

High Temperature Superconductor R&D at Superconducting Magnet Division

Ramesh Gupta
Superconducting Magnet Division
Brookhaven National Laboratory
Upton, NY 11973 USA

HTS : Historical Hype and The Present Status

High Temperature Superconductors were discovered ~20 years ago (1986)

- Some thought that it's going to change the world significantly & quickly
 - Well, that was mostly a media hype !

However, slowly and surely HTS have made major progress

- Long length wires are now commercially available from several vendors
 - American Superconductor is the leading developer & manufacturer

HTS have now reached a level of maturity and economical viability that they are being used in key applications and can be considered in many others

- A well known example in accelerators: HTS current leads
 - BNL is pushing the frontiers of HTS accelerator magnet technology

Note: Development of HTS technology is driven by non-accelerator applications. However, the benefits of it's development can be very well utilized in high performance and/or cost effective operation of particle accelerators.

Advantages of using HTS in Accelerator Magnets

As compared to LTS, the critical current density (J_c) falls slowly

- as a function of temperature
- as a function of field

Translate this to magnet design and accelerator operation:

- HTS based magnets can work at elevated temperatures
 - Potential of a significant saving in operating cost as compared to conventional superconducting or conventional copper magnets
 - Since the regulation of operating temperature can be relaxed by an order of magnitude as compared to that in conventional sc magnets, the cryogenic can be significantly simpler and cheaper
- HTS has a potential to produce very high field magnets

BNL is developing magnet designs and technologies to exploit both of these advantages in a variety of applications.

HTS Challenges and Implications

- HTS materials are brittle and critical current depends on the direction of field
 - Develop magnet designs that can accommodate these challenges (“conductor friendly magnet designs”).
- HTS materials are expensive
 - Cost / Amp has been coming down; hope the trend continues.
 - Moreover, for some applications it is already acceptable (either because of the savings in operating cost or because of their higher performance).
- Field quality and quench protection issues
 - Need to understand & develop techniques. It seems we can handle them.

HTS R&D at Magnet Division

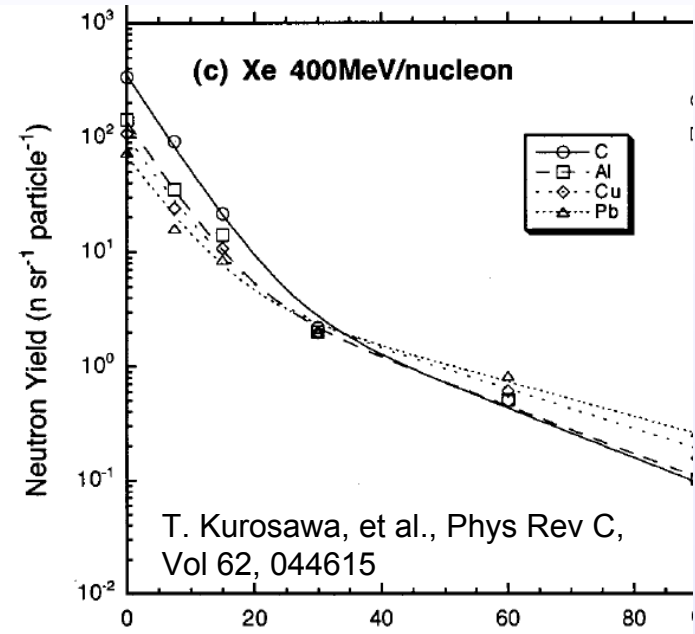
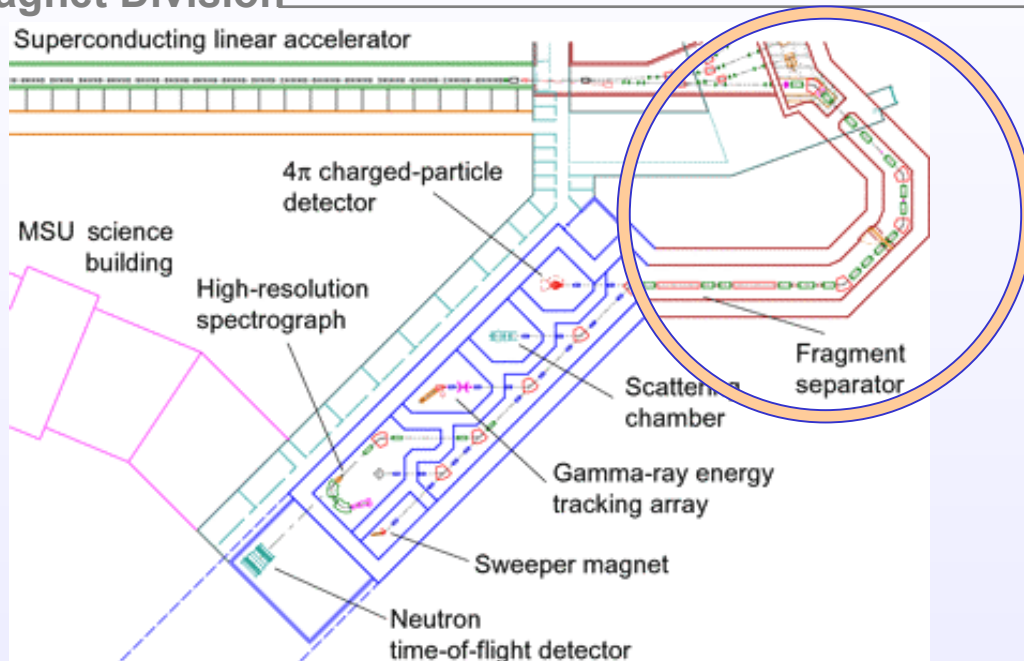
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- We have developed a number of magnet designs that are suitable for brittle High Temperature Superconductors.
- We have built and tested a large number of HTS coils and R&D magnets for various applications.
- In addition, we have a unique world class facility to test superconducting tapes, wires and cables.

HTS Quads for Rare Isotope Accelerator (RIA)

(A medium field, high operating temperature application of HTS)

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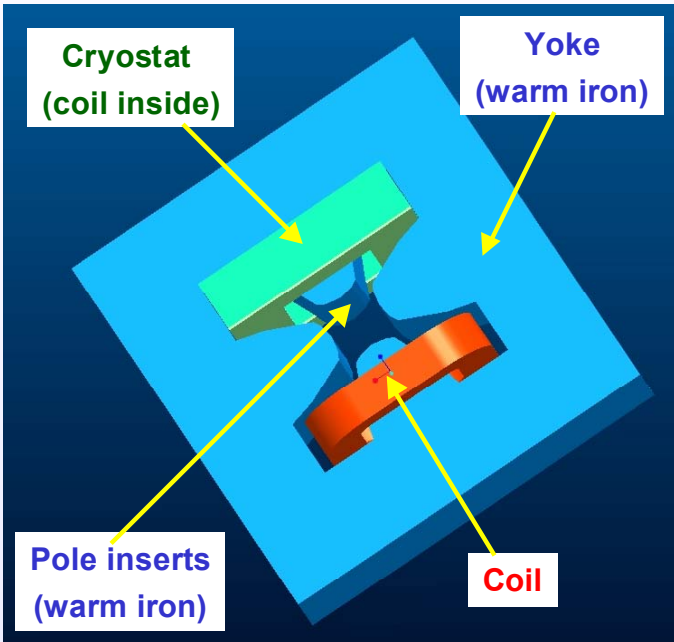


- Beam loses 10-20% of its energy (several hundred kW) in the production target. This produces several kW of fast neutrons with yield peaking strongly at the forward angle.
- Quads are exposed to very hostile environment with a level of radiation (10^{19} neutrons/cm² in 0° to 30° region) and energy deposition (15 kW in the first magnet) never experienced by any magnet system before.

Need “*radiation resistant*” superconducting magnets that operates at higher temperature and can withstand large heat loads.

HTS QUAD for RIA Fragment Separator

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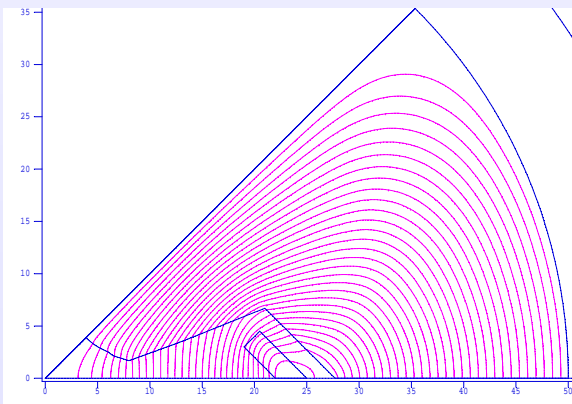


Requirements: ~3 T field, operating at >20K.

✍ Can be achieved with the commercial HTS.

- HTS Quads can operate at a higher temperature (20-40 K instead of 4K). Higher operating temperature makes large heat removal (few hundred kW) more economical.
- In HTS magnets, the control of operating temperature can be relaxed by an order of magnitude. This simplifies cryogenic system.
- A warm iron yoke brings a major reduction in amount of heat to be removed at lower temperature.
- The coils are moved outward to significantly reduce the radiation dose.
- Insulation is a major issue. We plan to use stainless steel which is radiation resistant.

Coils inside the cryostat at the end of the magnet



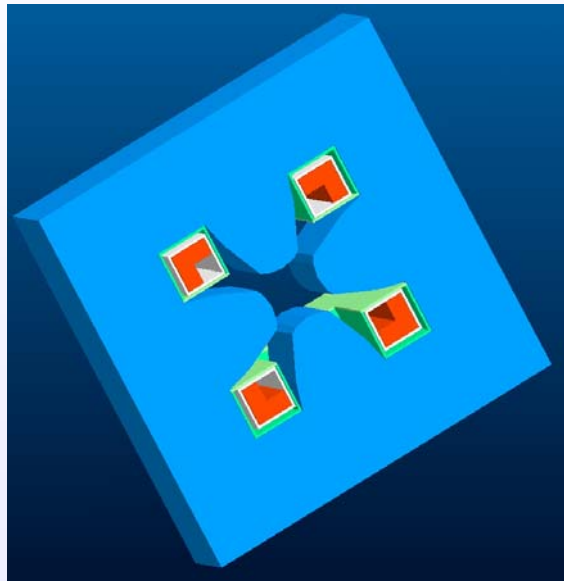
HTS Coil for RIA (Being made from HTS from ASC)



These magnets have been identified as high priority item. BNL is receiving funding from DOE to develop them - the only technology that is currently receiving R&D funding for these magnets.

Similarities Between RIA and NSLS II Magnets

Magnet design for RIA contains many features that are similar to those needed in NSLS II magnets proposed by George Rakowsky and John Skaritka.



Super-ferric design with two racetrack HTS coils

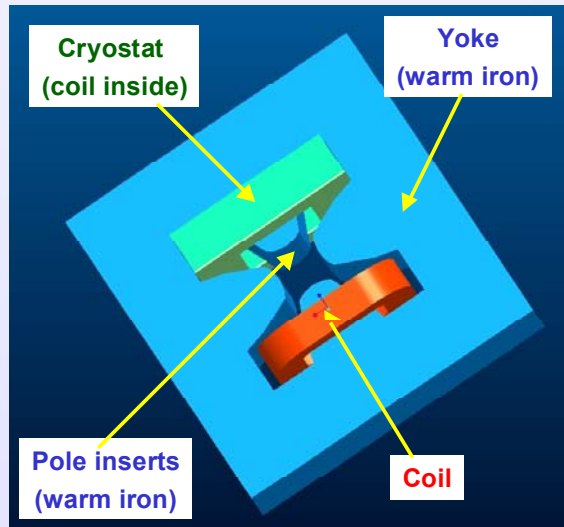
- The coil cross-section is about the same
- Coils are made with HTS tape (flat wire)

Coils are placed inside compact cryostat

HTS coils operate at high temperature ($\gg 4K$)

Warm iron design

- Only a small fraction of the volume is cold



Sometime, we get lucky by coincidence !

More BNL Magnets With HTS Tapes



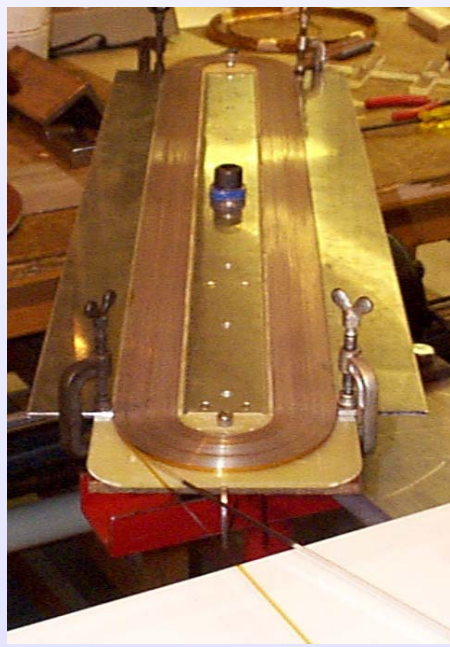
Double pancake NMR coils



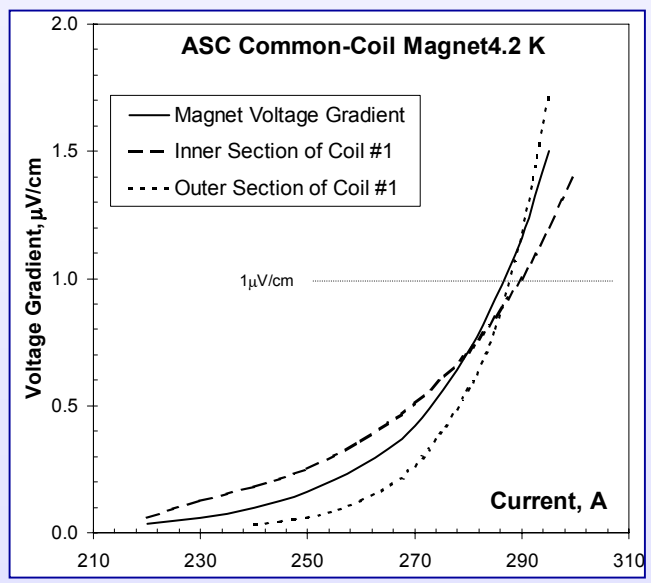
Two HTS tape coils in common coil configuration



A coil being wound with HTS tape and insulation.

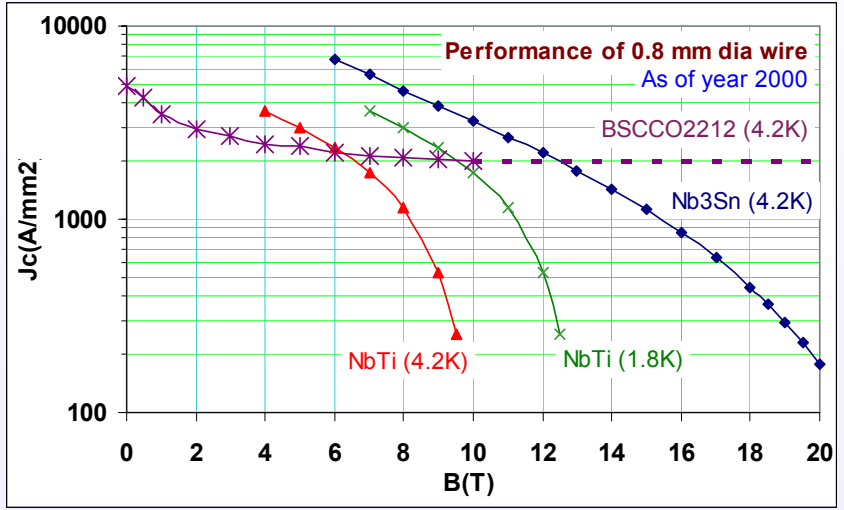


A Coil for an Accelerator Magnet

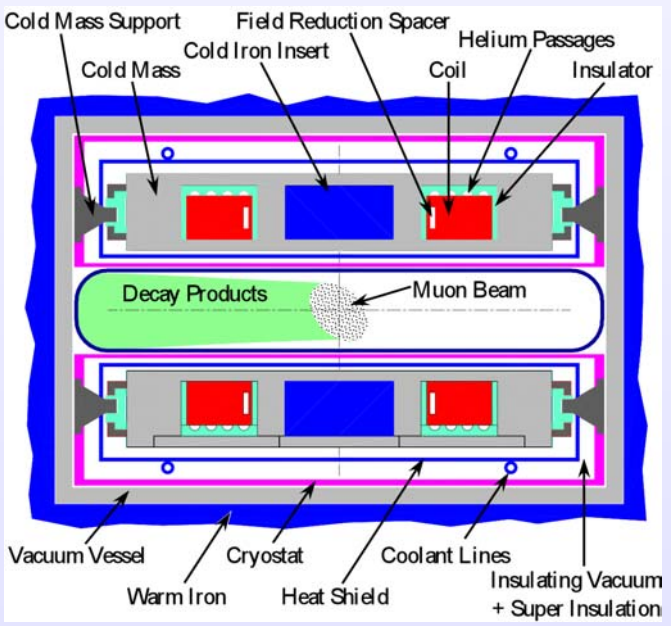
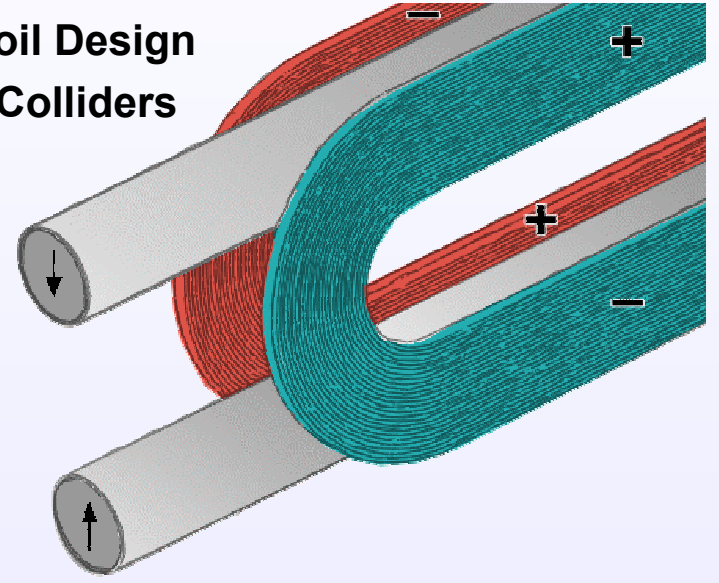


A Few High Field Magnet Designs Developed at BNL That are Suitable for HTS

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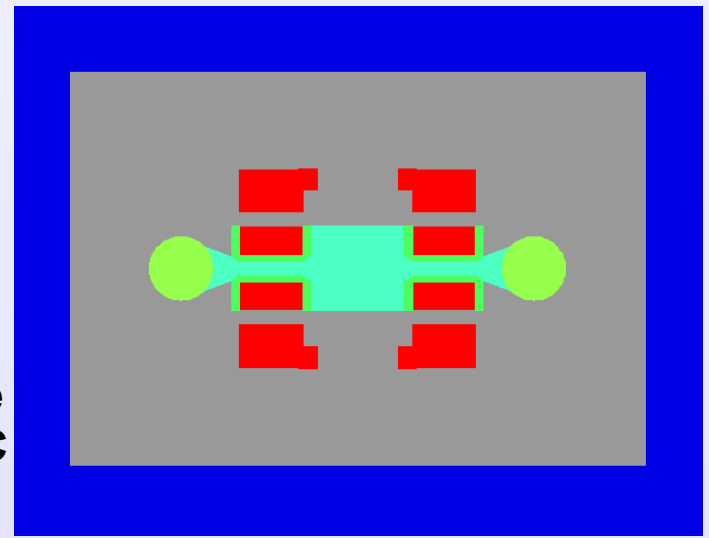


Common Coil Design for Hadron Colliders



Magnet Design for ν Factory

Open Midplane Design for LHC Upgrade

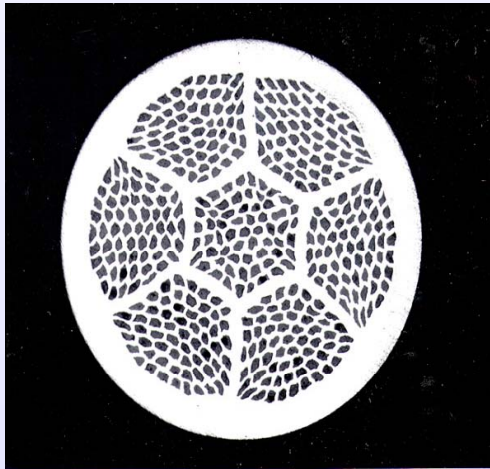


Construction and Test Results from HTS Technology Development Program at BNL

Next Few Slides will Show:

- Results of HTS cable tests showing the continuing progress in the field
- Construction and Test Results of HTS Coils and R&D Magnets

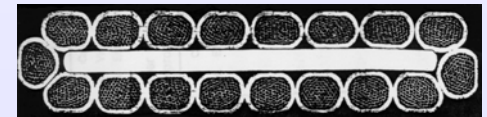
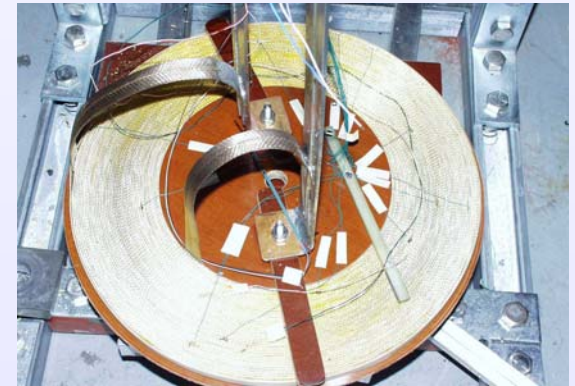
Please see the tape and cable being distributed



HTS Wire



A coil with HTS Tape

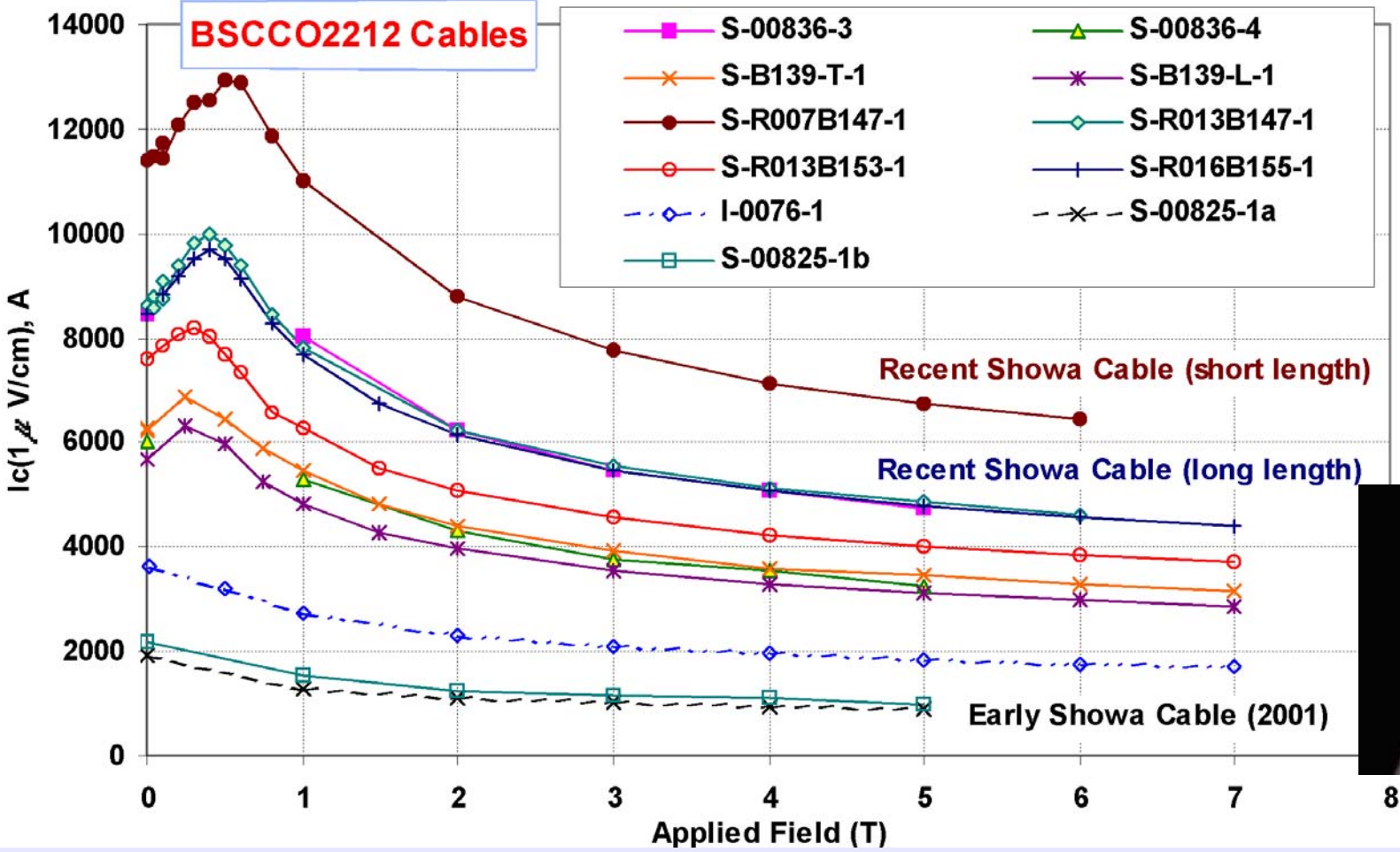


**10+ kA HTS Rutherford Cable
BNL/LBL/Industry collaboration**

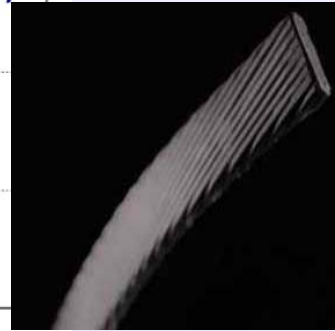
HTS Cables: A Remarkable Progress

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BSCCO2212 Cables



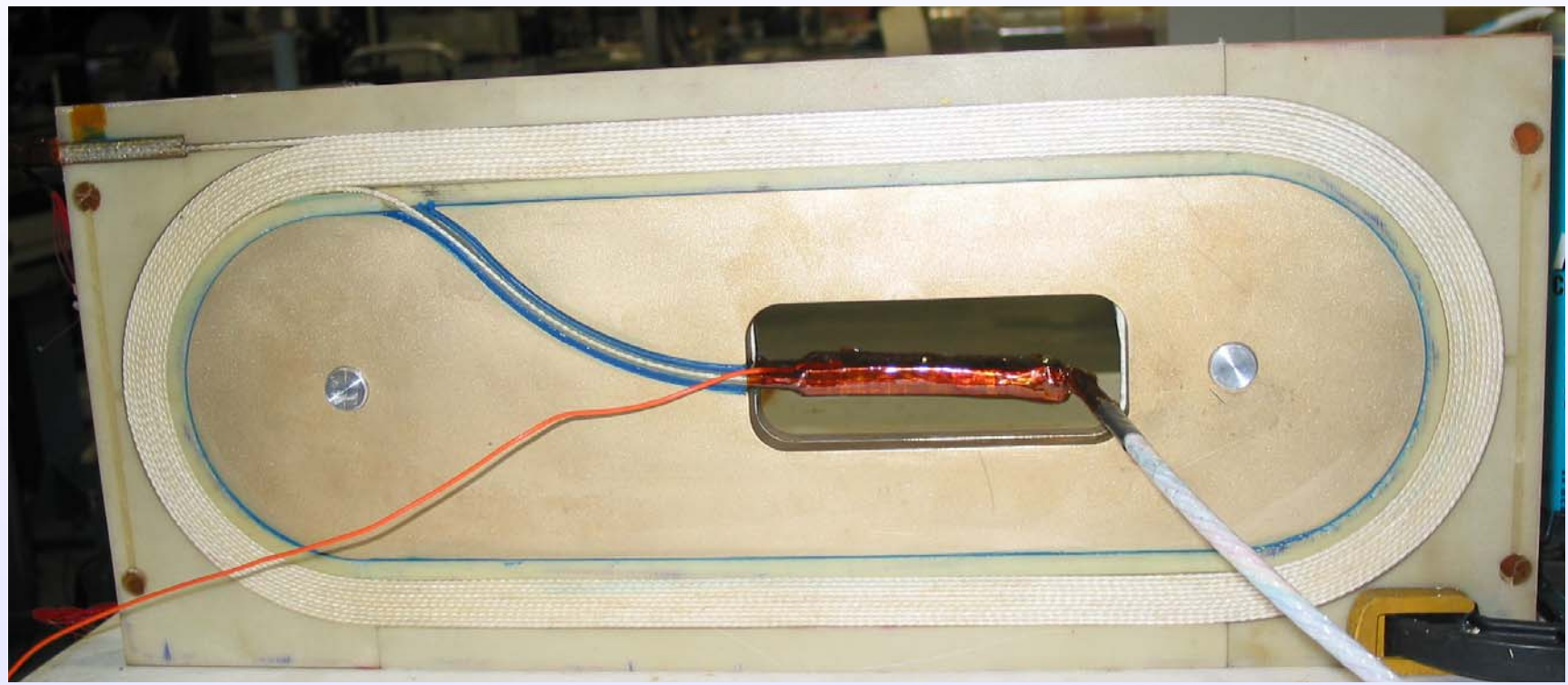
HTS Cables Tested at BNL Short Sample Test Facility



➡ **Modern HTS Cables Carry A Significant Current.**

Significant self-field at high currents.

HTS Coil for Accelerator Magnets

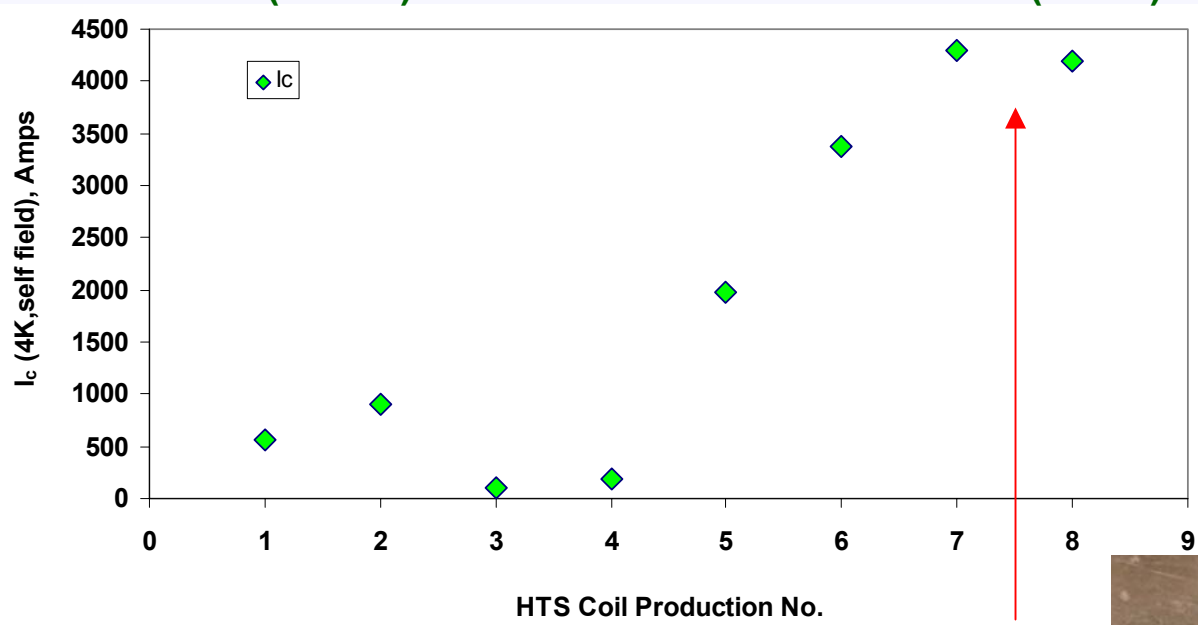


A 10-turn racetrack HTS cable coil built and tested at BNL.

Test Results of HTS Coils in Magnet Support Structure

**Earlier coils
<1 kA (~2001)**

**Latest coils
4.3 kA (10/03)**



**Self-field
<0.05 T**

**Self-field
~ 1.85 T**

Note:
HTS cables now carry significant currents in magnet coils.



Two structures



Summary

- HTS technology has made a significant progress over time.
- HTS leads are now widely used. It appears that HTS is ready to be used in accelerator magnets. It is desirable in certain applications for potential savings in operating cost and/or for high performance.
- HTS magnets can operate at a much higher temperature (20-40 K, possibly much higher with second generation HTS from ASC).
- HTS can tolerate an order of magnitude higher temperature variations during operation.

BNL is the leading accelerator laboratory in developing HTS magnet technology. We are excited in joining NSLS to explore the feasibility of using HTS in NSLS II magnets. Magnet Division is in a unique position to support NSLS and to do necessary R&D in developing HTS magnets.