William (Bill) Sampson's Contributions to HTS Coil and Magnet R&D from Early Days

-Ramesh Gupta

September 4, 2024

ASC SALT LAKE CITY 24
SEPTEMBER 1 – 6
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William Sampson Memorial Session

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William Sampson Memorial Session: Accelerator Magnets from the Beginning

3LOr1E-01: Introduction by Kathleen Amm
9:15am-9:30am Sep 4 (Mountain)

3LOr1E-02: [Invited] The early work of William B. Sampson and the 1968 Summer Study
9:30am-9:45am Sep 4 (Mountain) — Michael Green

3LOr1E-03: [Invited] A Review of HTS Coil and Magnet R&D from Early Days
9:45am-10:00am Sep 4 (Mountain) — Ramesh Gupta

3LOr1E-04: [Invited] Things I learned from Bill Sampson…
10:00am-10:30am Sep 4 (Mountain) — Peter McIntyre

3LOr1E-05: [Invited] Bill Sampson, more than half centuries for superconductivity: a personal recollection
10:30am-10:45am Sep 4 (Mountain) — Lucio Rossi

Content

Personal Recollections of Bill Sampson

- ❖ **My Best Guru**
- ❖ **My Best Friend**
- ❖ **My Best Colleague**

I would share a few memories while highlighting Bill's contributions to the HTS magnet technology and his unique and remarkable way of working

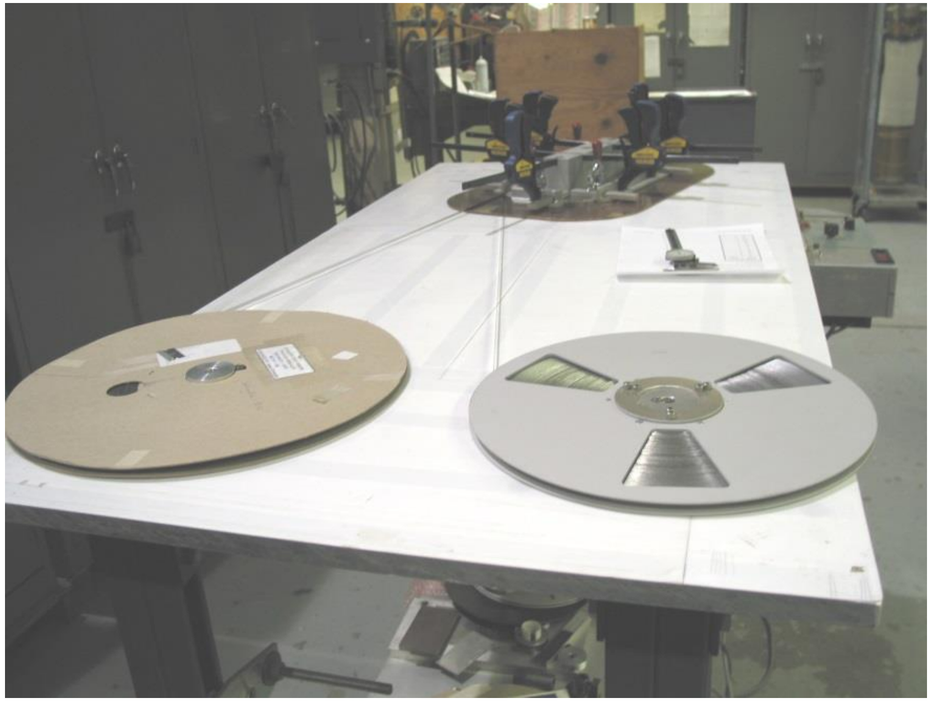
✓ Honor of my life – working with Bill Sampson
Many of non-conventional proposals would have ended up as impractical if not for Bill Sampson

➢ Pushing HTS magnet science from early days
… and continuing it as long as he could do!

Bill Sampson and HTS Magnet R&D (made for each-other)

- Simple coil winding & 77K tests with his basic but highly accurate system
- Fast turn-around and low cost (test results in weeks/months, not years)
- Did as much work as possible by himself (super-tech and super-scientist)
- Scientific approach from the first principle (back to the envelop to PC)
- Special (dis)regard for non-sense oversight (boasted his safety record)

Table-top coil winding



Cryostat made with Styrofoam and Duct-tape

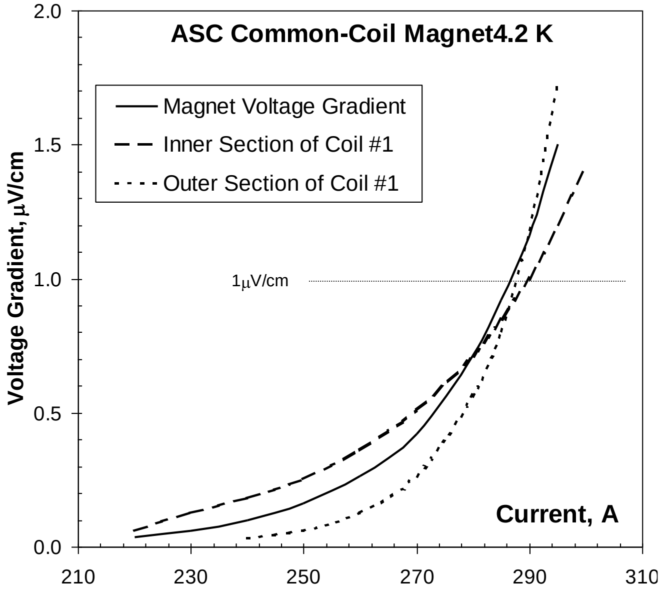
Specific Contributions of Bill Sampson to HTS Magnet Technology (1)

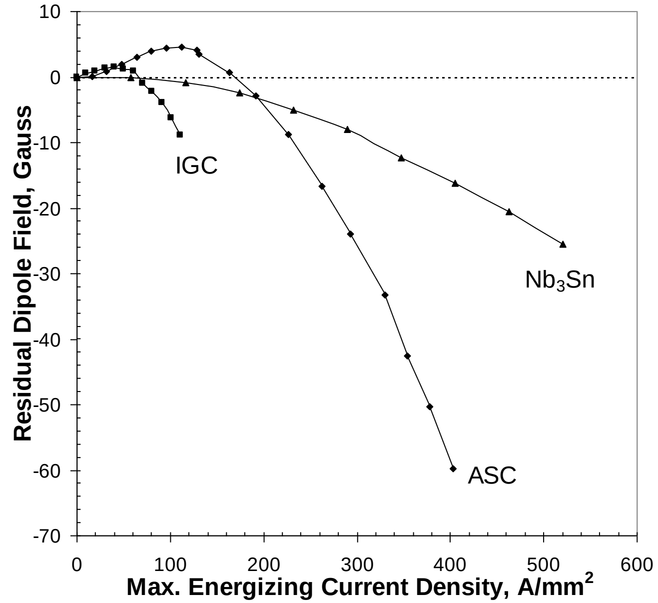
- BNL was the first major national lab (starting in late 90's) to do substantive HTS coil and HTS magnet R&D, thanks to Bill Sampson.
- Bill Sampson made HTS coils in a variety of geometries or configurations: solenoids, dipoles, quadrupoles, racetrack coils, cos θ coils, curve coils, clover-leaves coils, ...
- Even though I was the PI or the person arguing the viability and benefits of HTS, Bill Sampson was the person responsible for demonstrating those HTS coils and magnets, either by directly working on them or by providing the technical guidance.
- It will be an understatement to say that the HTS R&D at BNL would not have been like it was, without Bill. Arup Ghosh, who worked very closely with Bill for a long time (and just as big admirer of Bill Sampson as I am), will vouch for this.

Specific Contributions of Bill Sampson to HTS Magnet Technology (2)

- Bill Sampson always found easy and practical ways of demonstrate the performance of HTS coils over a wide range of temperature.
- He used a variety of HTS (Bi2223, Bi2212, ReBCO, MgB2) in a variety of form (wire, cable, tape). Amount of HTS: over 60 km (4 mm equivalent).
- No. of HTS coils and HTS magnets tested by Bill: well over 150 coils and well over 15 magnets.
- That speaks for quantity & quality of work Bill did in age defying demonstrations.
- Doing science was the passion and life for Bill. He enjoyed it. He will be animated in explaining the basic principles to fellow scientists, technicians, etc…
- Next set of slides will be a rapid tour showcasing some of Bill's contributions. Please get ready to visualize the genius in action...

Start of the R&D: Common Coil Dipole with Tapes(Nb_3Sn, Bi2223)



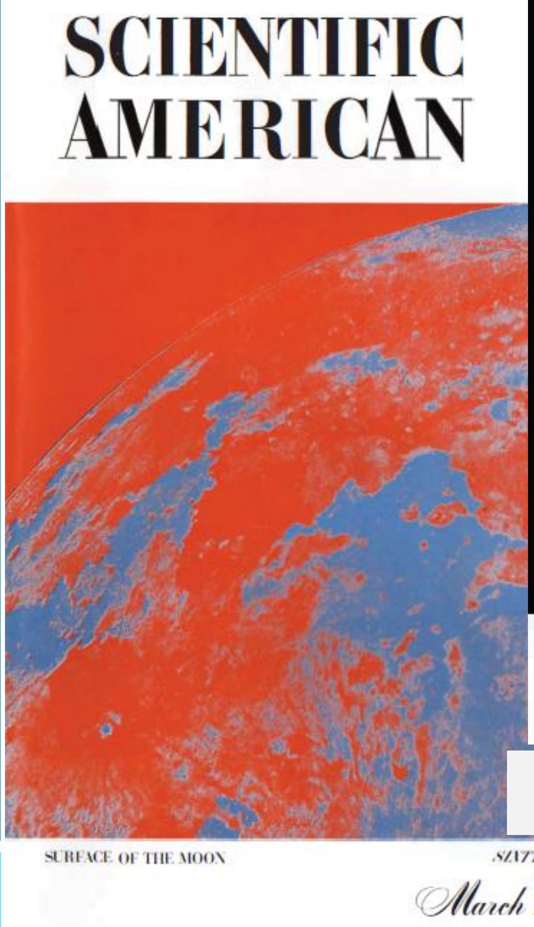


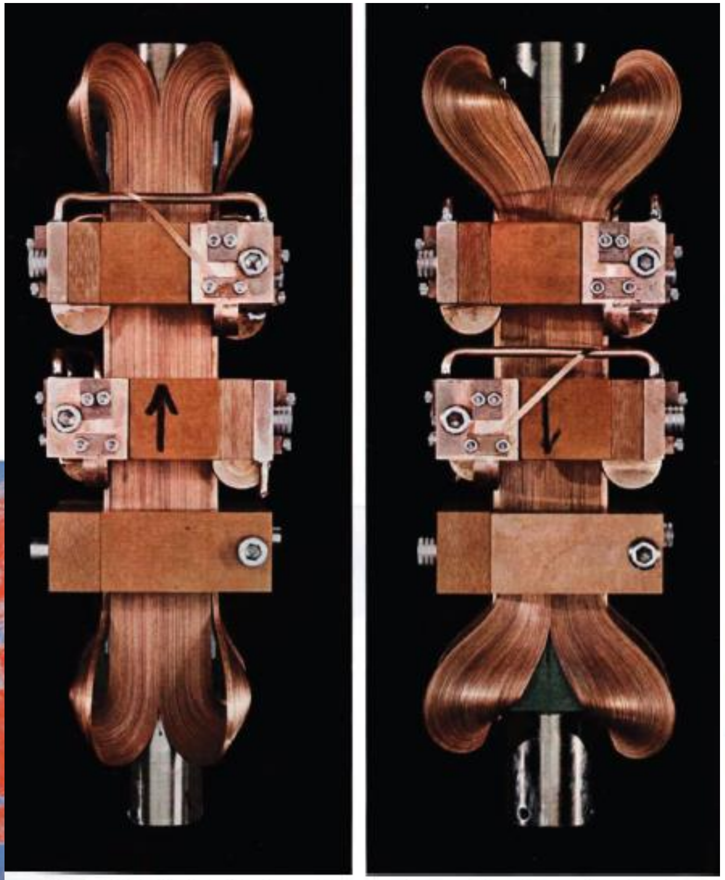
	Size, mm	Turns
Nb_3Sn	0.2 x 3.2	168
IGC	0.25 x 3.3	147
ASC	0.18 x 3.1	221
NST	0.20 x 3.2	220
VAC	0.23 x 3.4	170

Bill had reels of Nb_3Sn Tapes and kept pointing similarities between HTS and Nb_3Sn tape coils

Bill Sampson, the Pioneer & his Pretty Nb_3Sn Tape Magnets

Bill Sampson 1967

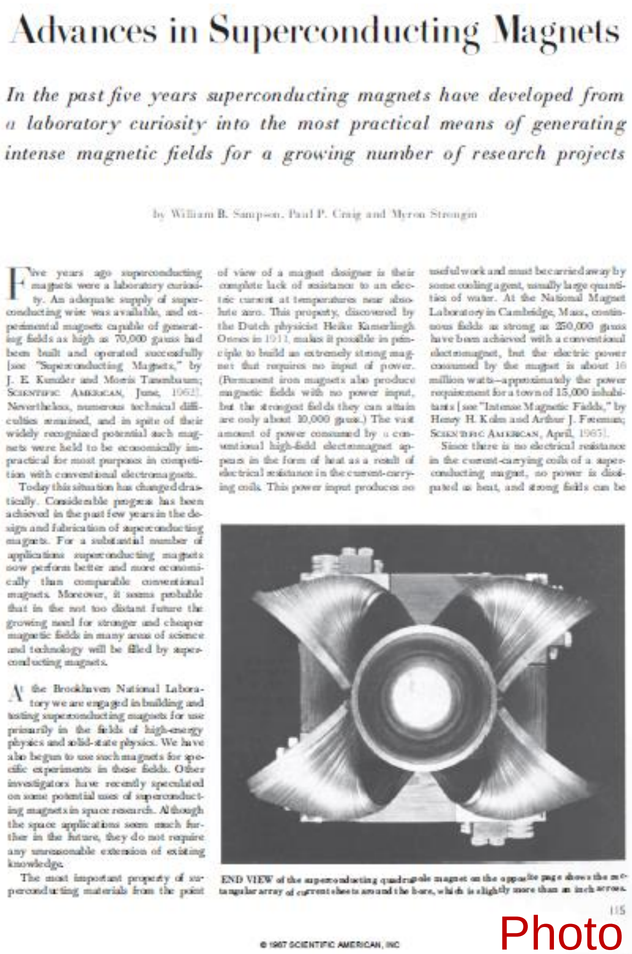




SUPERCONDUCTING MAGNET was designed by one of the authors (Sampson) as a prototype of a class of magnets that will be used to focus the beam of protons from the 33-billion-electron-volt accelerator at the Brookhaven National Laboratory. The device, called a rectangular quadrupole magnet, consists of four mutually perpendicular current sheets made of superconducting niobium-tin ribbon encased in copper. The direction of the current (*pointed black arrows*) is opposite on adjacent sheets, two of which are visible in these two side views. The magnet is shown approximately actual size. When it is in use, it is immersed in liquid helium.

The first no-insulation coil?

Nb_3Sn Tape Quadrupole (still available to touch)



Advances in Superconducting Magnets

In the past five years superconducting magnets have developed from a laboratory curiosity into the most practical means of generating intense magnetic fields for a growing number of research projects

by William B. Sampson, Paul P. Craig and Myron Strongin

Five years ago superconducting magnets were a laboratory curiosity. An adequate supply of superconducting wire was available, and experimental magnets capable of generating fields as high as 70,000 gauss had been built and operated successfully [see "Superconducting Magnets," by J. E. Kunzler and Morris Tanenbaum; SCIENTIFIC AMERICAN, June, 1962]. Nevertheless, numerous technical difficulties remained, and in spite of their widely recognized potential such magnets were held to be economically impractical for most purposes in competition with conventional electromagnets.

Today this situation has changed drastically. Considerable progress has been achieved in the past few years in the design and fabrication of superconducting magnets. For a substantial number of applications superconducting magnets now perform better and more economically than comparable conventional magnets. Moreover, it seems probable that in the not too distant future the growing need for stronger and cheaper magnetic fields in many areas of science and technology will be filled by superconducting magnets.

At the Brookhaven National Laboratory we are engaged in building and testing superconducting magnets for use primarily in the fields of high-energy physics and solid-state physics. We have also begun to use such magnets for specific experiments in these fields. Other investigators have recently speculated on some potential uses of superconducting magnets in space research. Although the space applications seem much further in the future, they do not require any unreasonable extension of existing knowledge.

The most important property of superconducting materials from the point of view of a magnet designer is their complete lack of resistance to an electric current at temperatures near absolute zero. This property, discovered by the Dutch physicist Heike Kamerlingh Onnes in 1911, makes it possible in principle to build an extremely strong magnet that requires no input of power. (Permanent iron magnets also produce magnetic fields with no power input, but the strongest fields they can attain are only about 10,000 gauss.) The vast amount of power consumed by a conventional high-field electromagnet appears in the form of heat as a result of electrical resistance in the current-carrying coils. This power input produces no useful work and must be carried away by some cooling agent, usually large quantities of water. At the National Magnet Laboratory in Cambridge, Mass., continuous fields as strong as 250,000 gauss have been achieved with a conventional electromagnet, but the electric power consumed by the magnet is about 16 million watts—approximately the power requirement for a town of 15,000 inhabitants [see "Intense Magnetic Fields," by Henry H. Kolm and Arthur J. Freeman; SCIENTIFIC AMERICAN, April, 1965].

Since there is no electrical resistance in the current-carrying coils of a superconducting magnet, no power is dissipated as heat, and strong fields can be

END VIEW of the superconducting quadrupole magnet on the opposite page shows the rectangular array of current sheets around the bore, which is slightly more than an inch across.

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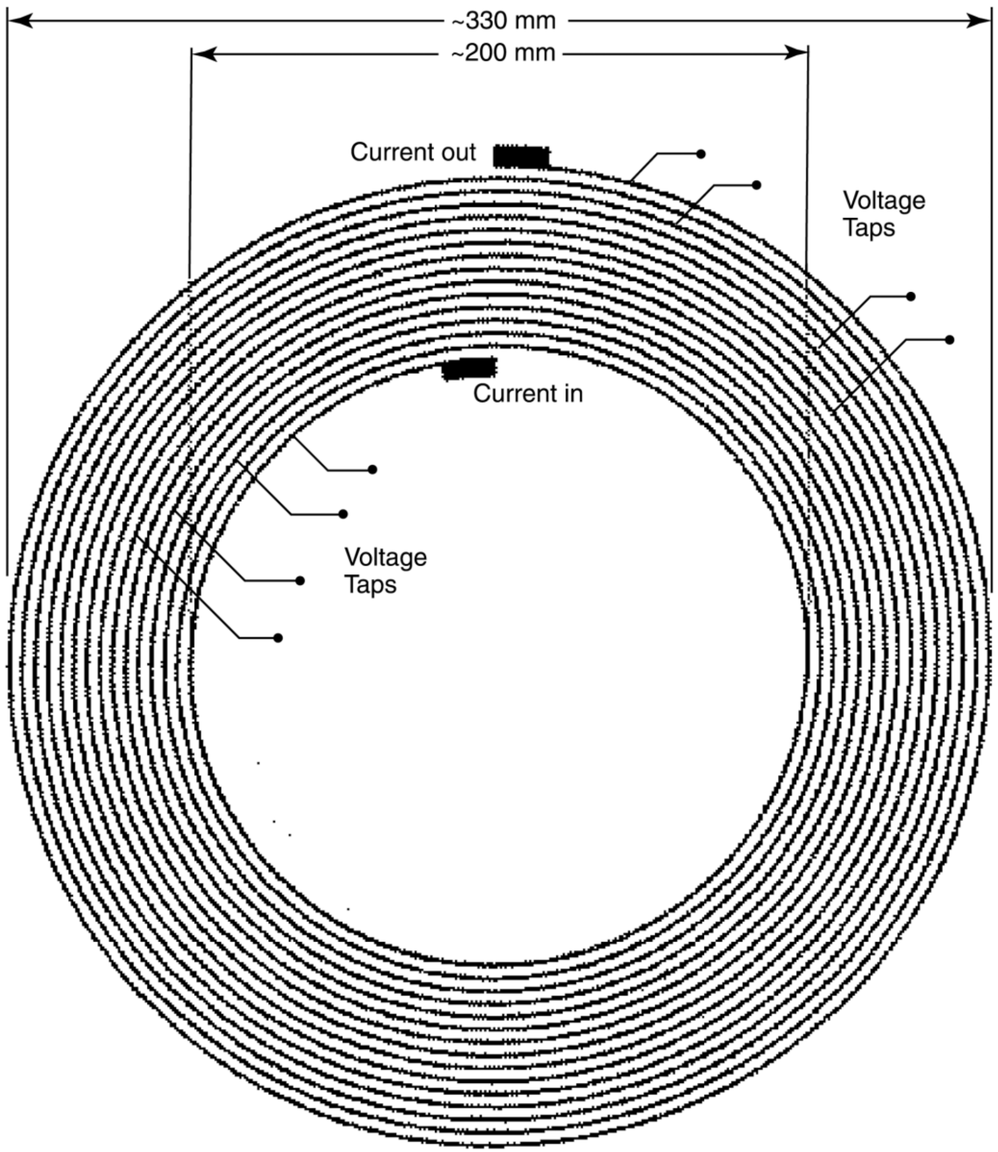
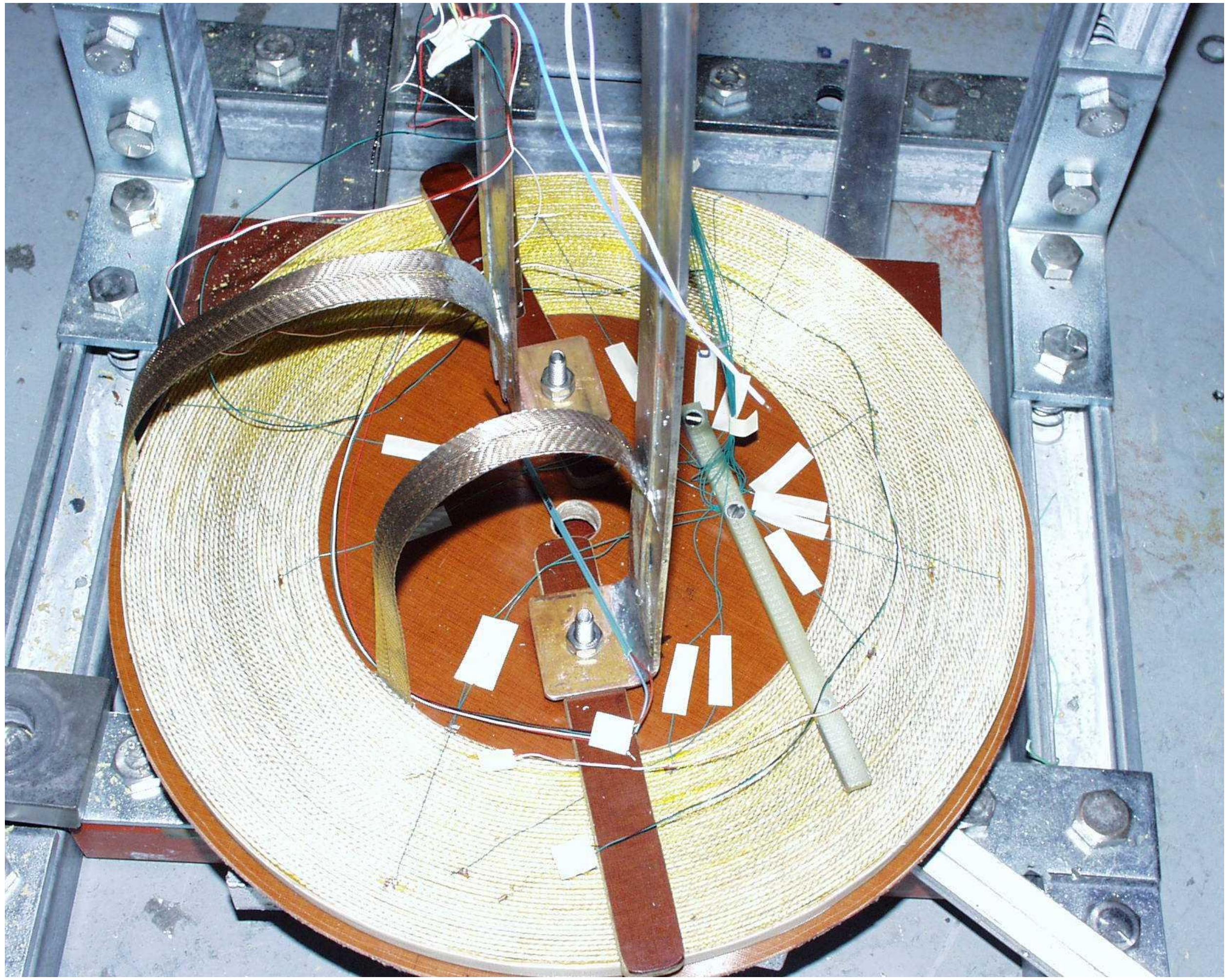
Photo Courtesy David Larbalestier
March 2023

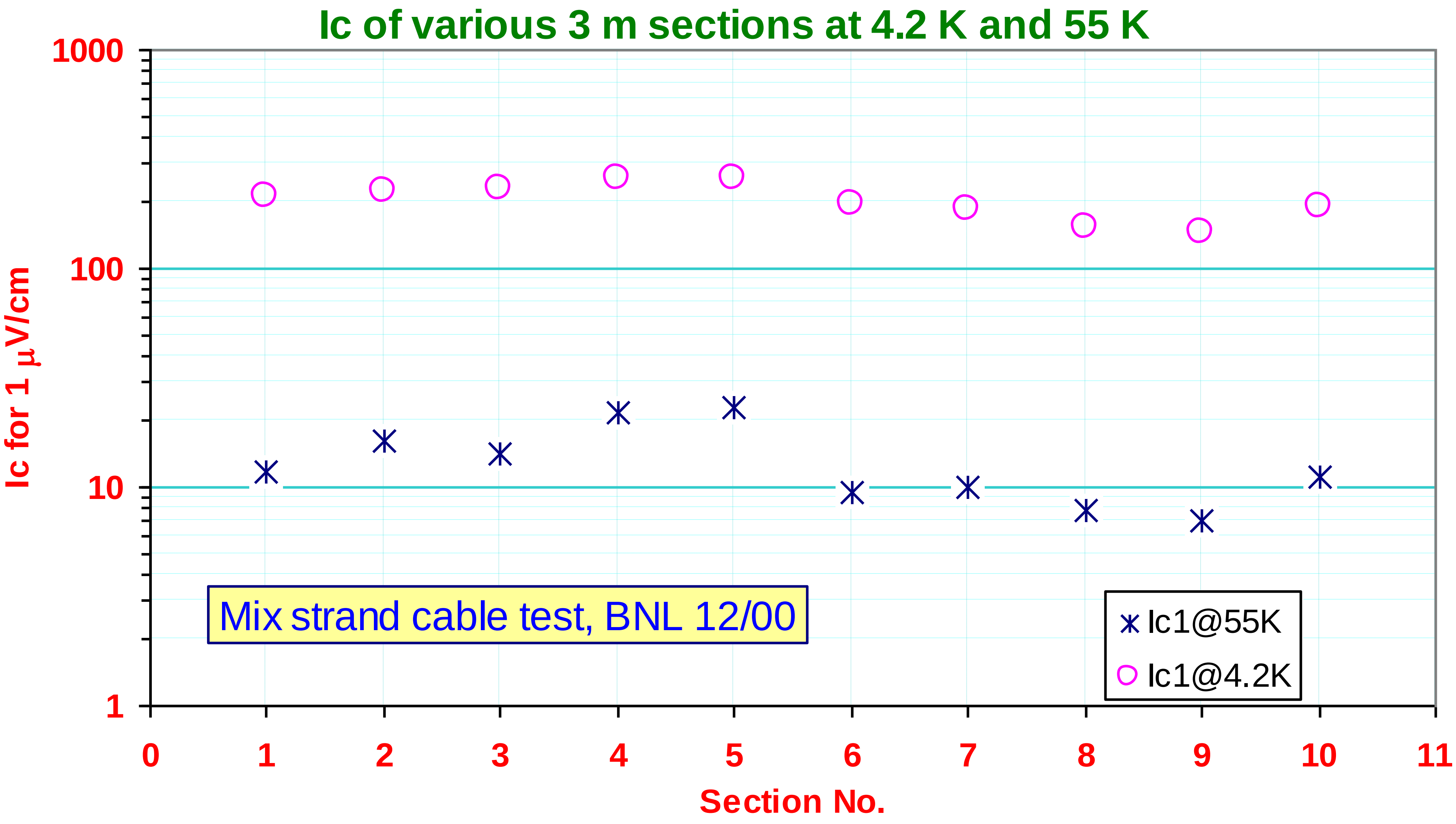
Bill Sampson Enters BSCCO-2212 Cable Era (Pre-reacted cable)





Pre-reacted Bi2212 cable, re-wound for testing
A typical Bill's approach with penalty of v-taps

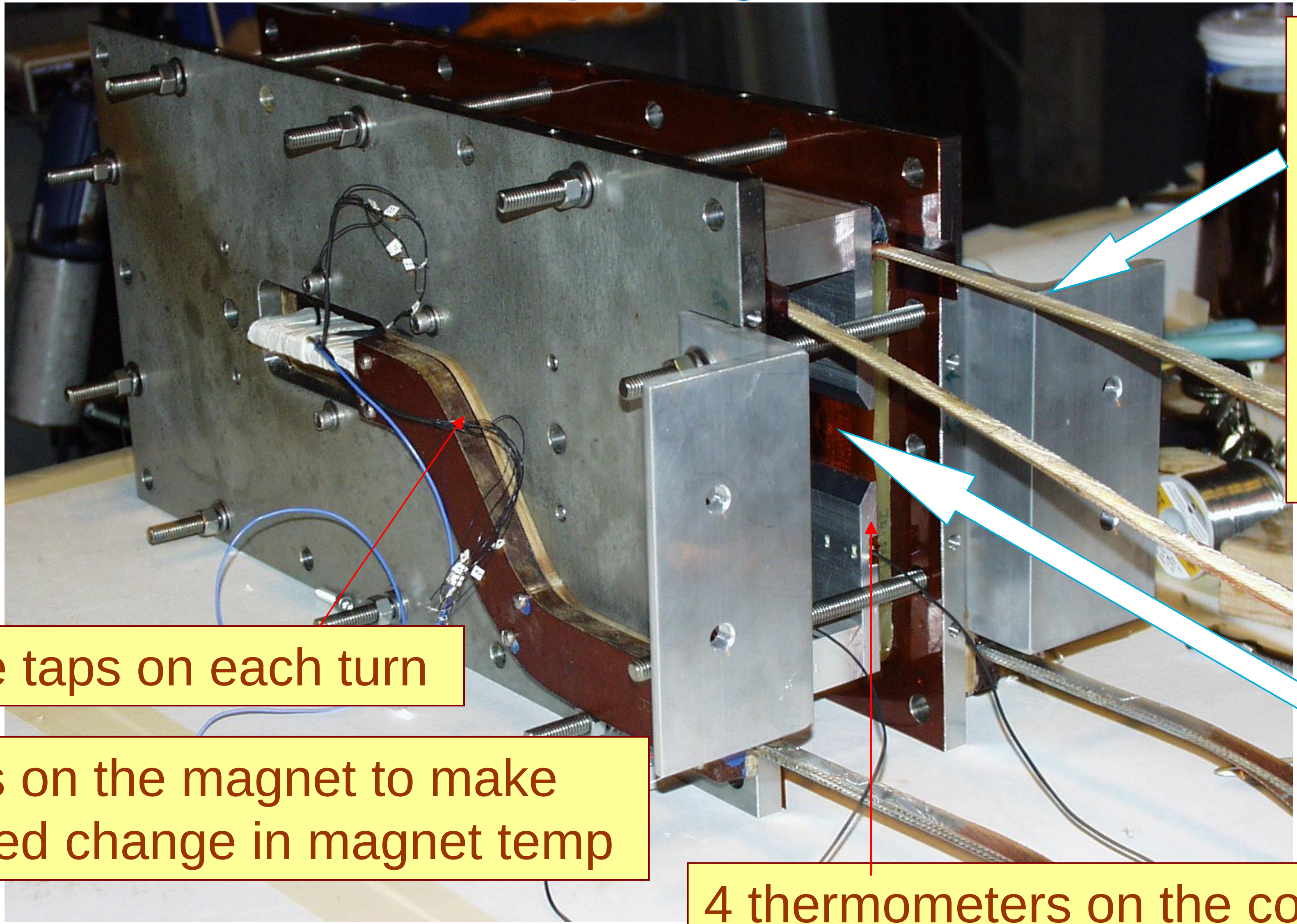
Critical Current Tracking of Bi2212 Cable between 4.2 K and 55 K



55 K with pumped nitrogen - one of Bill's signature setup

Magnet DCC006: The 2nd HTS Dipole at BNL (a lot of HTS magnet R&D at BNL in early stages, thanks to Bill Sampson)

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



HTS Cable Leads to make high temp measurements

74 mm aperture to measure field quality

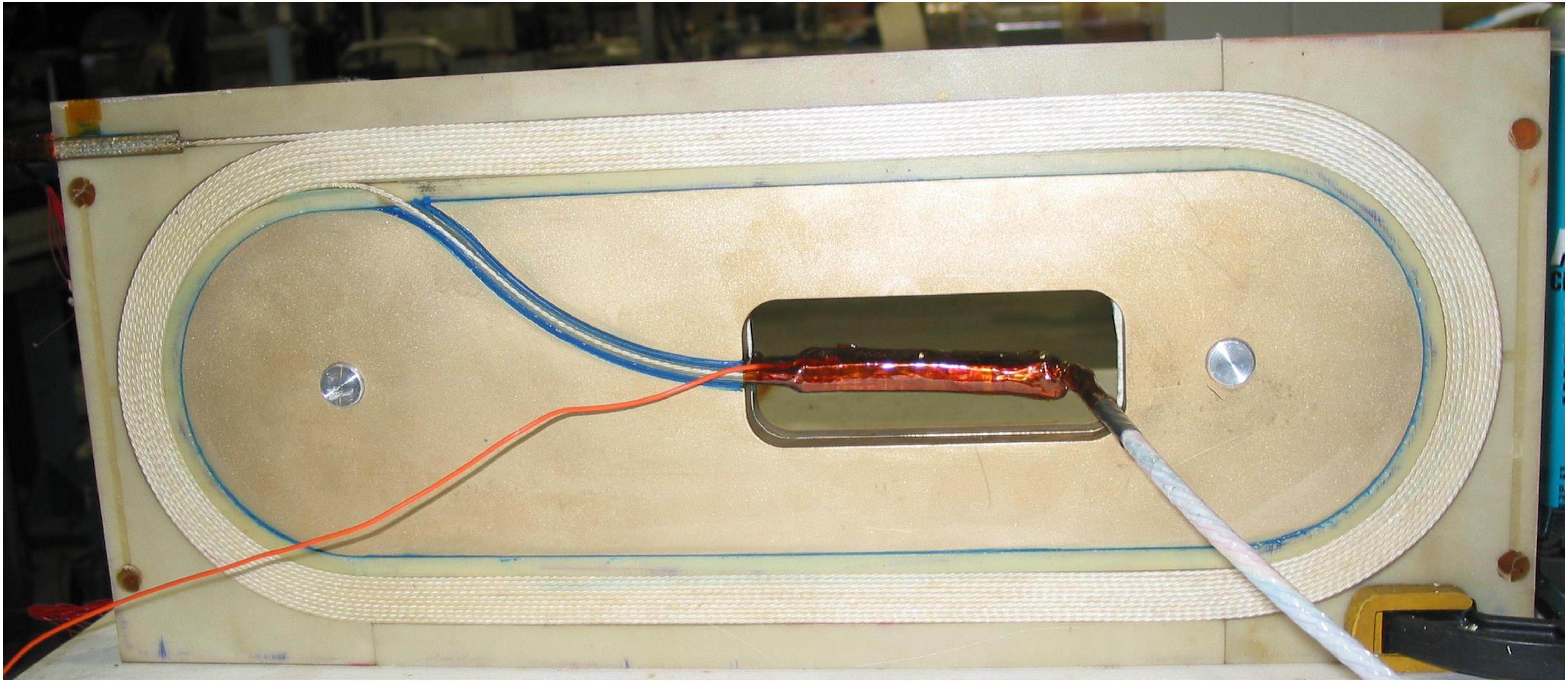
Voltage taps on each turn

Heaters on the magnet to make controlled change in magnet temp

4 thermometers on the coils

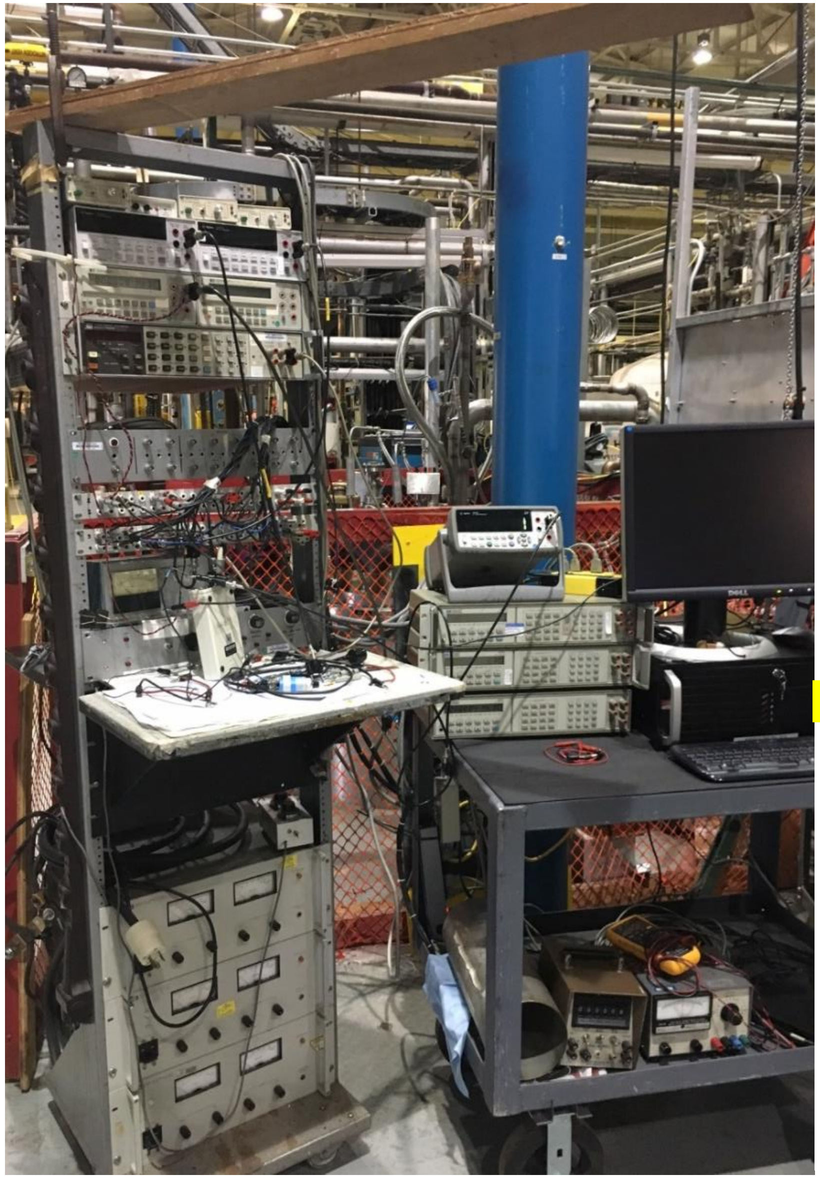
Bi2212 React & Wind Rutherford Cable Coil (Pretty)

Center-lead to test two coils either independently – another Bill Sampson's favorite



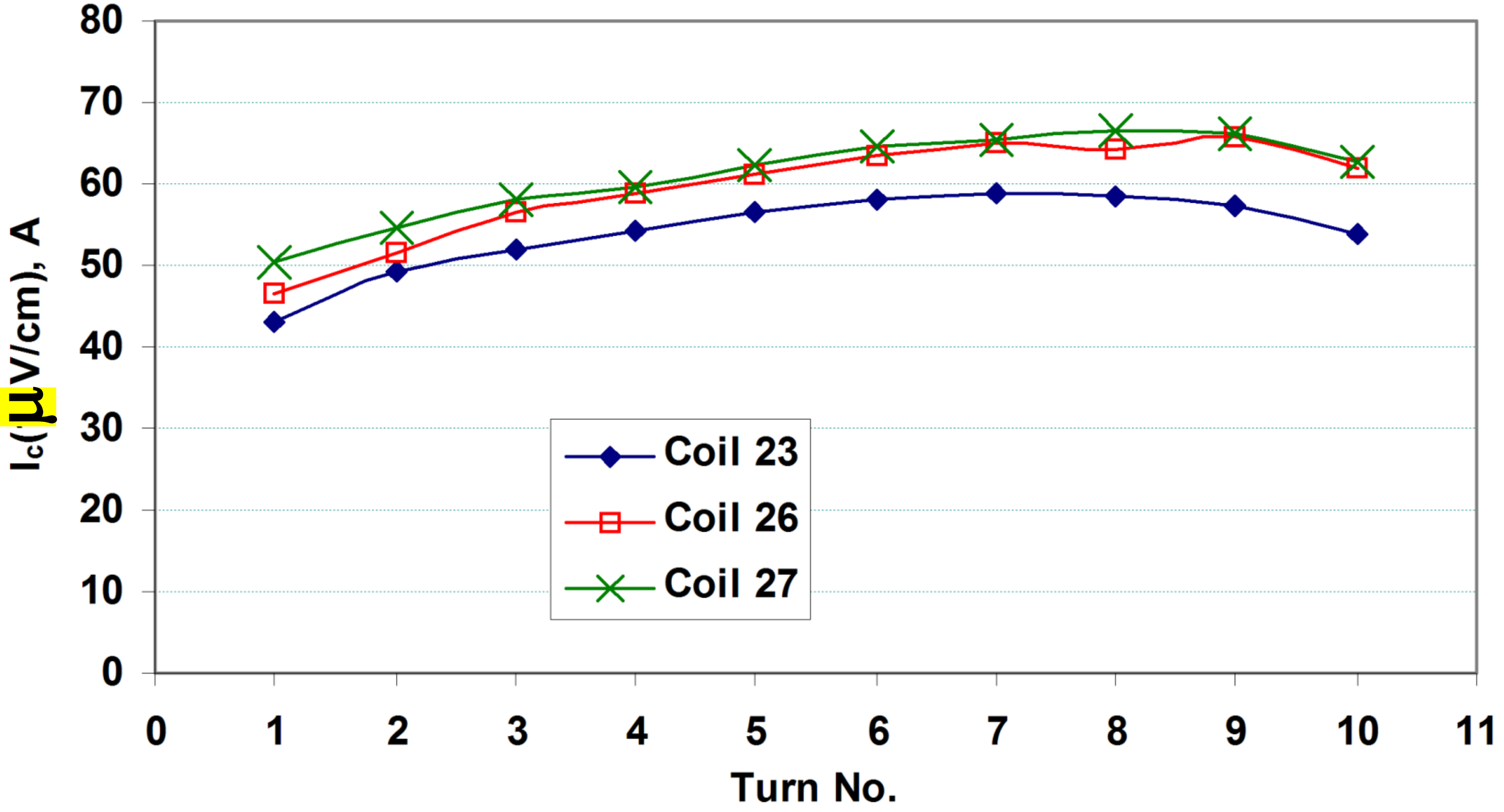
A 10-turn racetrack R&D coil. Minimum bend radius 70 mm; Cable thickness ~1.6 mm.

Bill's Versatile and High-Resolution Test Setup



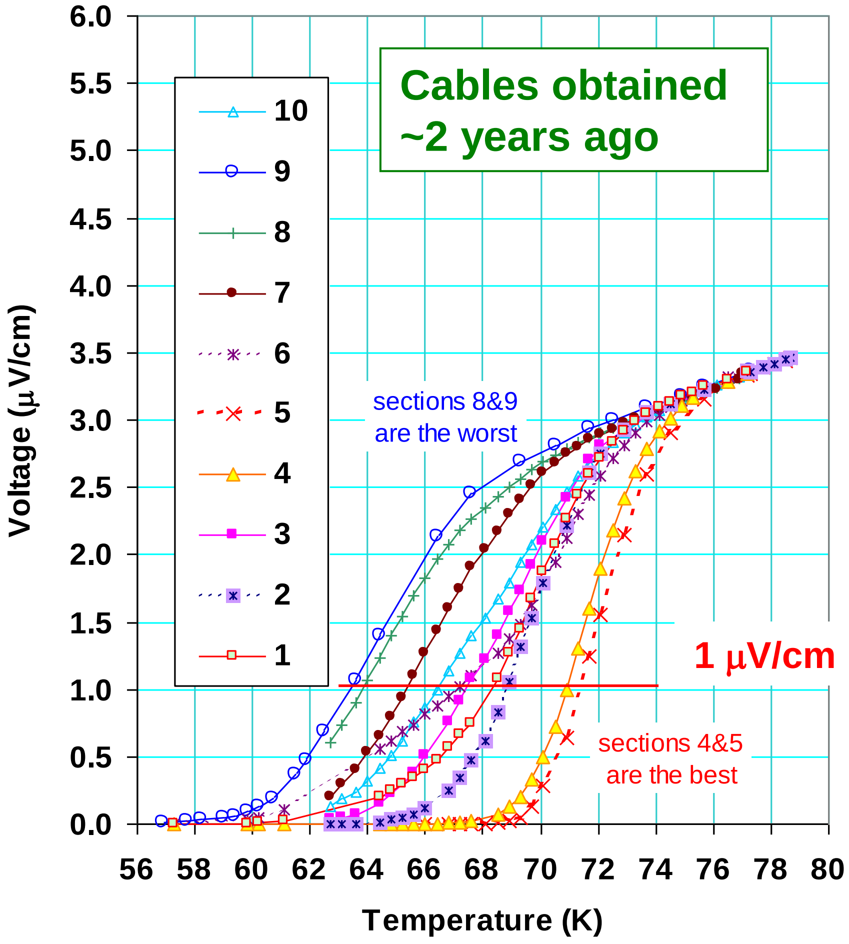
Bill wanted test results quickly with a simple system

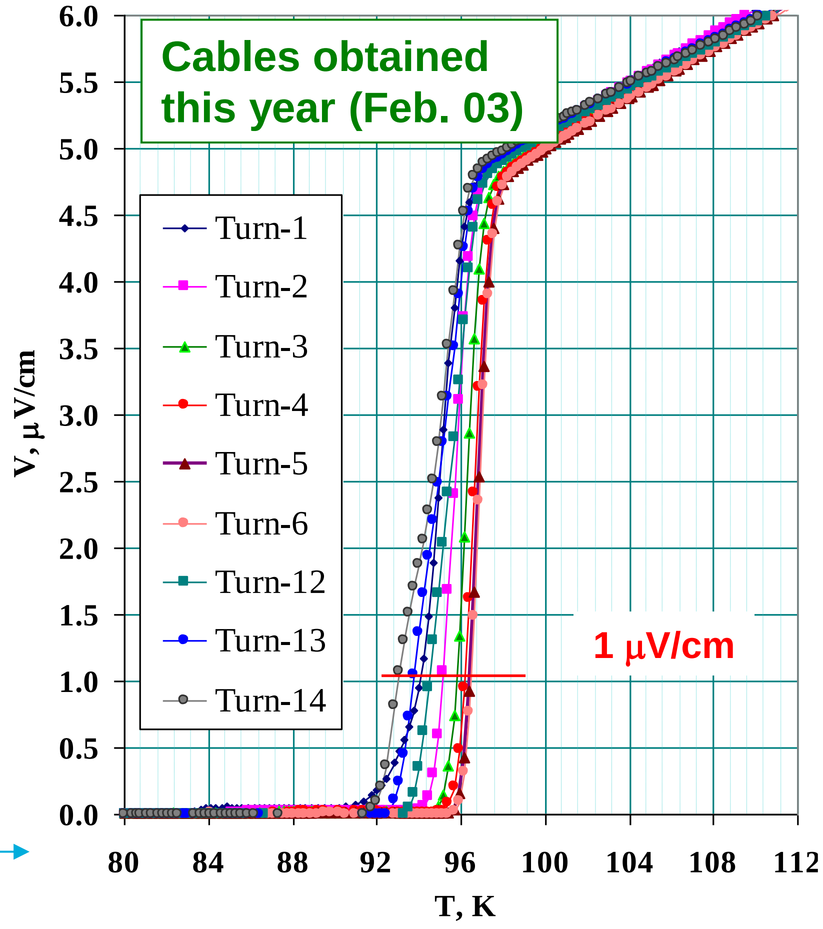
V-taps at each turn of Bi2212 HTS Coils



Bill's interest in putting v-taps on each turn in R&D magnet gave a qualitative insight in the improvement of Bi2212 coils

Measuring I_c at a fix current while temperature is drifting, reduced inductive noise - a Bill's favorite technique

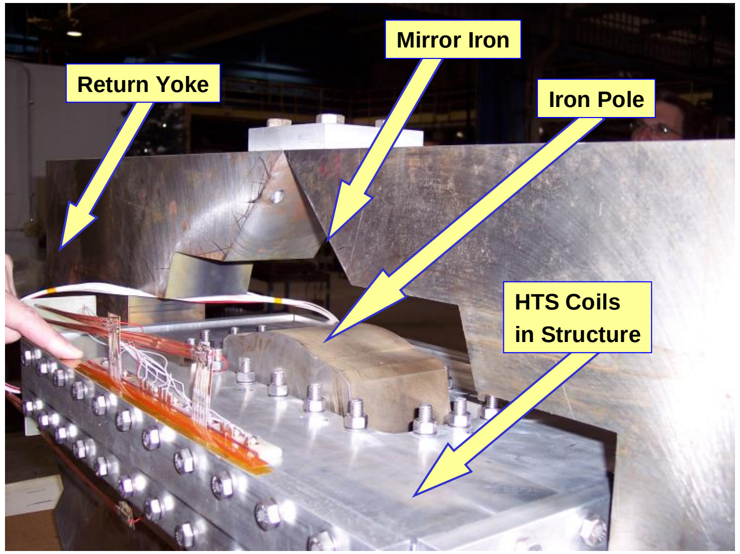




Note the improvements both, in the absolute value and the spread in T_c.

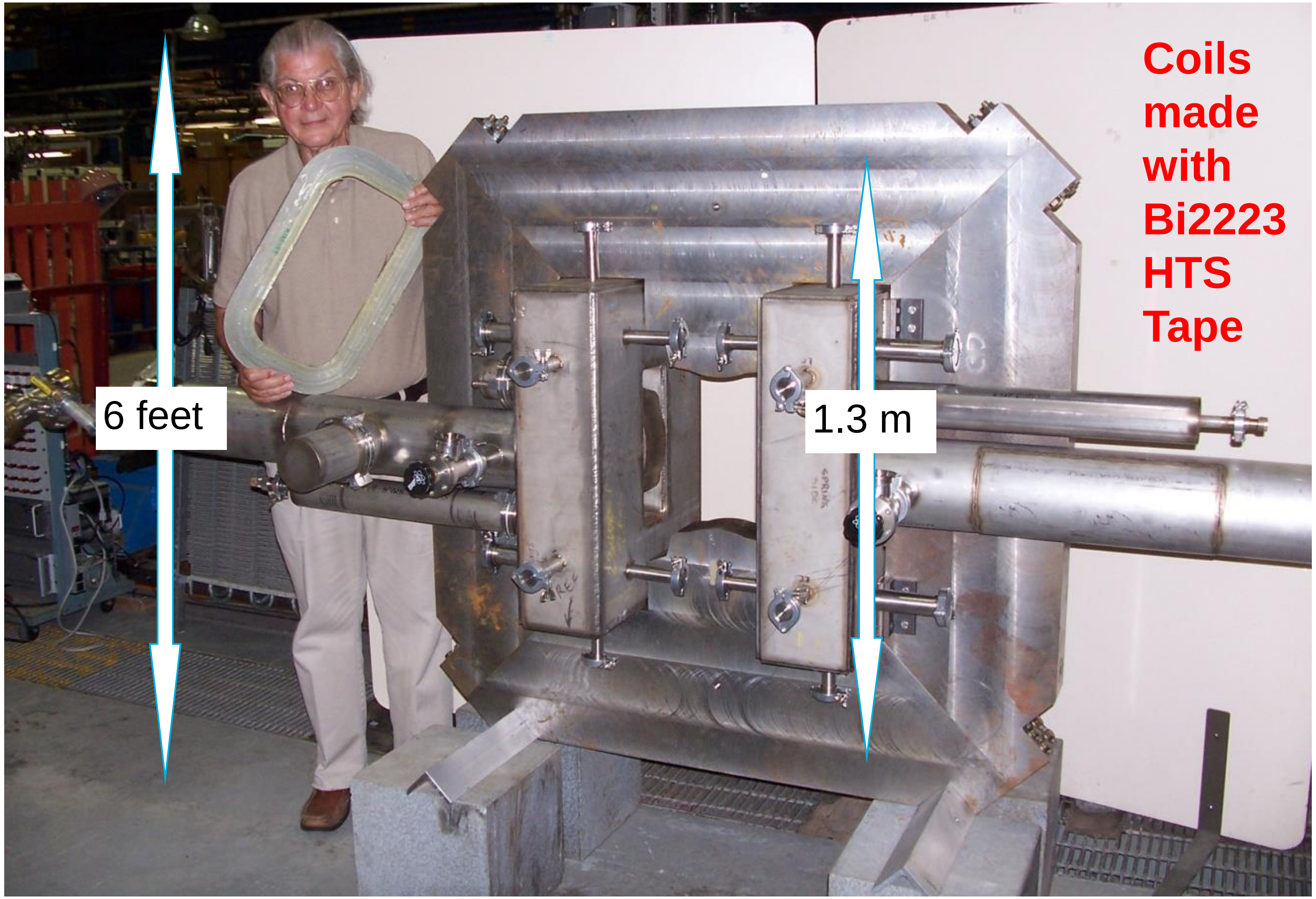
RIA (FRIB) 1st Generation HTS Quad

Three magnet structures



Mirror cold iron

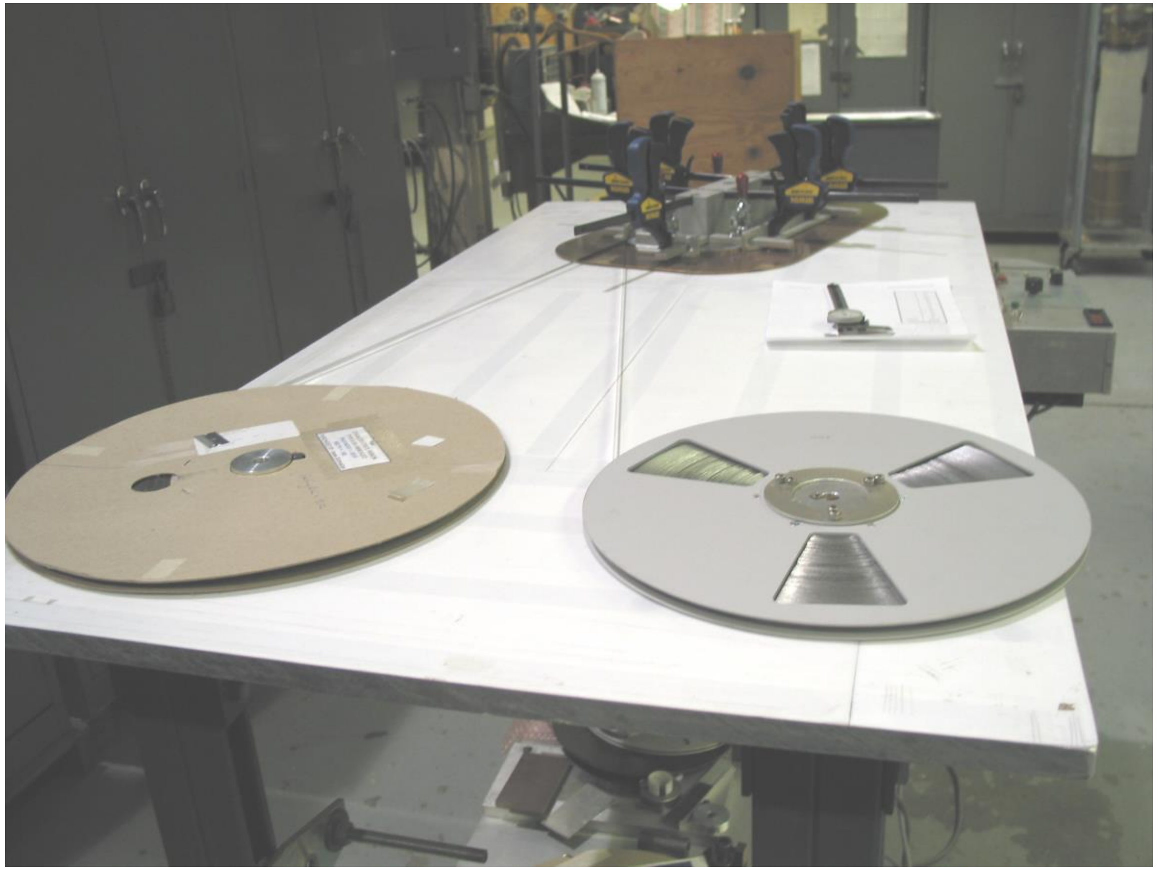
Mirror warm iron



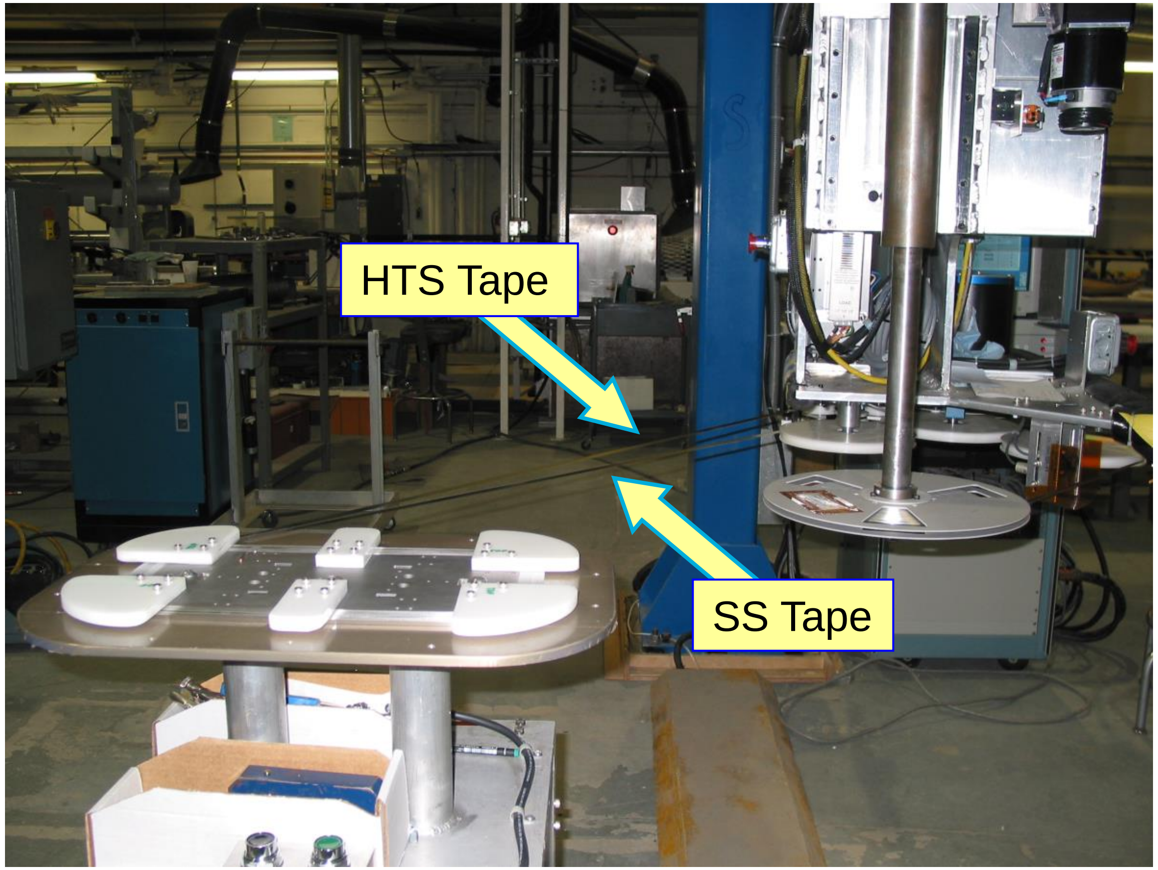
Warm Iron Design to Reduce Heat Load

Bi2223 HTS Coil Winding for RIA (FRIB)

Bill's winding machine with precision manual control (used in earlier coils)

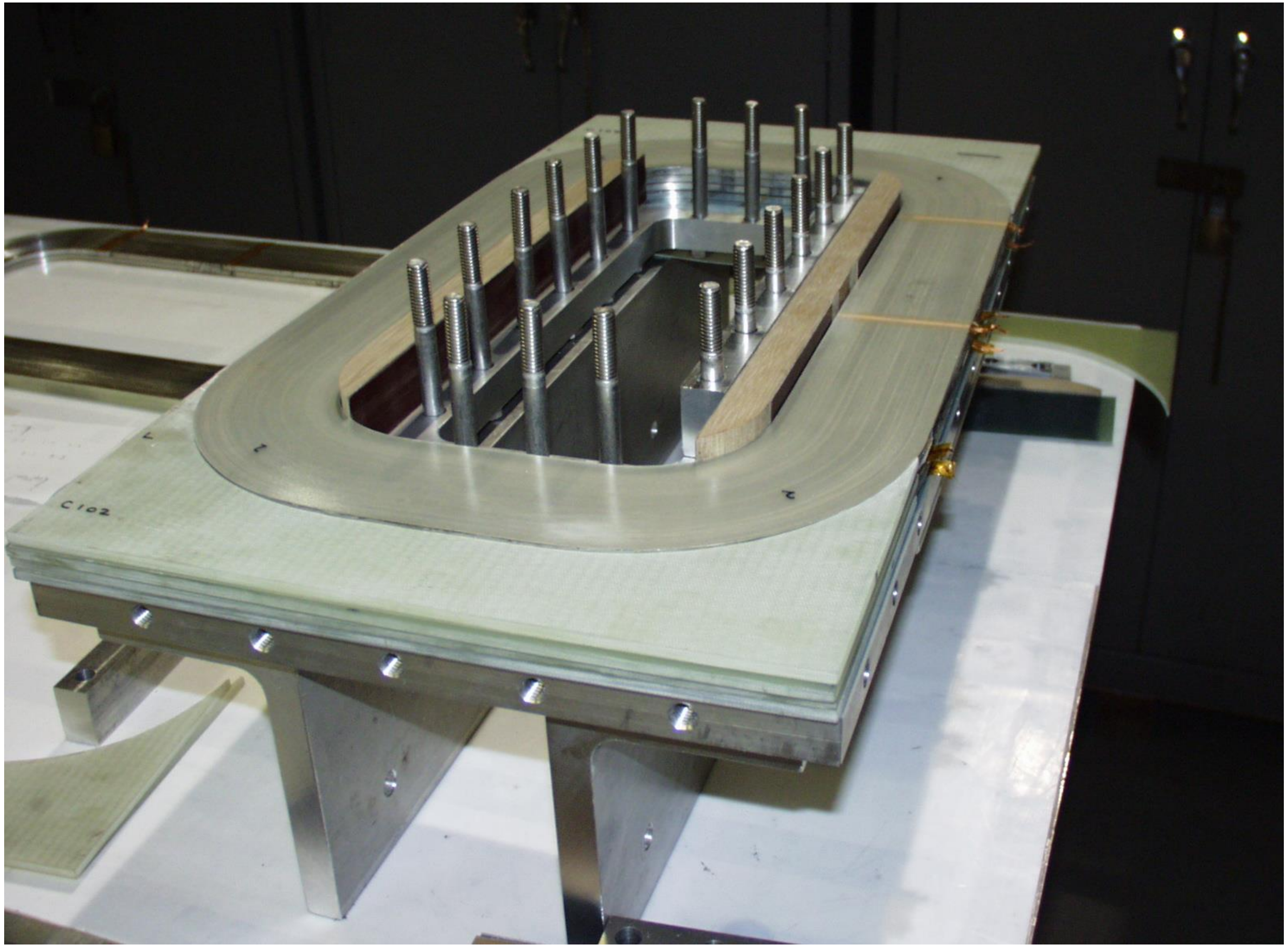


Computer controlled winding machine (used in the later RIA coils)



Stainless steel tape as turn-to-turn insulator (radiation tolerant)

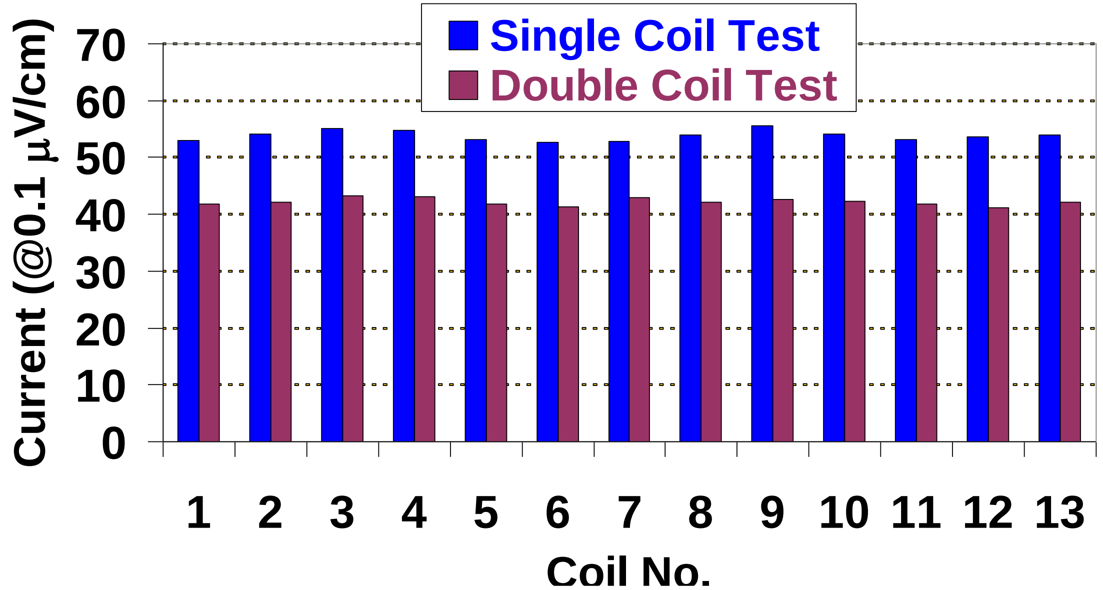
Three Pairs of HTS RIA Coils Assembled with Splices

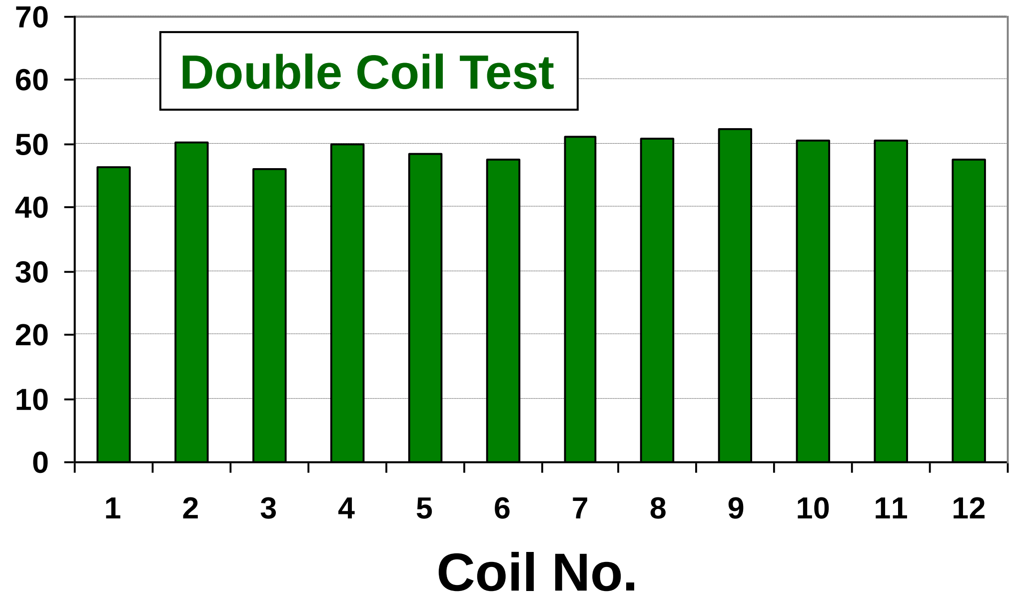


Bill painted the surface of the coil with a very thin layer of epoxy to hold the turns and coil together (no epoxy between turns)

Bill used a set of HTS tapes for perpendicular splice (worked well)

25 BSCCO 2223 HTS Coils Tested for RIA (77 K)

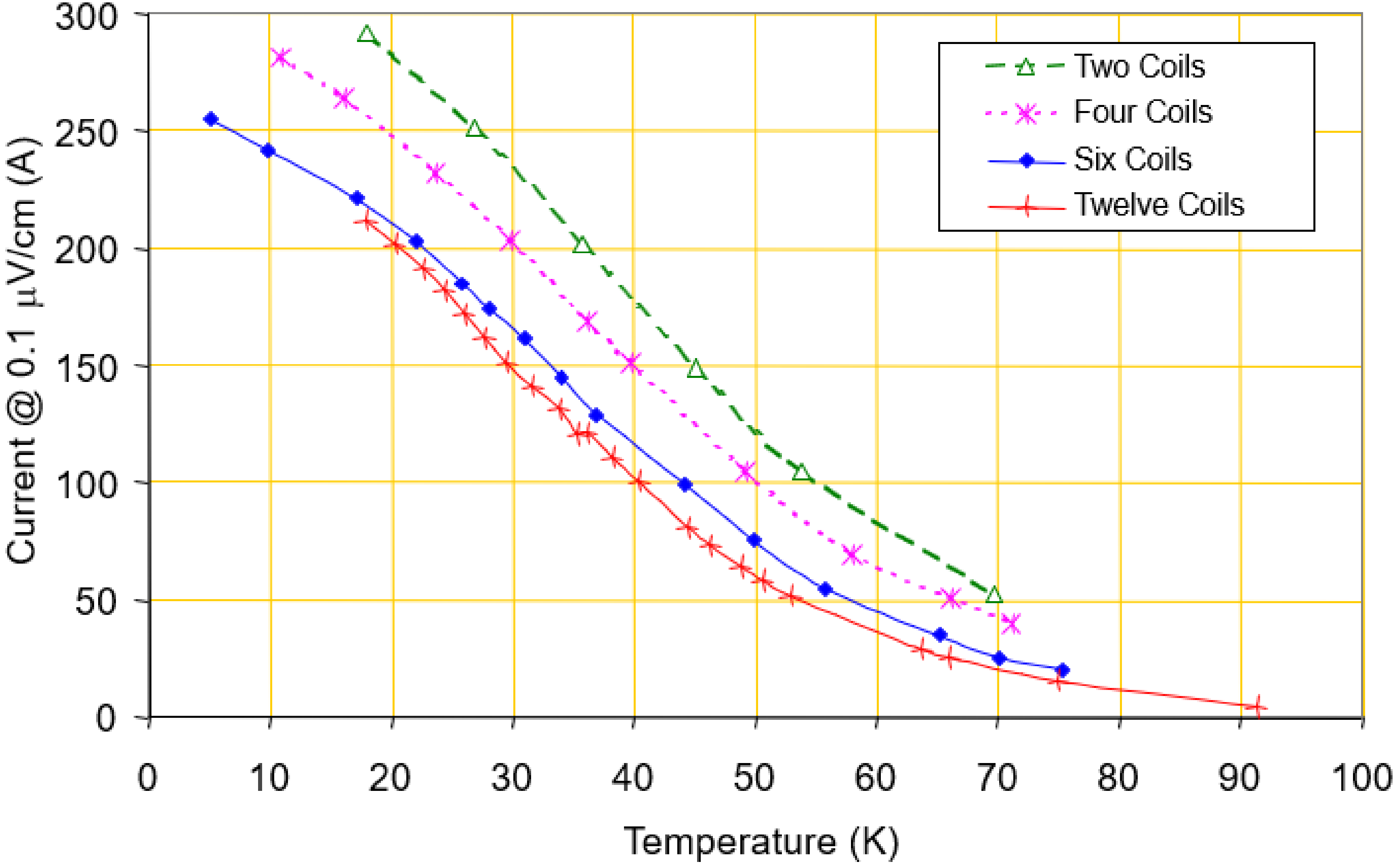




IEEE Award for Applied Superconductivity Research (2010)

"I'm glad that my contributions to the development of superconducting magnets are being recognized," Sampson said. "I hope to continue to contribute to the field for many years to come."

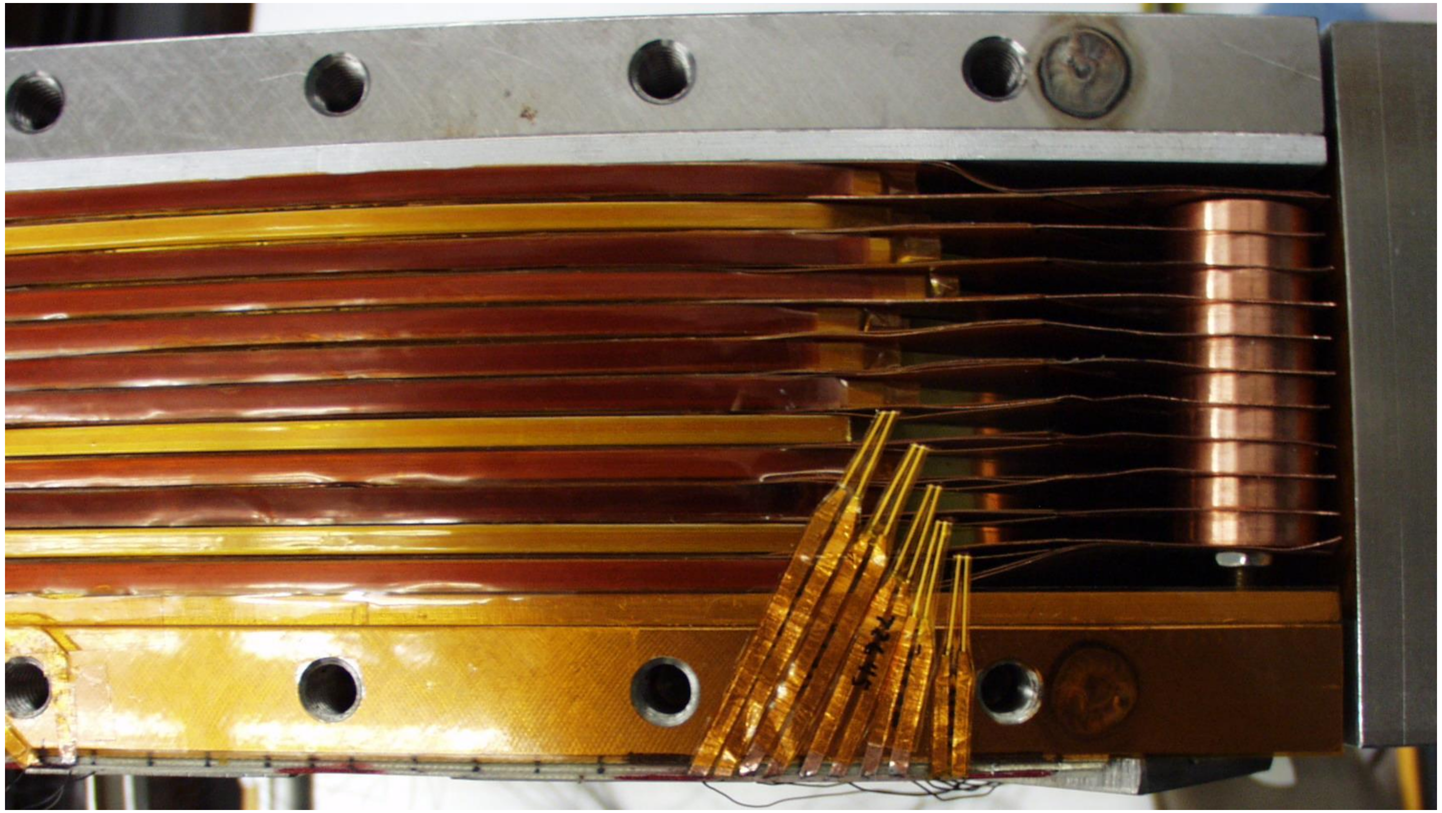
RIA HTS Mirror Model Test Results
(operation over a large temperature range)



Bill routinely tested HTS coils over a wide operating range in gaseous Helium by adjusting the flow rate and stabilizing home-made HTS tape leads with copper.

All without any fuss. So much to learn from Bill!

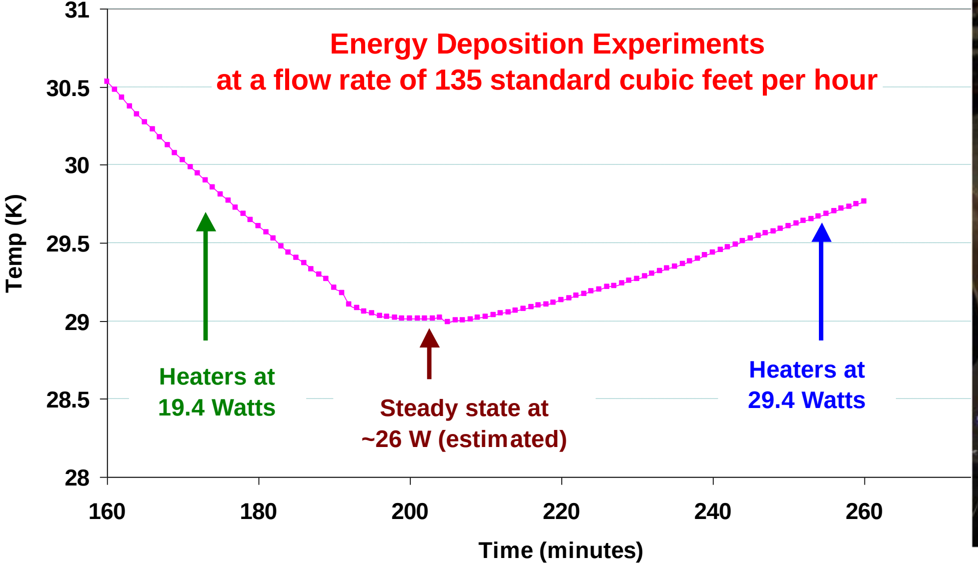
Energy Deposition & Cryogenic Experiments for Conduction Cooling

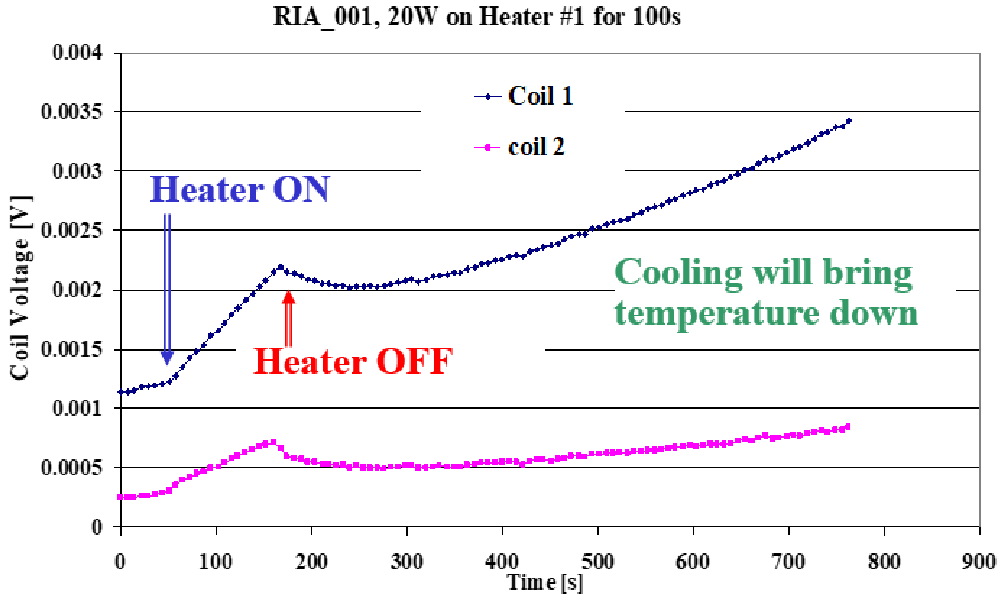


Stainless steel tape heaters for energy deposition experiments

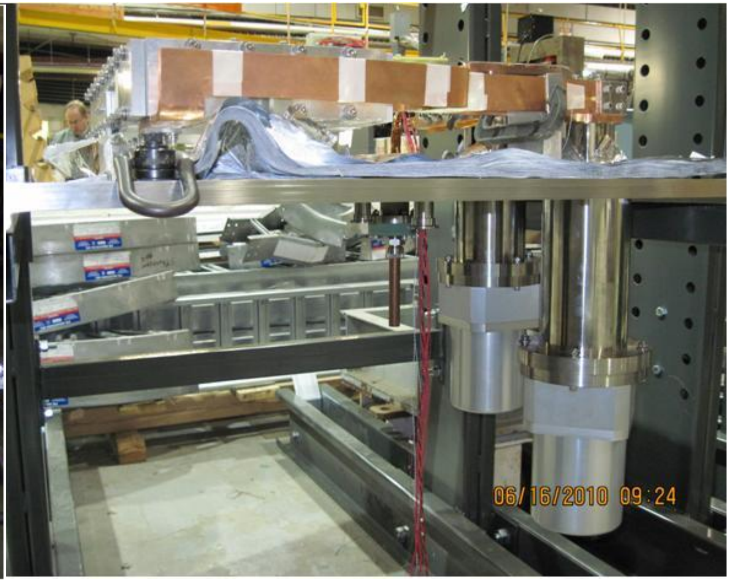
Copper sheets between HTS coils with copper rods and copper washers for conduction cooling

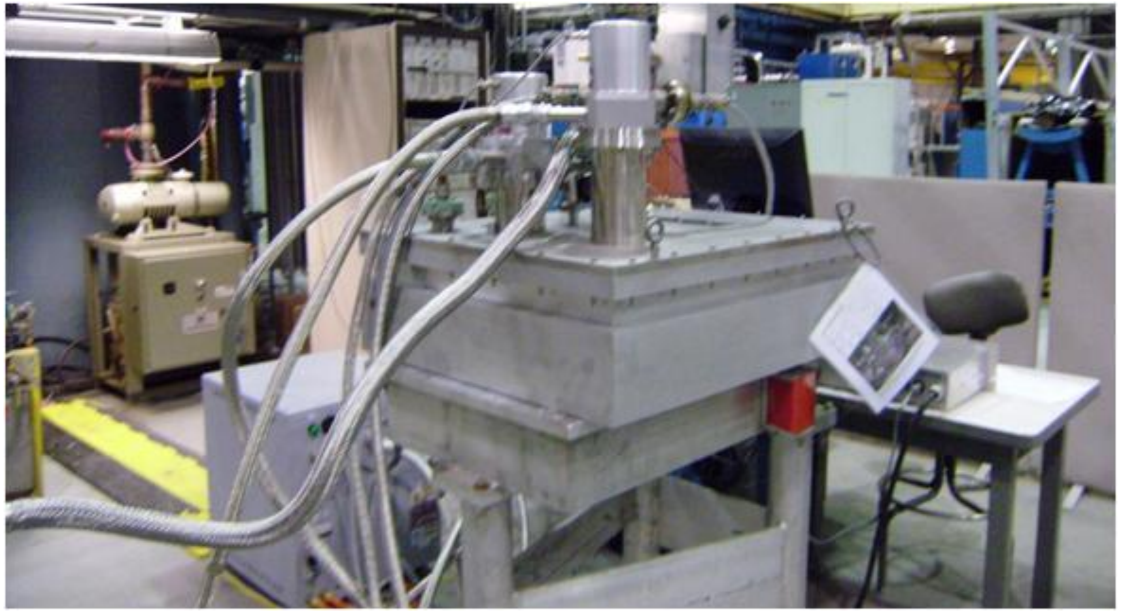
Energy Deposition Experiments for FRIB



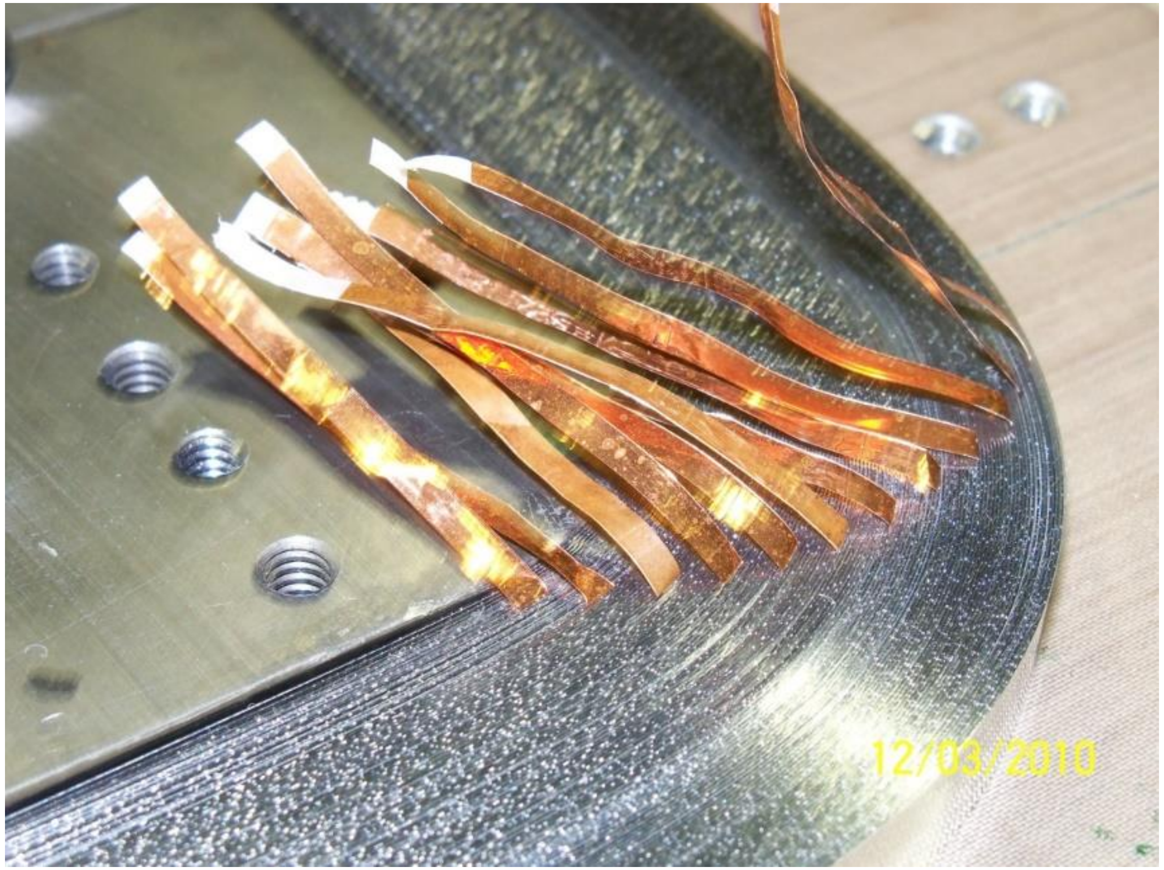


Cryo-cooler Experiments





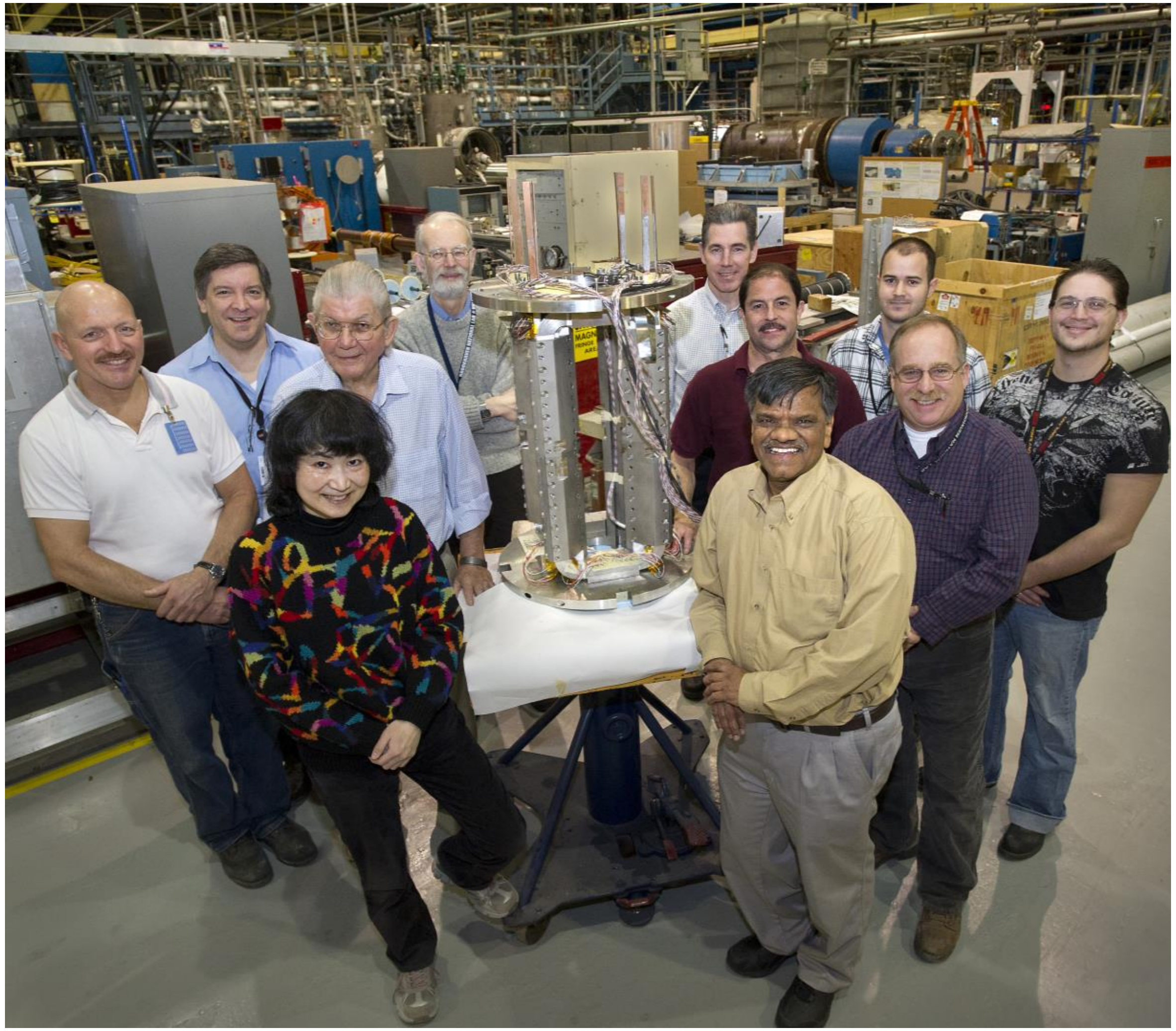
HTS Coils for FRIB with the 2nd Generation (2G) 12 mm HTS Tape from ASC and SuperPower



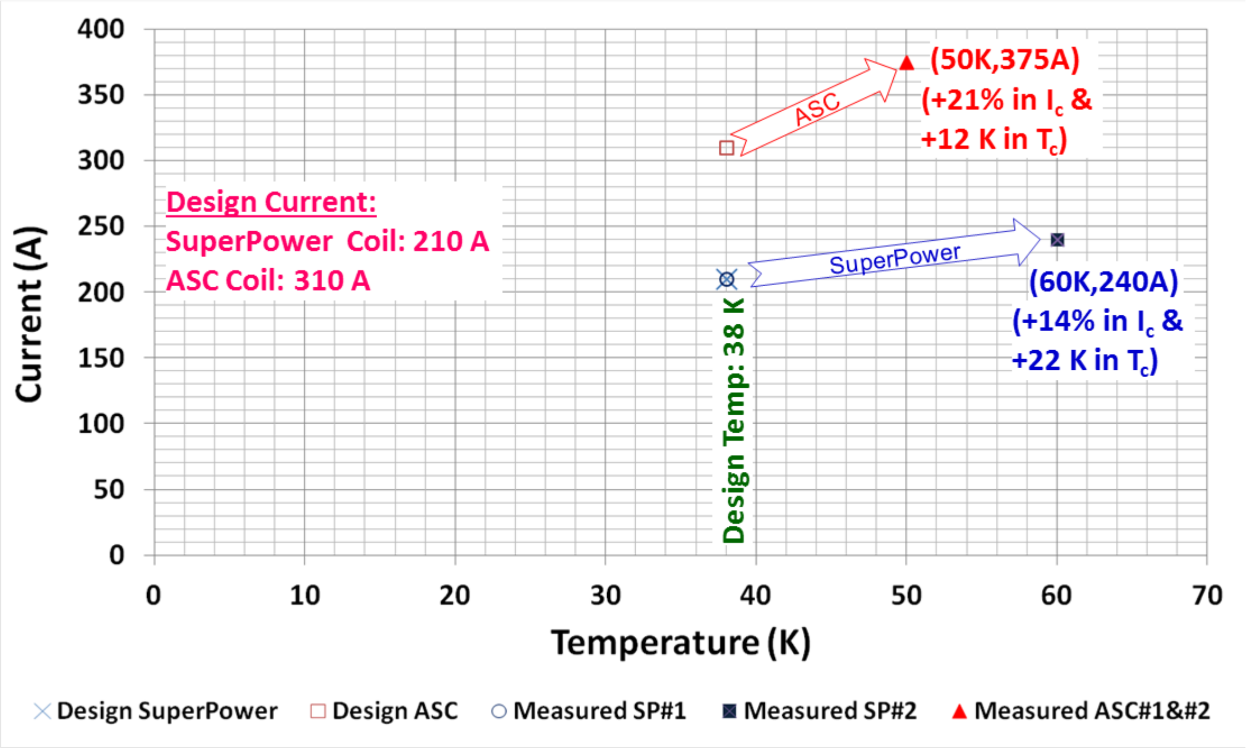
Generous v-taps for understanding, placed with only tension holding them (no solder). Typical Bill Samson.

2^{nd} Generation FRIB HTS Quad with ReBCO Tape

A happy team with Bill Sampson (2013)



Large Temperature Margins (only possible with HTS)

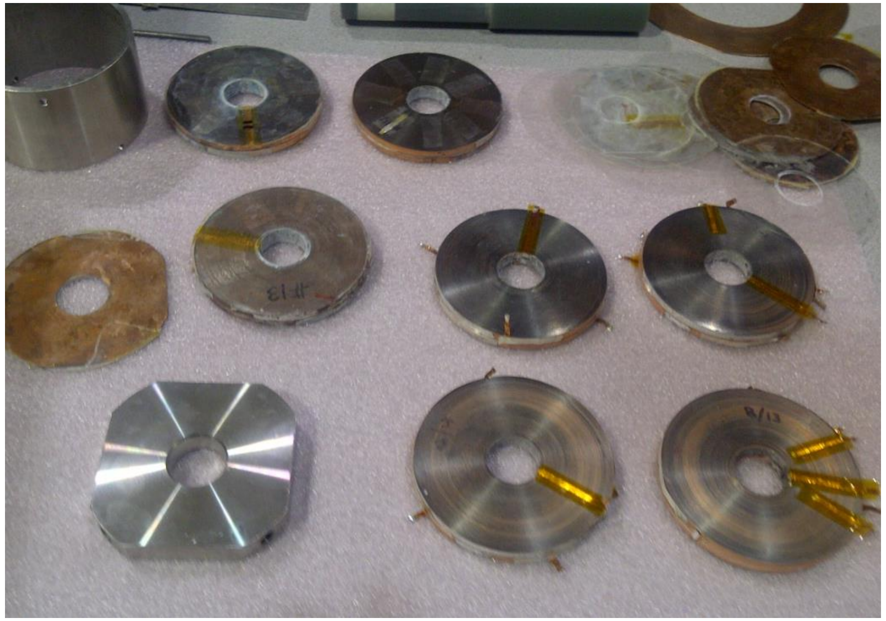


A strong case for HTS made

Contributions to High Field HTS Solenoids from Bill

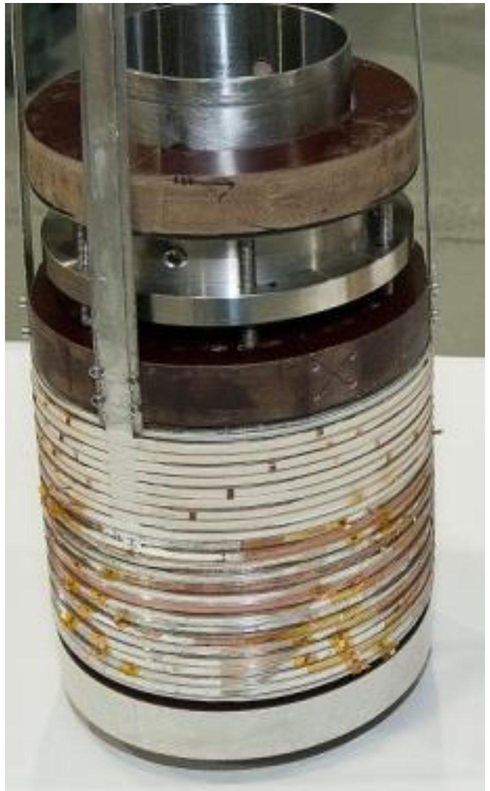
- **Bill Sampson, either directly wound and tested or intellectually contributed to several high field HTS solenoids.**
- **These coils were wounded with Kapton insulation, SS tape, or NO insulation.**
- **They were made as a part of SBIR with PBL for muon collider, SMES, Axion search, neutron scattering, etc.**

PBL/BNL coils and solenoid with 2G HTS tape and SS insulation (SS helps in structure and quench protection)



pancakes

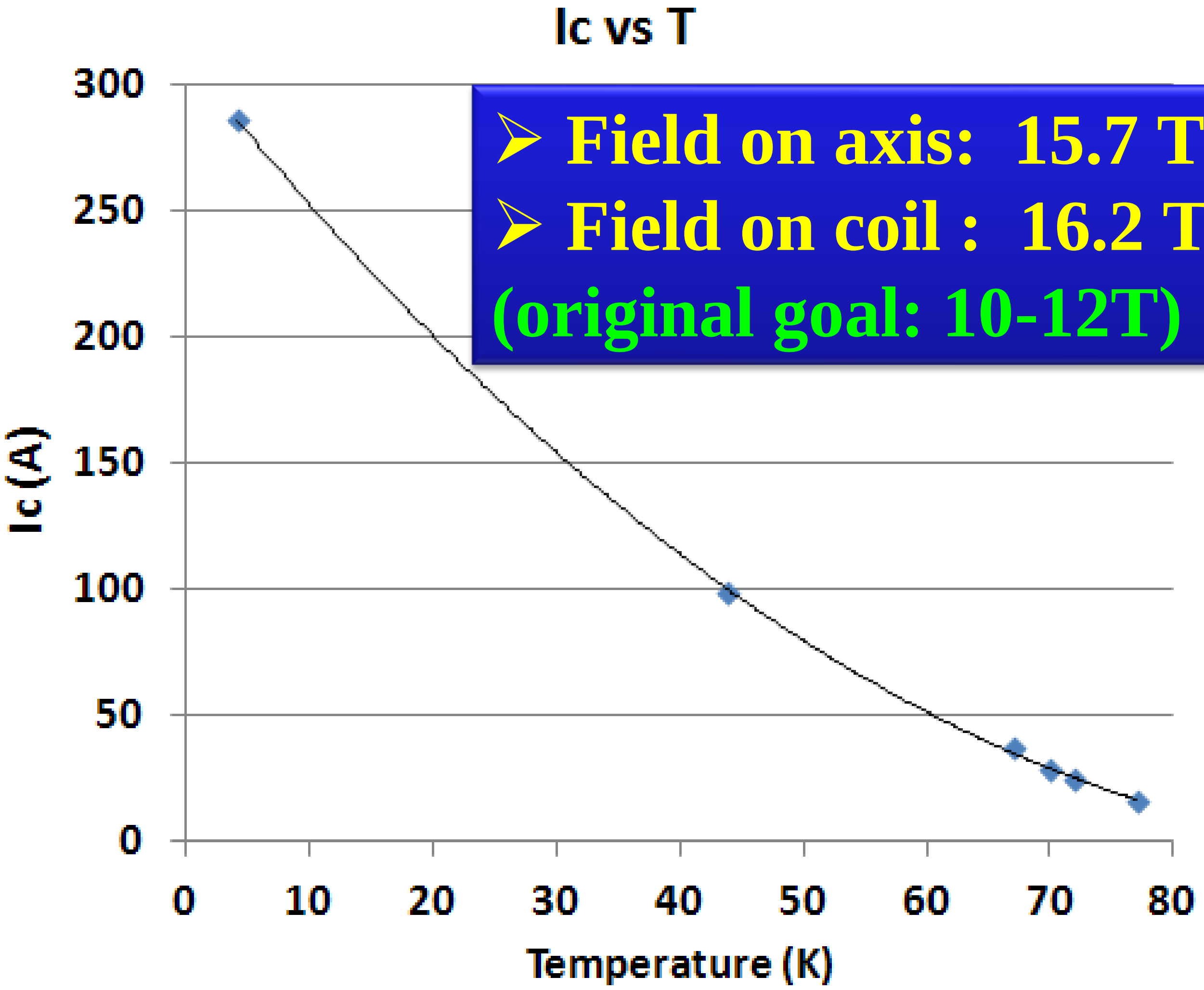
Insert solenoid



Outsert solenoid

Record Field PBL/BNL HTS Solenoid (2013)

Proud Bill Sampson with a group of admirer



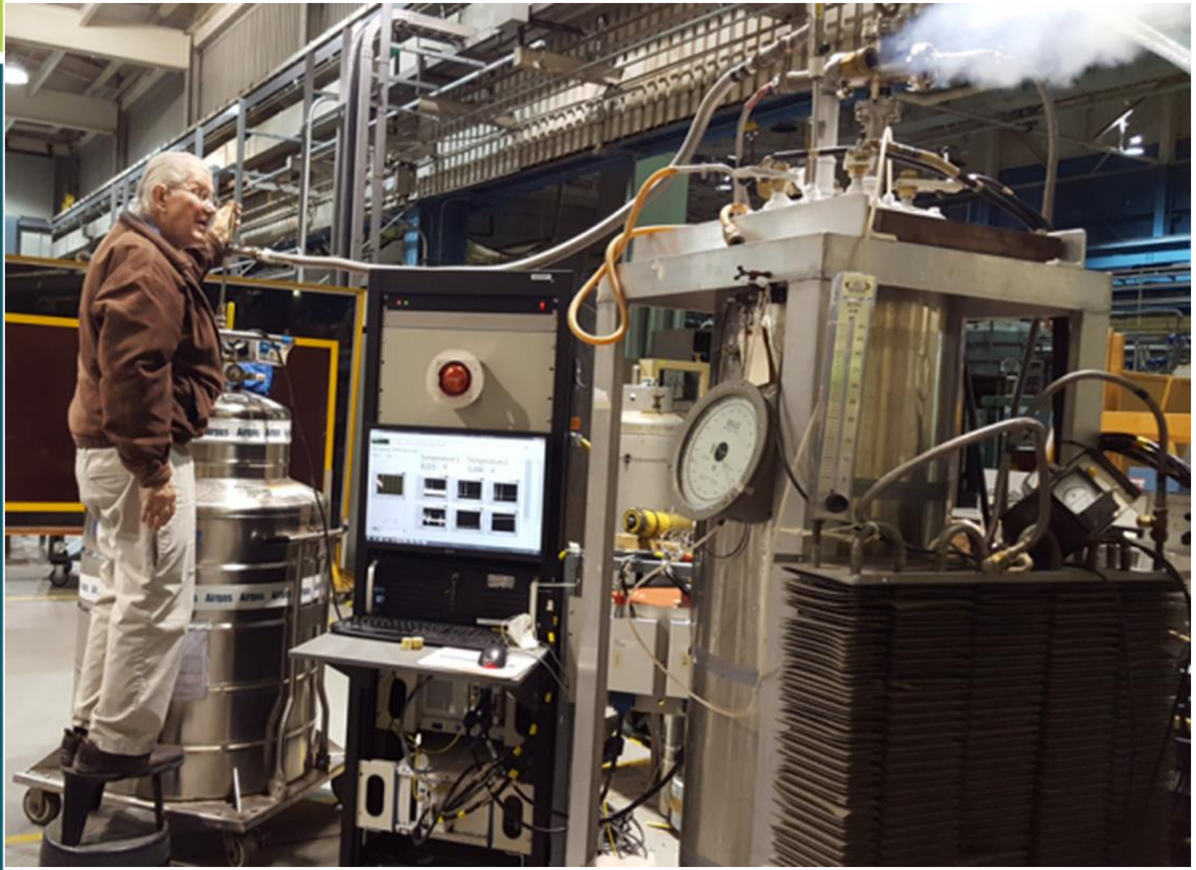
- Field on axis: 15.7 T
- Field on coil : 16.2 T

(original goal: 10-12T)

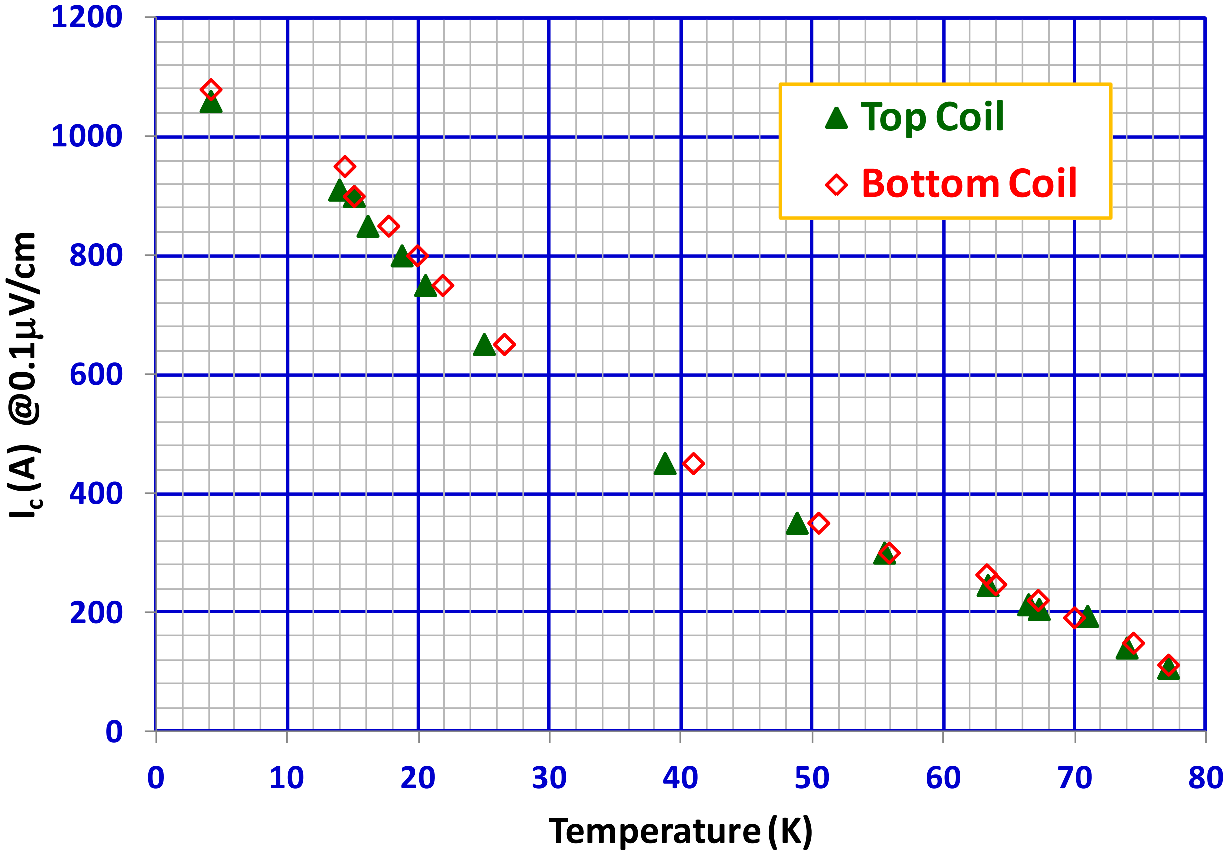
14 pancakes, 25 mm aperture

Critical Current Measurement as a Function of Temperature

➢ **Bill Samson adjusting Helium flow to control temperature**



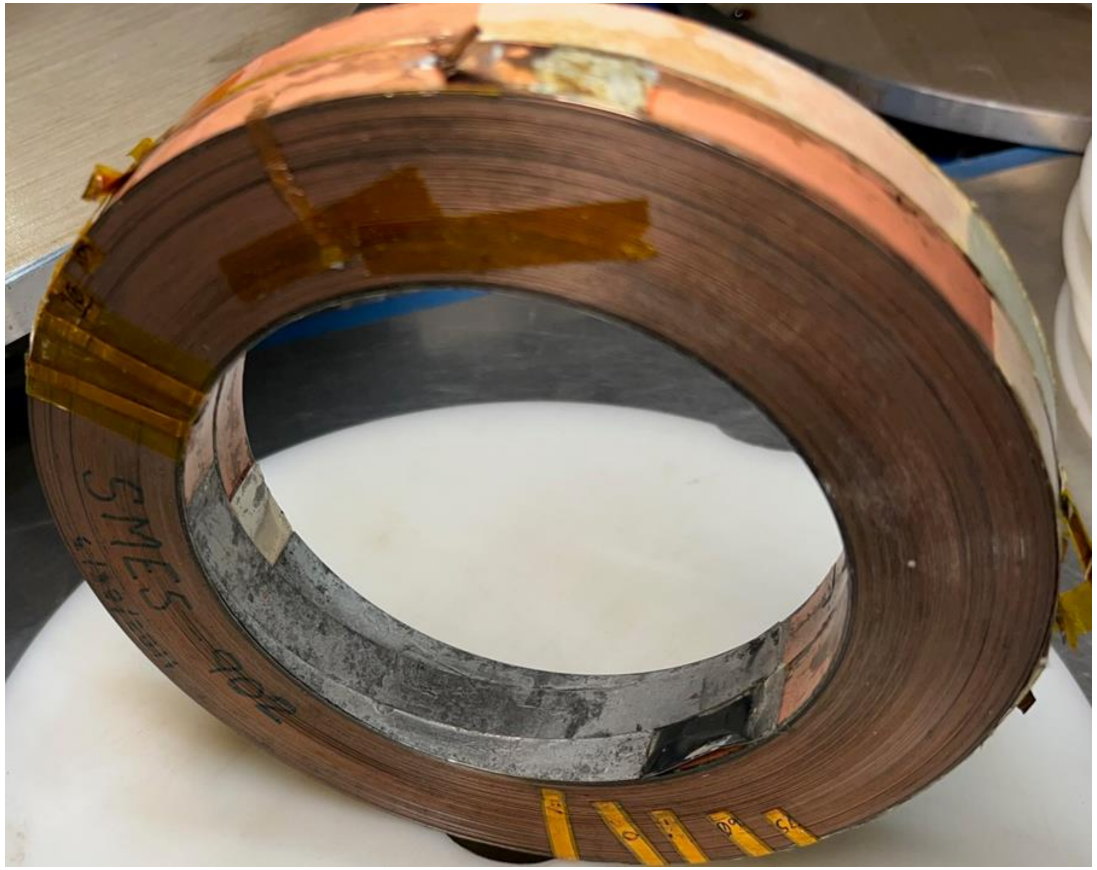
Bill made critical current measurements as a function of temperature routinely



- 100 mm bore SMES coil with 12 mm wide HTS tape
- Center lead to measure Ic of the two coils independently

Spiral HTS Splice-joint

➢ **Another Bill Sampson's Favorite**



Two single pancakes (12 mm tape, 100 mm bore) to double pancake with spiral joint

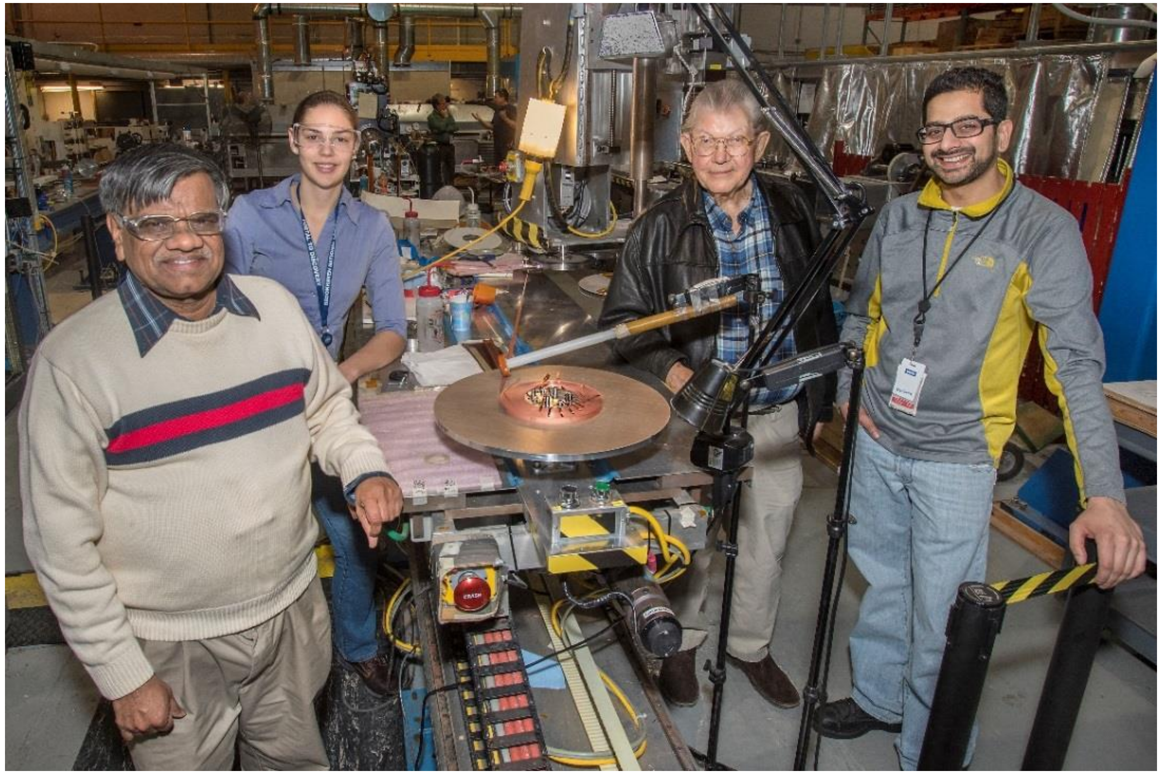
✓ Bill's splice never had an issue despite being in high field area

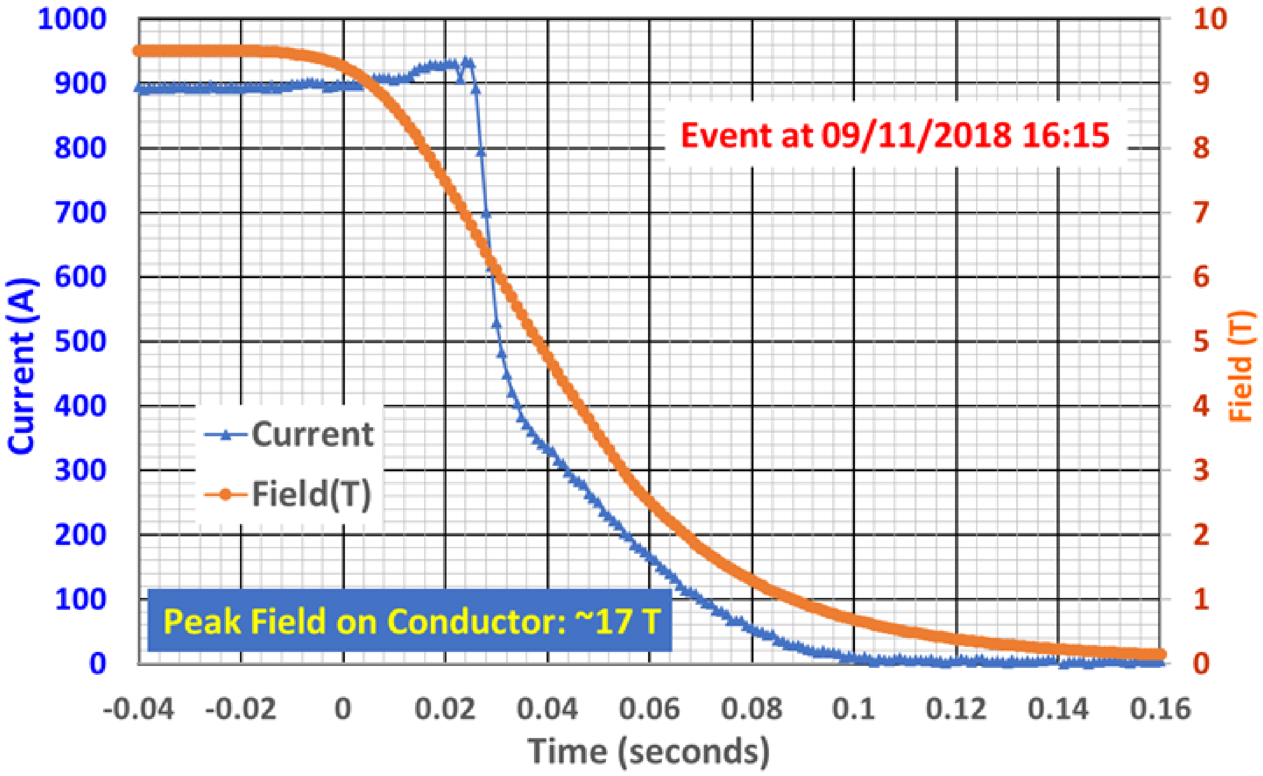
100 mm HTS SMES Coil (record field@27K)

Peak fields higher

Bill Sampson in Hard Hat

Bill Sampson Work on No Insulation (NI) HTS Coils for IBS



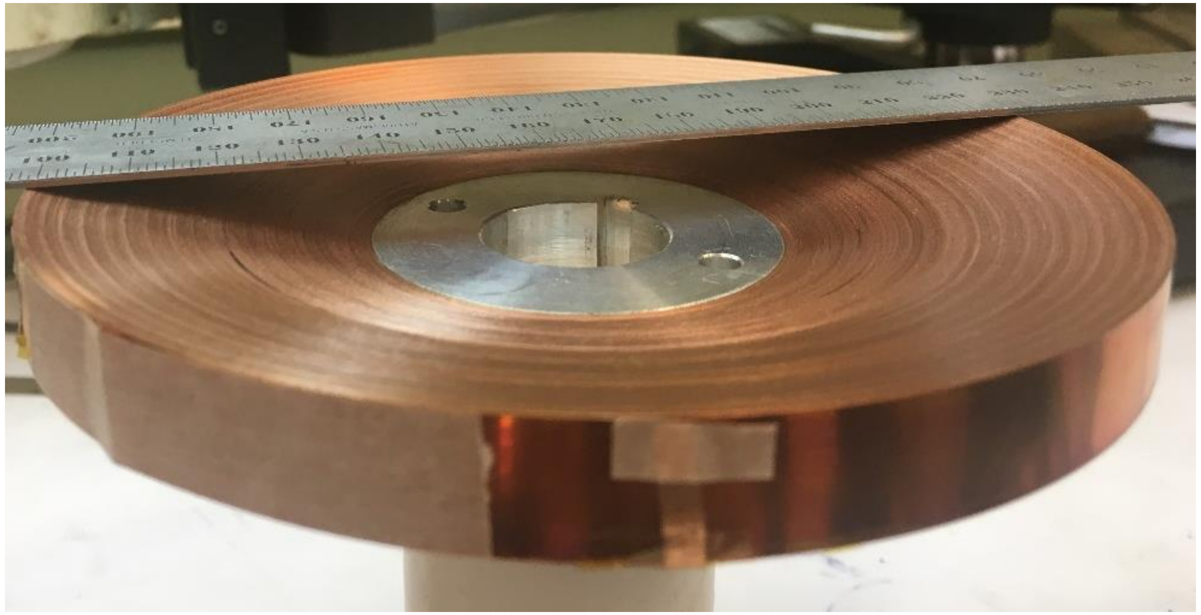


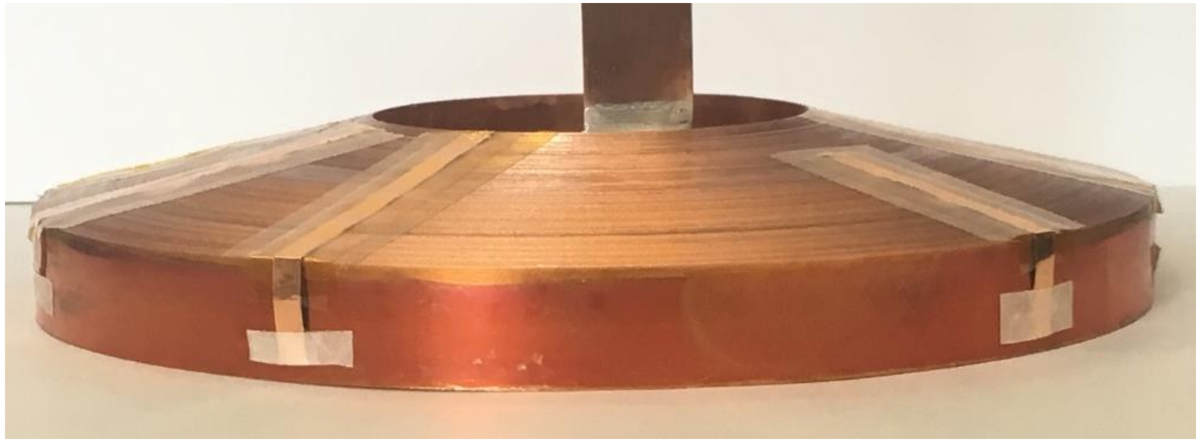
Bill invented a very simple tool to assure that coil came out flat (turns are aligned). Worked really well.

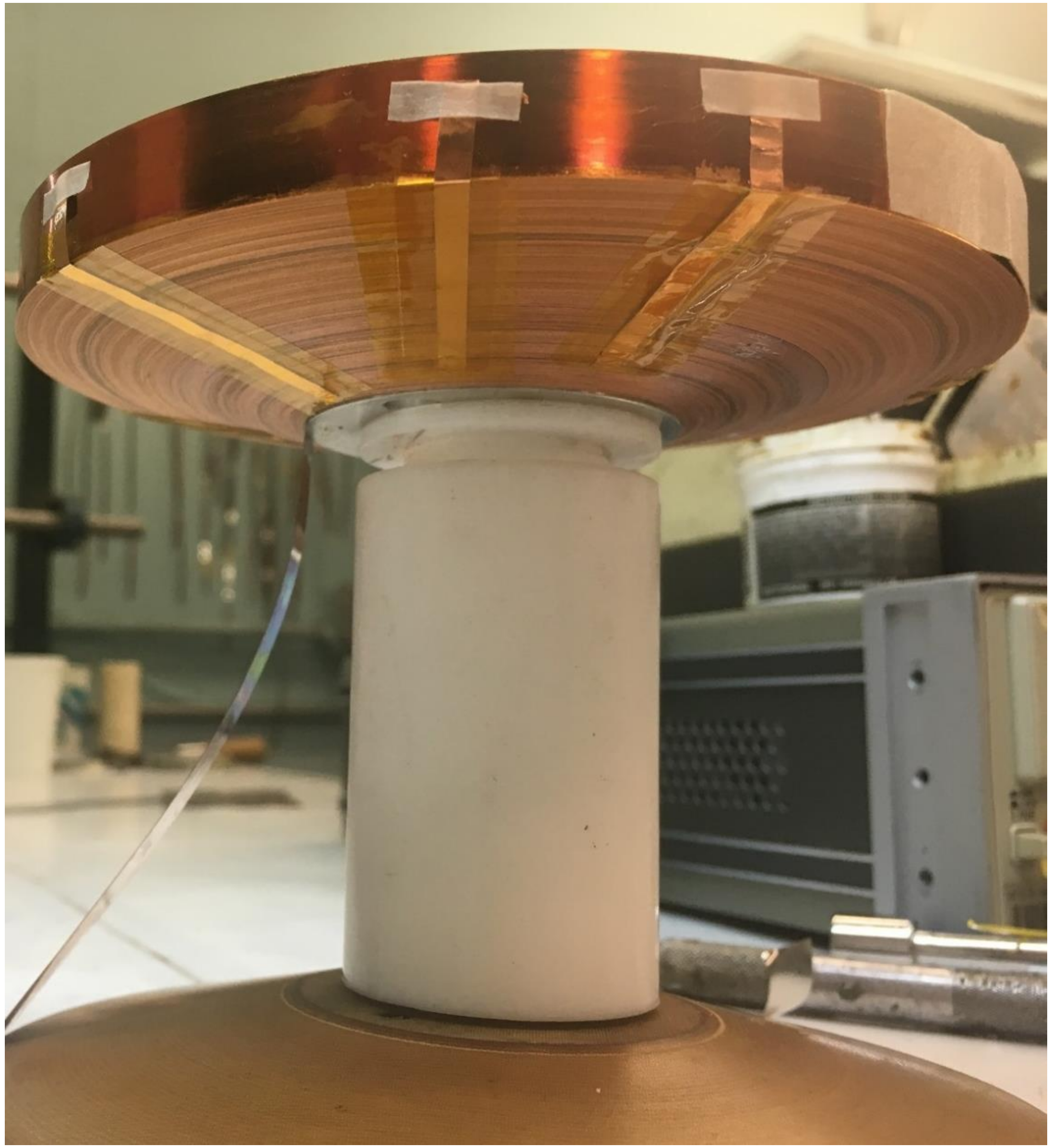
- **Working with the next generation.**

PBL/BNL SBIR on Neutron Scattering (conical shape HTS coils)

Bill found an easy way to wind a conical coil

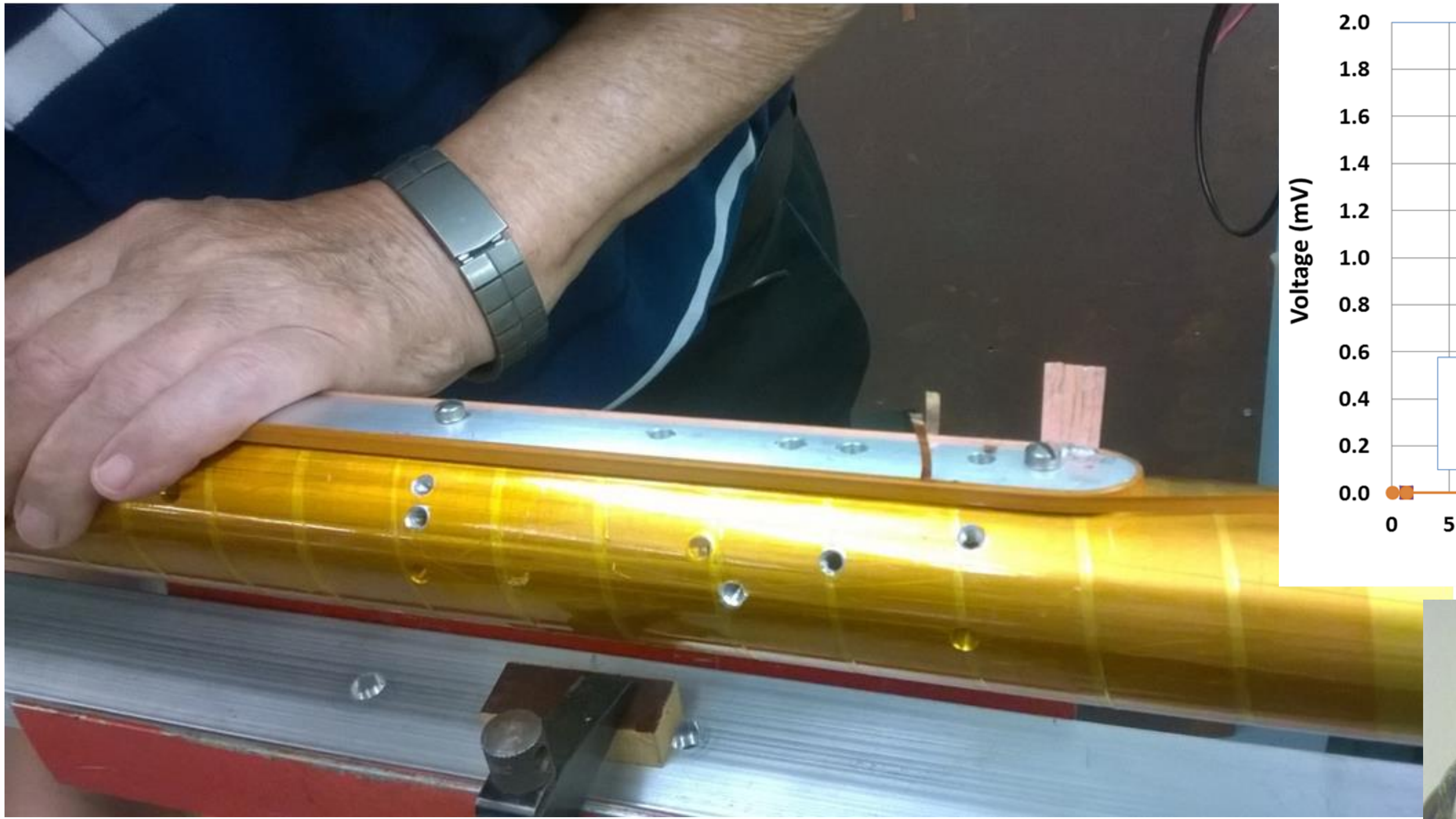


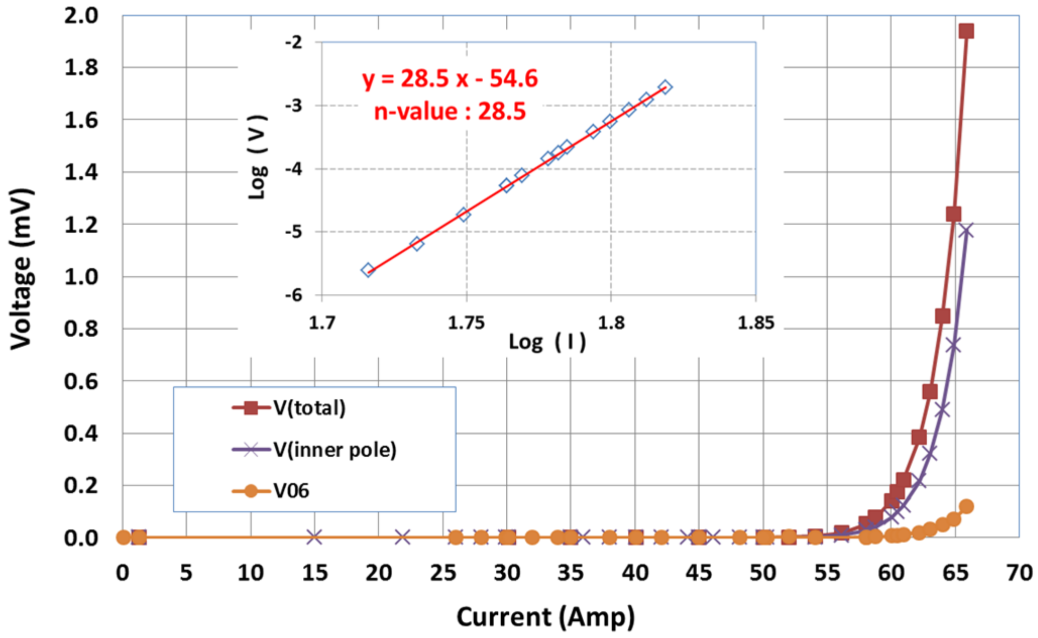




Bill Sampson's Contributions to R&D on High Field HTS and HTS/LTS Hybrid Dipoles

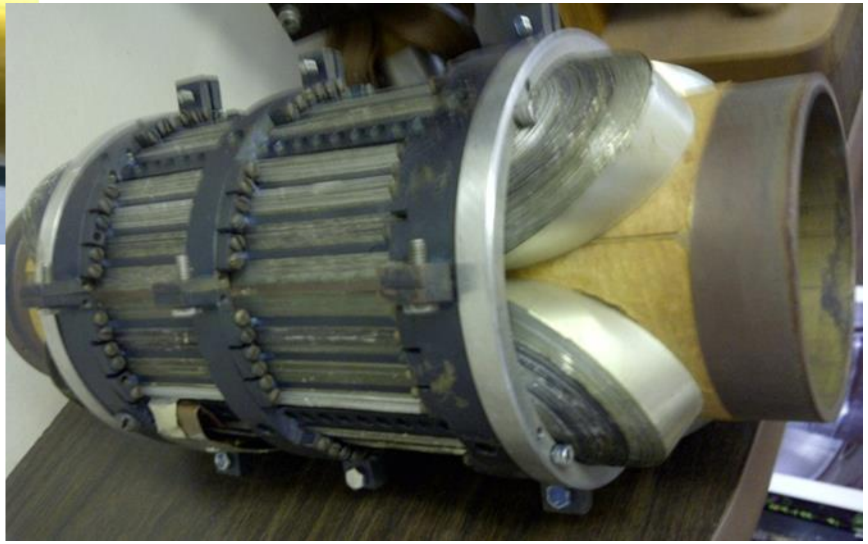
Cos(θ) Coil **with** 2G HTS Tape - PBL/BNL SBIR



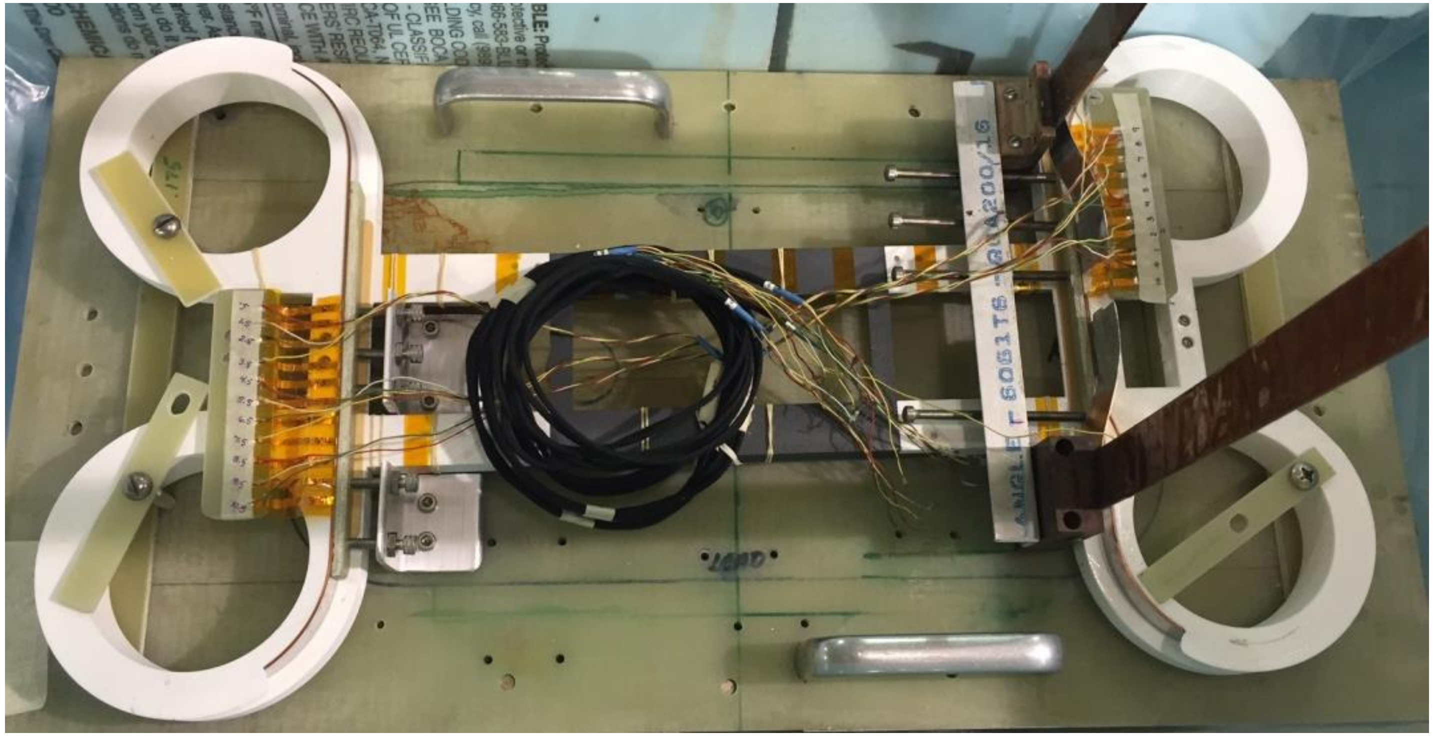


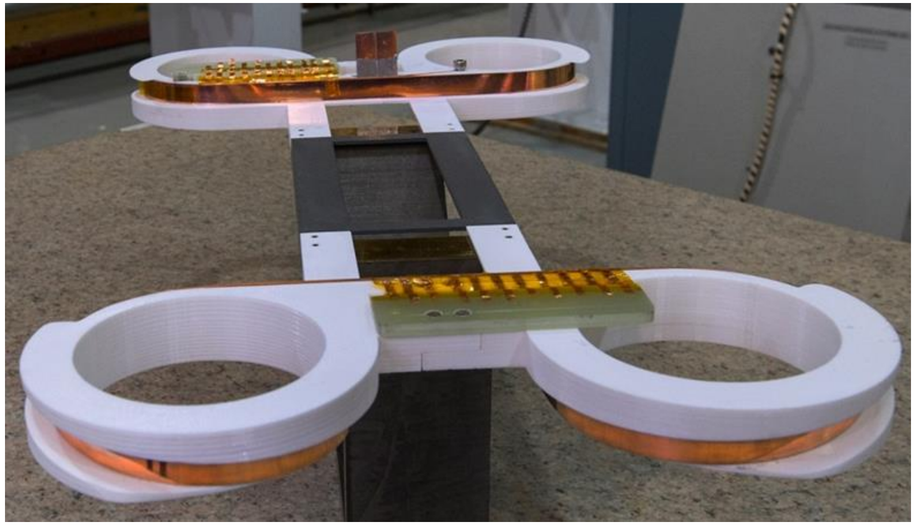
Steady hand of Bill Sampson
cos(θ) coil with HTS tape

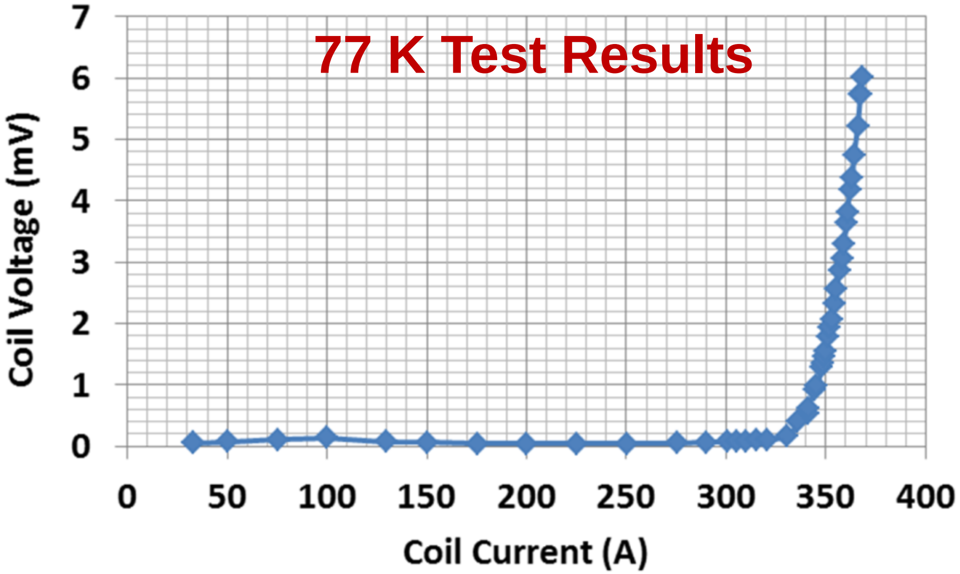
Bill had done it before with Nb_3Sn tape



Bill Testing the Overpass/Underpass (cloverleaf) 2G HTS Tape Coil for e2P/BNL SBIR







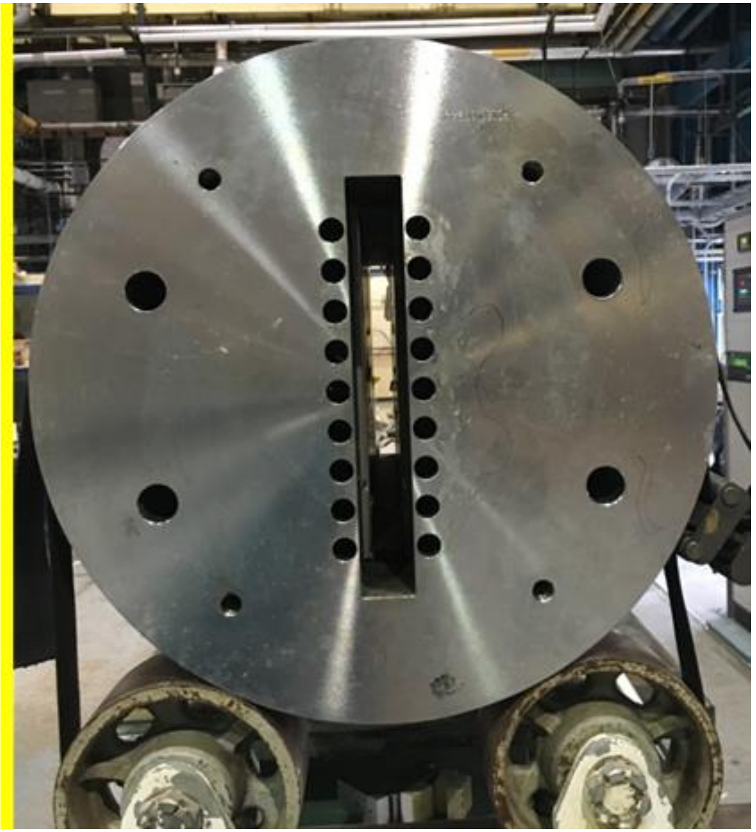
Sufficiently instrumented, low-noise, detailed, reliable and NO non-sense test (hallmark of Bill, the master at work)

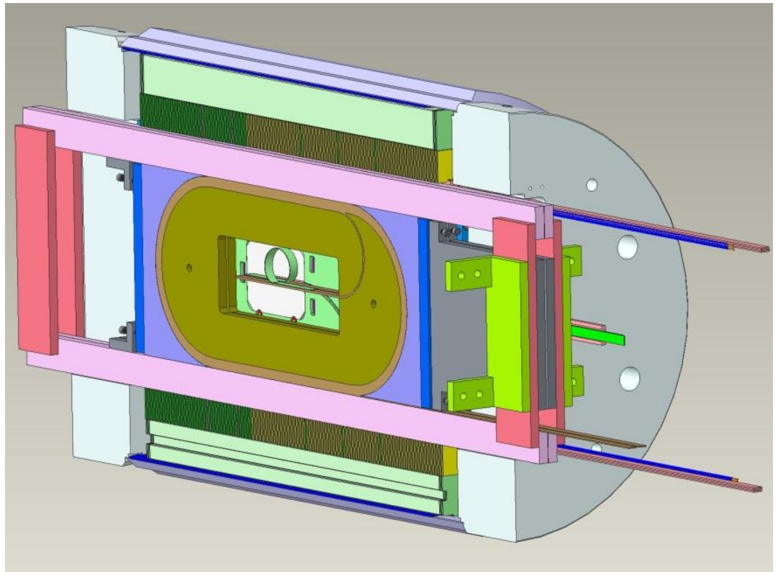
Bill Sampson's Contributions to HTS/LTS Hybrid Magnet Program (PBL/BNL STTR & MDP)

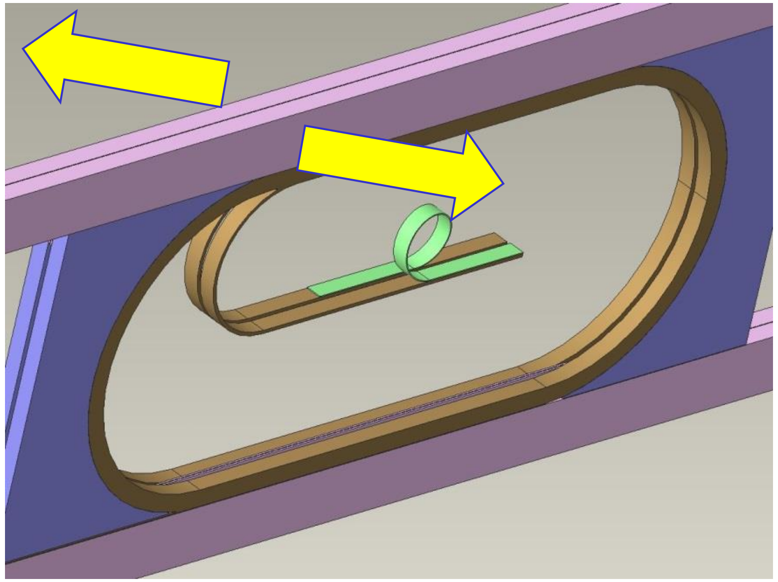
Bill will insist on sufficient v-taps for 77 K QA test before the more involved 4 K test

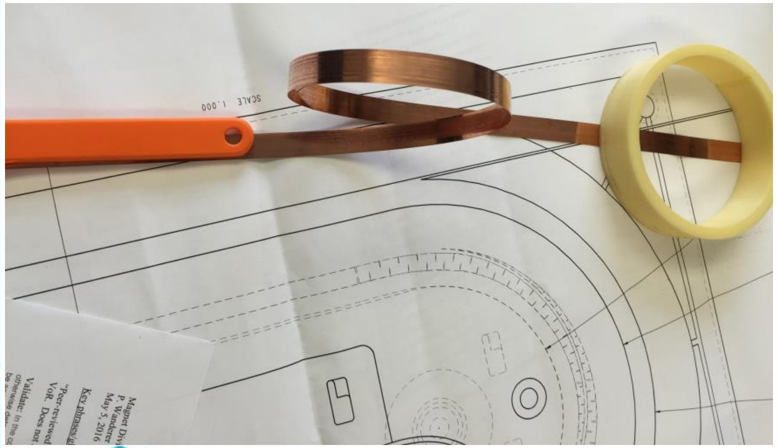
Bill will make sure that everything looks OK under the microscope

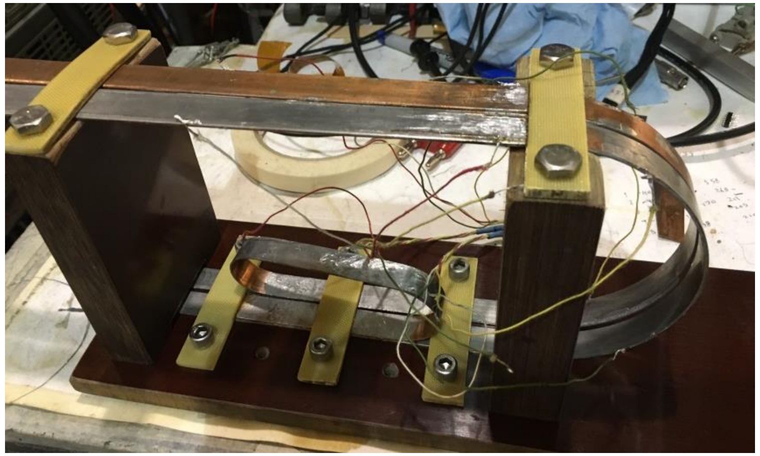
Common coil insert configuration - a key component - splice that accommodate coils moving apart under Lorentz forces (Bill implemented a clever solution)



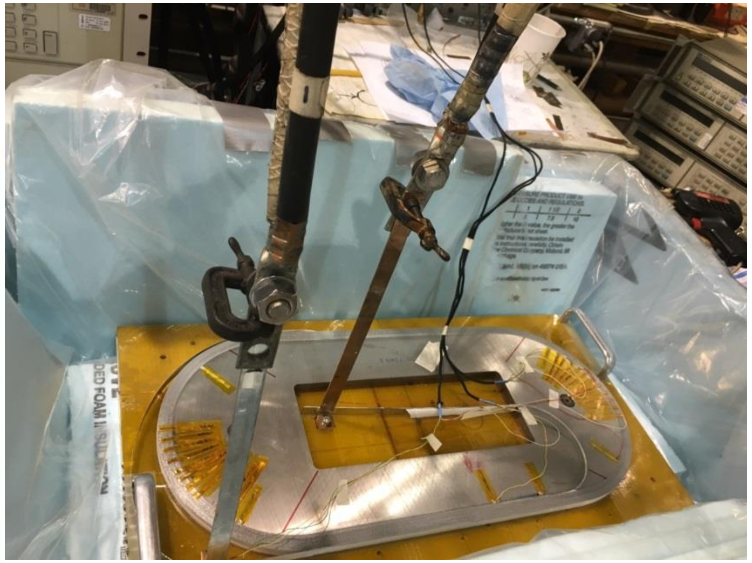


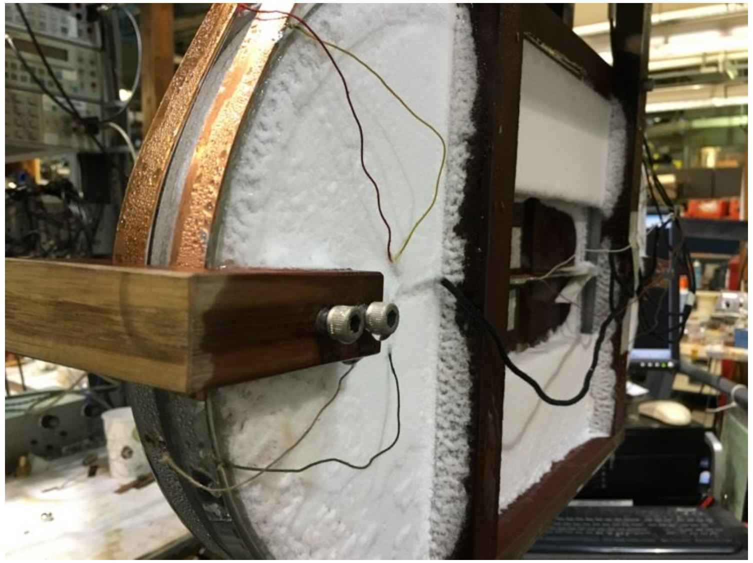


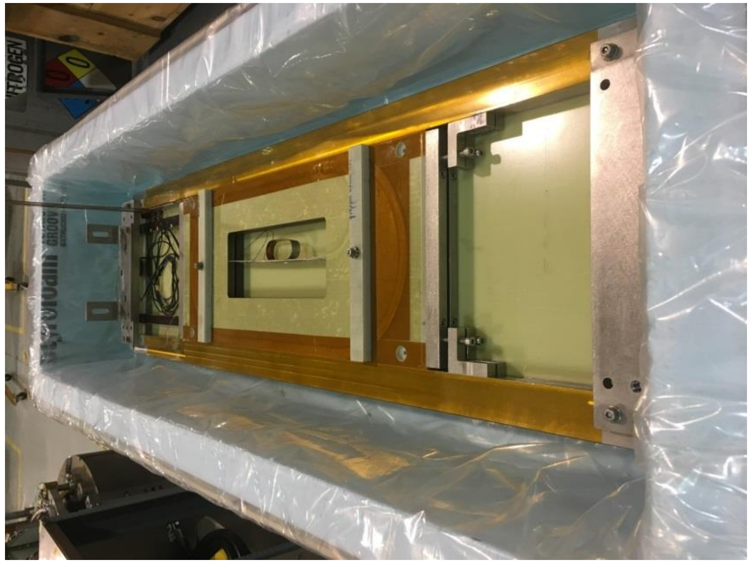


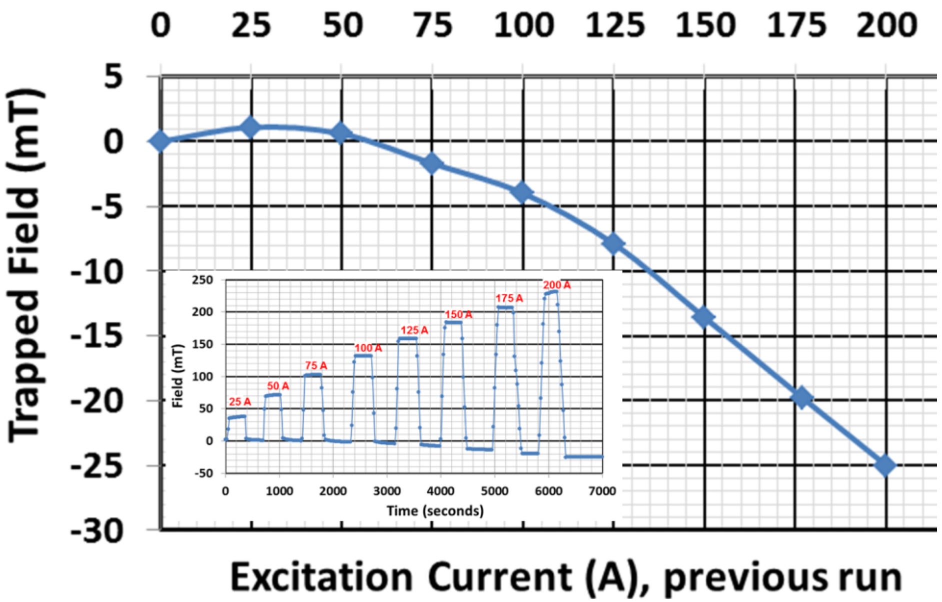


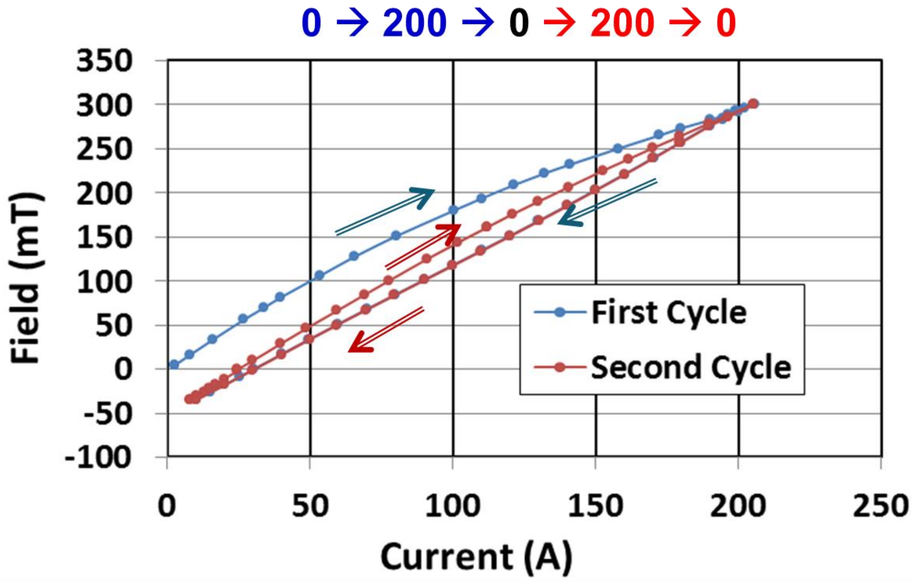
Bill Performed a Variety of 77 K Measurements of the HTS Coils in Various Configurations for Critical Current and Magnetization





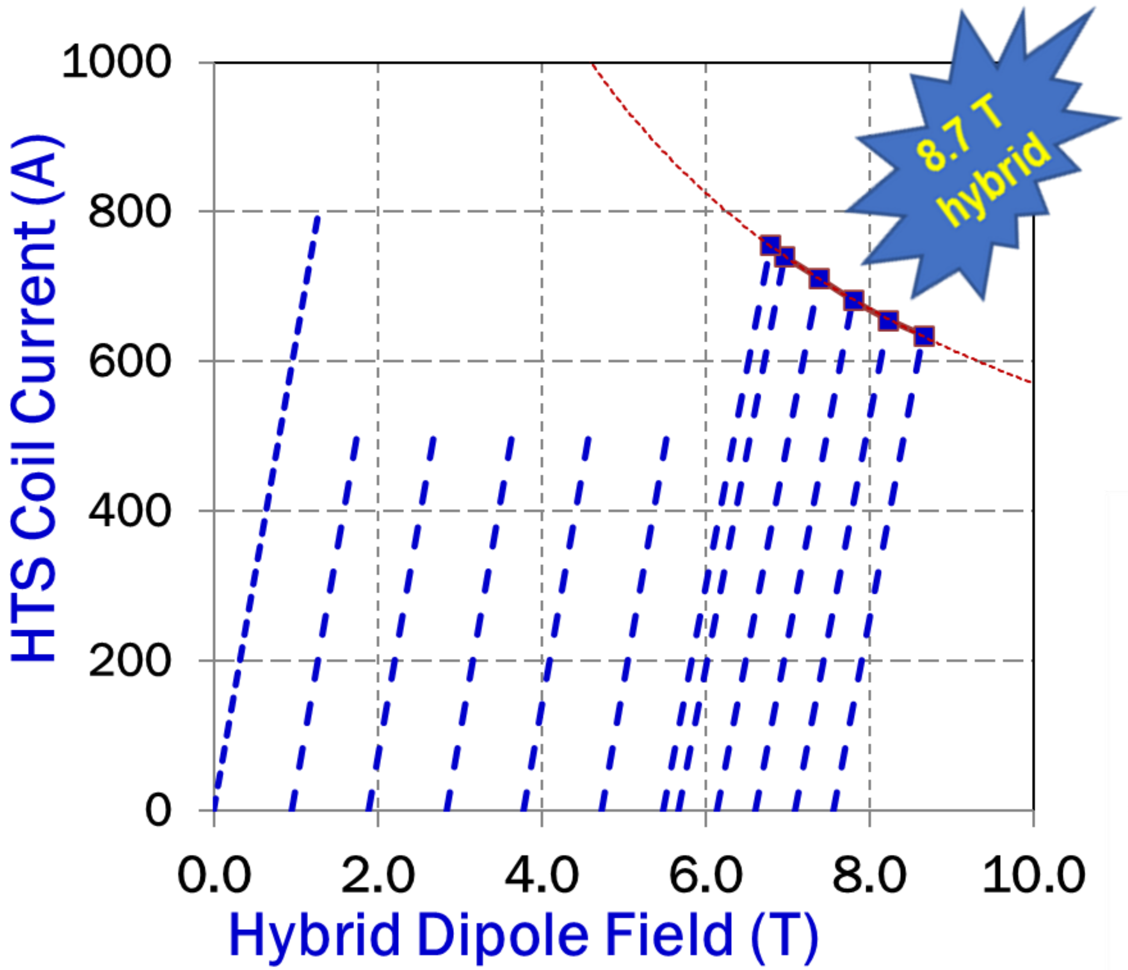






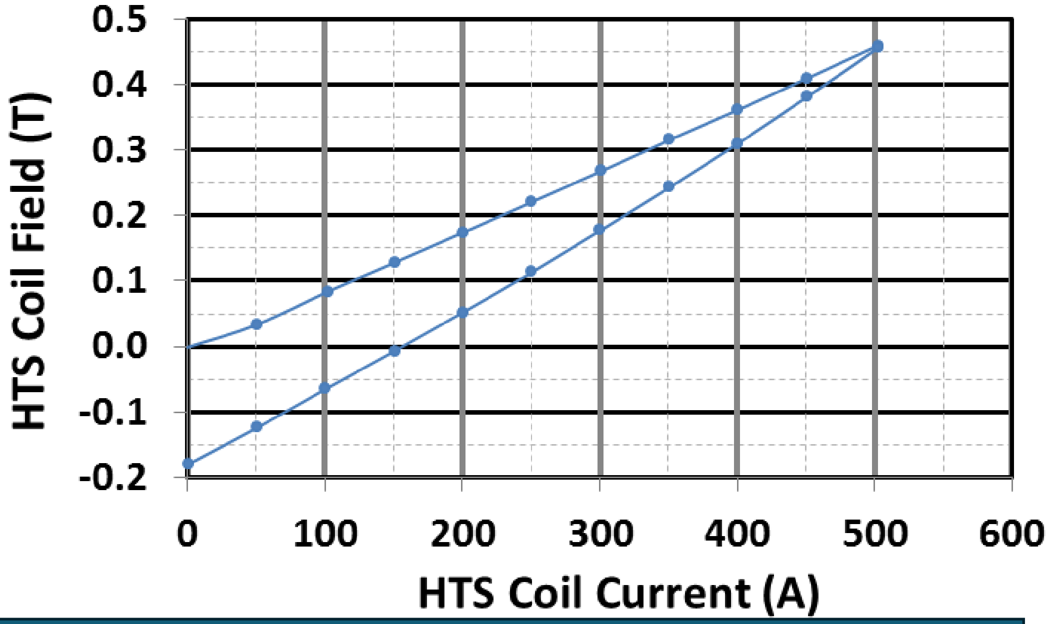
An Important Demonstration of a Significant HTS/LTS Hybrid Dipole

Bill made sure that we did all measurements carefully (record field and magnetization)

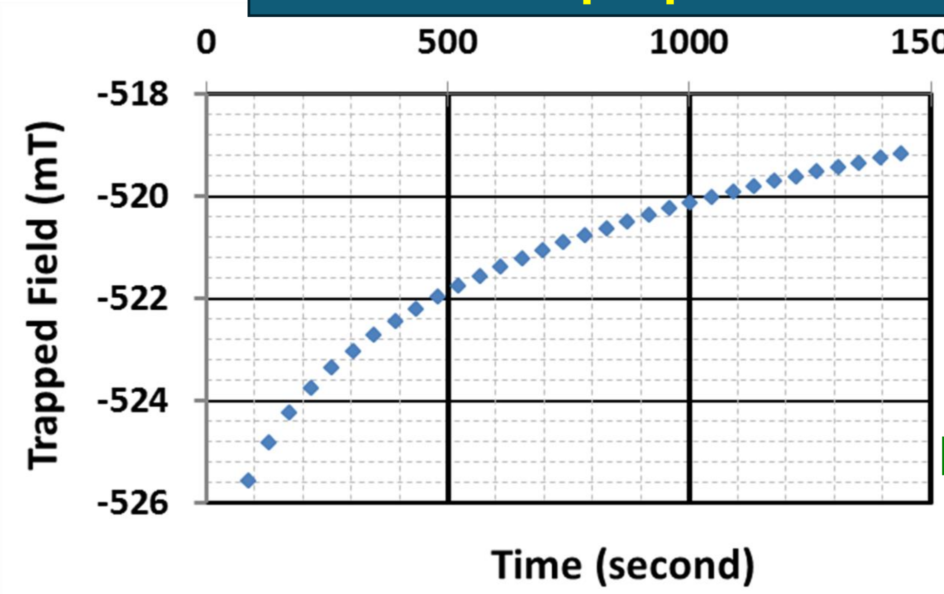


Test Run at 4 K

(2T from Nb_3Sn coils)



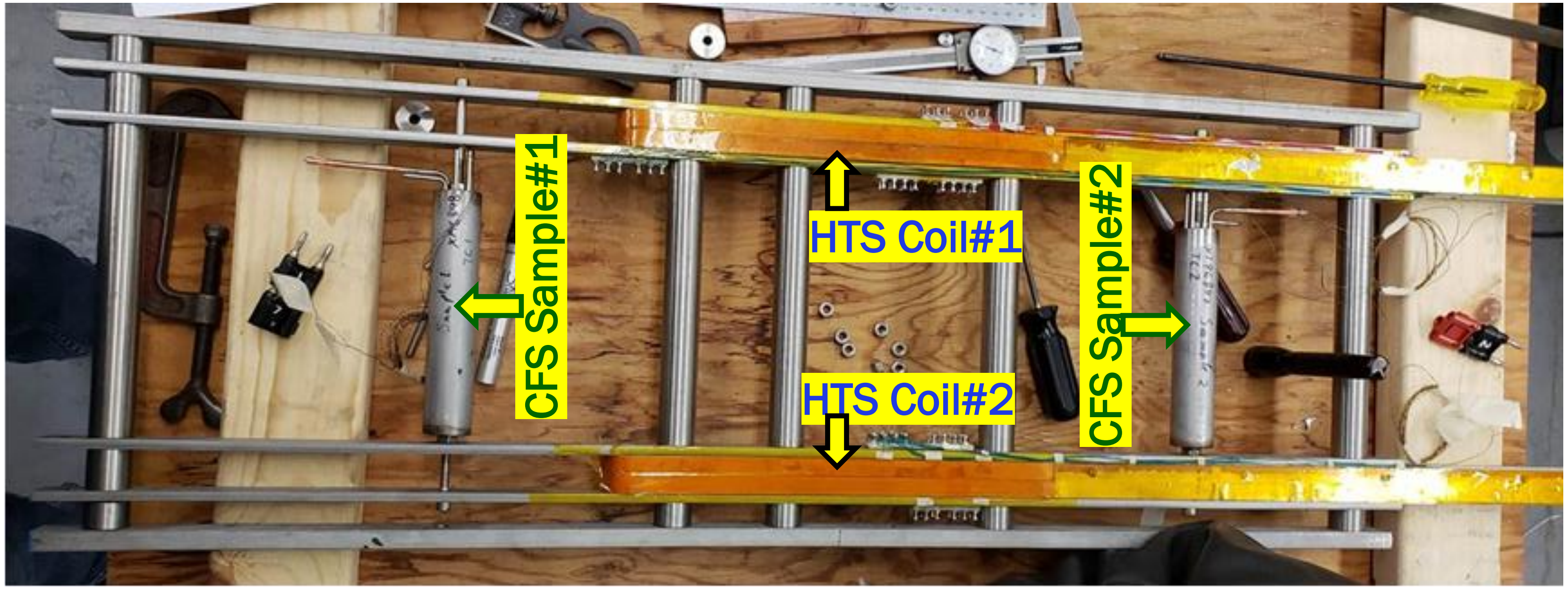
STTR: Field perpendicular configuration



Decay of Trapped Field

after the final run to ~8.7 T hybrid field @4K

HTS Coils Primary Parallel to the Field for HTS/LTS Hybrid High Field Test (MDP)

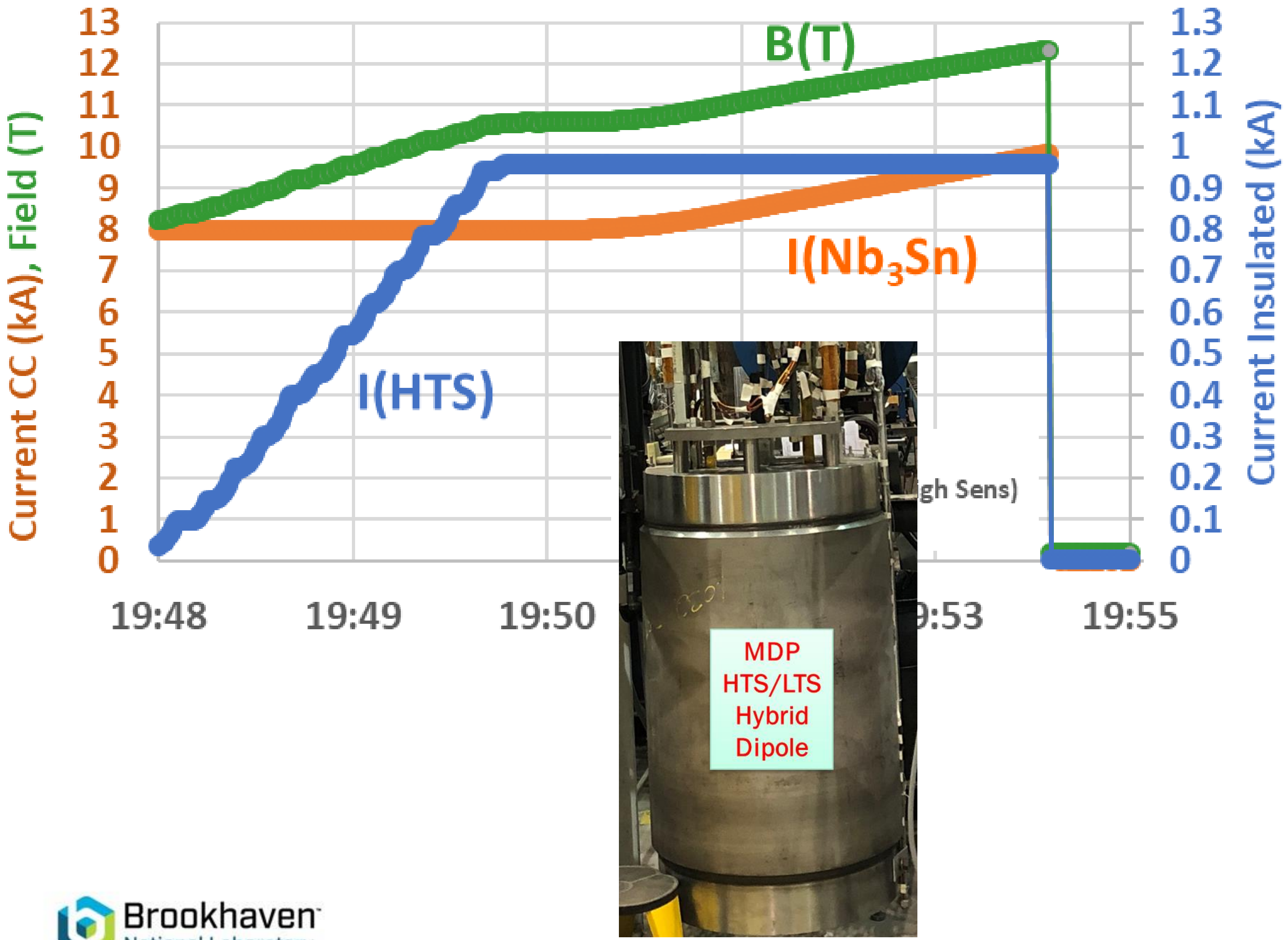


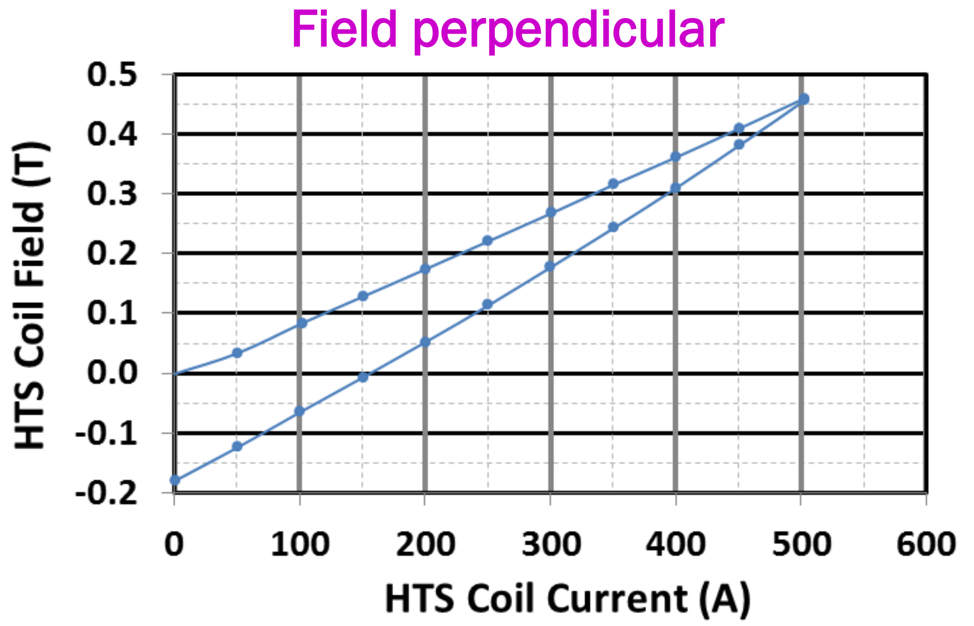
Bill Sampson came-up with a very simple structure, made by the technicians of his sketches, using the off-the-self parts.

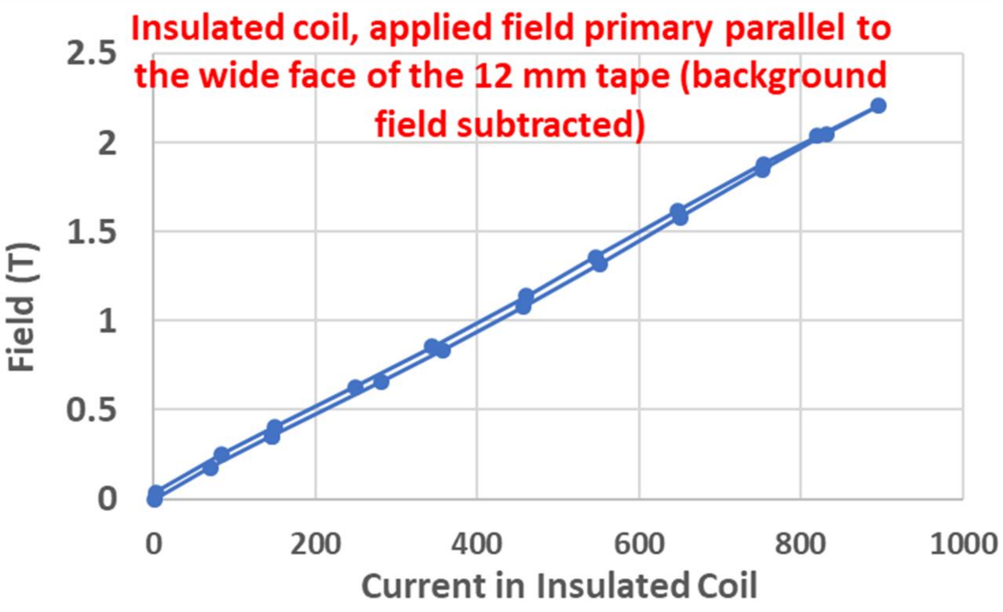
Typical mode of operation for Bill.
Low-cost, fast-turn-around, and it worked.

HTS/LTS Hybrid Magnet Test (MDP) with Magnetization Studies

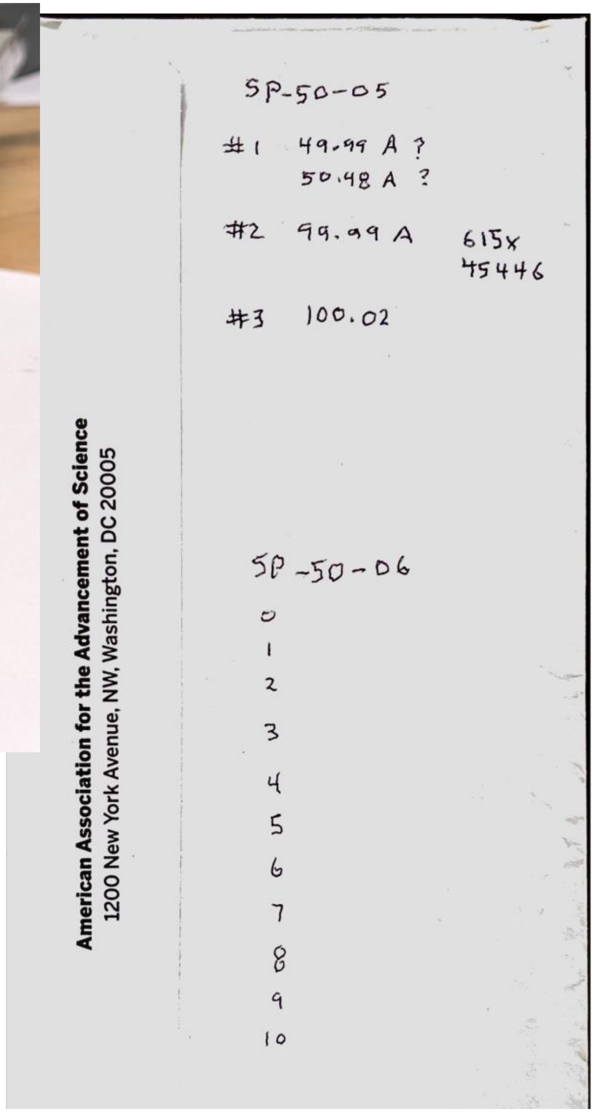
Record Hybrid Field: 12.3 T







Bill's Last HTS Measurements @ 77K



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SP-50-05

#1 49.99 A ?
50.48 A ?

#2 99.99 A 615x
45446

#3 100.02

SP-50-06

0
1
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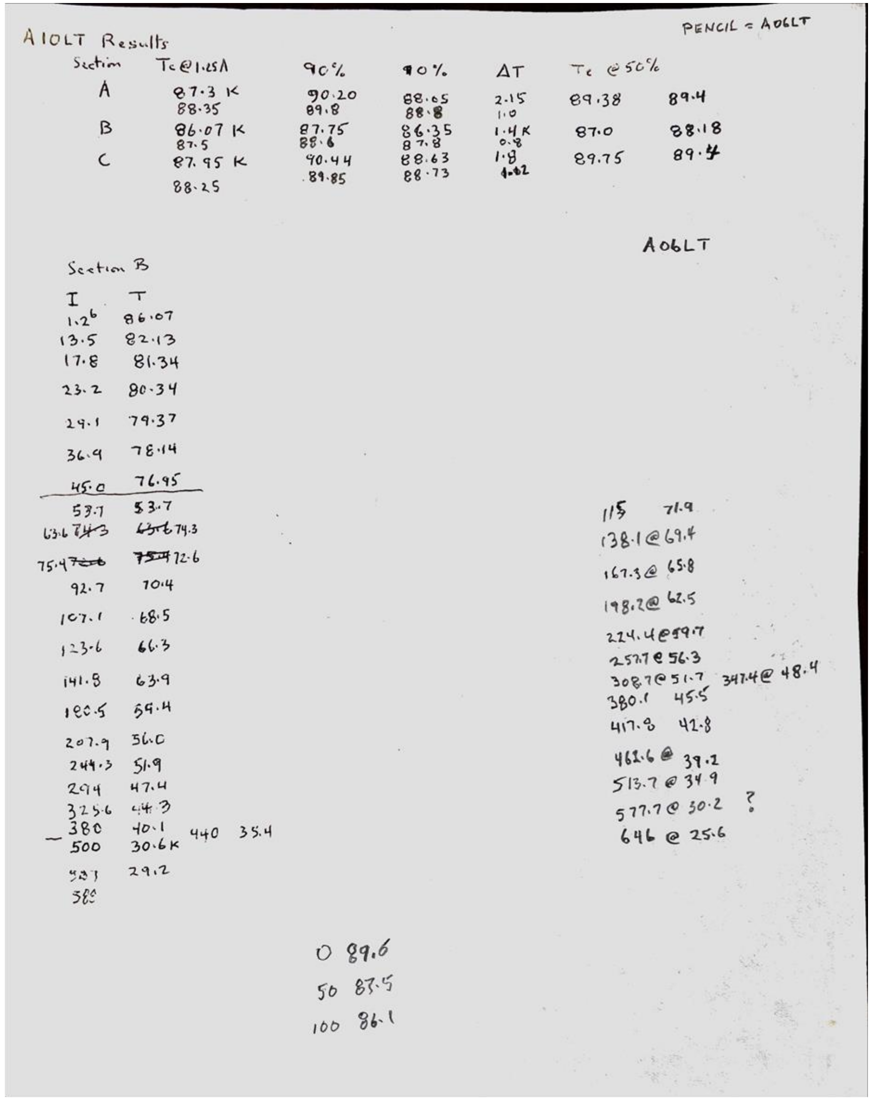

PENCIL = A06LT

A10LT Results

Section	Tc@1.25A	90%	10%	ΔT	Tc @50%	
A	87.3 K 88.35	90.20 89.8	88.65 88.8	2.15 1.0	89.38	89.4
B	86.07 K 87.5	87.75 88.6	86.35 87.8	1.4 K 0.8	87.0	88.18
C	87.95 K 88.25	90.44 89.85	88.63 88.73	1.8 1.02	89.75	89.4

A06LT

Section B

I	T
1.26	86.07
13.5	82.13
17.8	81.34
23.2	80.34
29.1	79.37
36.9	78.14
45.0	76.95
53.7	53.7
63.6	74.3
75.4	72.6
92.7	70.4
107.1	68.5
123.6	66.3
141.8	63.9
180.5	59.4
207.9	56.0
244.3	51.9
294	47.4
325.6	44.3
380	40.1
500	30.6K
523	29.2
580	

440 35.4

115 71.9
138.1 @ 69.4
167.3 @ 65.8
198.2 @ 62.5
224.4 @ 59.7
257.7 @ 56.3
308.7 @ 51.7 347.4 @ 48.4
380.1 45.5
417.8 42.8
462.6 @ 39.2
513.7 @ 34.9
577.7 @ 30.2 ?
646 @ 25.6

0 89.6
50 87.5
100 86.1

Acknowledgments (on behalf of Bill Sampson)

- Tenure program at the national laboratories - without which such a talent would not have been able to contribute so much
- Support from the SBIR/STTR program – without which HTS R&D in so many variety of programs would not have been possible
- Conductor manufacturers – who gave conductor to us, particularly in early days, at a highly discounted rate; sometimes even free of charge in return of testing and highlighting their progress
- Fellow technicians (plus scientific and engineering staff) who will work from Bill's sketches and sometimes work during their lunch time or extra hours to help Bill – so was the force of his personality

To Wrap up, in Summary

- Bill Sampson was a passionate scientist, who wanted to demonstrate scientific principles in an as simple way as possible. ... and he was successful in doing that, so many times.
- Bill Sampson was pioneer in superconducting magnet technology for about 60 years. He made several important contributions.
- As I tried to convey, they were enormous in developing and demonstrating HTS coil and HTS magnet technologies themselves.
- We miss Bill. I personally miss Bill for so much of what he did, and how he did. I, forever, will be grateful and indebted to him.
- Thank you for organizing this memorial session for William (Bill) Sampson and thank you for allowing me to share my memories.