BNL Program and Possibilities

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HTS Magnet R&D Program at BNL

We are developing "conductor friendly designs" for several applications based on flat racetrack coils with large bend radius. All can use HTS.

We have started a magnet R&D program that systematically develop technology and design principle for future HTS magnets. 10-turn coil program has been quiet successful so far.

BNL has expertise in a variety of areas which provide an opportunity to develop not only good vendor-user relation but a collaboration to further develop this field. We have common interest.

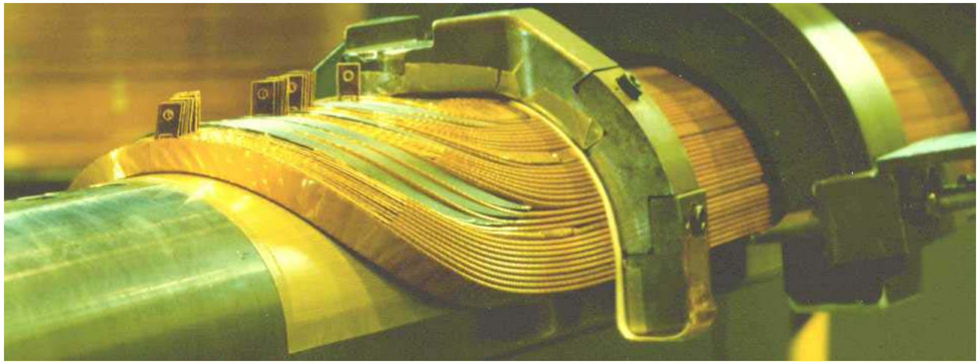
High Field Magnet Design

Design Issues:

- Must use brittle superconductors

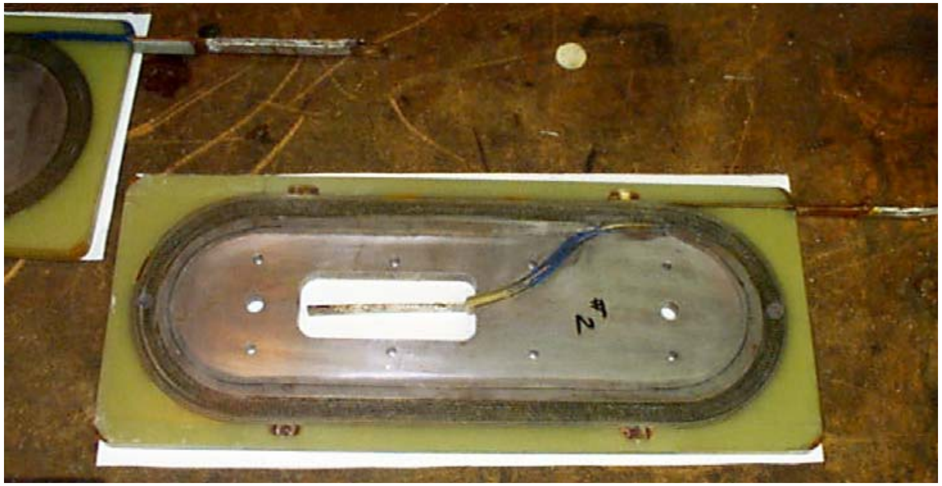
  Nb_3Sn, HTS

- Large Lorentz forces
- Large energy deposition



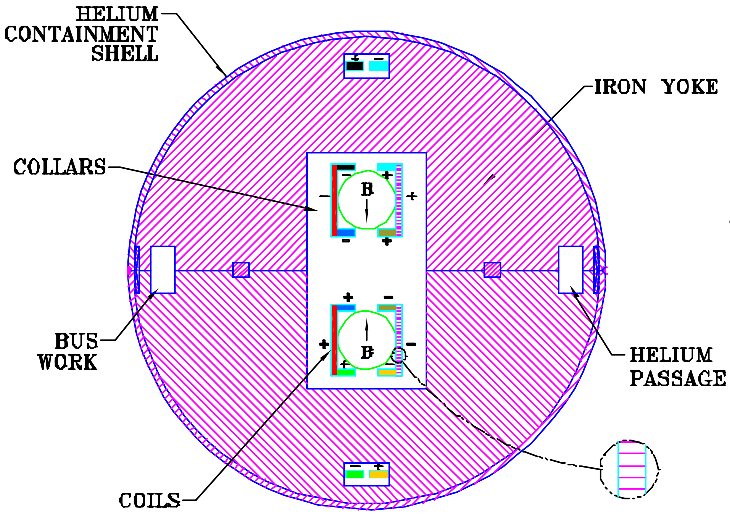
Conventional design (e.g., RHIC magnets)

- Complex 3-d geometry -- not suitable for high fields



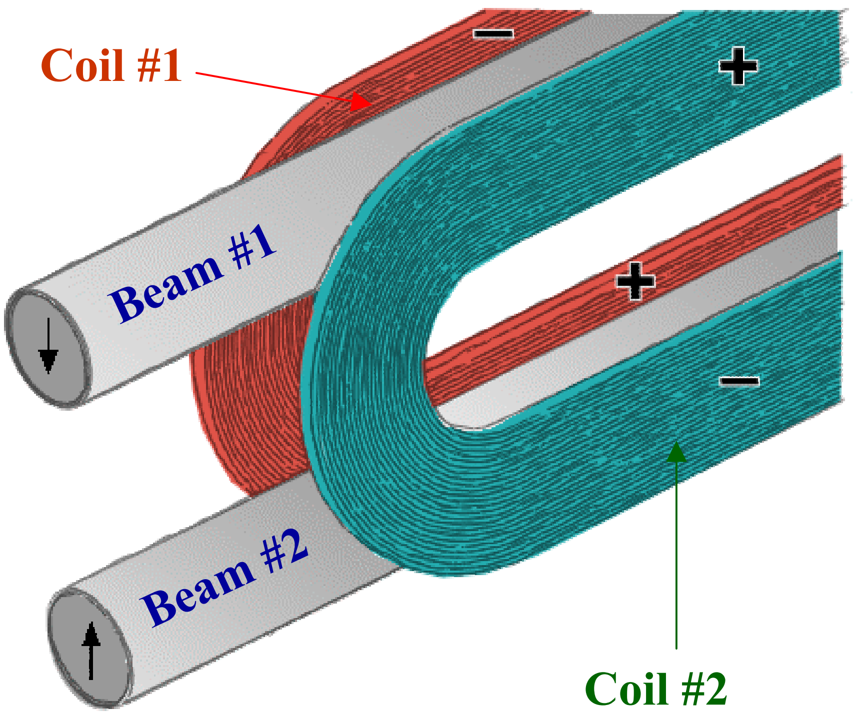
Conductor friendly racetrack coil geometry (separate program)

- Suitable for high field magnets with brittle material



Common Coil Design
(The Basic Concept)

- **Simple 2-d** geometry with large bend radius ()
- **Conductor friendly** (no complex 3-d ends, suitable for brittle materials - most for H.F. are - Nb_3Sn and HTS)
- **Compact** (compared to single aperture LBL's D20 magnet, half the yoke size for two apertures)
- **Block design** (for handling large Lorentz forces at high fields)
- **Combined function** magnets possible
- **Efficient** and methodical **R&D** due to simple & **modular design**
- **Minimum** requirements on big expensive **tooling and labor**
- **Lower cost magnets** expected



Main Coils of the *Common Coil Design*

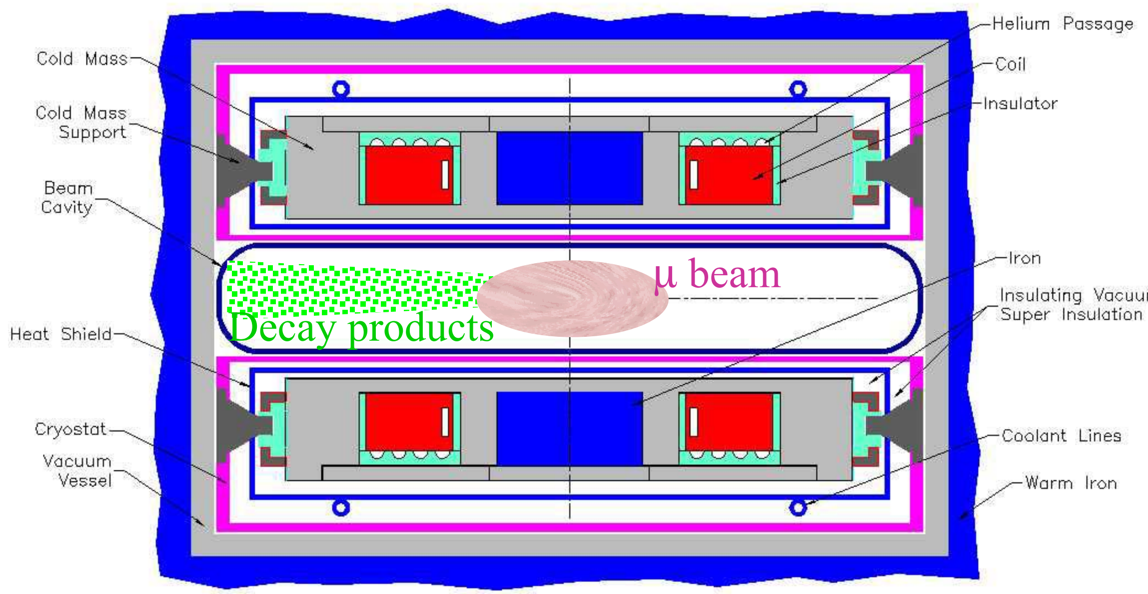
Magnet Design for ν Factory Storage Ring

Design Principles and Requirements:

Decay products clear superconducting coils

Compact ring to minimize the environmental impact (the machine is tilted)

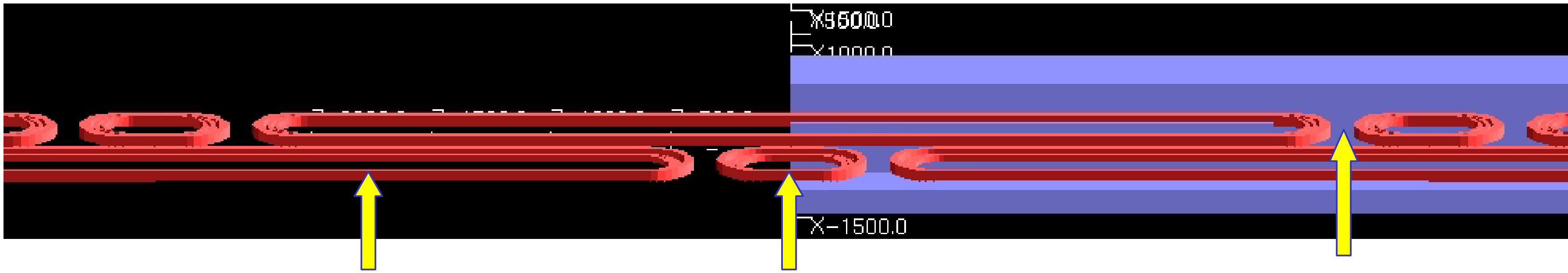
⇨ Need high field magnets and efficient machine design



Storage ring magnet design

(simple racetrack coils with open midplane)

Efficient Magnet System Design for Good Field Quality in Body & in Ends

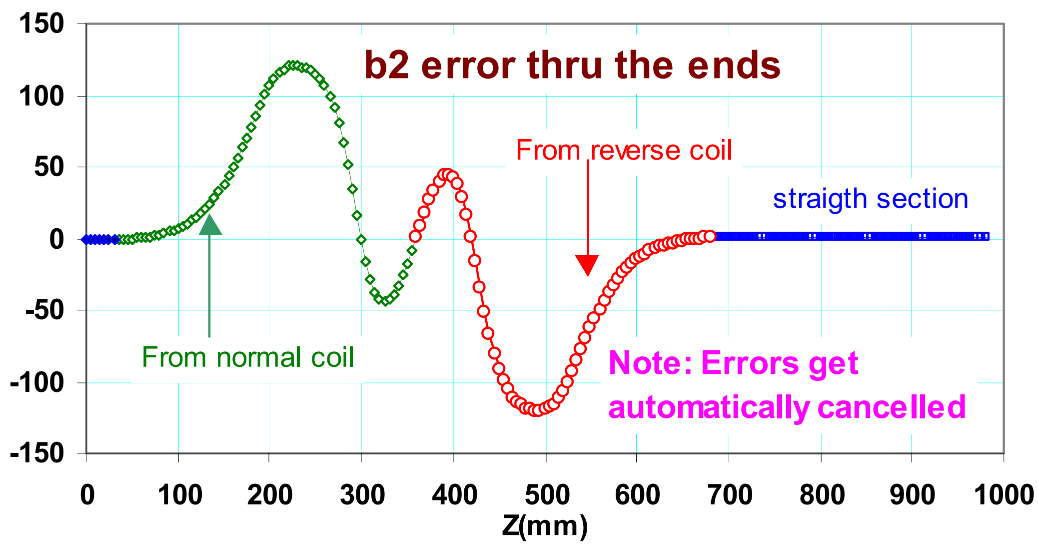


Normal Coils
Dipole

Reverse Coils
Skew Quad

(Reverse coils cancel field errors in the ends)

One Coil
1/2 & 1/2



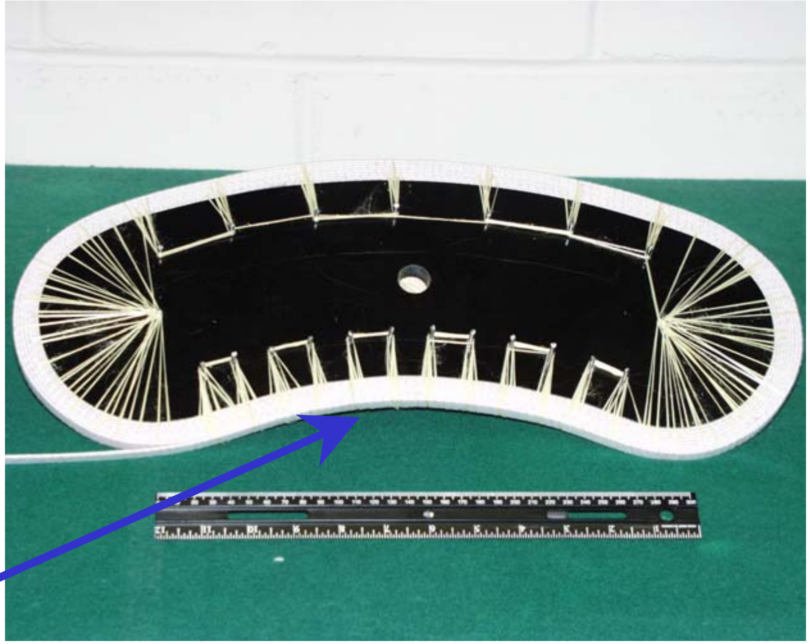
No space is wasted.

- Two normal coils makes a dipole
- Reverse field coils makes a skew quad
- Space between the two coil ends makes a combined function magnet region

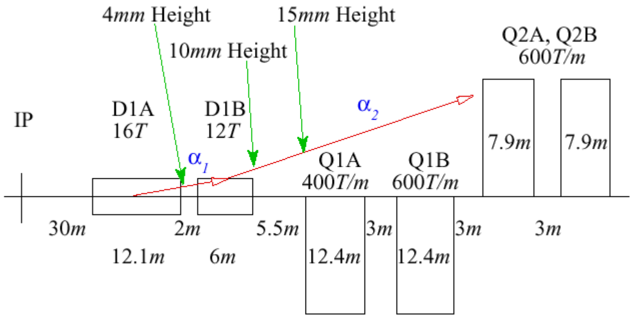
Status and Progress

Significant progress (accomplishments) and innovations to date

- **Conceptual design completed**
- **Initial magnetic and mechanical analysis performed**
  - magnet design is strongly coupled with the lattice design (being developed in parallel under different funding)
- **A method to obtain large reverse curvature devised**



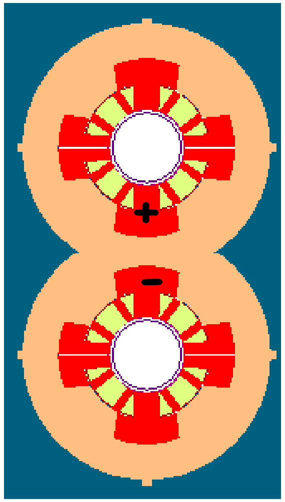
New Magnet Design For Efficient VLHC-2 Interaction Region



Optics and magnet requirements (field & aperture) depends crucially on the minimum spacing in the first 2-in-1 IR Quad (doublet optics)

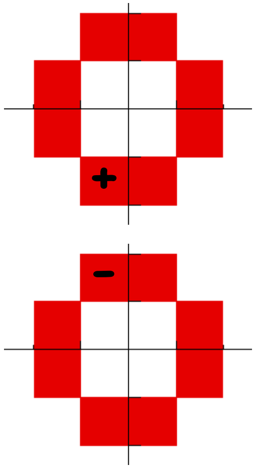
23KW of beam power radiated from the IP makes this a natural for HTS

Conventional 2-in-1 cosine theta design

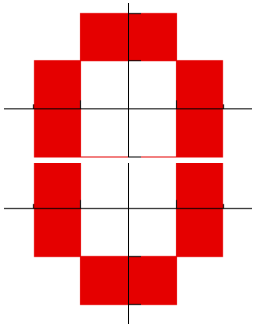


Spacing depends on the conductor and support structure requirements

Panofsky 2-in-1 quad design

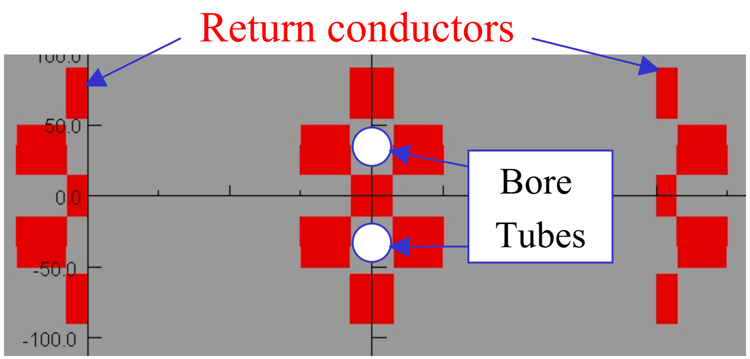


Modified Panofsky Quad



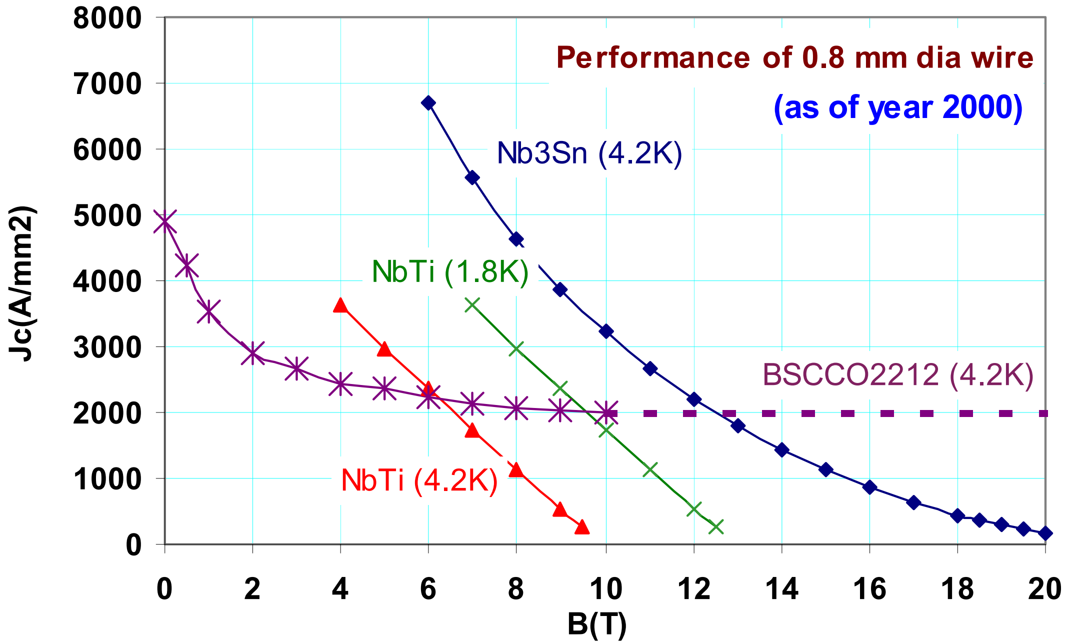
(Bo not zero)

Conductor friendly and better field quality design



Support structure and middle conductor is removed/reduced. This reduces spacing between two apertures significantly.

Expected Performance of HTS-based Magnets



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

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)

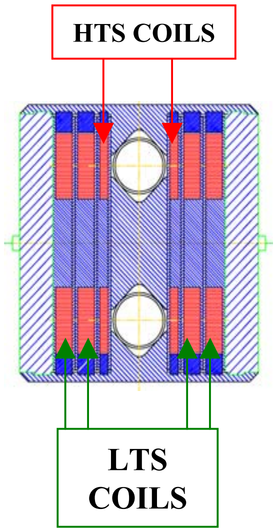
BSCCO-2212: 4000 A/mm^2 (2X from today)

Cu(Ag)/SC Ratio

BSCCO: 3:1 (all cases)

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

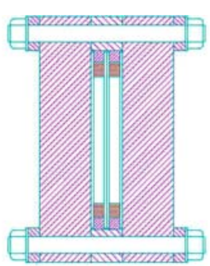
Common Coil Magnet R&D at BNL



Primary Goal of the Program:

Design and build a ~12.5 Tesla, "React & Wind" Common Coil Magnet with HTS playing a major role.

R&D Plan to Develop Technology:



A "*mini 10-turn magnet R&D program*" to systematically develop and test new ideas, designs and technologies (React & Wind HTS) in a time and cost effective manner.

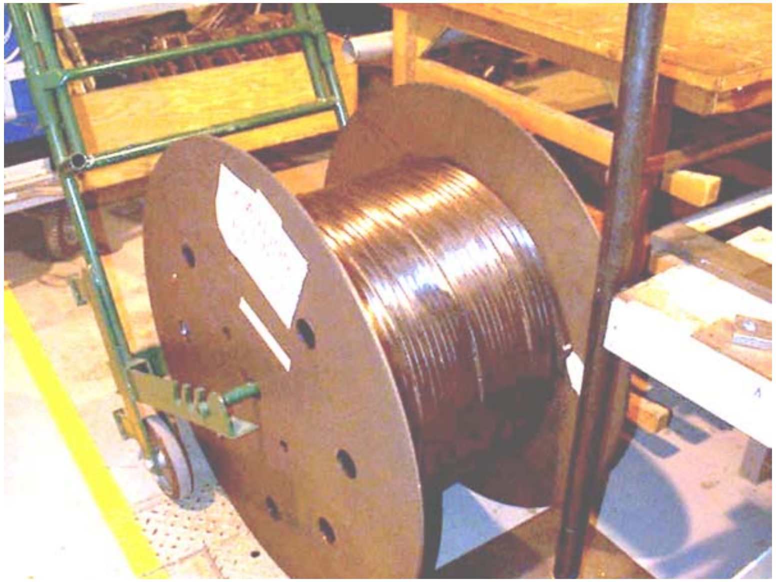
With a fat turn-around and relatively lower developmental cost, we can afford to built many coils in order to systematically develop new technology.

That philosophy is in-built in the "Program Design"!

Nb_3Sn Reaction Facility at BNL

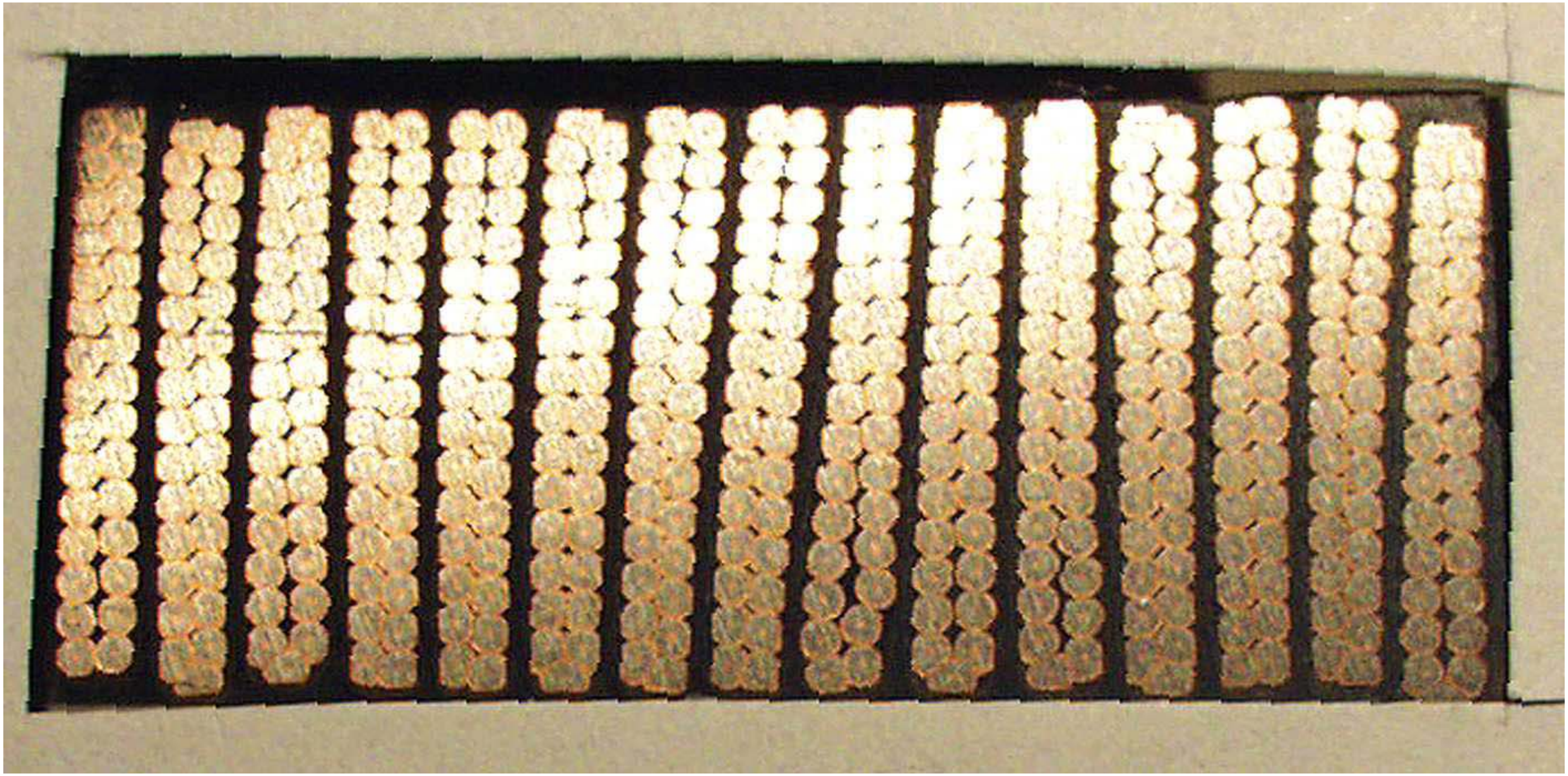
Large (1.5 m^3) reaction furnace at BNL.

It was used for making full length Nb_3Sn magnets.

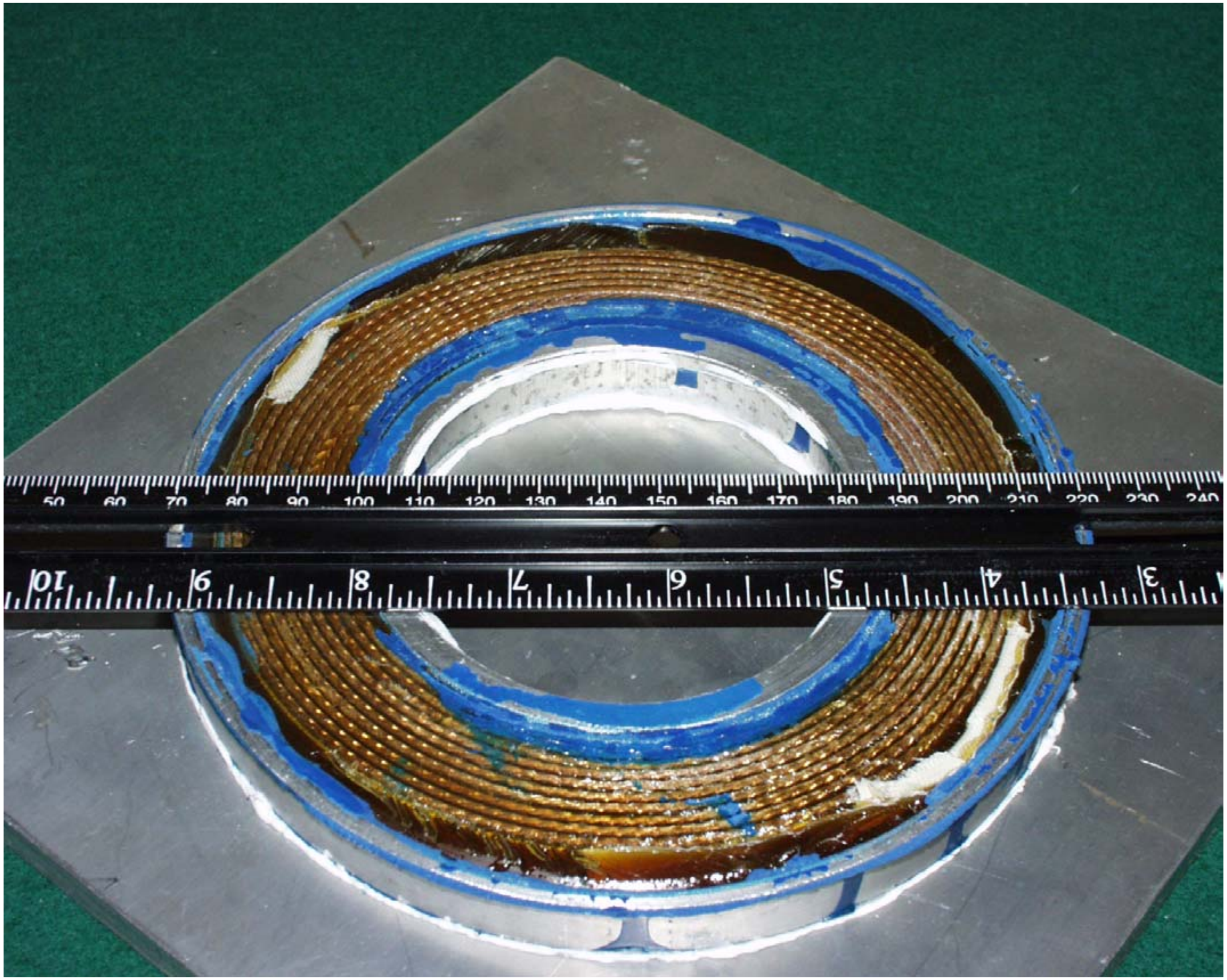


Nb_3Sn cable after reaction.

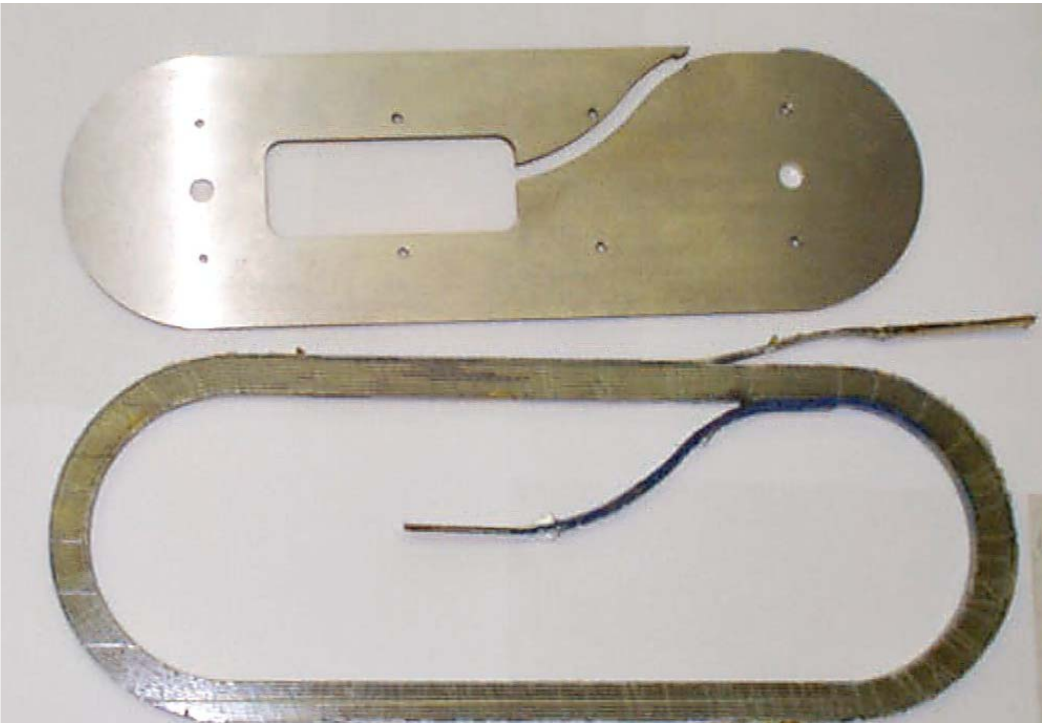
10-turn Vacuum Impregnated Cable sample



Cable Insulation Test Setup



The Bobbin and the 10-turn Coil

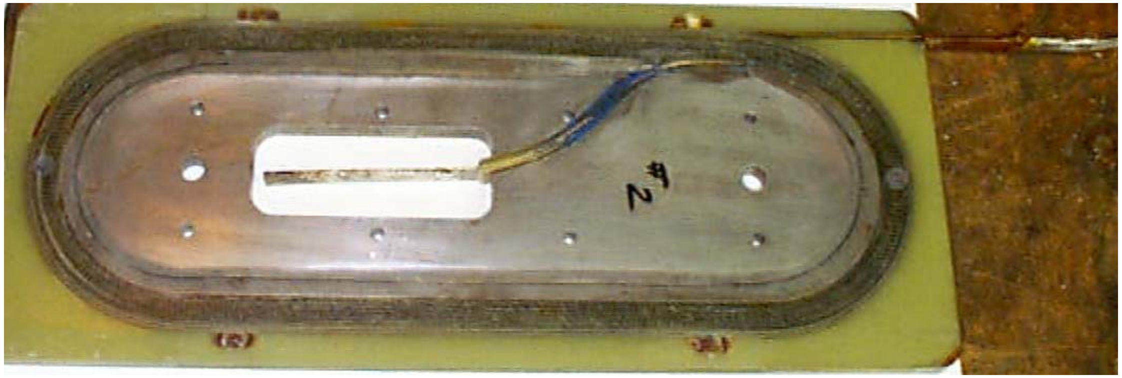


The bobbin

(the coil is wound on it)

The first 10-turn practice coil

(removed from bobbin after impregnation)

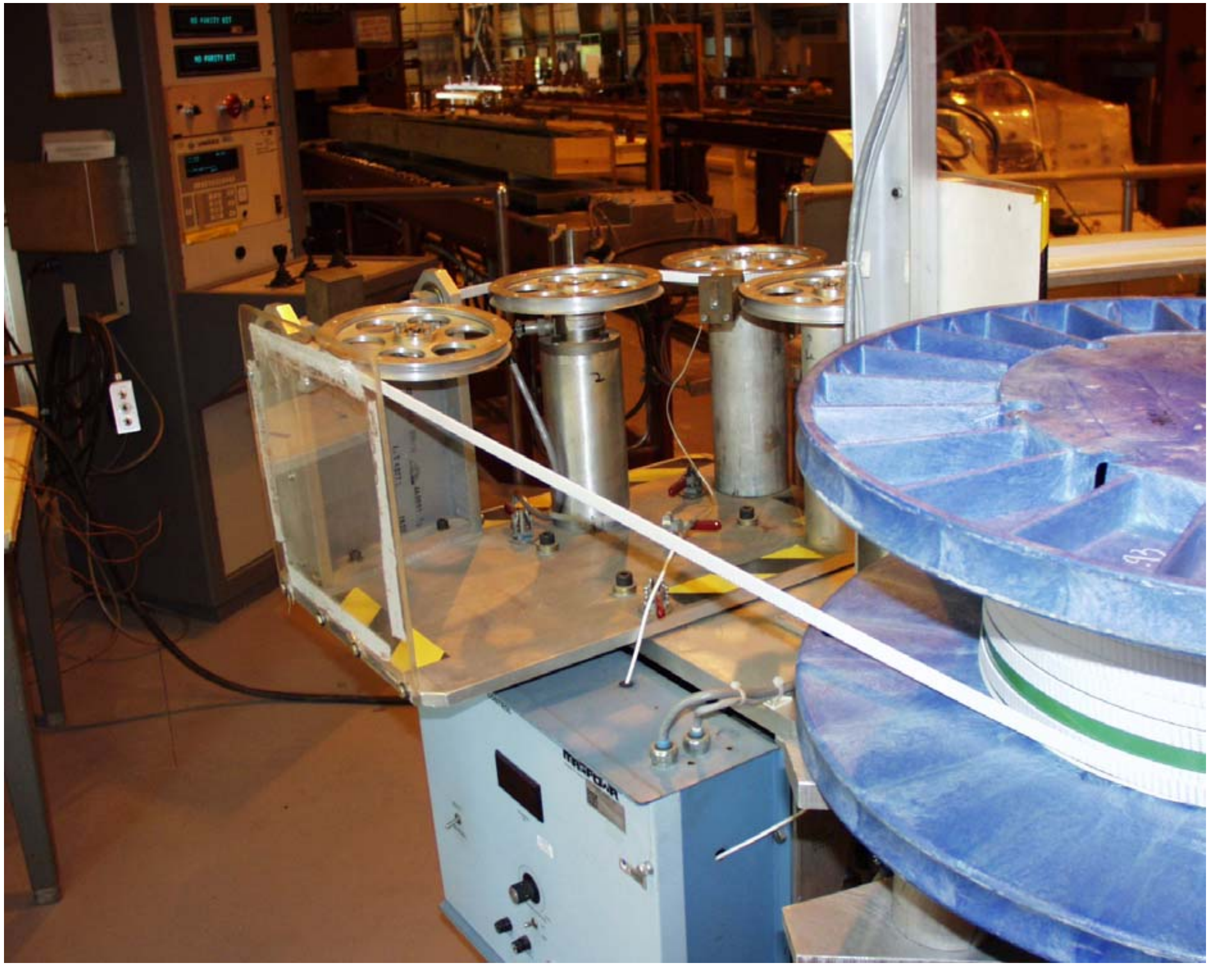


The complete cassette module

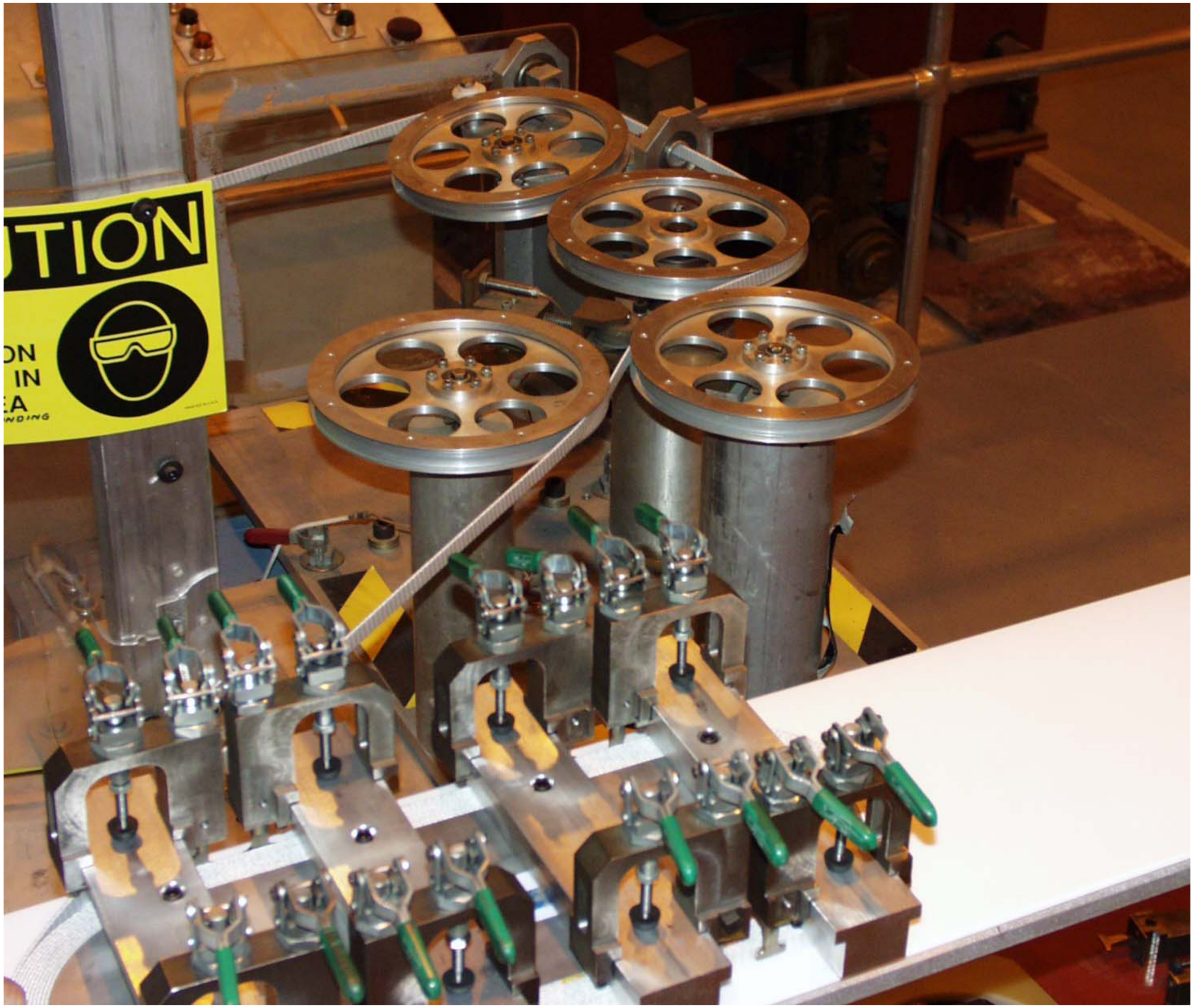
(vacuum impregnated coil in bobbin)

Nb_3Sn Cable Coming Out of Spool

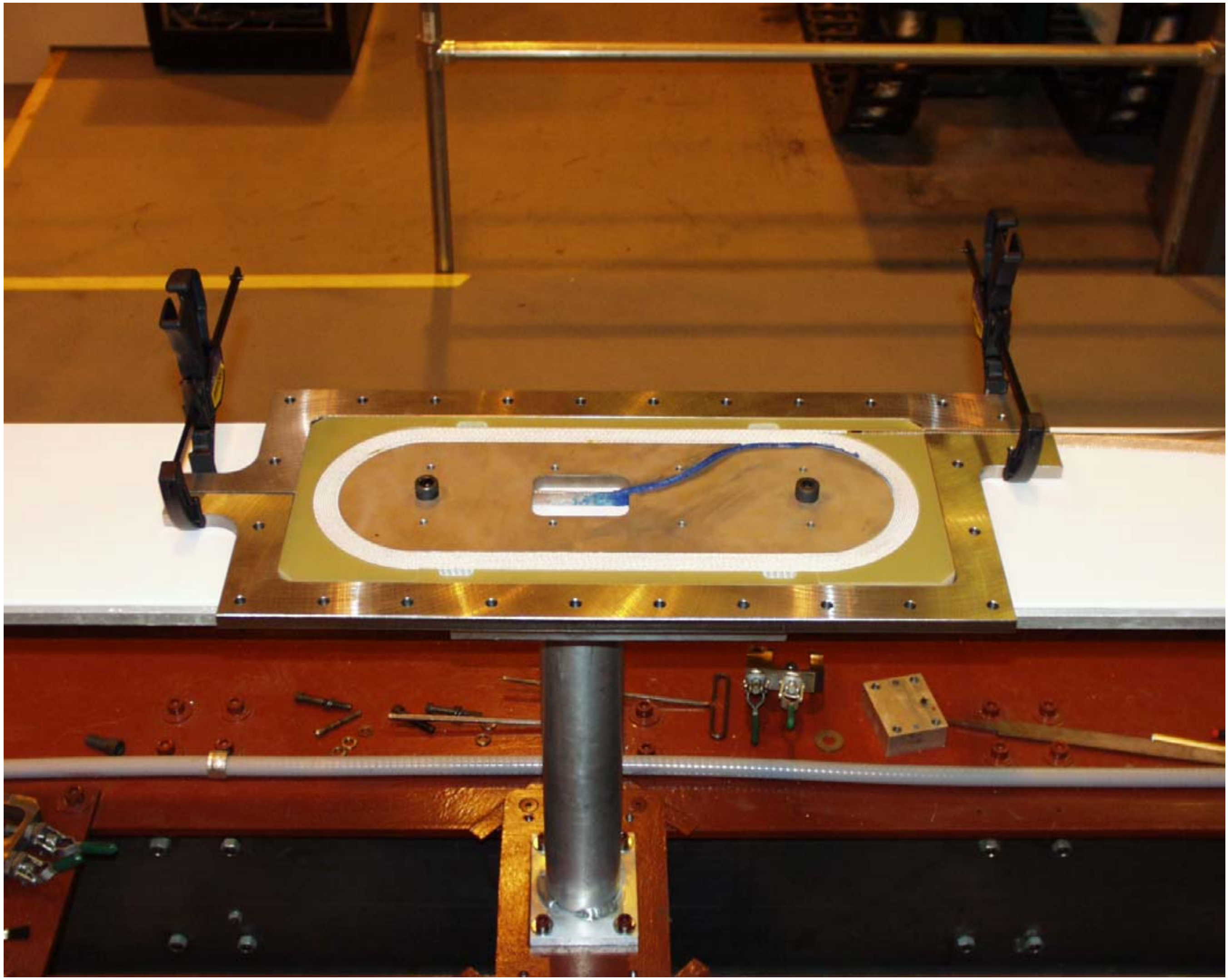
The coil is wound like a regular NbTi coil, of course with proper care (e.g., lower tension). This should help establish procedure, care (cost) required for Nb_3Sn magnets.



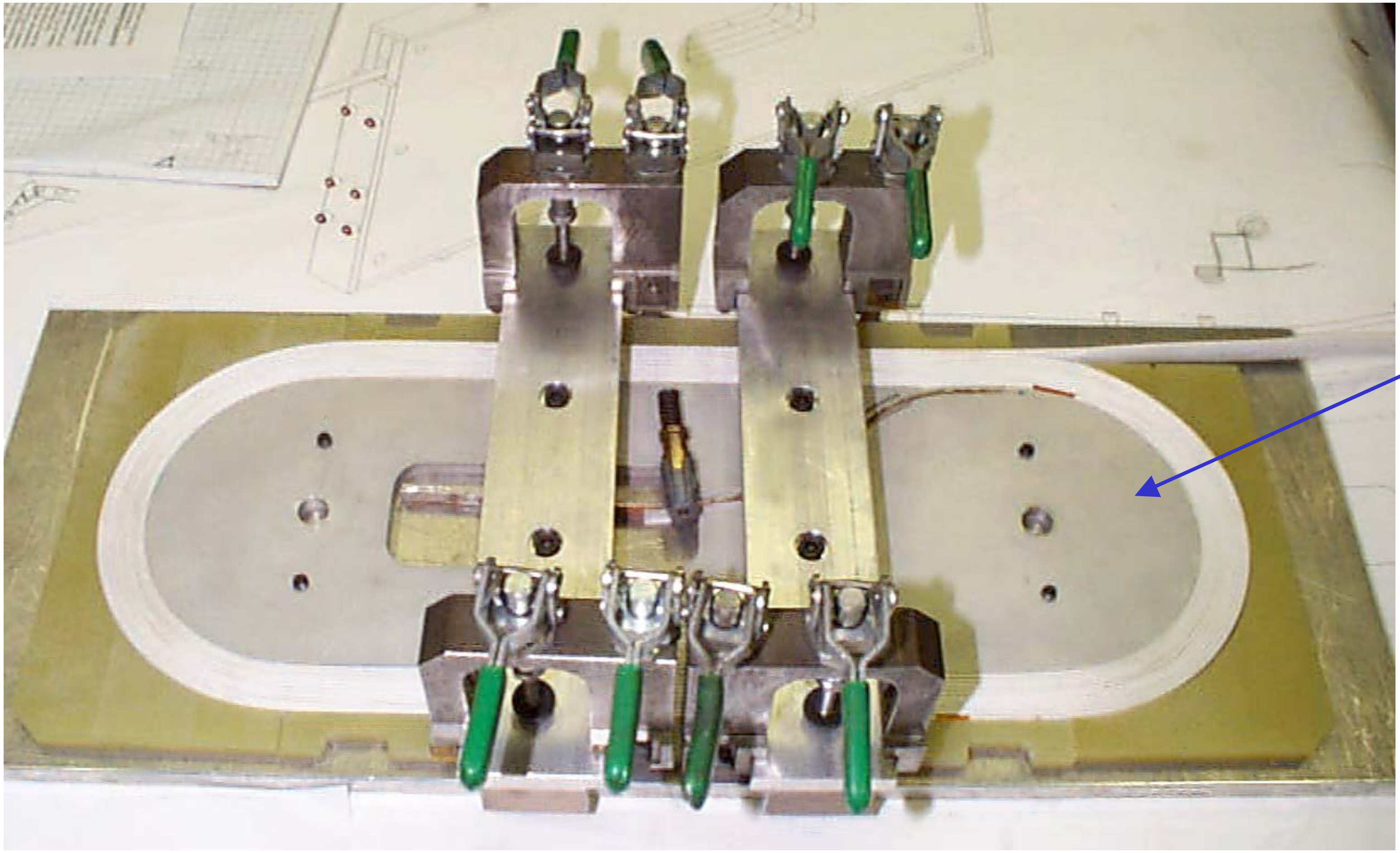
Coil Tensioner with 10-turn coil on the Winding Table



10-turn Coil Being Prepared for Vacuum Impregnation



HTS Coil Wound by Hand

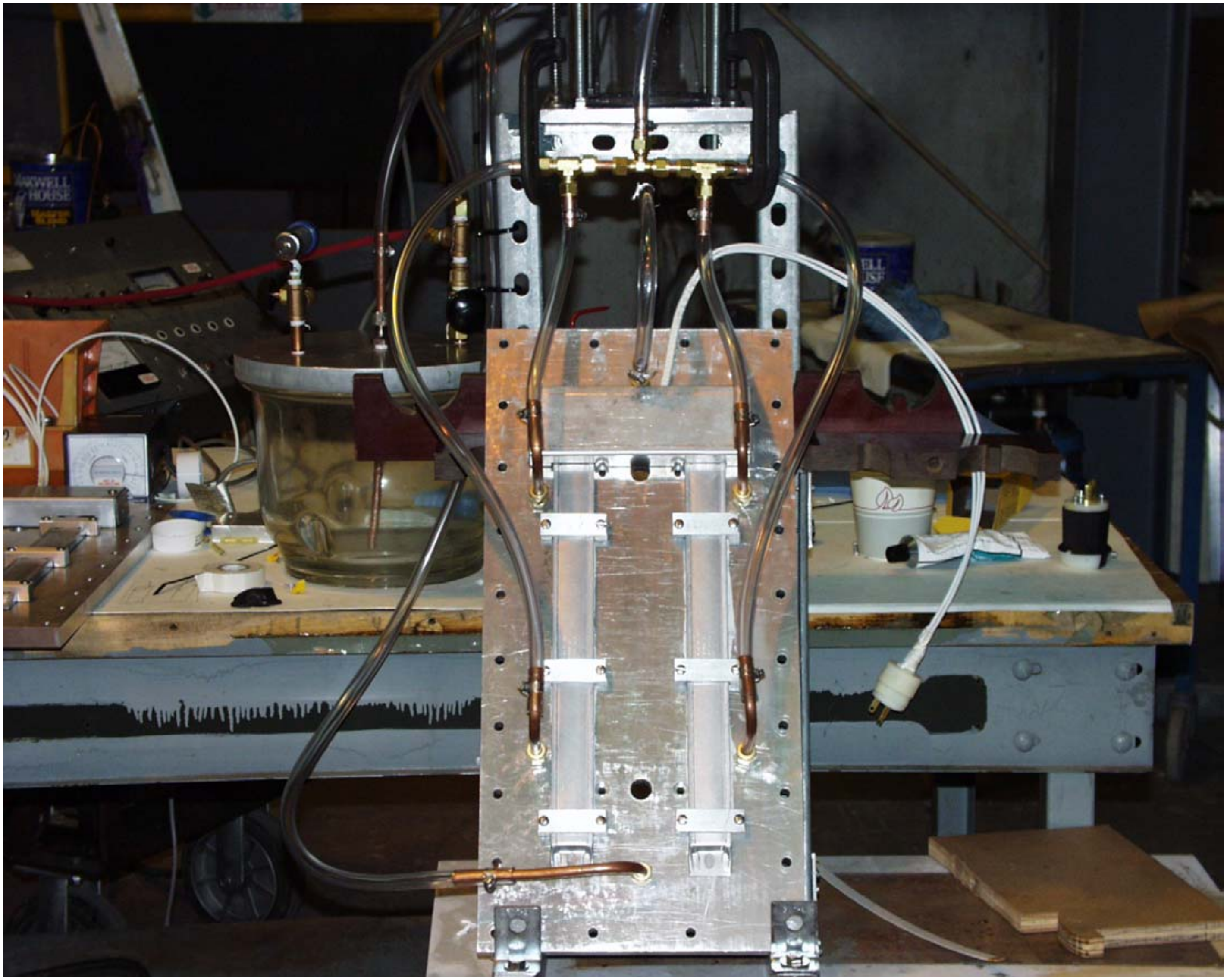


Al Bobbin
(Next SS Bobbin)

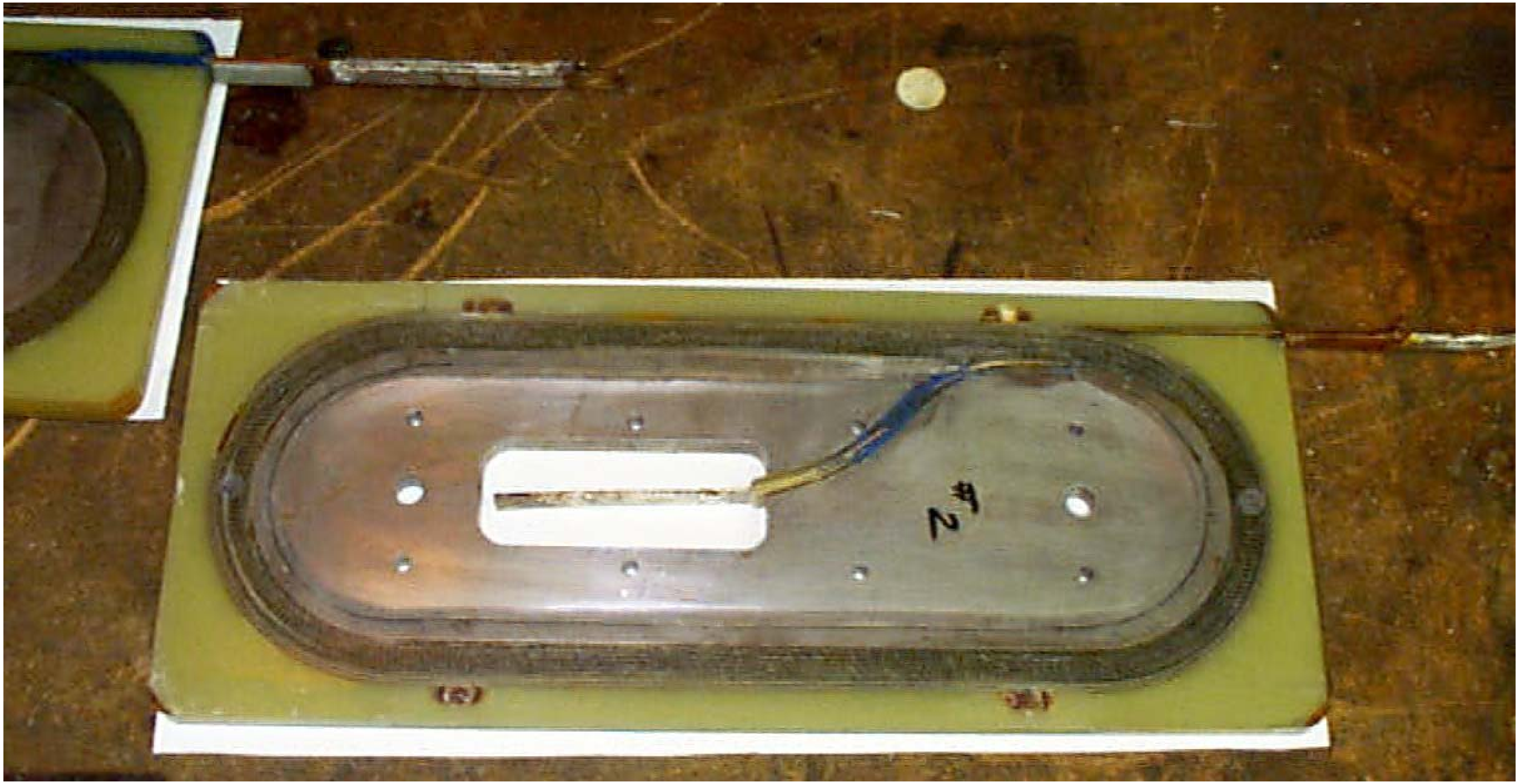
HTS Cable: IGC/Showa/LBNL/BNL collaboration

Fiberglass Sleeve from LBNL

Vacuum Impregnation Setup



Vacuum Impregnated Coils



Vacuum impregnated coils made after "react and wind" technique.

This picture was taken after the coils were tested and removed from the support structure.

HTS Coils in Support Structure

Coils are heavily instrumented. There is a voltage tap after each turn. Data were recorded from all 26 voltage taps.

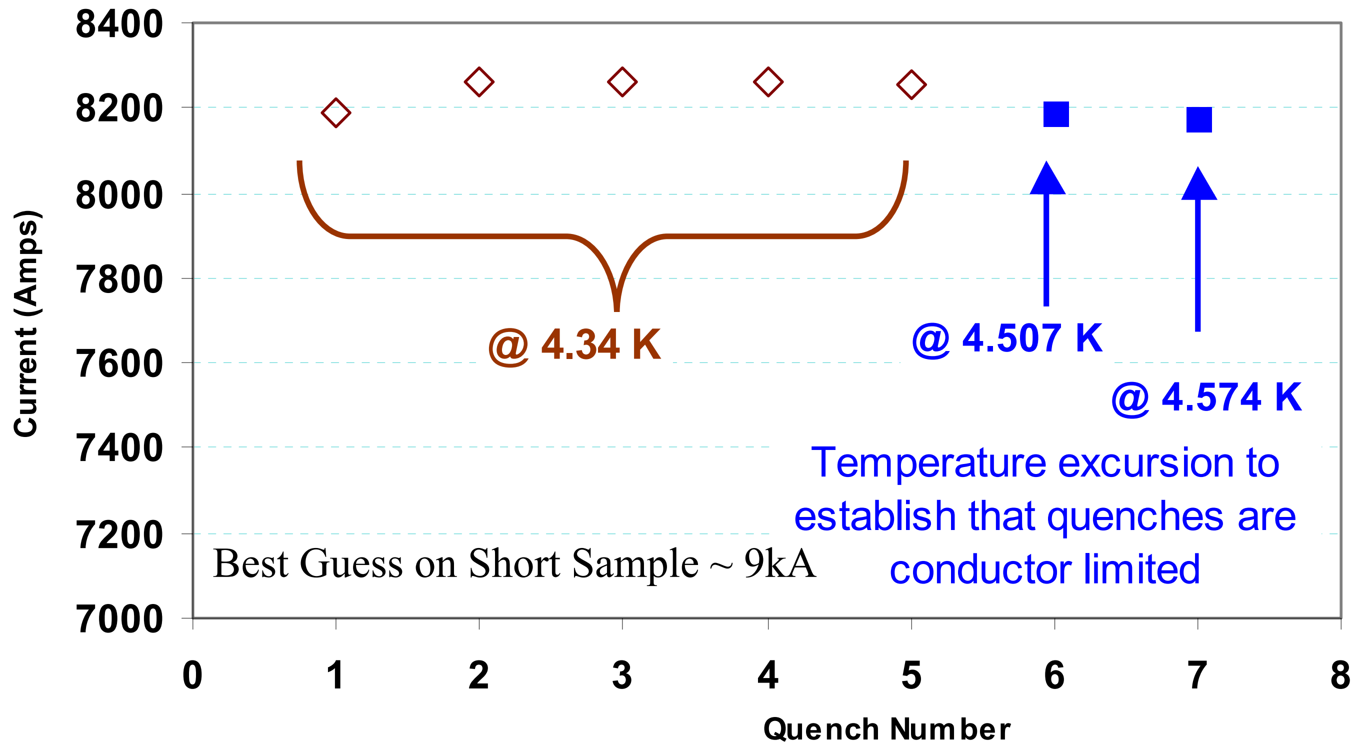
Coils are assembled for the most flexible and extensive testing. Four leads are taken out of the cryostat. During the test the coils were powered separately and together in "common coil" and "split-pair solenoid mode".

Two hall probes (in between two coils and at the center of two coils) also recorded the central field.

First Step: Test The Design and Construction Techniques with React & Wind Nb_3Sn Coils

Test the design with Nb_3Sn coils to eliminate major design & construction flaws

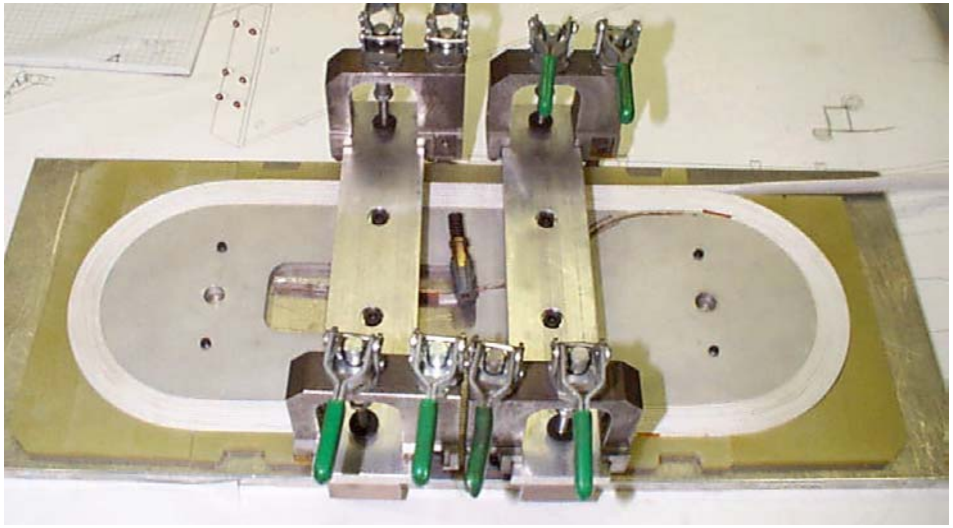
same design (common coil) and similar technology (react & wind)



A reasonable quench performance (one training quench) and relatively small additional cable degradation in first attempt, despite brittle Nb_3Sn being subjected to high strain of NbTi coil making process, is an encouraging sign for the future of "React & Wind" common coil magnets (including scale up process).

Nb3Sn coils were wound by machine and HTS Coils were wound by hand but both have the same 70 mm bend radius.

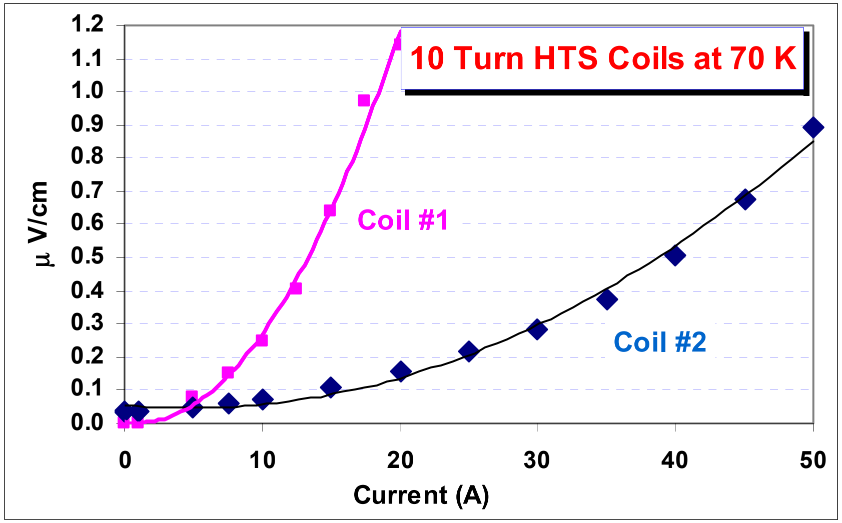
Common Coil Magnets With HTS Cable



HTS cable coil prior to vacuum impregnation

A coil cassette made with HTS cable after vacuum impregnation and instrumentation

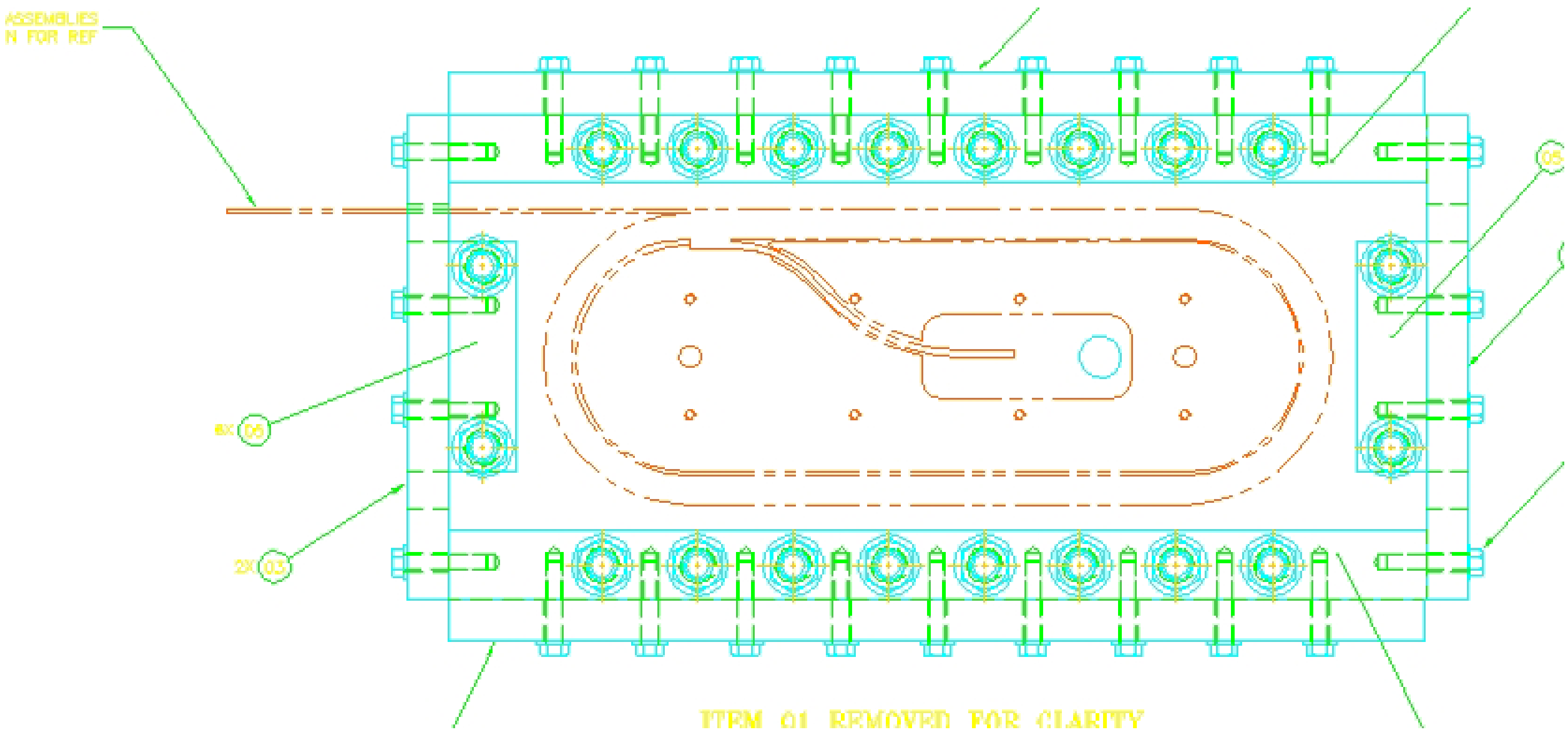
Two coils were tested in Liquid Nitrogen

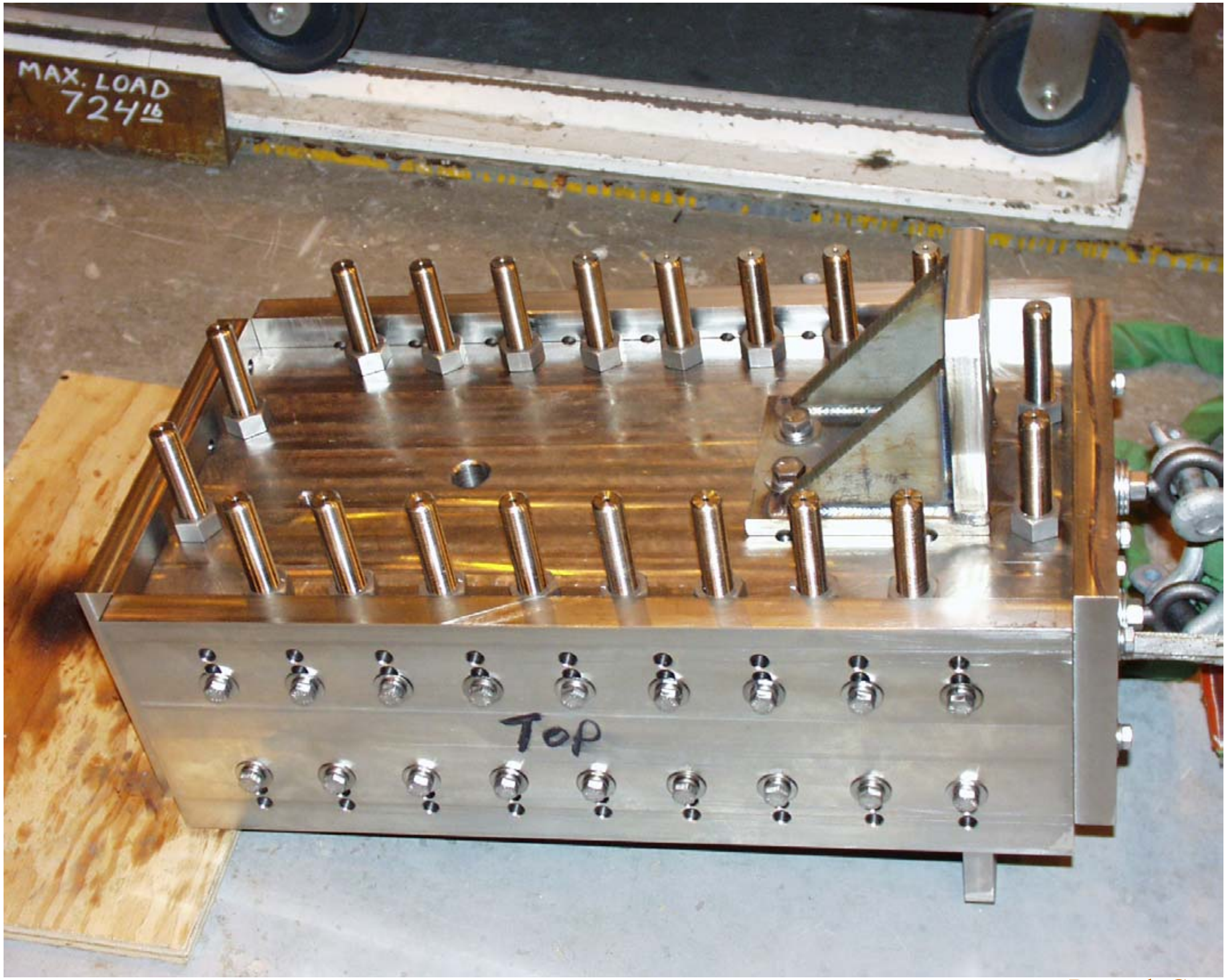


The HTS cables were from two different batches. They behaved differently:

- Different Ic
- Different Tc

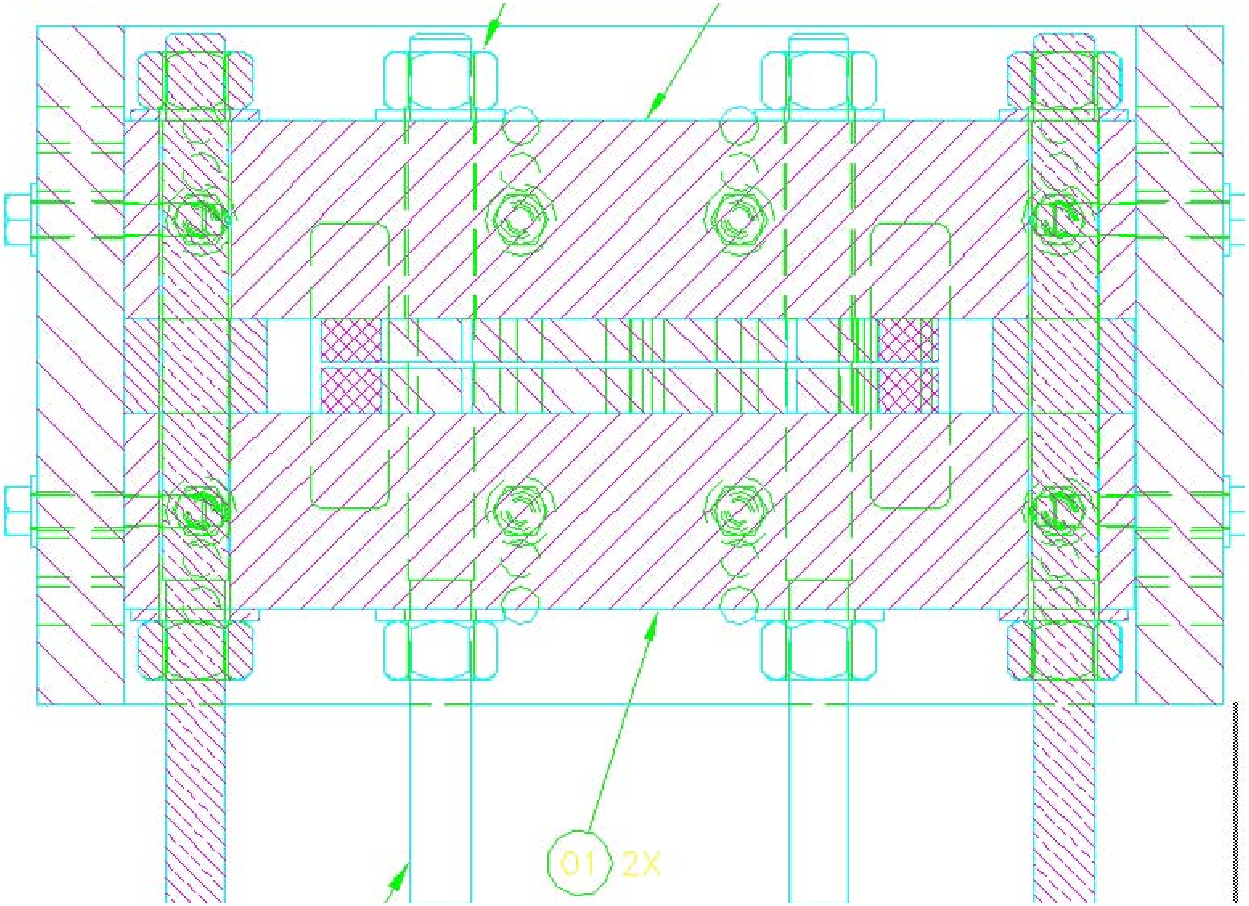
Based on preliminary analysis, no large degradation was observed.


ASSEMBLIES
N FOR REF
8X 06
2X 03
05
ITEM 01 REMOVED FOR CLARITY


MAX. LOAD
724 lb
Top


Top

Potential Cable Test Facility for Testing Small Samples



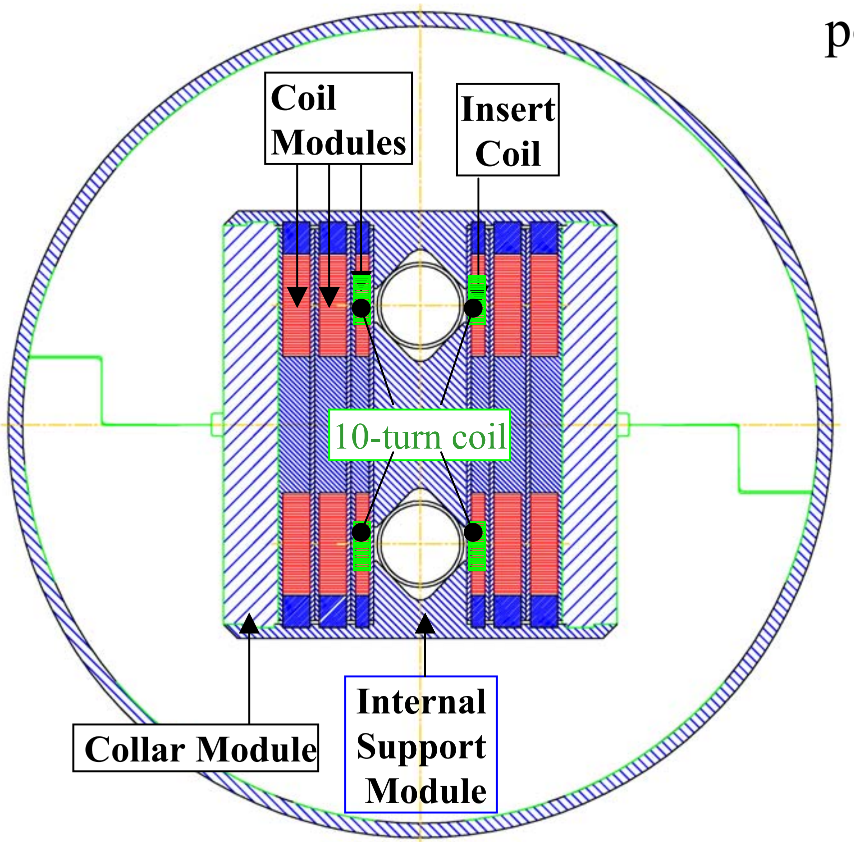
Flat cable (or wire) can be put in the little space between the coil and it becomes a cable test facility.

A Personal Opinion

The "Common Coil Geometry" provides a unique and flexible *"Test Facility*"* for conductor and magnet development.

*a.k.a.:
Magnet R&D Factory

Life of 10-turn Coil Program After 12.5 T Magnet



While we optimize the 12.5 T design for cost, performance and large scale production,

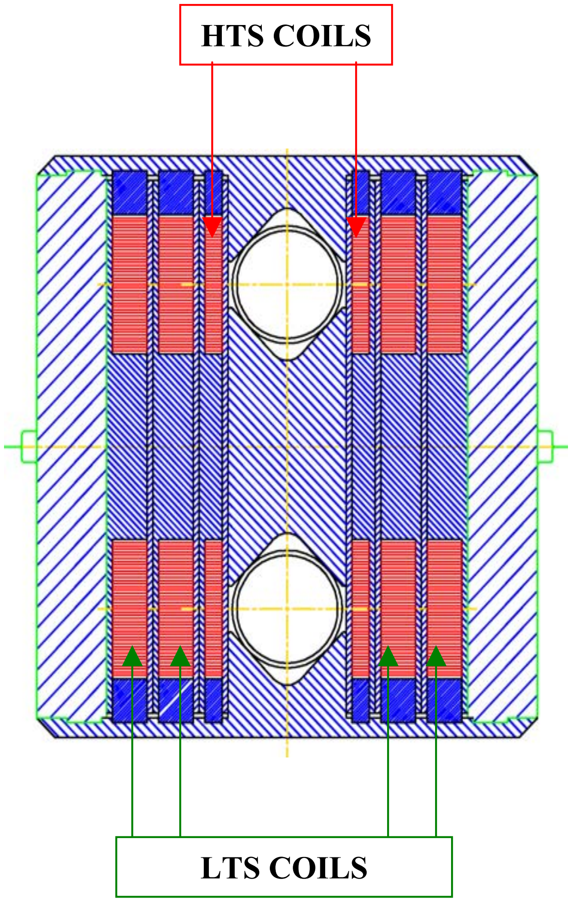
the 10-turn coil technology development program continues in parallel!

12.5 T magnet becomes a part of "magnet R&D test factory"

The 12.5 T magnet provides a significant background field facility for testing coil modules (HTS, Nb_3Sn) with large Lorentz forces on them -- try to simulate high field magnet situation.

Ideal approach for HTS/Hybrid magnet development !

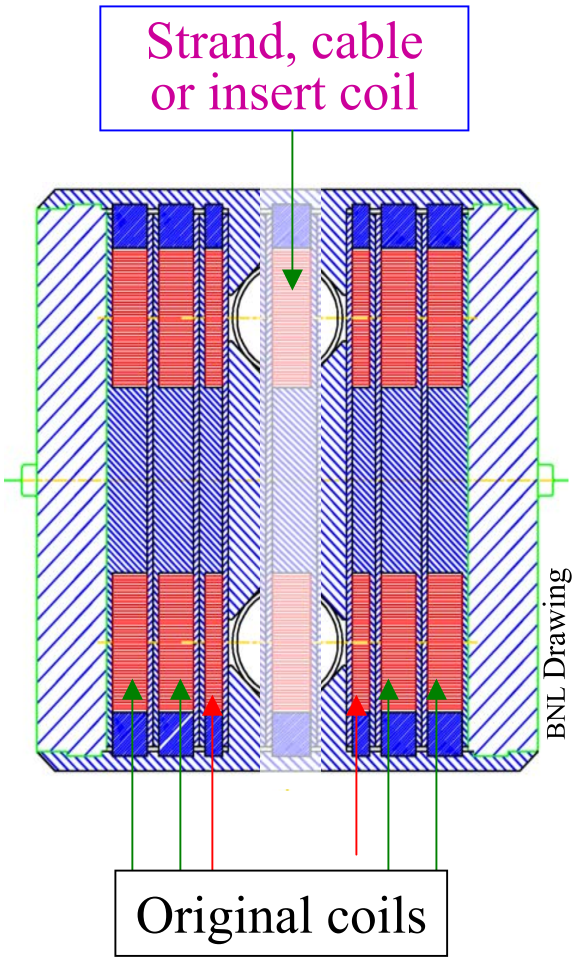
HTS in a Hybrid Magnet



- Perfect for R&D magnets now.

  HTS is subjected to the similar forces that would be present in an all HTS magnet. Therefore, several technical issues will be addressed.
- Also a good design for specialty magnets where the performance, not the cost is an issue. Also future possibilities for main dipoles.
- Field in outer layers is ~2/3 of that in the 1st layer. Use HTS in the 1st layer (high field region) and LTS in the other layers (low field regions).

Common Coil Magnet As A Test Facility

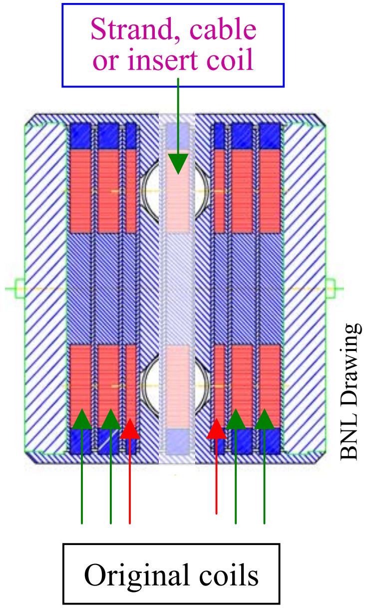


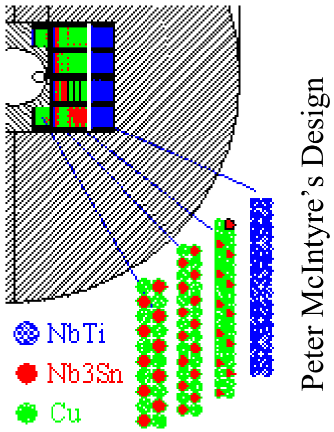
- **A Modular Design with a significant flexibility.**
- **Coil geometry is vertical and flat. That means a new coil module having even a different cable width can be accommodated by changing only few parts in the internal support structure.**
- **The central field can be increased by reducing the separation between the coils.**
- **The geometry is suitable for testing strands, cables, mini-coils and insert coils.**
- **Since the insert coil module has a relatively small price tag, this approach allows both *“systematic”* and *“high risk”* R&D in a time and cost-effective way. This might change the way we do magnet R&D.**
- **Can use the successful results in the next magnet.**

A Few Possible Topics for Cable and Magnet Designs

Examples of systematic and non-conventional design studies:

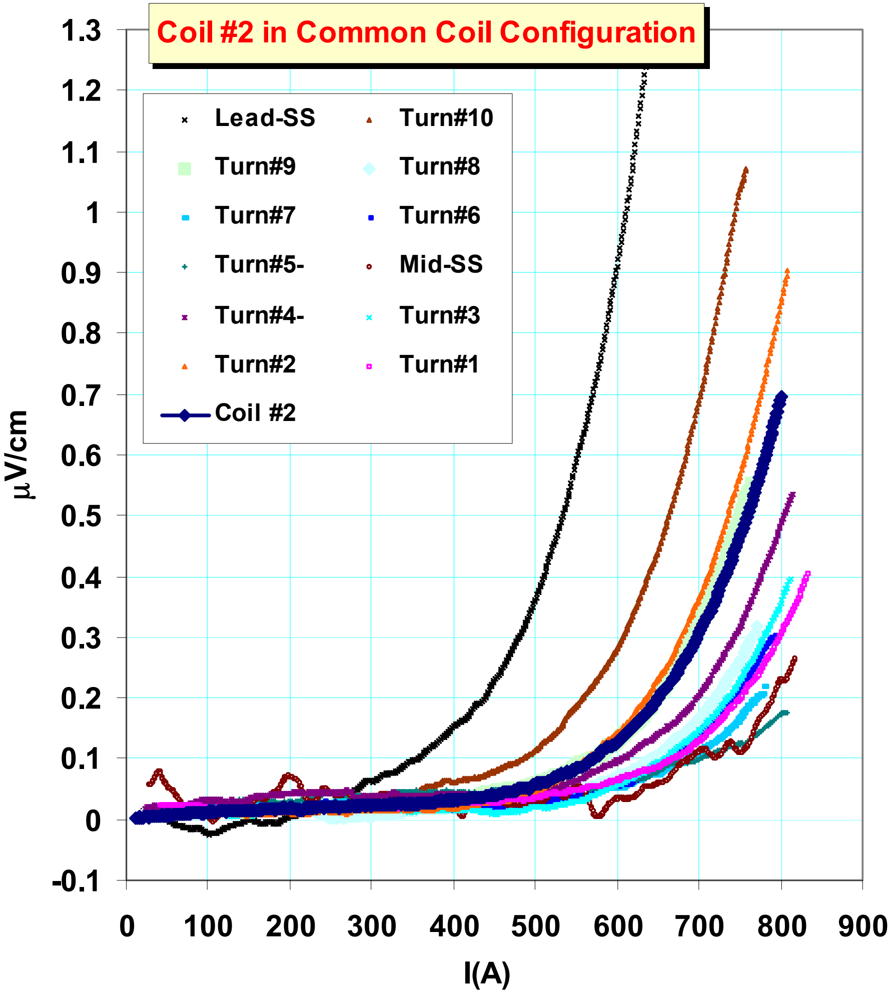
- Variation in cable/conductor configuration
  - Mixing Cu strand with Nb_3Sn superconductor
  - Heat treatment studies
- Different technologies
  - "*Wind & React*" Vs. "*React & Wind*"
- Different type of conductors
  - Nb_3Al, HTS, etc.
- Different type of conductor geometry
  - Tape, cable
- Stress management module
- Different type of mechanical structures and variations in them
- Different cable insulation and insulating schemes





Magnet Test Results

10-Turn HTS coil: Measurements at every turn



Typical criterion for HTS to turn normal: 1µV/cm

Common coil magnet with Nb_3Sn

Ramped to 86% (power supply limit) of cable short sample limit (11kA) measured at BNL

One quench at 9.7 kA flattop

Another quench at ~6500 A at a ramp rate of 62,000 A/sec (NO TYPO)

Magnet does not quenching after ~10 ramps, tried various ramp rates.

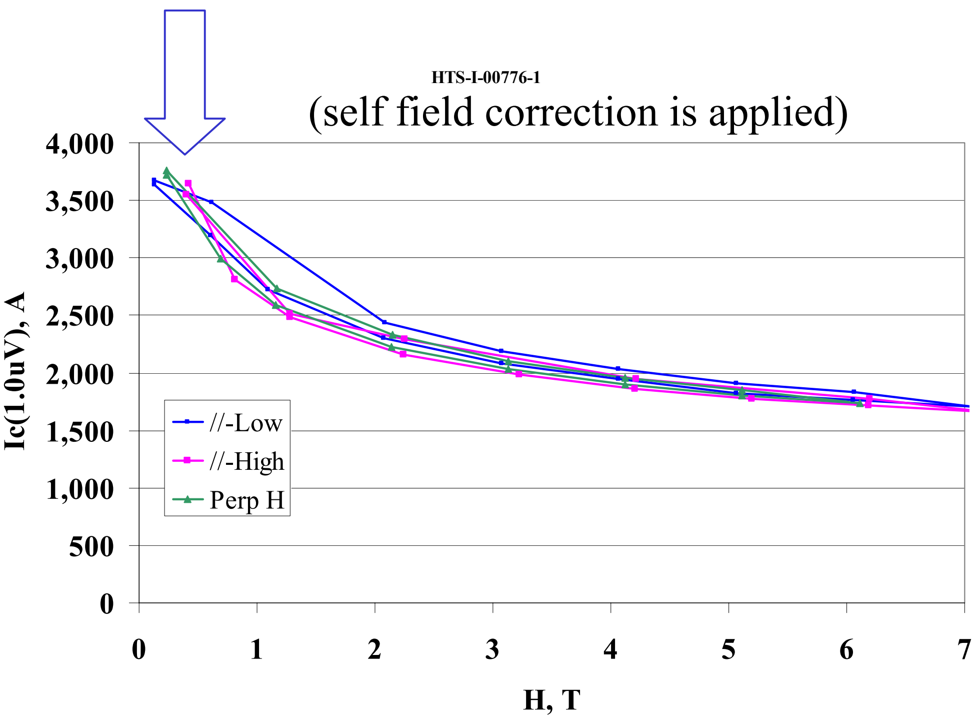
Unlike others, we do not see any large ramp rate degradation till 1500 A/sec

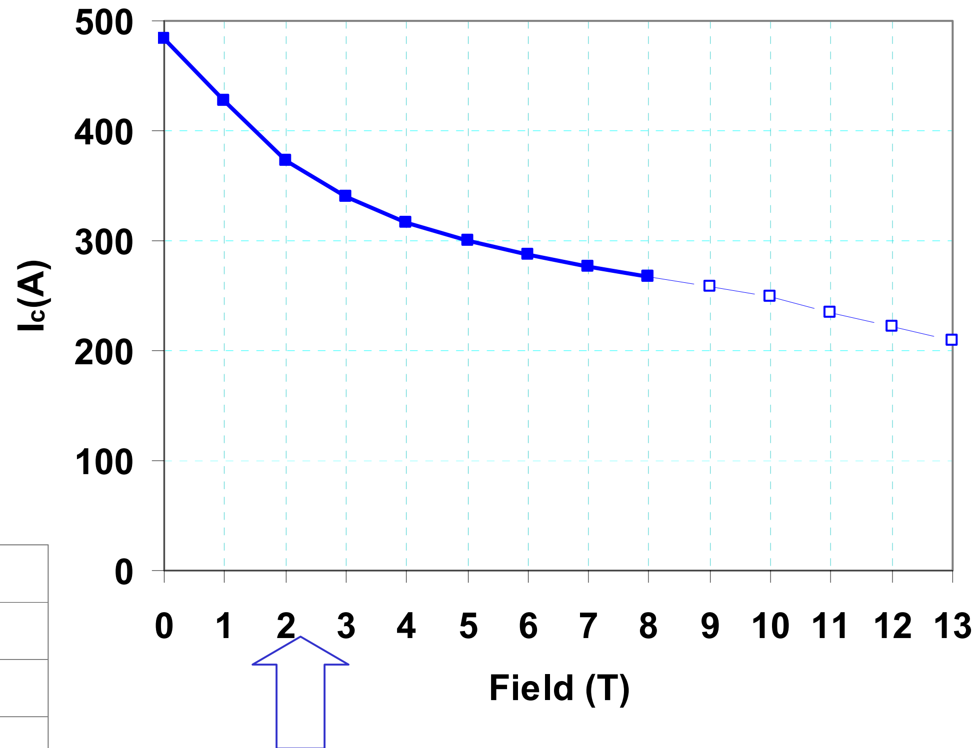
Measured Performance of HTS Cable and Tape As A Function of Field at BNL

Note: Tape and wire have about the same area. Cable has 18 wires (strands).

Measurement of "***BSCCO-2212 cable***" at BNL test facility

(Ic is better by a factor of 2 now)





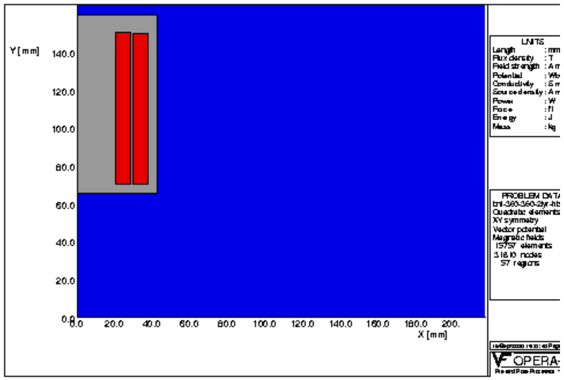
Measurement of "***BSCCO 2223 tape***" wound at 57 mm diameter with applied field parallel (1μV/cm criterion)

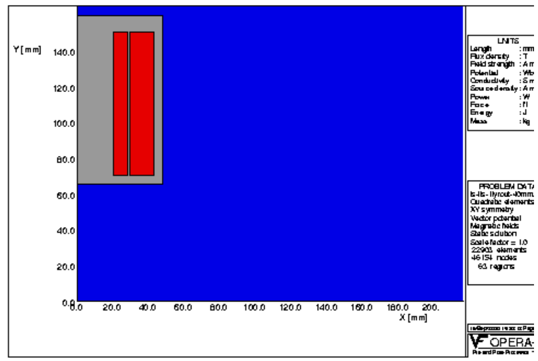
(field perpendicular value is ~60%)

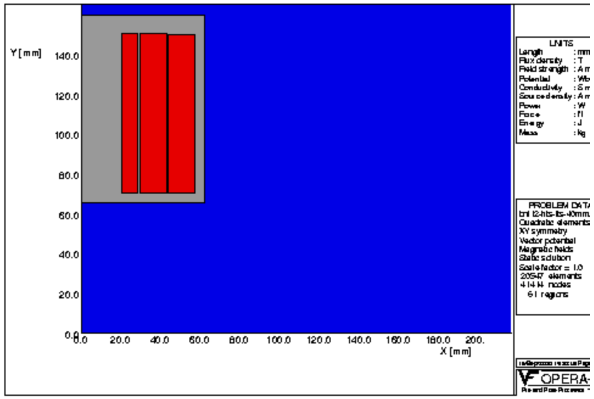
BROOKHAVEN NATIONAL LABORATORY

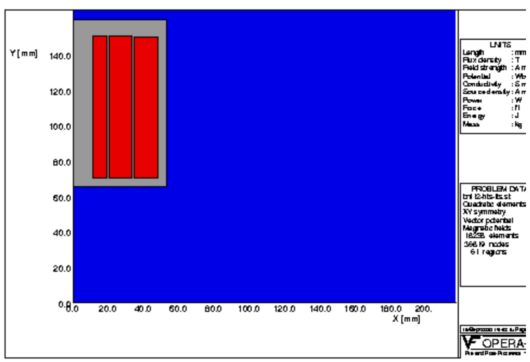
Superconducting Magnet Division

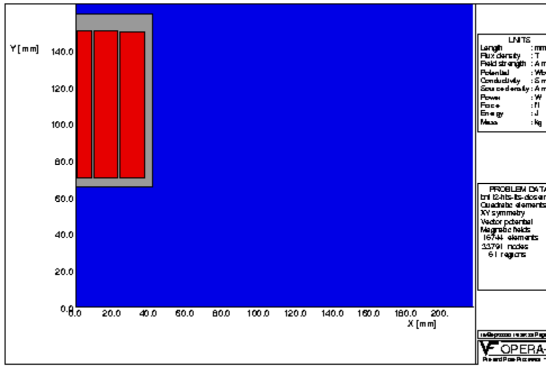
Possible HTS Hybrid Magnet designs with Nb3Sn coils of 12.5 T Design

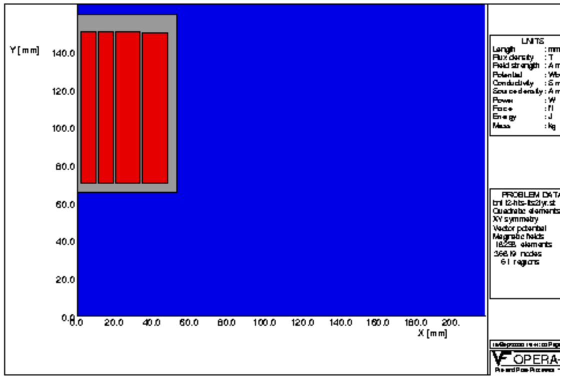












Field Test Range: 8-20 Tesla (with BSCCO 2212 wire carrying 600 A at 4K and 0T)

Aperture (coil spacing) Range: 0 to 40 mm

Above design use 1 or 2 layes of HTS coils with 0 to 2 layes of Ns3Sn coils