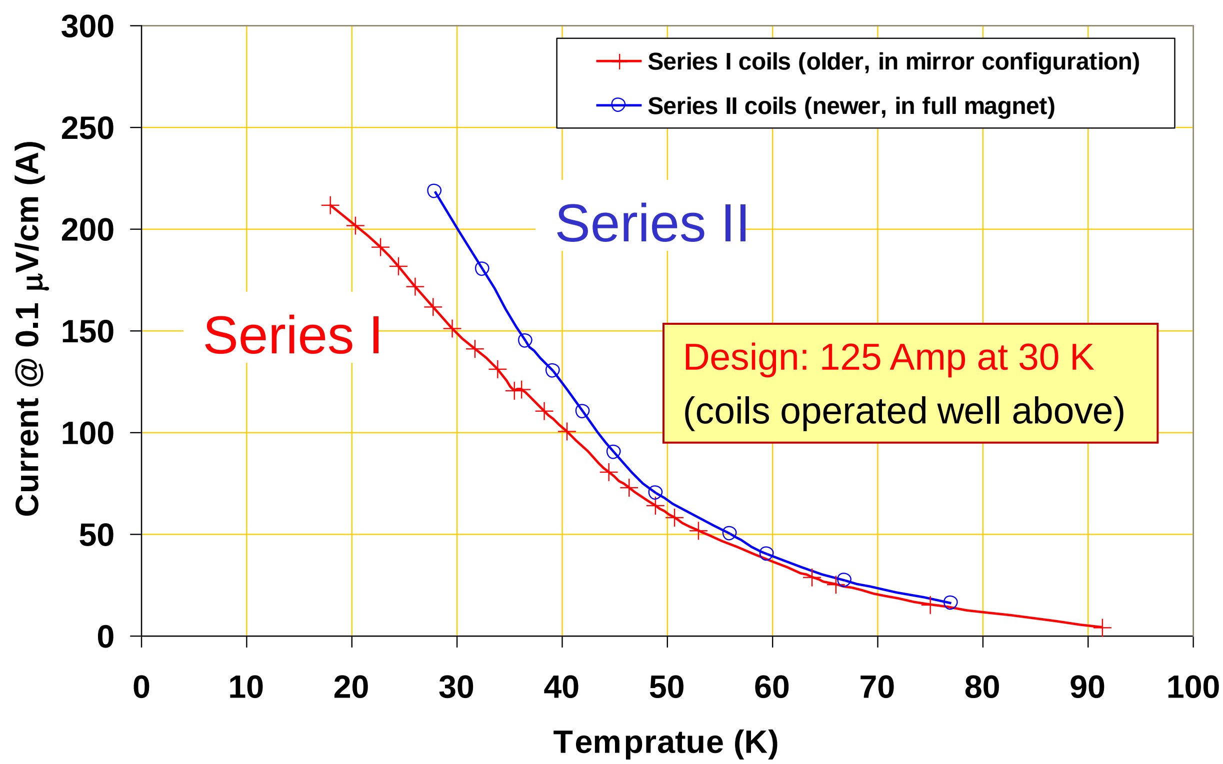
12 Coils made with newer tape (HTS ~180 meters)

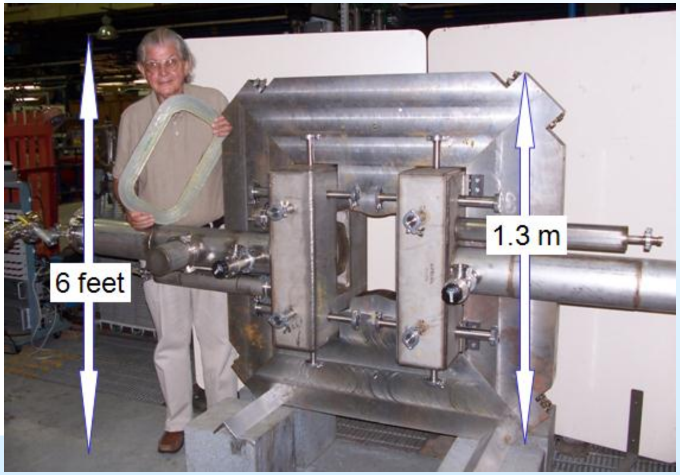


Note: Uniformity in performance of a large number of HTS coils.

Shows that HTS technology is now maturing !

Summary of Test Results
(operation over a large temperature range)

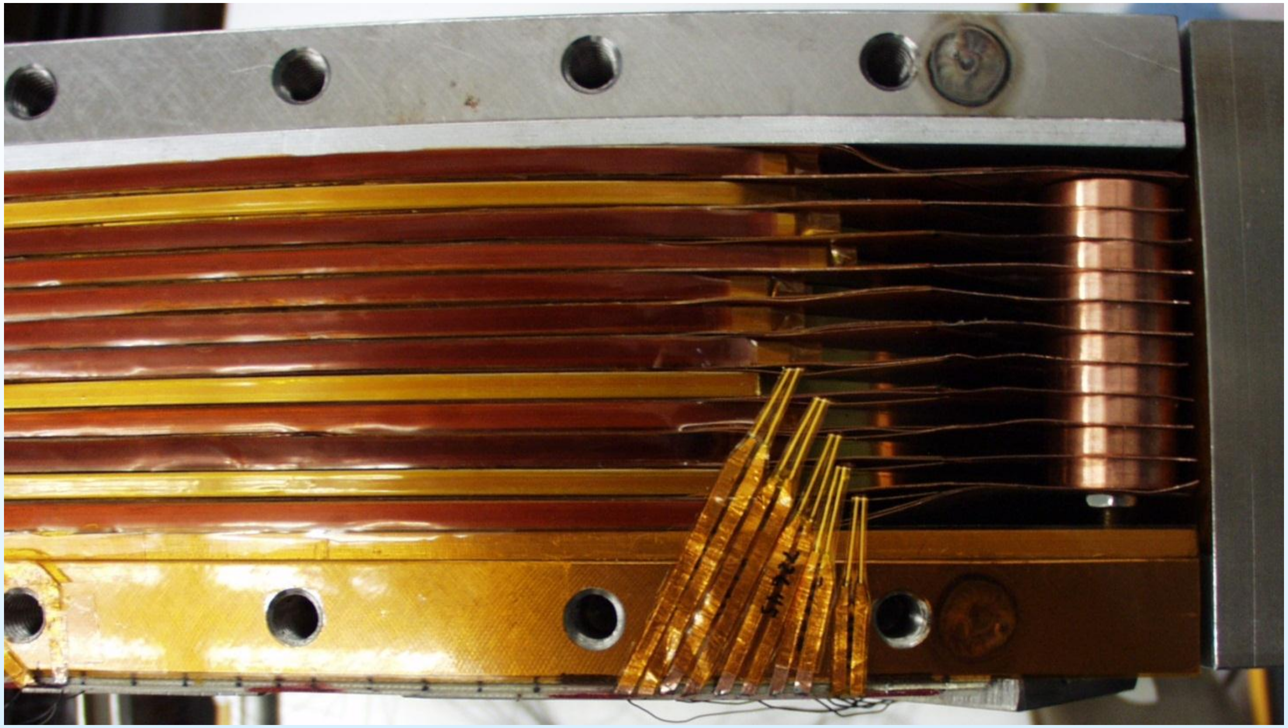




<u>Benefits of HTS over conventional LTS demonstrated:</u>

- Large change in temperature causes only a small change in critical current
- To obtain significantly higher performance, just lower the operating temperature

Energy Deposition and Cryogenics Experiments



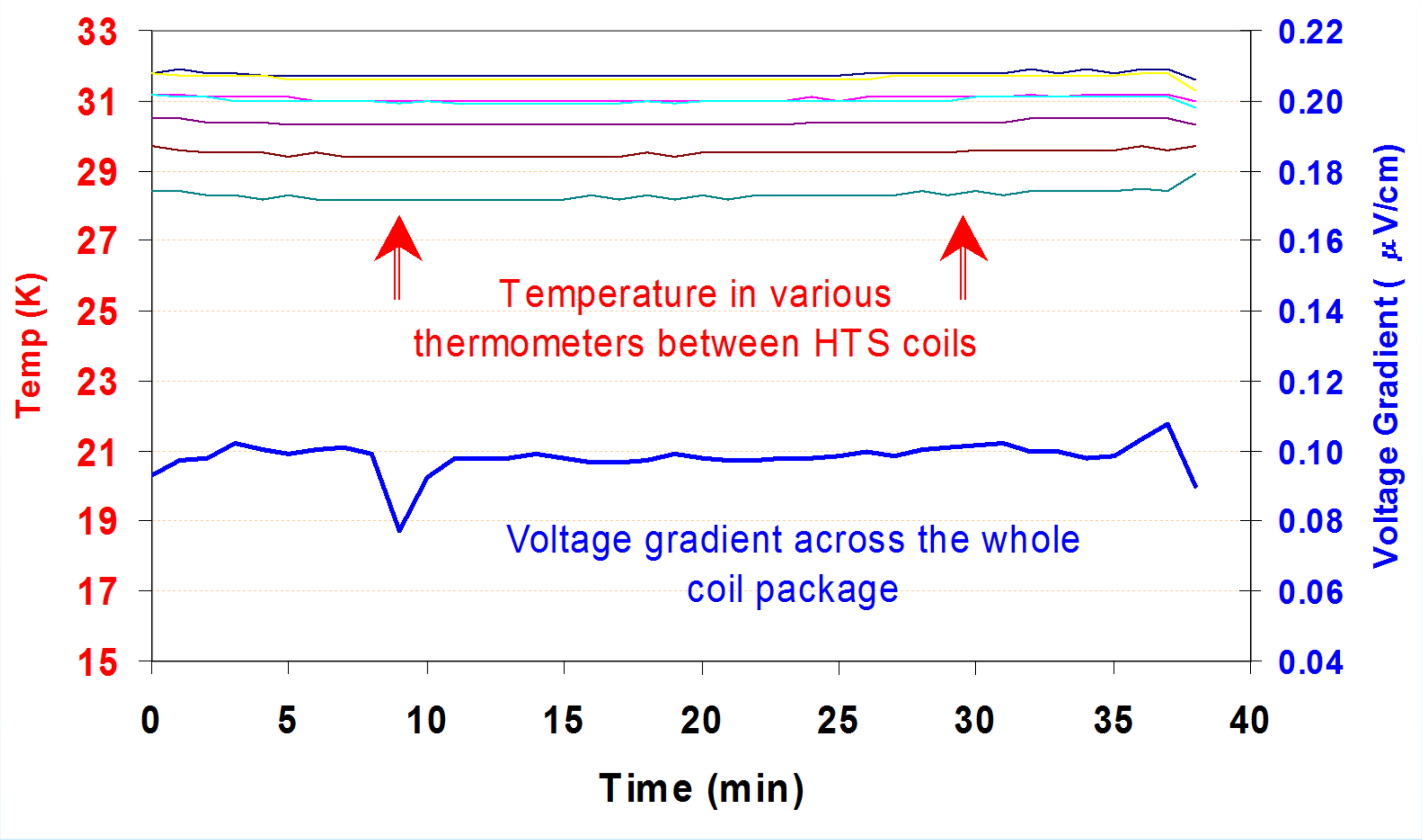
Stainless steel tape heaters for energy deposition experiments

Copper sheets between HTS coils with copper rods and copper washers for conduction cooling

- **In conduction cooling mode, helium flows through top and bottom plates only.**
- **In direct cooling mode, helium goes in all places between the top and bottom plates and comes in direct contact with coils.**
- **Energy deposition in magnet worked well in both cases.**

Large Energy Deposition Experiment

Magnet operated in a stable fashion with large heat loads (25 W, 5kW/m³) at the design temperature (~30 K) at 140 A (design current is 125 A).



Stable operation for ~40 minutes

Voltage spikes are related to the noise

Coils Assembled in Quadrupole Support Structure

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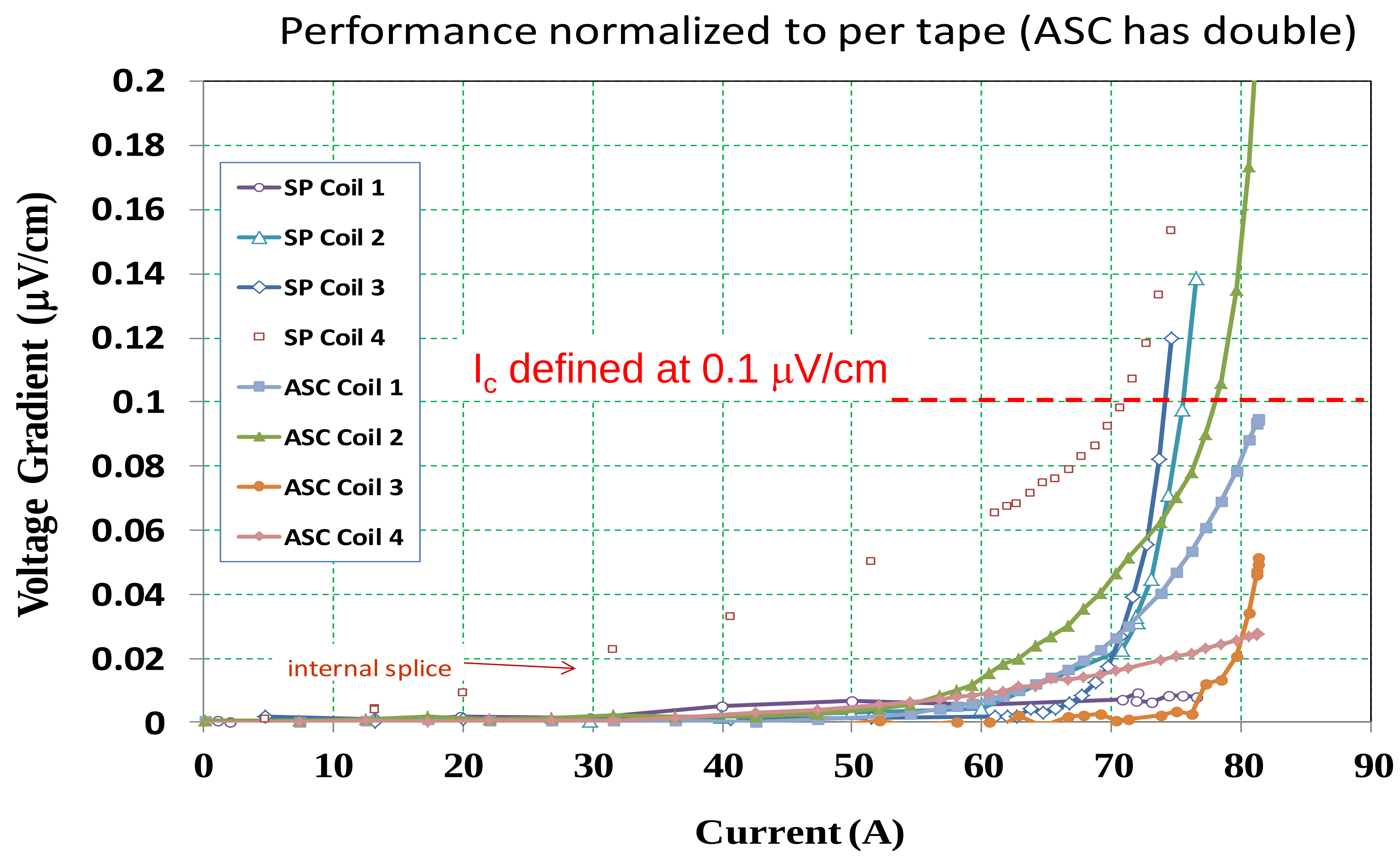
Coils in FRIB Quad Structure @77 K
(made with 2G HTS from SuperPower and ASC)



High Field HTS Magnets (operating at low temperatures)

Two ambitious programs:

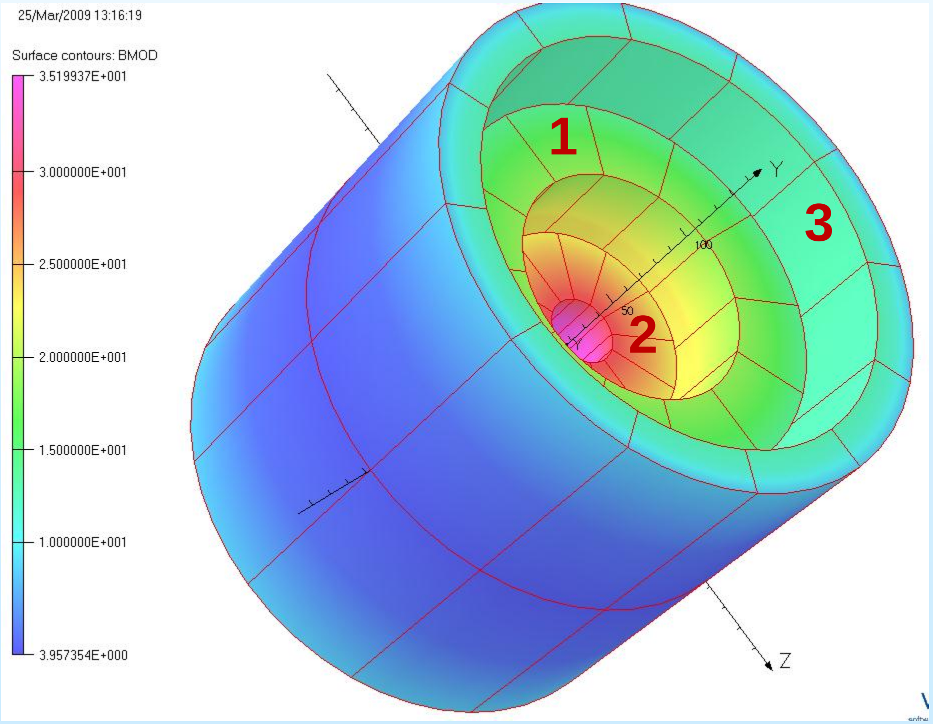
- 20-22 T HTS solenoid for cooling in muon colliders
- 24-30 T HTS solenoid for magnetic energy storage

Both would be the highest field HTS magnets ever built!

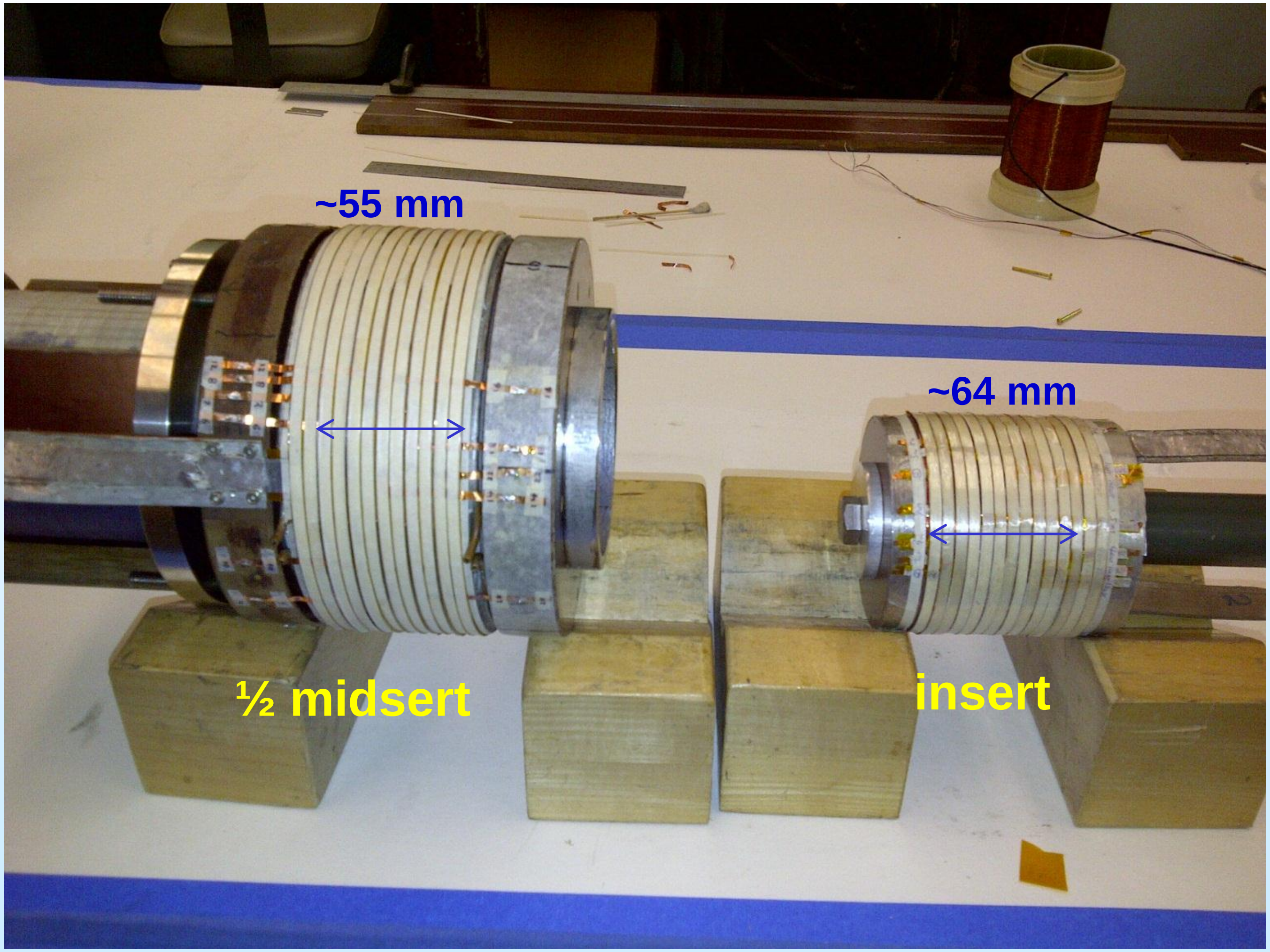
- **Both programs are being carried out in partnership with industry**

Very High Field Solenoid

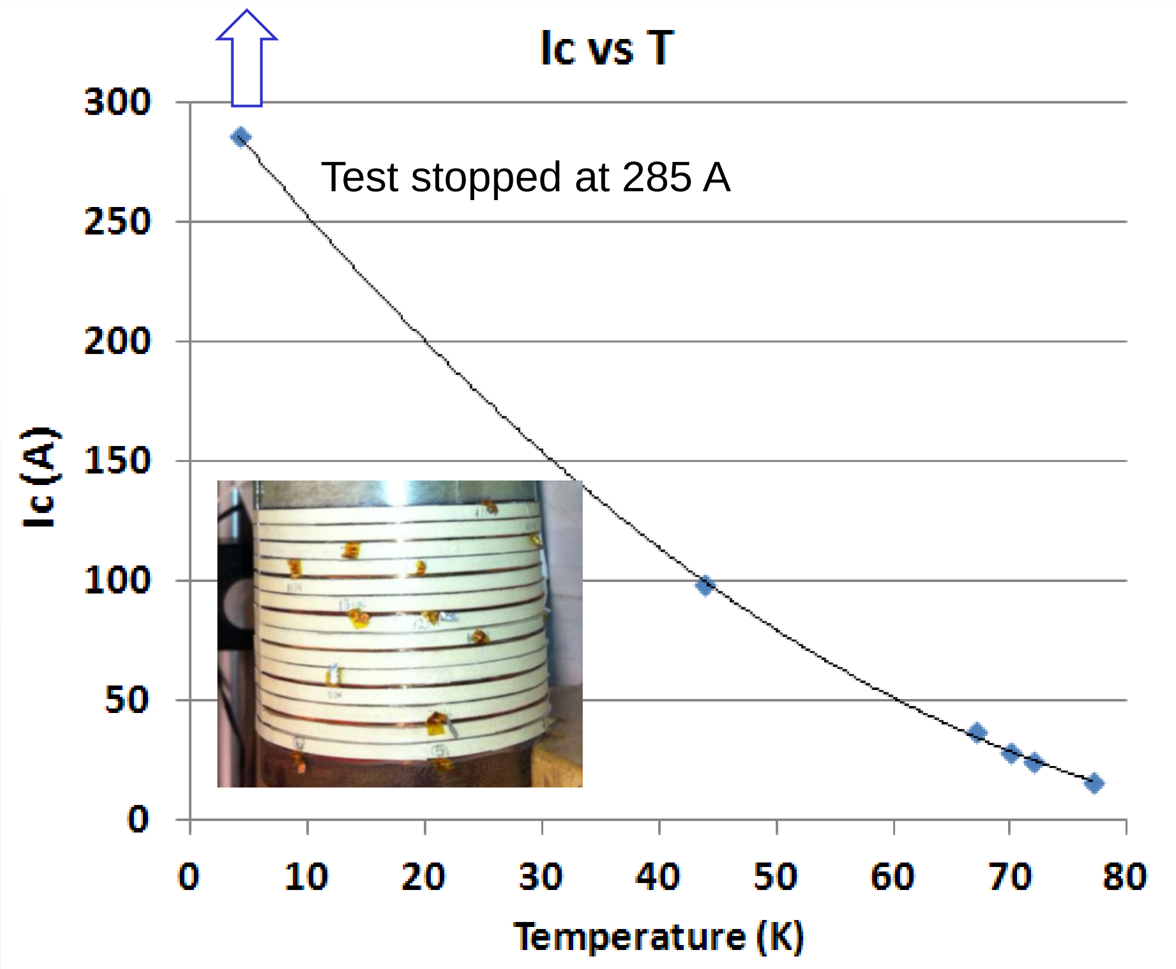
- Ambitious SBIR route to evaluate magnet technology for ~35 T
- Significant demonstrations so far:
  - **Highest field (>15 T) HTS magnet ever built**
  - **Large use (1.2 km) of HTS in a high field magnet**



High Field HTS Solenoids for Muon Accelerator Program



Demo of Highest Field HTS Magnet



Field on axis:

- **over 15 T**

Field on coil:

- **over 16 T**

Real demo of 2G HTS to create high field

Highest field in an all HTS solenoid (previous best SP/NHMFL ~10.4 T)

Overall current density J_o in coil: >500 A/mm^2 at 16 T

Superconducting Magnetic Energy Storage (SMES)

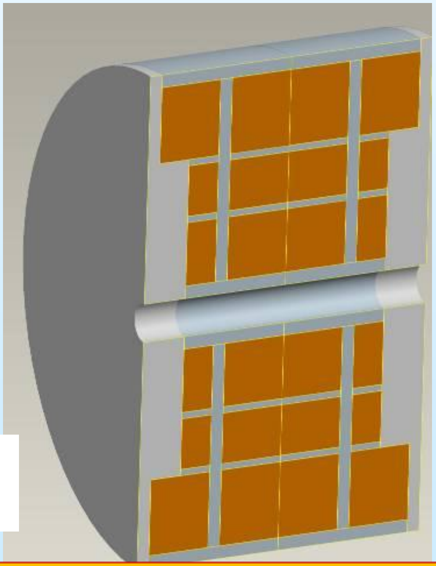
High field, large aperture, HTS solenoid is a highly ambitious goal:

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

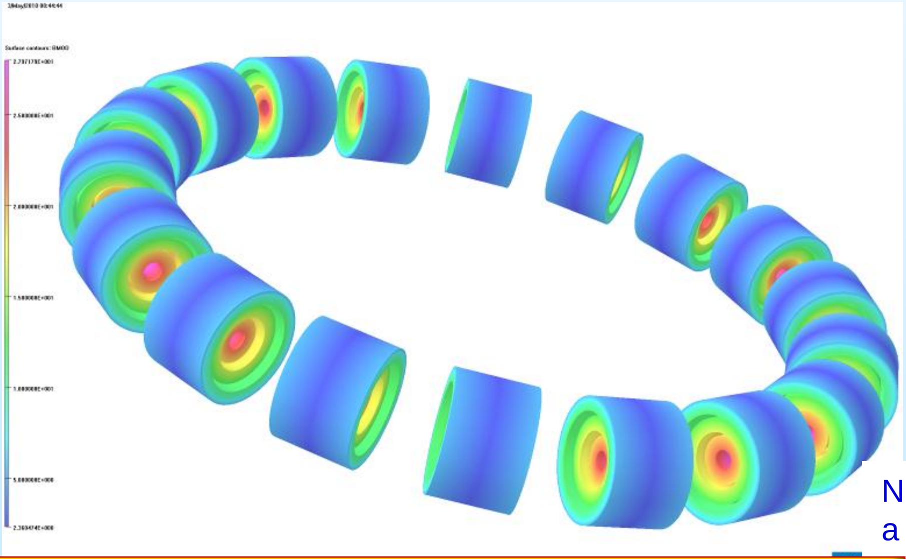
- **37 were selected out of ~3,700 proposals submitted !!!**

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

Superconducting Magnetic Energy Storage (with High Field HTS)

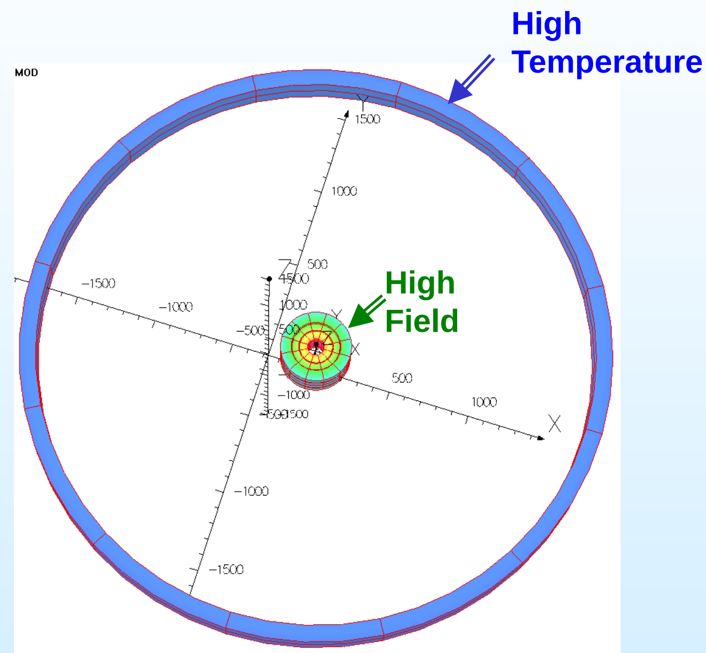
Two options examined for HTS:

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***

Shielding with HTS Tape

- We did experiments with HTS tape providing shielding
- It worked well
- This route can also be explored for HTS bearing

Possible BNL Contributions

- HTS magnets with cryogenic system
- Possibility of exploring wide 2G tape in addition to HTS bulk material for "HTS Bearing"
- Engineering support for complex systems