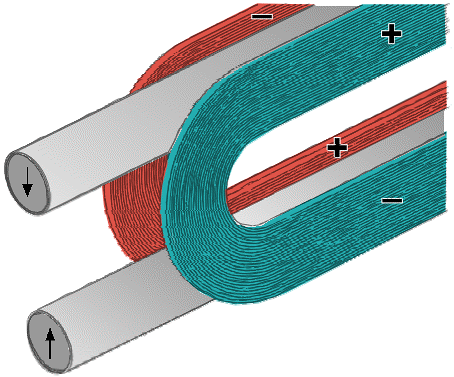

# HTS Magnet R&D Activity at BNL

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# Overview of the Presentation

- Why HTS in Accelerator Magnets?

  Note: HTS leads are already being used in accelerator magnets (Fermilab and CERN); Let’s continue the march!

- 🕒 Why Start HTS Magnet R&D Now?

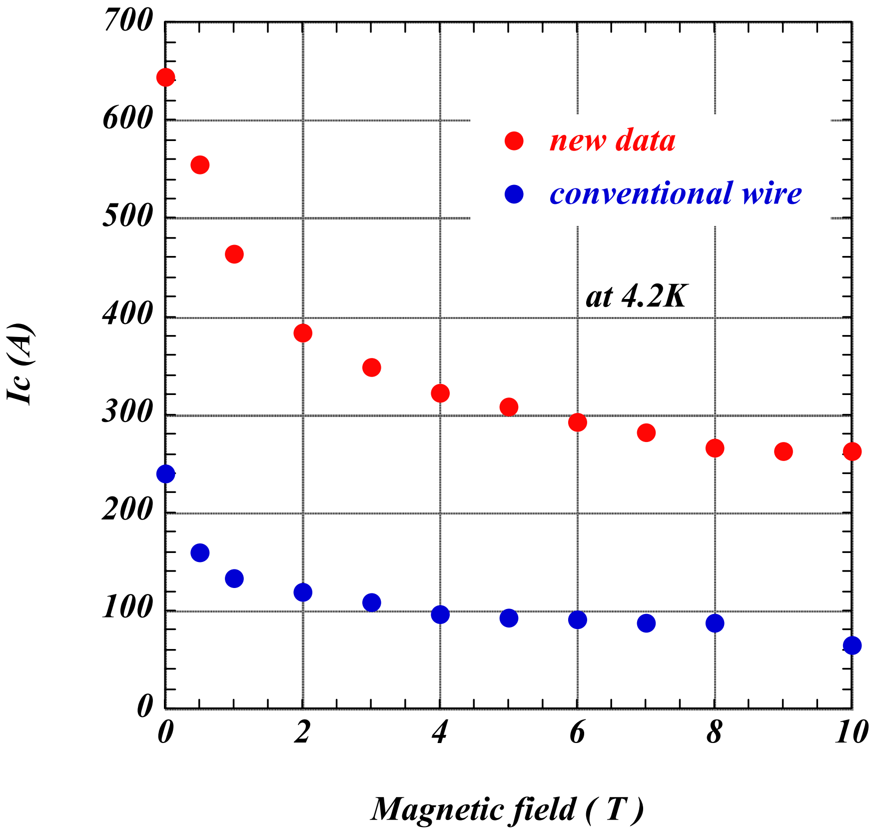
- Test Results of HTS Technology Magnets

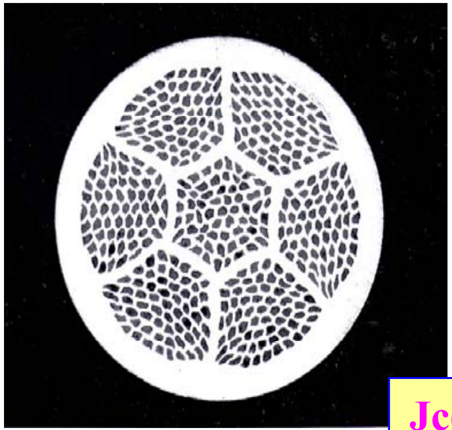
- The Next Step and the Summary

# BSCCO Wire (Year 2000)

*Ic-B characteristics of new wire*

## Showa Electric





**Jc(12T,4.2K)**
**~2000 A/mm$^2$**

$I_c$ (4.2K 0T) : 640A
$J_c$ (4.2K 0T) : 490kA/cm$^2$
Size : 0.81mm$^d$
Number of filament : 427
Material of outer sheath
: Ag alloy
Material of inner sheath : Ag
Ag/SC ratio : 3.0
Tensile strength (R.T.)
: 120MPa

T. Hasegawa, “HTS Conductor for Magnets”, MT-17, Geneva.

20/05/00

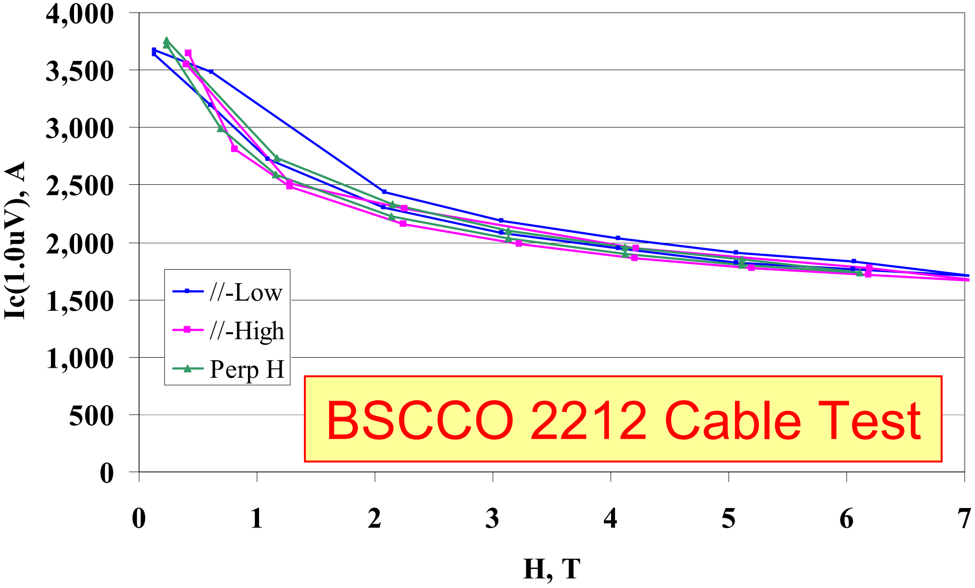
# Measured Performance of HTS Cable and Tape As A Function of Field at BNL

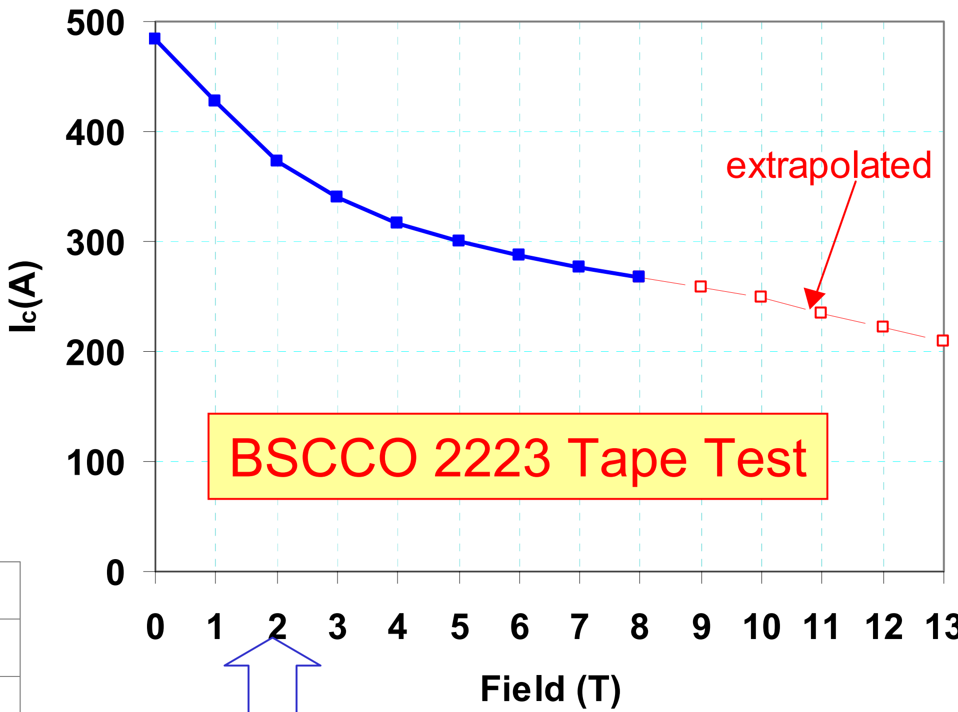
Measurements of "***BSCCO-2212 cable***" (Showa/LBL/BNL) at BNL test facility

Reported Ic in new wires is ~ 3x better than measured in the cable.

This was a narrow (18 strand) cable. Wider cable with new conductor should be able to carry 5-10 kA current at high fields!

(self field correction is applied)

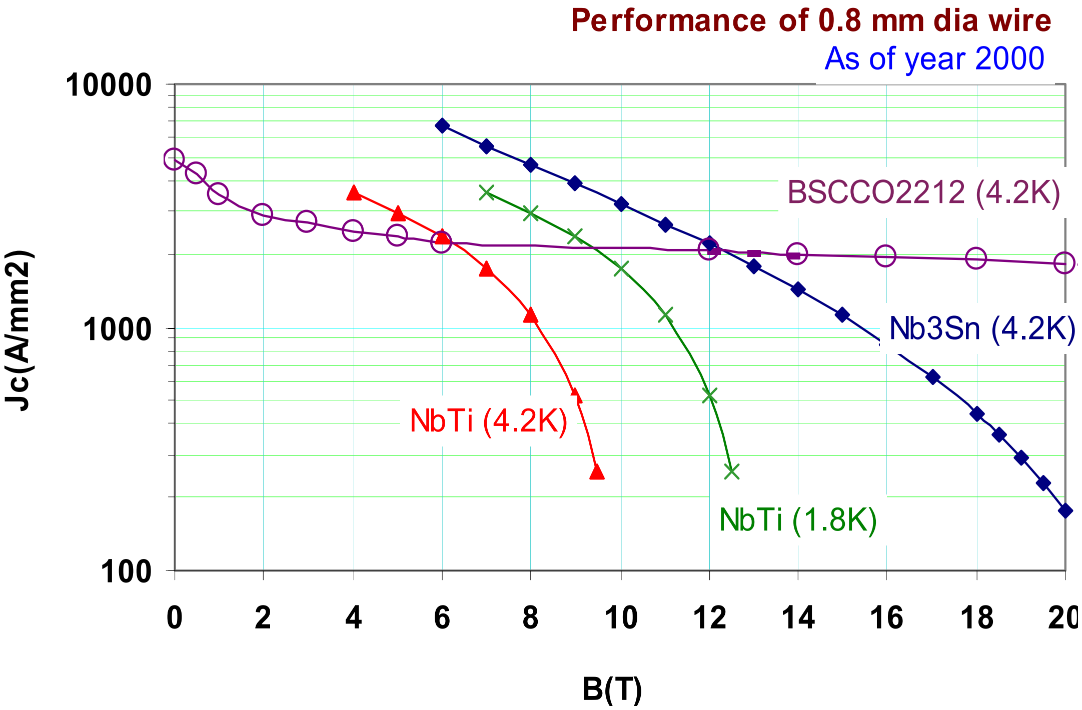




Measurements of "***BSCCO 2223 tape***" wound at 57 mm diameter with applied field parallel (1μV/cm criterion)

(field perpendicular value is ~60%)

# Expected Performance of HTS-based Magnets



(performance in ~100 meter or longer lengths)

**Year 2000 data for $J_c$ at 12 T, 4.2 K**

$Nb_3Sn$: 2200 A/mm$^2$

BSCCO-2212: 2000 A/mm$^2$

**Near future assumptions for $J_c$ at 12 T, 4.2 K**

$Nb_3Sn$: 3000 A/mm$^2$ (DOE Goal)

BSCCO-2212: 4000 A/mm$^2$ (2X today)

Expected performance of all $Nb_3Sn$ or all HTS magnets at 4.2 K for the same amount of superconductor:

| Year 2000 Data | |
|---|---|
| All $Nb_3Sn$ | All HTS |
| 12 T | 5 T |
| 15 T | 13 T |
| 18 T | 19 T* |

*20 T for Hybrid

| Near Future | |
|---|---|
| All $Nb_3Sn$ | All HTS |
| 12 T | 11 T |
| 15 T | 16 T |
| 18 T | 22 T |

Cu(Ag)/SC Ratio

BSCCO: 3:1 (all cases)

$Nb_3Sn$: 1:1 or $J_{cu}$=1500 A/mm$^2$

# Advantages of using HTS in Accelerator Magnets

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

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

Translate this to magnet design and accelerator operation:

- HTS has a potential to produce very high field magnets
- HTS based magnets can work at elevated temperatures
  - a rise in temperature from, e.g., decay particles can be tolerated
  - the operating temperature does not have to be controlled precisely

- HTS based magnets don't appear to quench in the normal sense
- Weak spots don't limit the magnet performance, instead the local temperature rises a bit (major difference from LTS magnets).

It becomes a question of heat load rather than a weak spot limiting the performance of the entire magnet

# Status of BSCCO 2212 Program

We (mostly Showa) have made a significant progress in BSCCO 2212 wire performance in last few years

- Note: as compared to BSCCO 2223 investment has been much less: that implies that there is still a significant room for improvement

Still, Results have been quiet impressive!

- $J_c$ is almost there ($J_c$ : > 2000 A/mm2 at 10-20+ T)
  - need an improvement of ~a factor of two; better if four
  - “n” within a factor of 2-4; “n” and Jc improve together
- Long wire lengths available (BNL purchase from Showa: ~1.5 km long)
- Cable has been manufactured (LBL: ~100 m long)
- BNL has made test coils that show only a small degradation

# HTS and HEP

In the present situation, it appears that the progress in HTS will be driven by communities other than High Energy Physics (HEP).

The most we can do is to give small but important support to industries to encourage a few small experiments that are critical to accelerator magnets and to keep the kind of product that matters to us viable (in U.S.).

In parallel, we learn how to use HTS technology in accelerators

- Magnet designs for HTS
- Experimental coil development and test in background field

But, looking at the progress, overall long term (~5 years) picture looks promising.

# First Likely Application of HTS: Interaction Region (IR) Magnets

Interaction region magnets for the next generation colliders

or luminosity upgrade of existing/proposed colliders

can benefit a lot from:

- ▣ the ability to produce very high fields
- ▣ the ability to deal with large energy deposition
- ▣ the ability to operate at elevated temperatures that need not be uniform

→ For IR magnets, the performance, not the material cost is the issue.

→ These magnets can be, and perhaps should be, replaced in a few years

(for LHC, the first installment may be due ~10 years from now)

*All of above makes HTS a natural choice for next generation IR magnet R&D.*

# Why Start HTS Magnet R&D Now?

Performance has become enough to do credible magnet R&D

Standard size cable can carry ~10 kA at high fields (10-20 T)

Hybrid magnets can create $15^{+}$T

It takes long time to do magnet R&D even with known NbTi technology

- Allow, at least five years for this new and challenging R&D
- Address magnet technology issues (allow new ideas to be tested)
- Address issues related to field quality, etc.

In the meantime HTS performance should improve by a factor of 2-4

With both done in parallel, we can make an informed decision in ~5 years

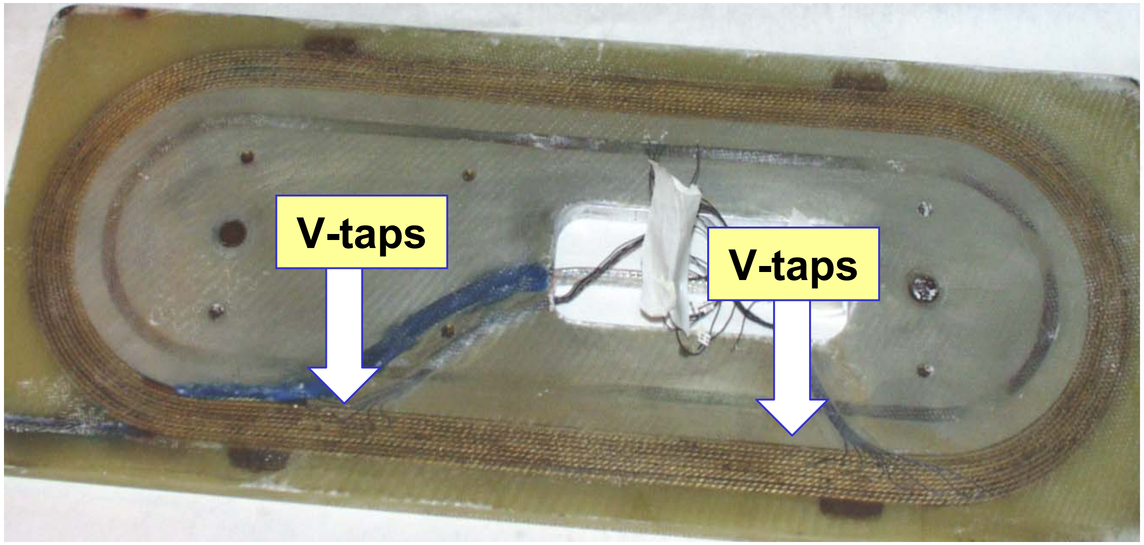
To do that, the right time to start HTS magnet R&D is <u>NOW</u>!

# Magnet DCC002: 1st HTS Dipole/Quad

Given the aggressive and R&D learning nature of the program we instrument the magnet, as much as we can.

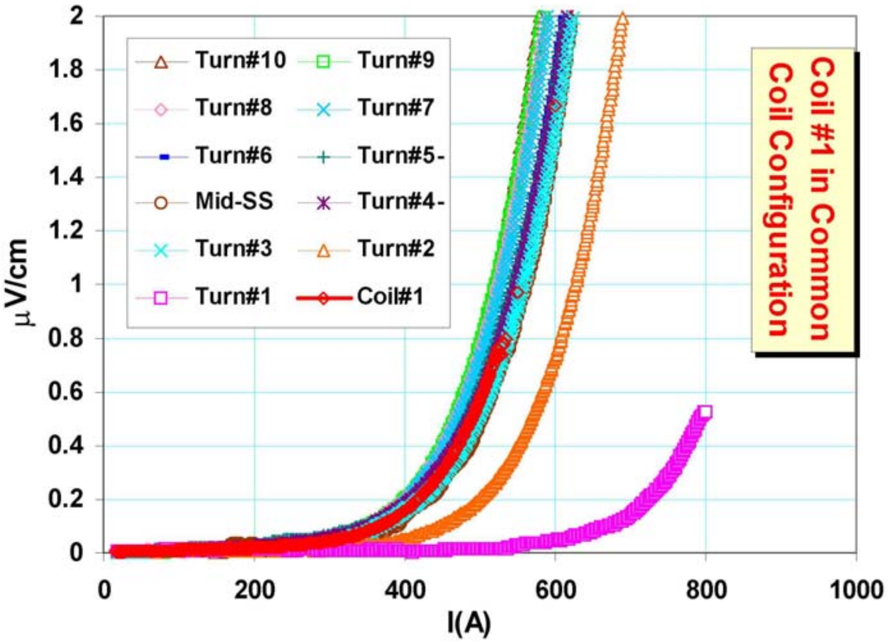
We put at least one voltage tap on each turn

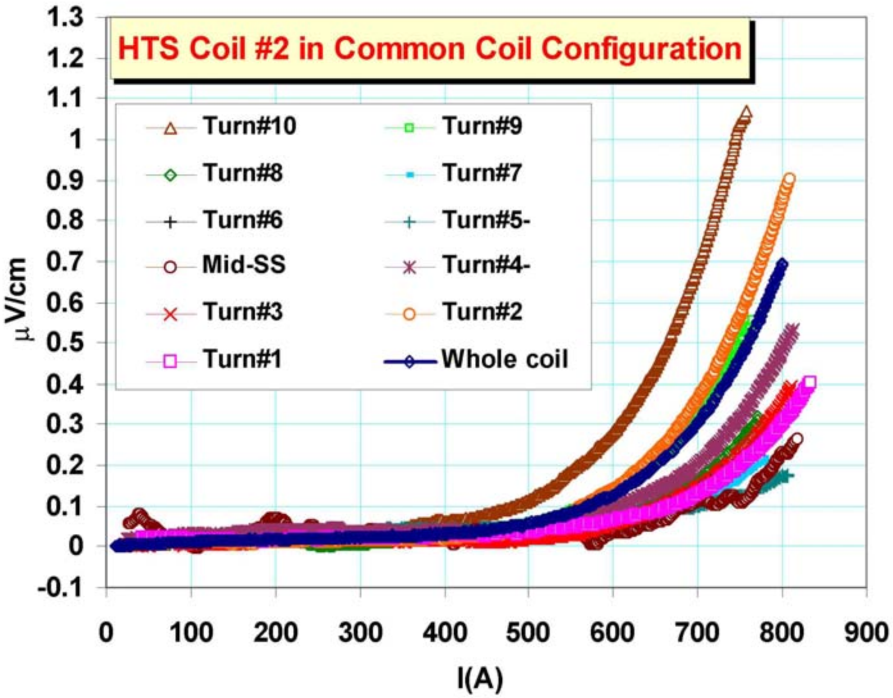
Coils are assembled for a flexible and extensive testing. Four leads are taken out of the cryostat.



# Magnet DCC002: 1st HTS Dipole/Quad

Voltage difference between each consecutive turn and on each coil at 4.2 K





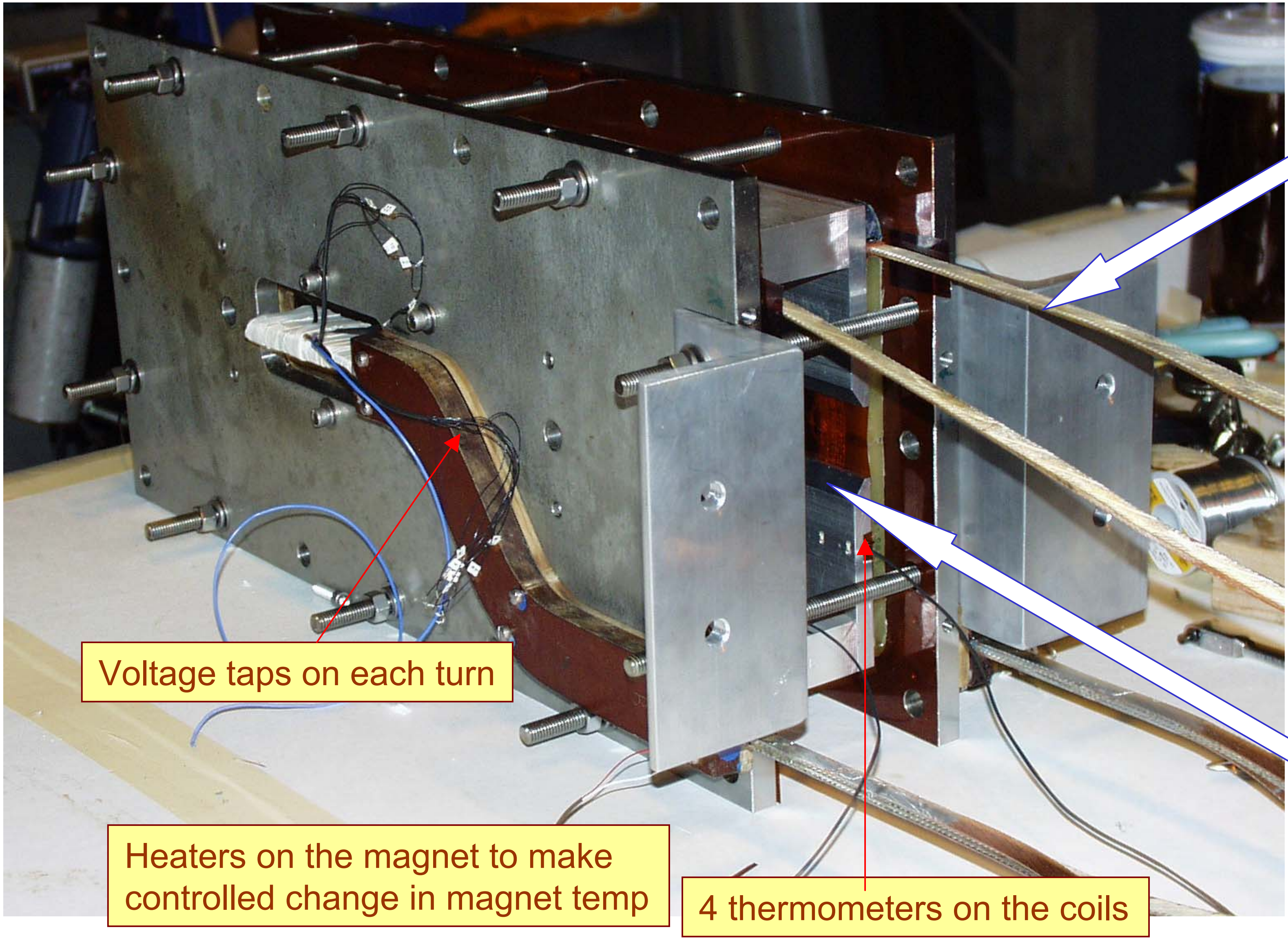
This test magnet was made with cable from early wire

The state-of-the-art wire is now about a factor of five better

# Magnet DCC006: 2nd HTS Dipole

(Magnet No. 6 in the common coil cable magnet series)

A versatile structure to test single or double coils in various configurations



Voltage taps on each turn

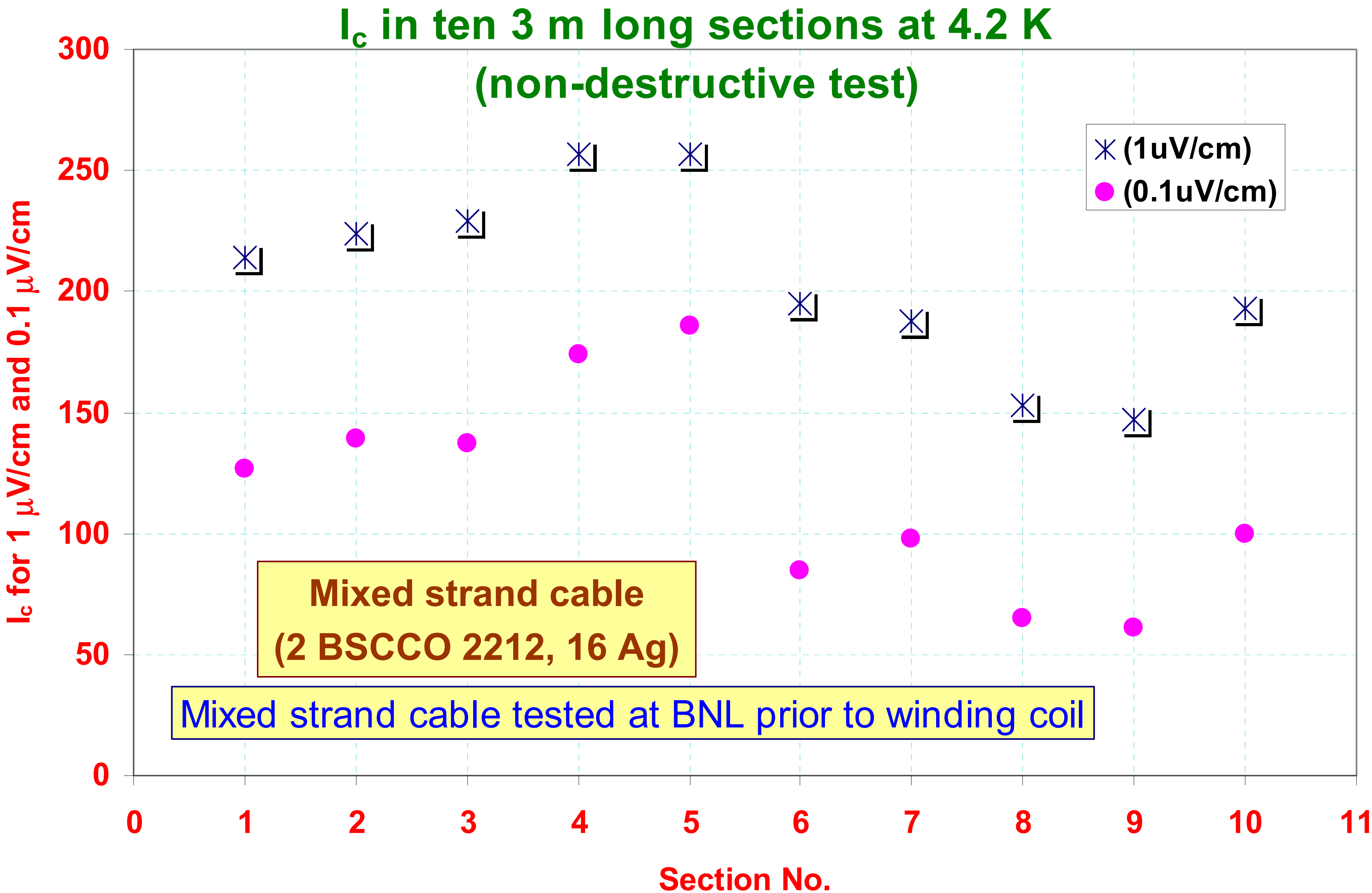
Heaters on the magnet to make controlled change in magnet temp

4 thermometers on the coils

HTS Cable Leads to make high temp measurements

74 mm aperture to measure field quality

# Critical Current in Mixed Strand (2 HTS, 16 Silver) Cable

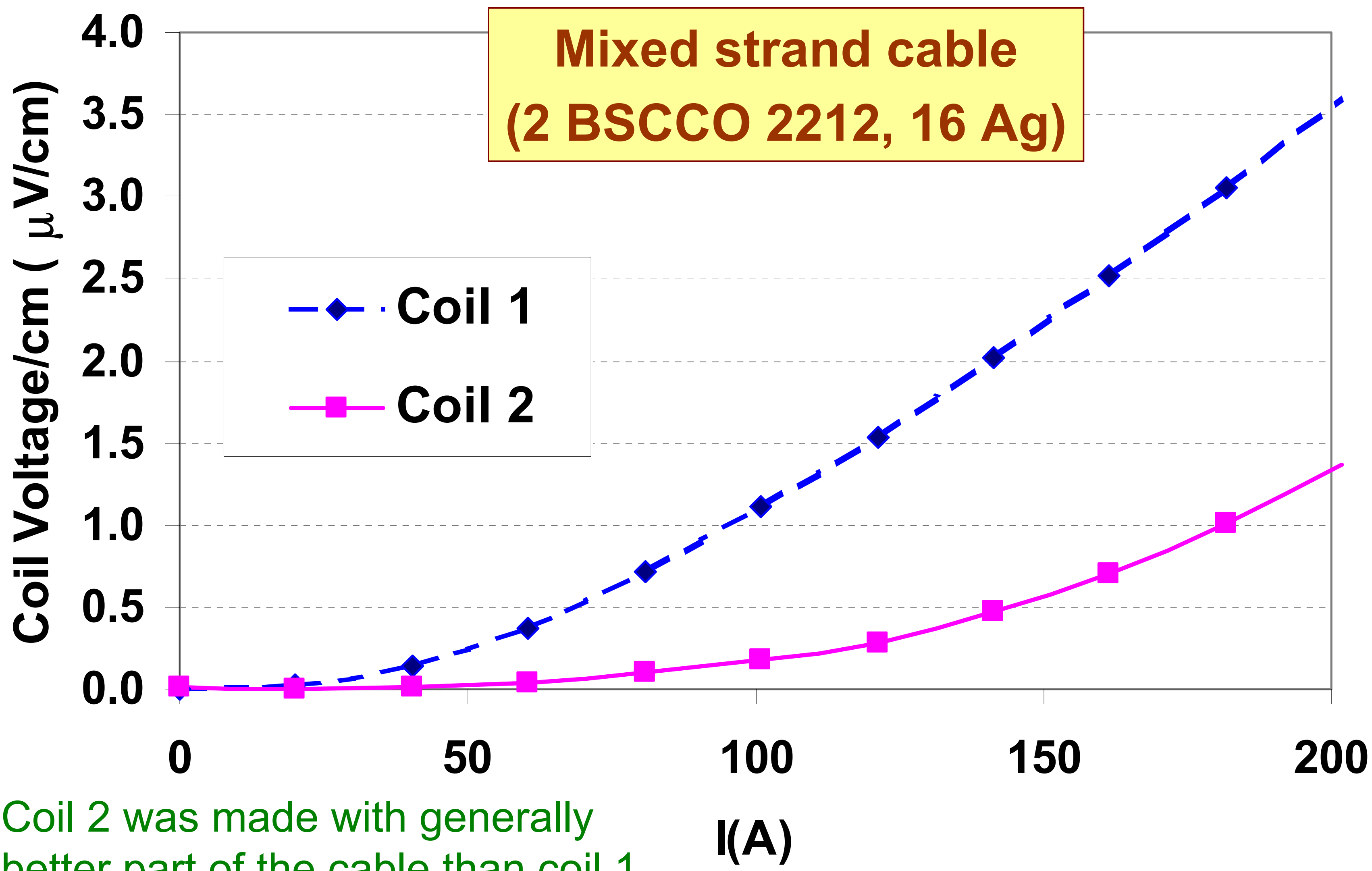


## $I_c$ in ten 3 m long sections at 4.2 K (non-destructive test)

**Mixed strand cable (2 BSCCO 2212, 16 Ag)**

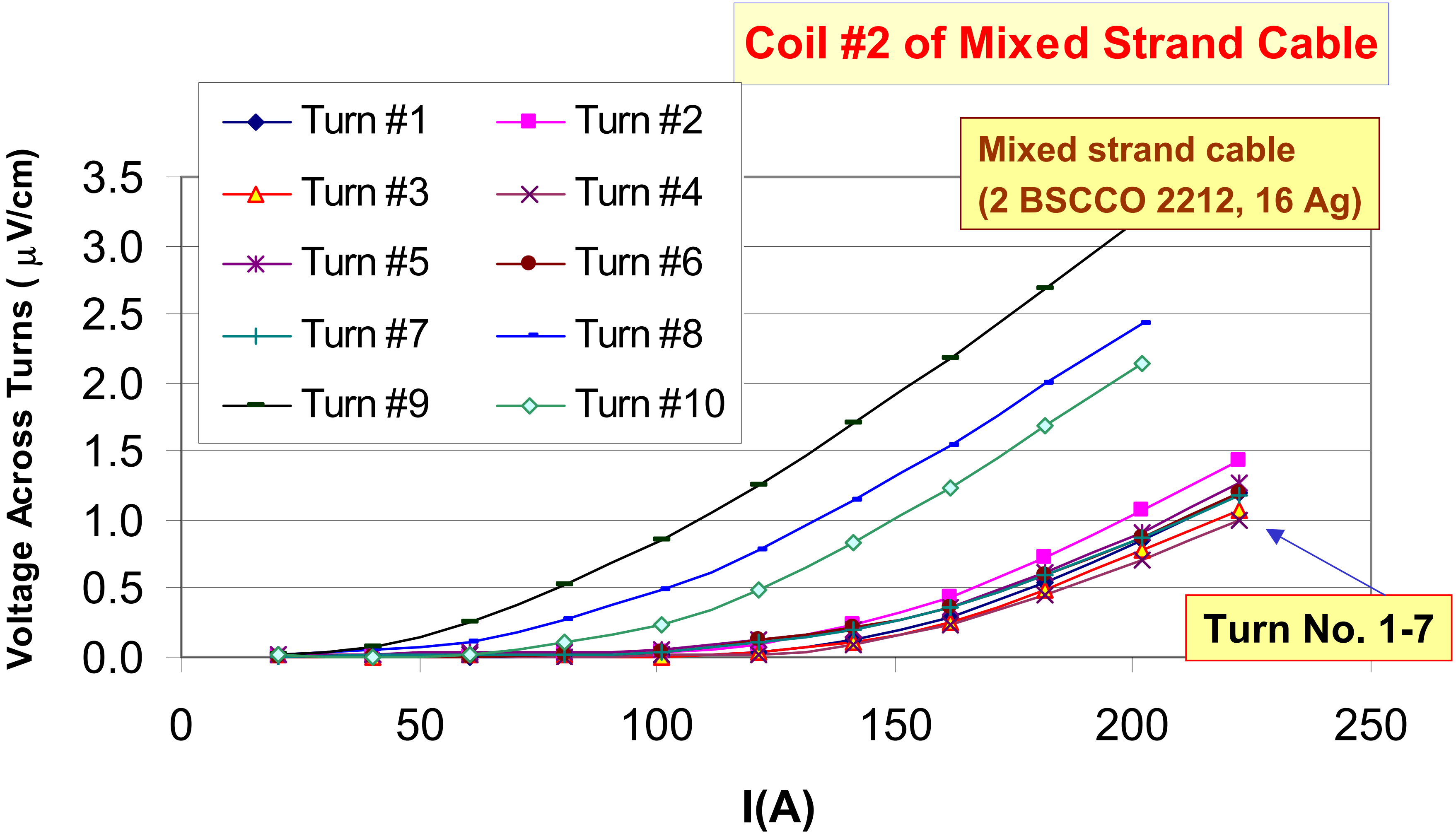
Mixed strand cable tested at BNL prior to winding coil

# Performance of 2 Coils in Muon Collider Dipole Configuration



Coil 2 was made with generally better part of the cable than coil 1

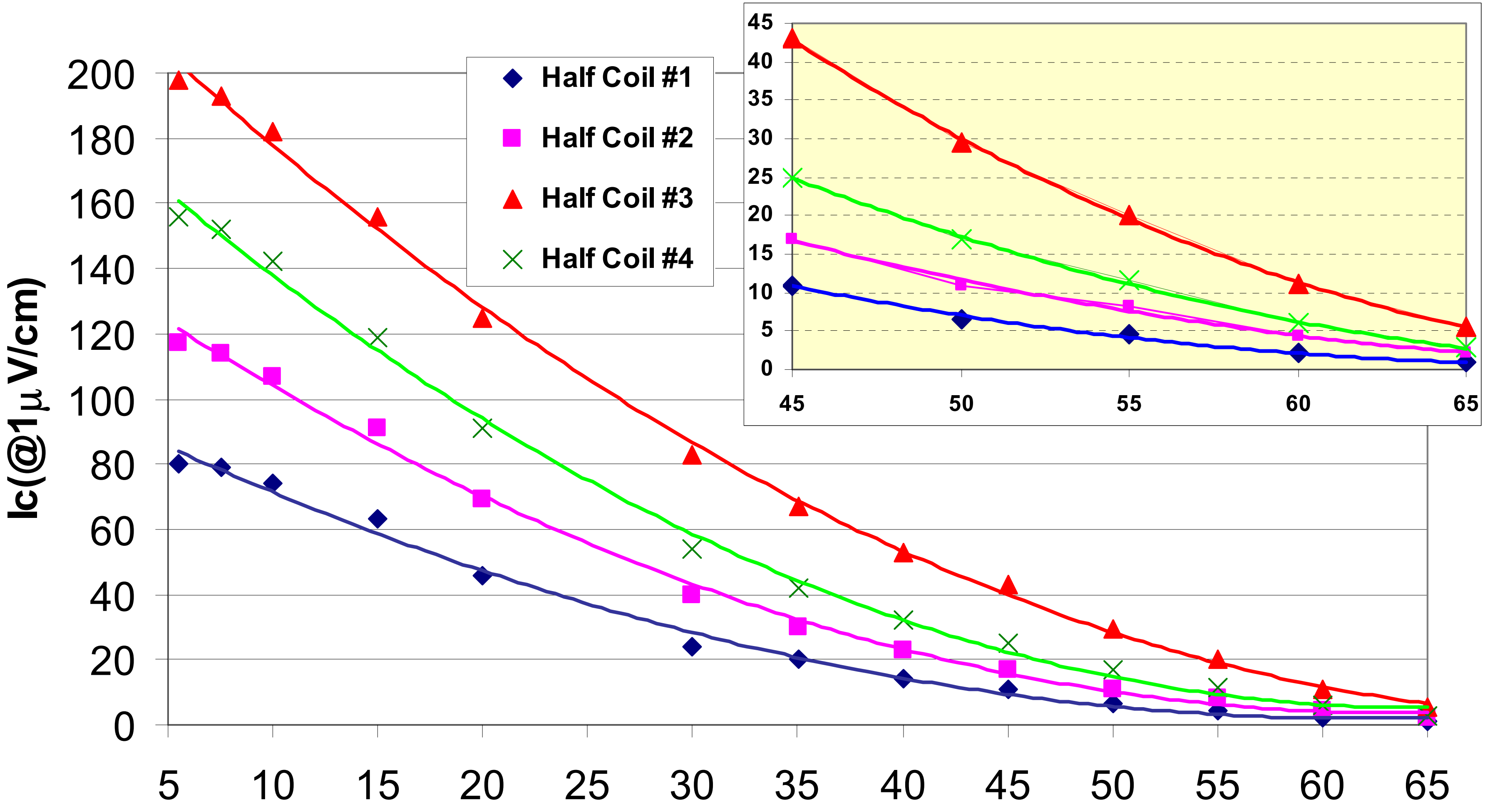
# Measured Ic of Various Turns



**Turns No. 1-7 show an $I_c$ close to the best measured in cable prior to winding.**

♥ This suggest a low level of degradation!

# Measured Critical Current as a Function of Temperature

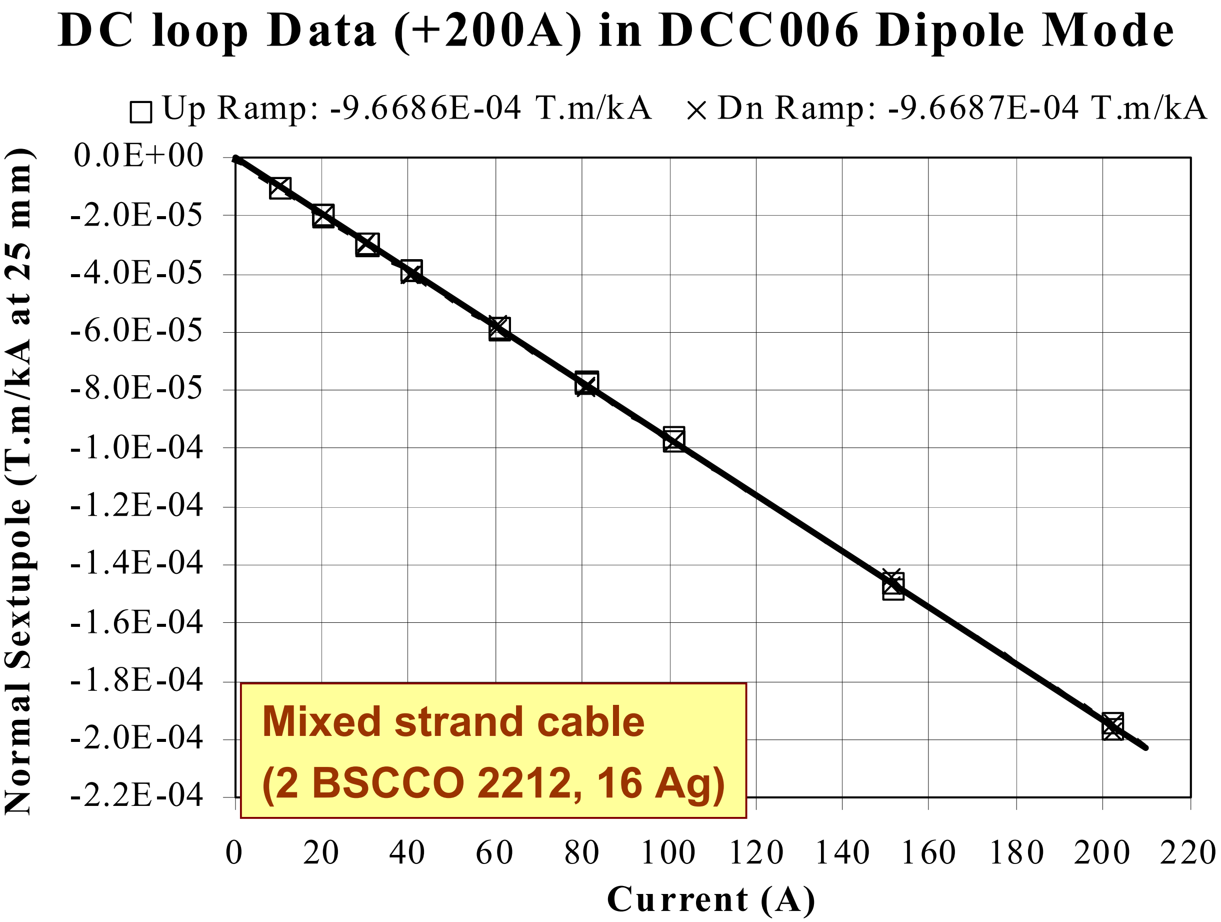


**Mixed strand cable**
**(2 BSCCO 2212, 16 Ag)**

**4 coil halves**
**(2 each of two coils)**

# Field Quality Measurements

**Sextupole Harmonic**



**Mixed strand cable**
**(2 BSCCO 2212, 16 Ag)**

Difference between up and down ramp values is within measurement errors.

Max field on conductor was only ~550 Gauss. Expect a relatively less measurement when the total current is high in an all HTS cable.

# Near Term R&D Program at BNL

- Build a series of 10 turn coils with better HTS cable
- Build ~40 turn coils after the technology is reasonably developed
- In parallel build ~12 T magnet with $Nb_3Sn$ to provide background field
- Assemble hybrid magnet to study issues related to the performance of HTS coils in high field environment
- Study field quality issues related to HTS magnets

Present the results to accelerator community so it can make an informed decision about the viability of HTS in accelerators to take advantage of exciting benefits it offers.

# SUMMARY

- HTS has potential to make a significant impact on IR Design
  - Can generate high fields
  - Can work at elevated temperature
- New “conductor friendly designs” allow HTS “React & Wind” technology to be incorporated in accelerator magnets
- HTS has reached a level that one can do meaningful magnet R&D and address various technical issues
  - The recent test results from Brookhaven are encouraging.
- Time to start HTS magnet R&D is now so that we can make a better informed decision (in ~5 years) about the feasibility of HTS in next project or upgrade of existing one at that time