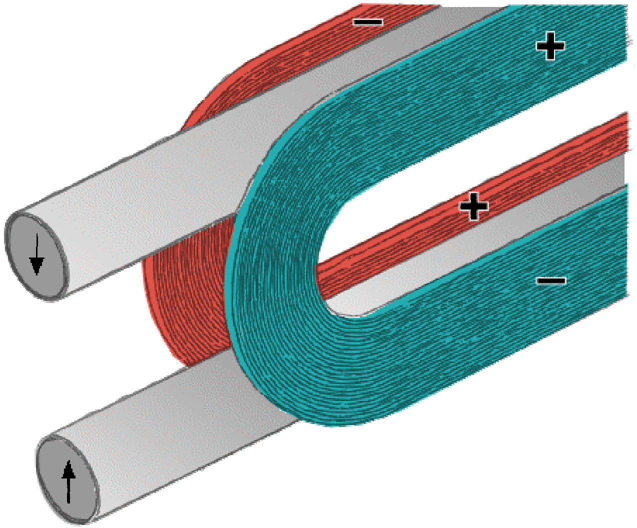


Magnet R&D at BNL

M. Anerella
J. Cozzolino
J. Escallier
G. Ganetis
A. Ghosh
R. Gupta

M. Harrison
A. Marone
J. Muratore
B. Parker
W. Sampson
P. Wanderer

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

Overview of the Presentation

- R&D on New Magnet Designs
  - ⊗ Muon Collider/Neutrino Factory Storage Ring
  - ⊗ Very Large Hadron Collider
  - ⊗ LHC IR Upgrade
- R&D on Magnet Technology
- Test Results and Discussion

Note:

This is only a small fraction of what we do at the Superconducting Magnet Division.

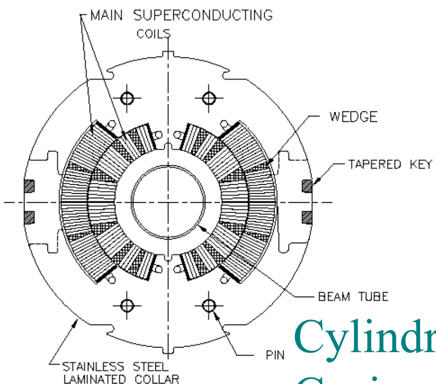
Attempt:

Explore & encourage alternate magnet designs & technologies at BNL and elsewhere.

Two Directions of Magnet R&D

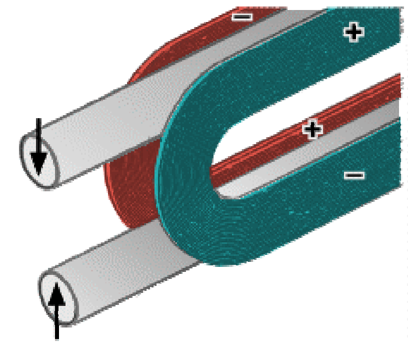
Conventional

Alternate



Cylindrical Cosine Theta

Magnet Designs



Example:
Racetrack Common Coil

Ductile: NbTi
Easy to make coil with

Conductors

Brittle: Nb_3Sn and High Temperature Superconductor (HTS)

Large resources committed to developing each magnet

R&D Approach

Experimental program:
Rapid turn around,
less expansive

BASICALLY, WE ARE LOOKING OUTSIDE THE BOX!

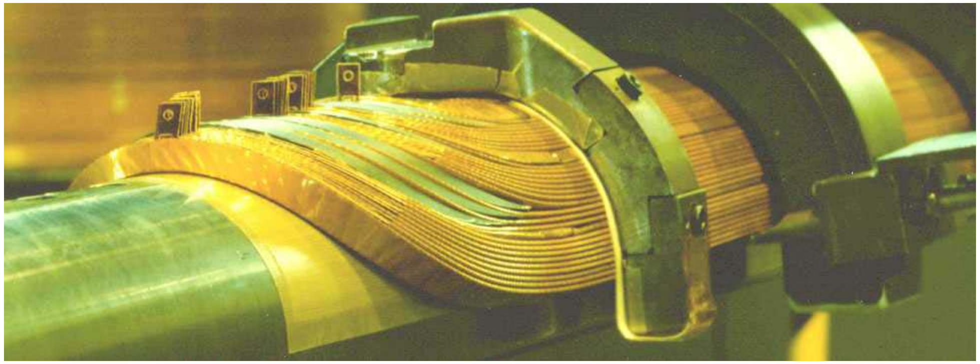
High Field Magnets for Muon Collider and ν Factory Storage Ring

Design Issues:

- Must use brittle superconductors

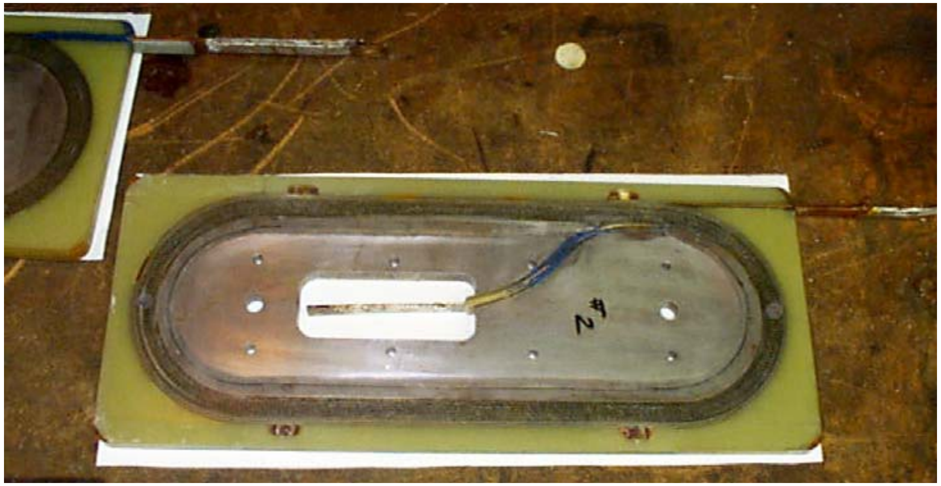
  Nb_3Sn, HTS

- Large Lorentz forces
- Large energy deposition
- Cold coils, Warm iron
- Need compact cryostat
- Large heat leak



Conventional cosine θ design (e.g., RHIC magnets)

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



Conductor friendly racetrack coil geometry

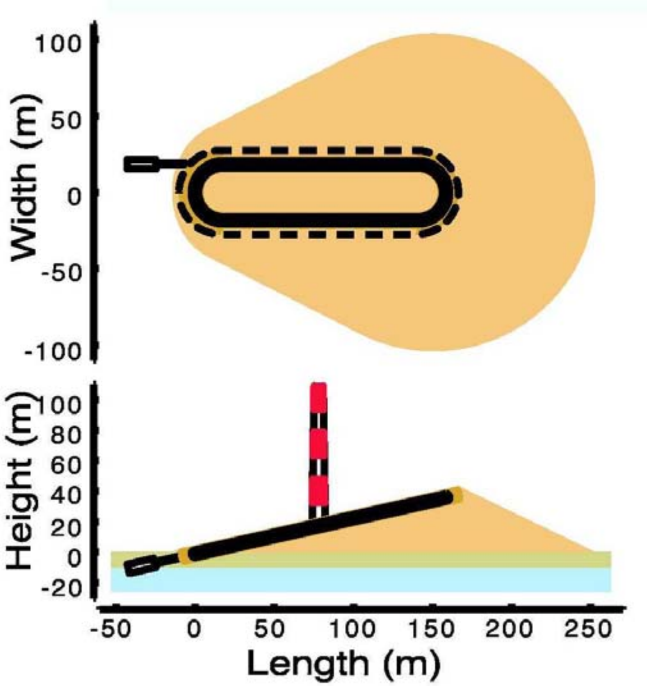
Suitable for high field magnets with brittle material

HTS is an interesting possibilities in such magnets.

Magnet Design for ν Factory Storage Ring Study II

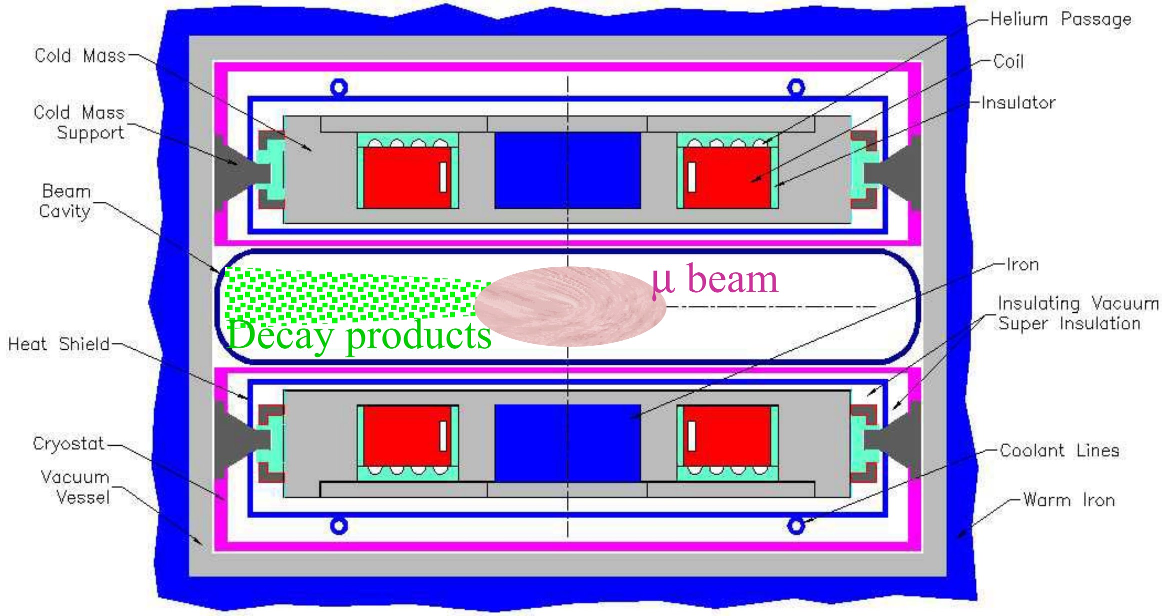
Design Principles and Requirements:

Compact ring to minimize the environmental impact



water table & tilted machine

Racetrack coils with open midplane* to minimize muon decay products directly hitting SC coils (does not require Tungeston liner)



*Earlier studies on open midplane design by **P. McIntyre** & **M. Green** (with some variations)

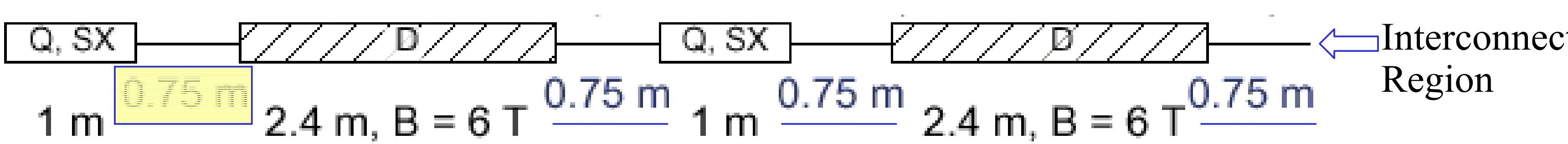
⇨ Need high field magnets & efficient machine + magnet system design

Lattice & Magnet Designs for a Compact Ring

• Dipoles are great but how about decay products hitting quads (more)

Skew quadrupoles <u>do NOT need</u> conductor at midplane (B. Parker)

•In study 1 (50 GeV), ~1/3 space was taken by inter-connect regions

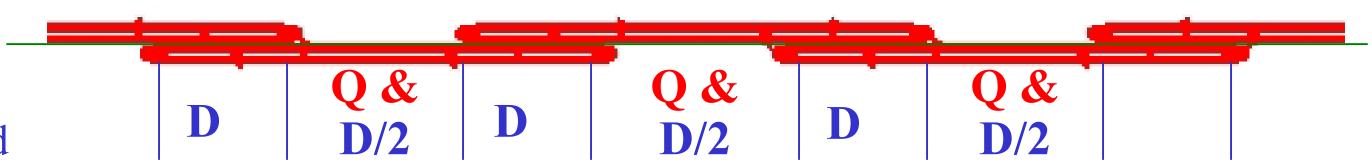


Gets worse at lower energy (50 => 20 GeV in study 2)

• New <u>magnet system design</u> makes a productive use of all space

Quadrupole(Q): Field Gradient

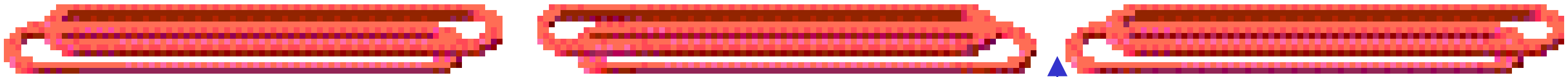
Dipole(D): Field

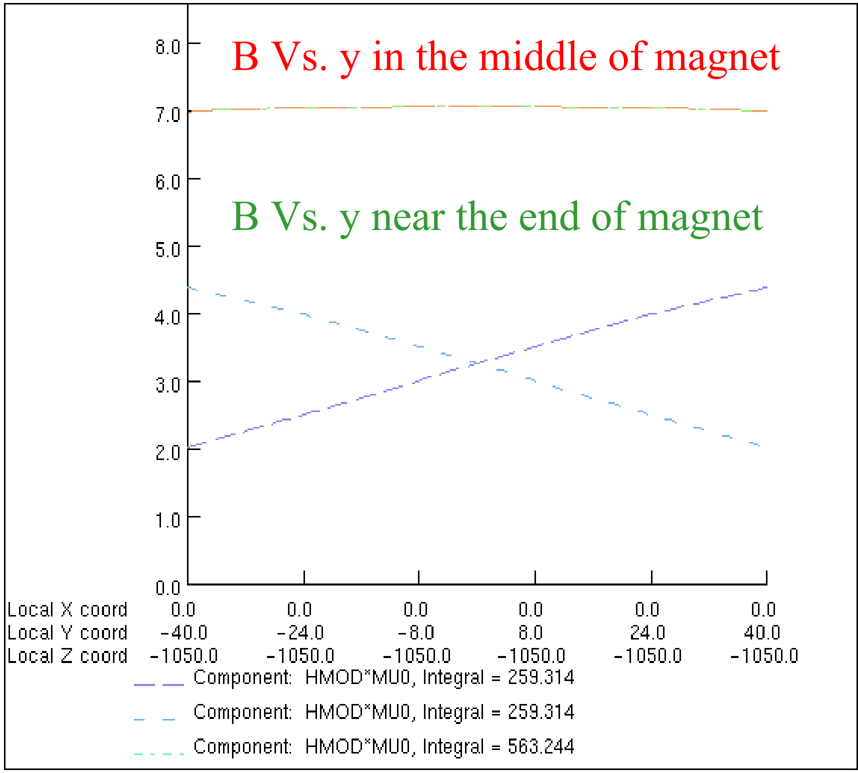


No space is wasted for interconnect

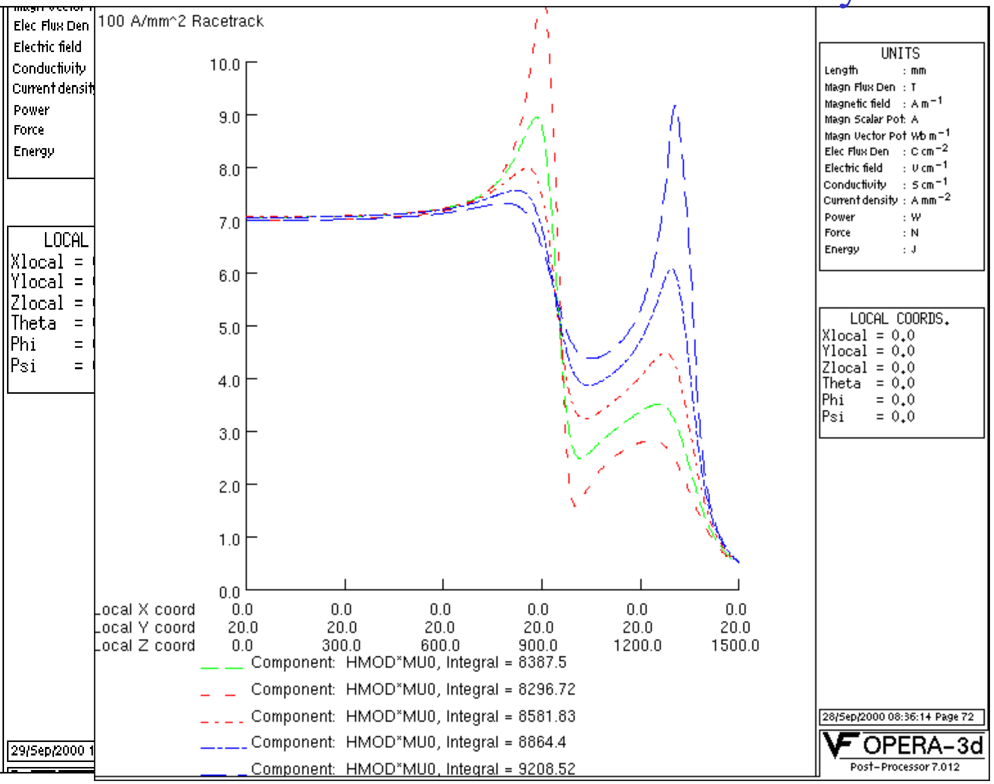
Shorter cells ⇨ smaller aperture, improved beam dynamics

Skew Quad Lattice by Axially Shifting Coils





Axial scan of B for various y



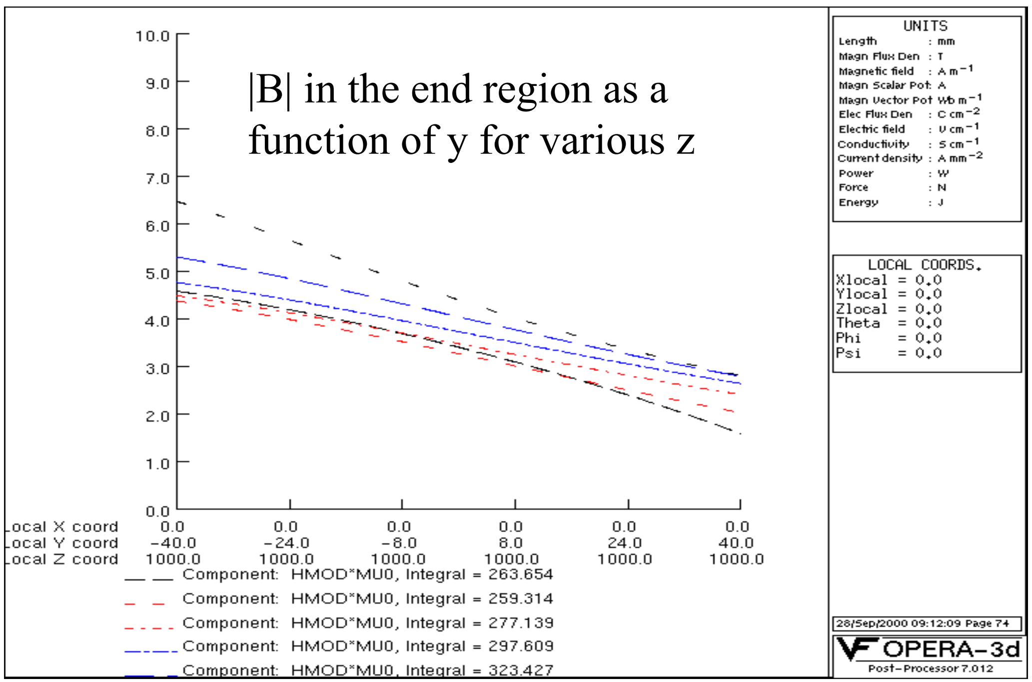
BROOKHAVEN
NATIONAL LABORATORY
Superconducting
Magnet Division

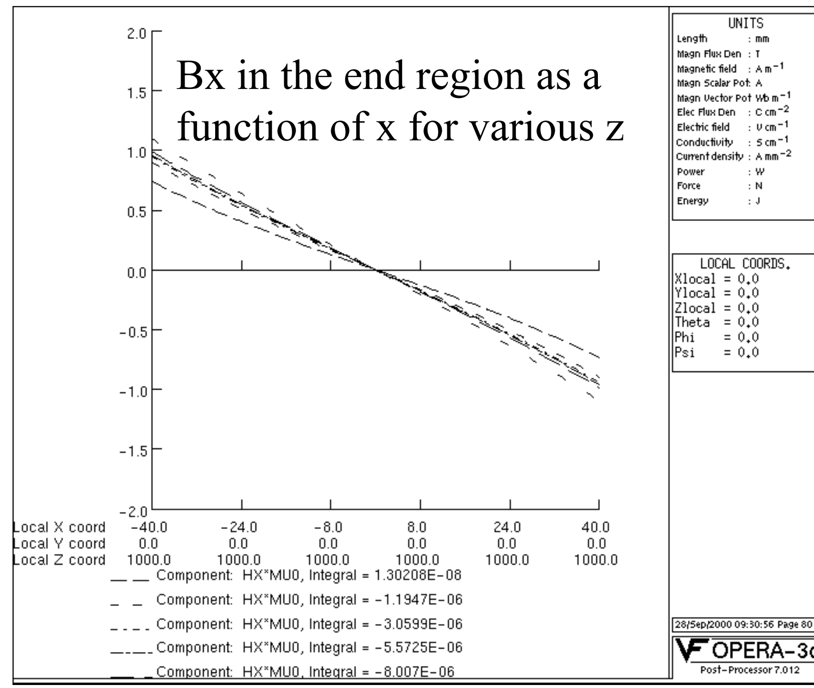
Skew Quad Lattice by Axially Shifting Coils

Dipole section

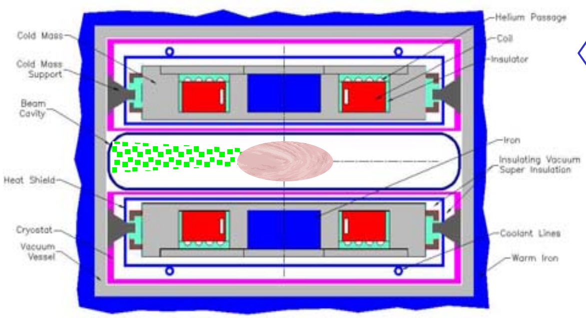
Combined function magnet section

Place for corrector, etc.





Modified Cross-section for Better Field Quality



This cross-section gives ~50 units of sextupole

Initially assumed OK for ~1000 turn

Beam Physicists demanded better field quality

All harmonics ~1 unit at 20 mm radius are obtained by taking coil horizontally further out

Penalty for such a design:

A higher peak field (~+50%); can be reduced by proper grading.

Rough argmument: center of the coil should be ~30 degree for zero sextupole

Saturation-induced harmonics are small. Not so important for fixed field magnets, but a small value allows some adjustment in field, if needed.

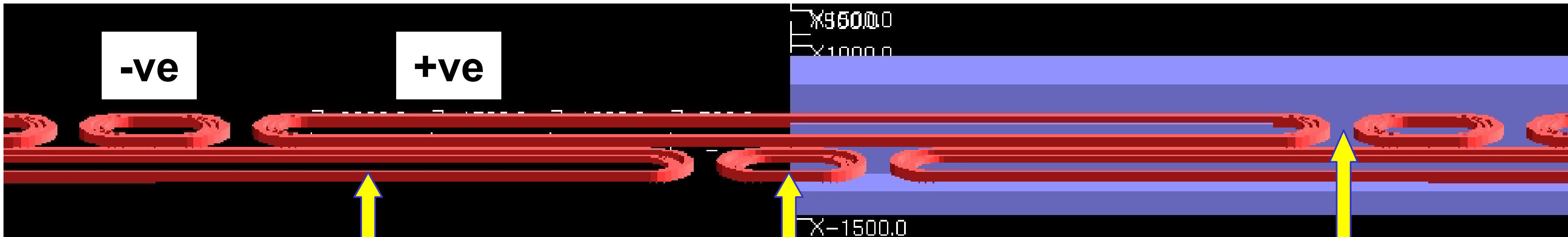
Penalty for making good field quality: A substantial increase in vertical Lorentz forces.

However, it still leaves field quality issues in the magnet ends

- Conductor at the pole give negative b2 and conductor at midplane negative b2.
- Typically, we take midplane conductor further out to compensate for extra conductor at the pole that must be present in the conventional ends.
- Here we do not have midplane conductor to provide that compensation for zero integral b2.

Alternate End Design Concept

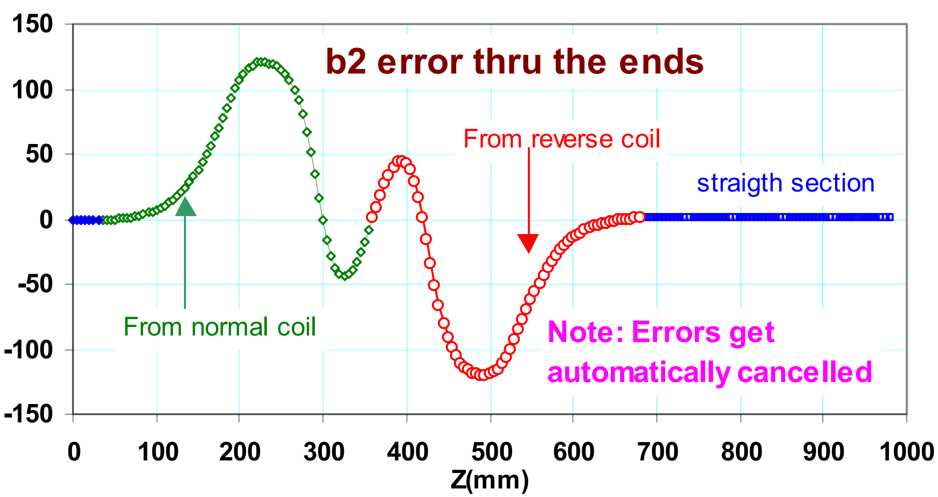
- Reverse coils to cancel field harmonics in ends (also generate skew quad)



Normal Coils
Dipole

Reverse Coils
Skew Quad

One Coil
1/2 & 1/2



New Magnet System Design

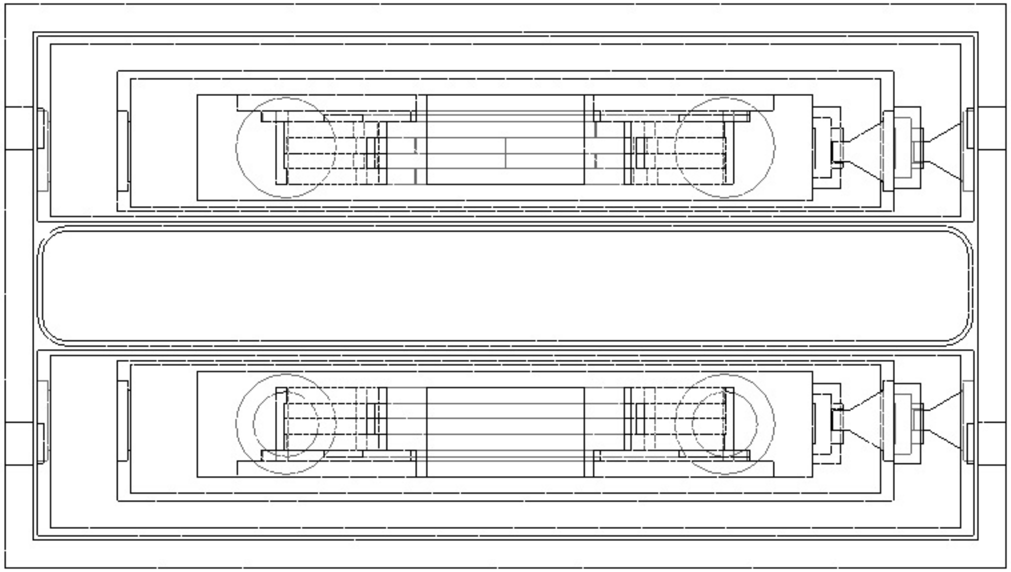
> Good field quality

> Makes ring small

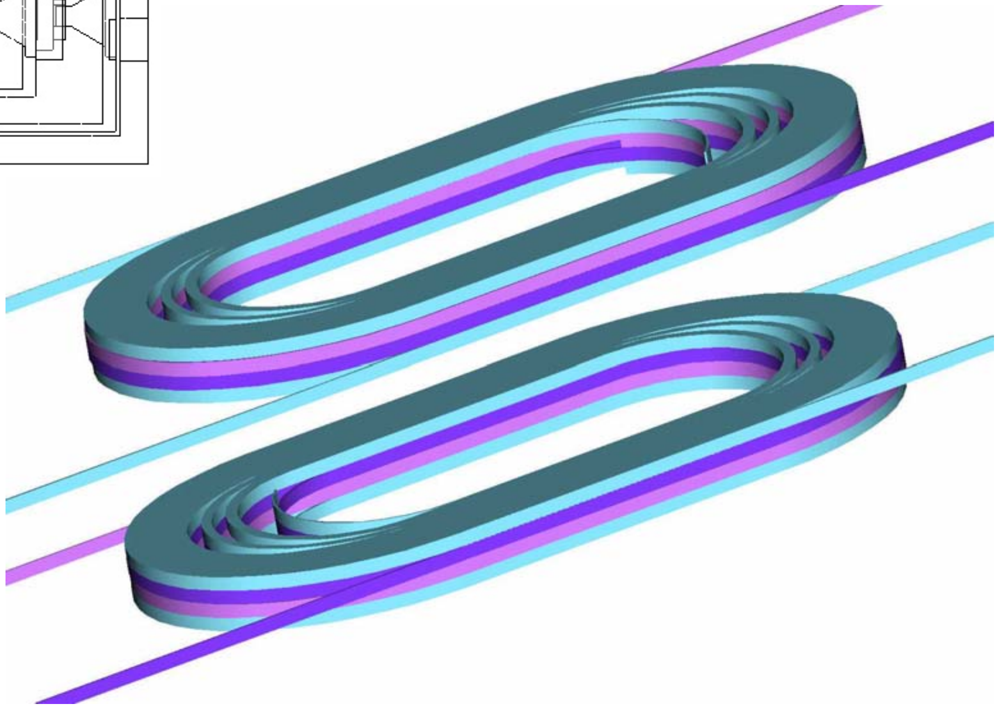
Important for BNL site

Note: Bx & By (normal and skew harmonics) are cancelled but Bz (axial field) is not.

Magnet Construction Plan for Neutrino Factory Storage Ring Dipole Model at BNL



We have got a limited funding under LDRD. With that we are building a series of short coils (length same as in study 2).



The cross section in the magnet under construction belongs to an earlier design; but all design principles remain the same.

The magnet will be made using ITER cable and therefore would reach a lower (~4 T) field.

Goals For the Next Year

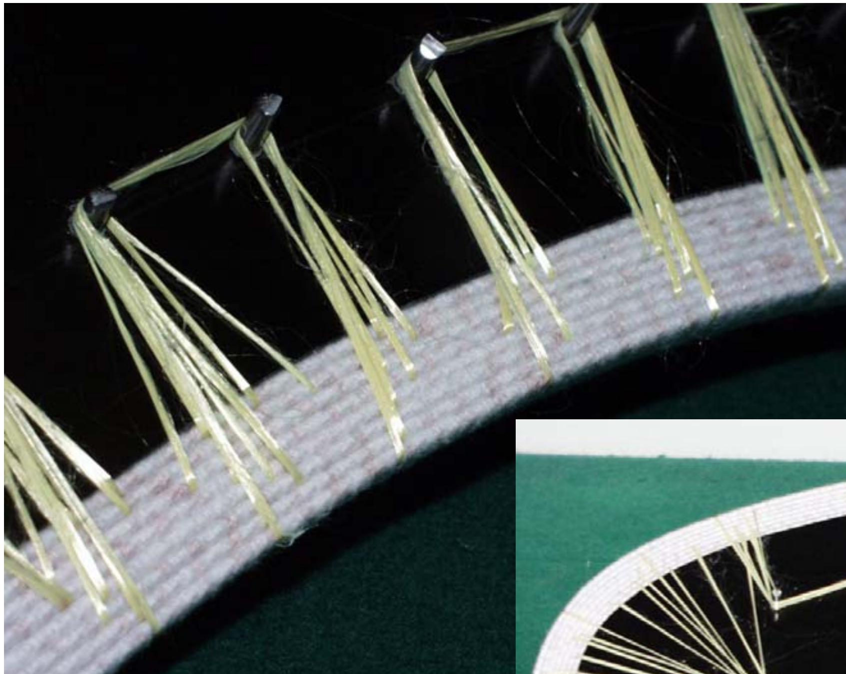
- Build necessary tooling for a model magnet
- Build short Nb_3Sn coils with ITER
- Test these coils in the following configurations:
  - Dipole 

  - Quadrupole 

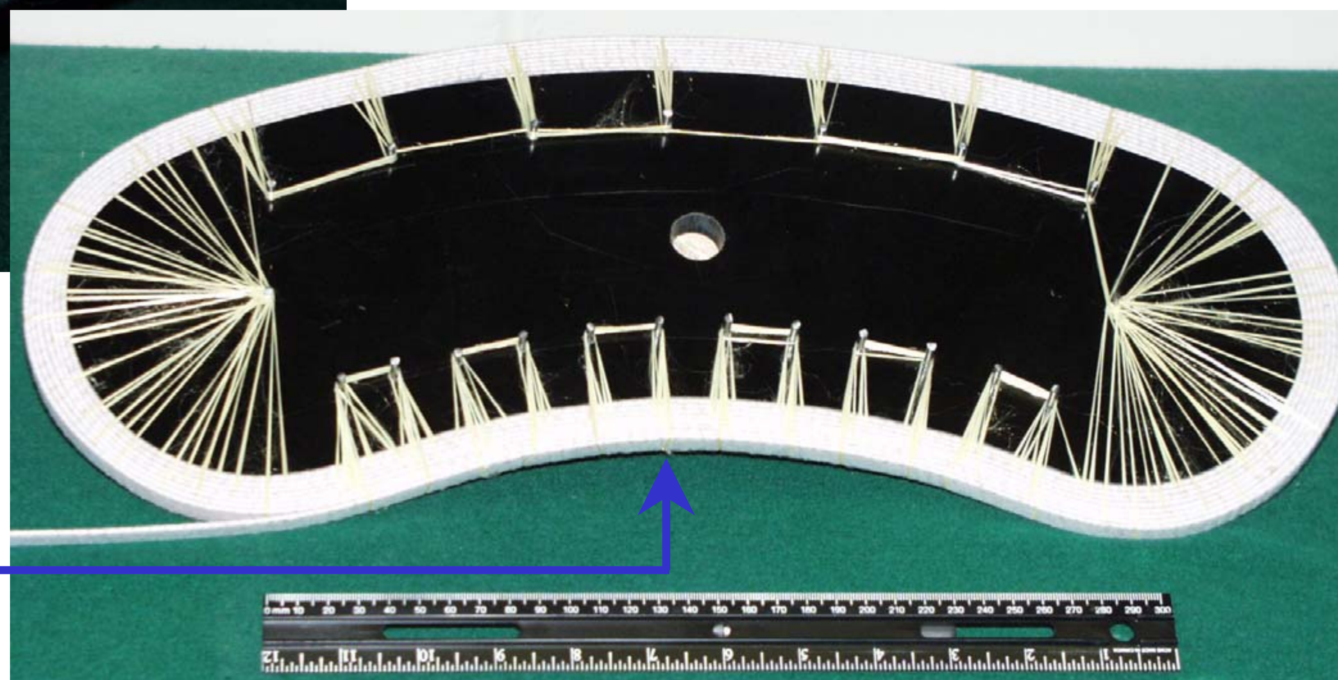
  - Combined function magnet 

- Continue work on improving design to make storage ring more compact and more efficient

Saggitta in Nb3Sn React & Wind Dipole



A new method to obtain large reverse curvature devised with Kavlar strings (John Escallier)



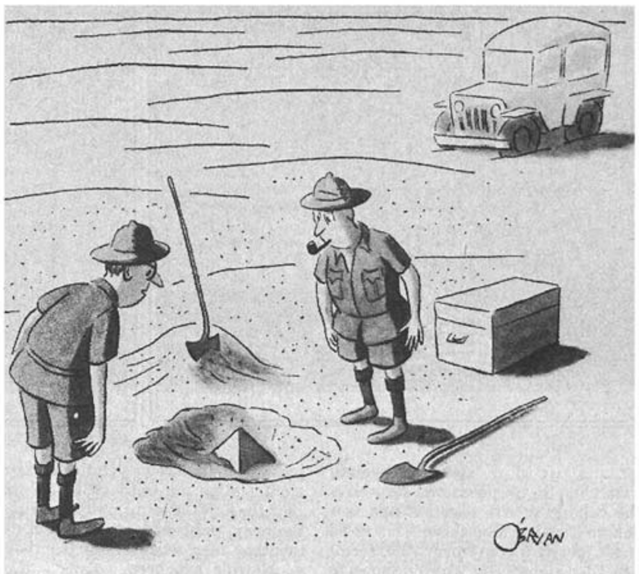
Good for making straight racetrack coils also for obtaining tightly packed turns

Reverse curvature

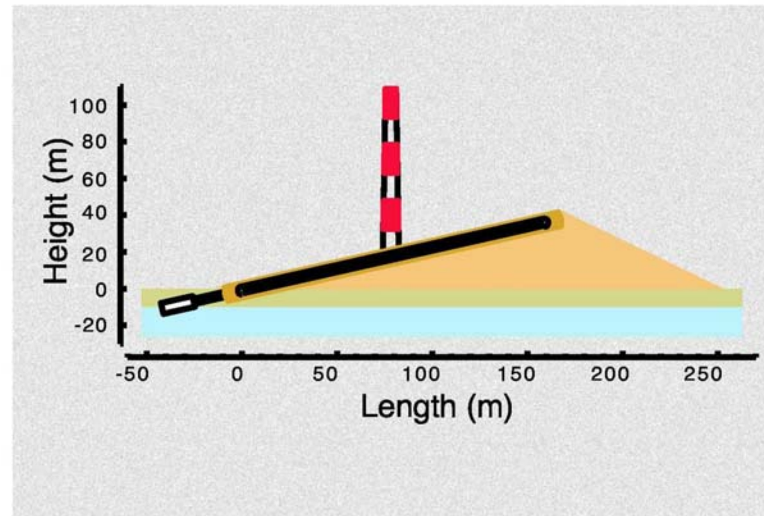
What do you think Prof. John Doe? Did we find some thing big?

A slide from Brett Parker's presentation

A Compact 20 GeV Muon Storage Ring



"This could be the discovery of the century. Depending, of course, on how far down it goes."



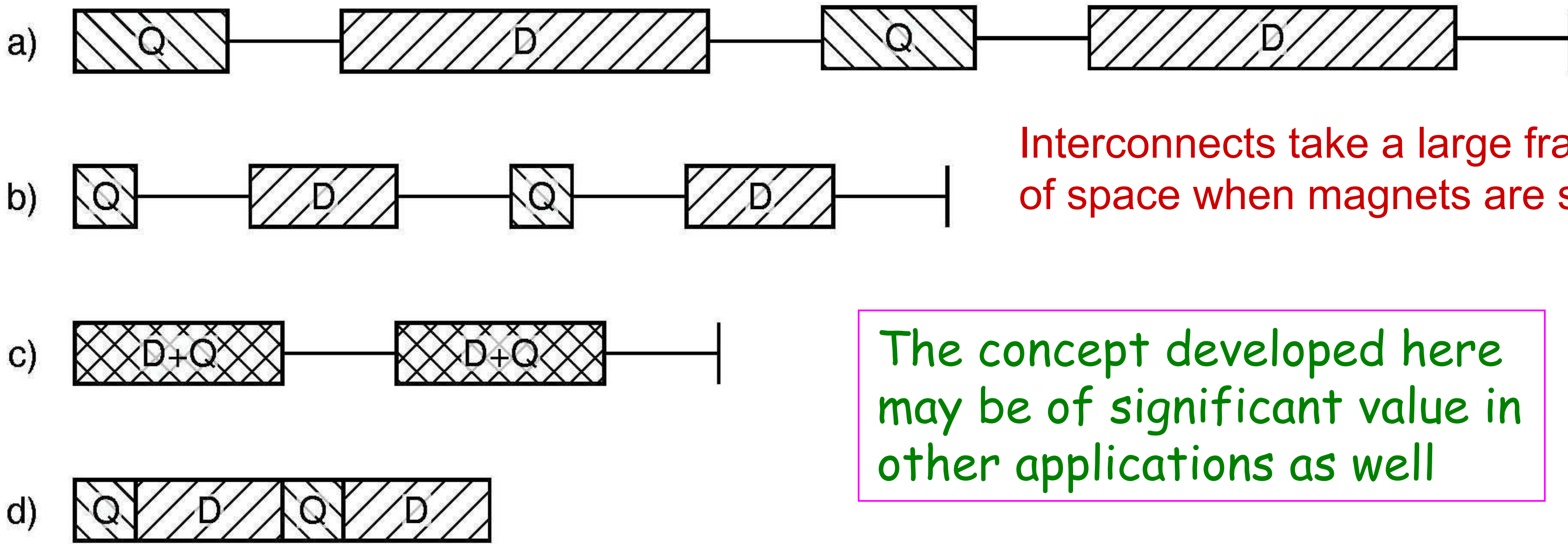
This could be a machine at Brookhaven. Depending of course, on how far it goes up and down.

BROOKHAVEN
NATIONAL LABORATORY
Superconducting
Magnet Division

Neutrino Factory at BNL,
A Special Symposium,
May 4, 2001 at BNL

fact
Muon Collaboration

Machine Size and Interconnects

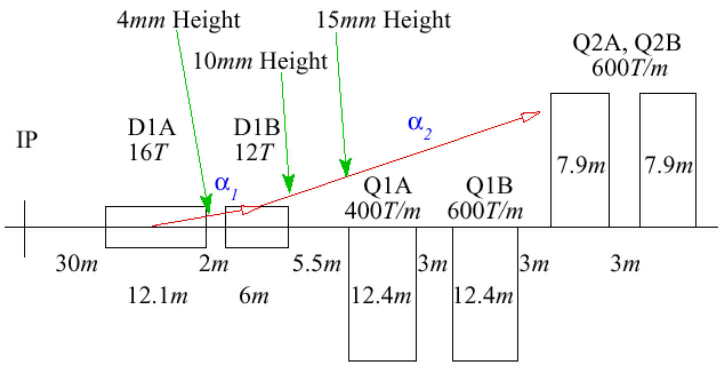


Interconnects take a large fraction of space when magnets are short

The concept developed here may be of significant value in other applications as well

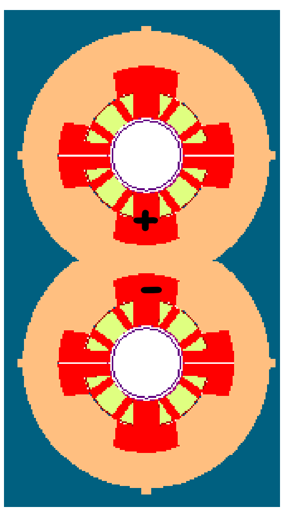
Figure 7.4: Demonstration of the effect of inter-magnet spacing on arc length. The top drawing (a) is the arc cell for a 50 GeV lattice from the Fermilab design study. Scaling that lattice to 20 GeV, but leaving the inter-magnet spacing fixed, does not reduce the cell length to 40% of the original length (b). In (c), we see that using combined-function instead of separated-function magnets can reduce the cell length substantially. In (d), we show what happens if the inter-magnet spacing is completely eliminated.

New Magnet Design For Efficient VLHC-2 Interaction Region

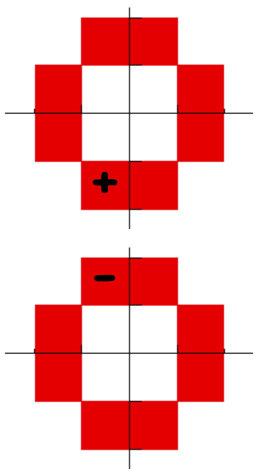


- Optics and magnet requirements (field & aperture) depends crucially on the minimum spacing in the first 2-in-1 IR Quadrupole **(doublet optics)**
- 23KW of beam power radiated from the IP makes this a natural for HTS

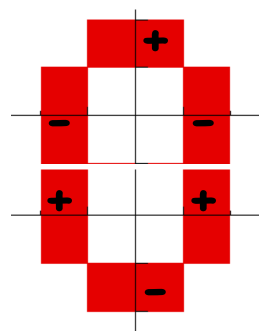
Conventional 2-in-1 cosine theta design



Panofsky 2-in-1 quad design

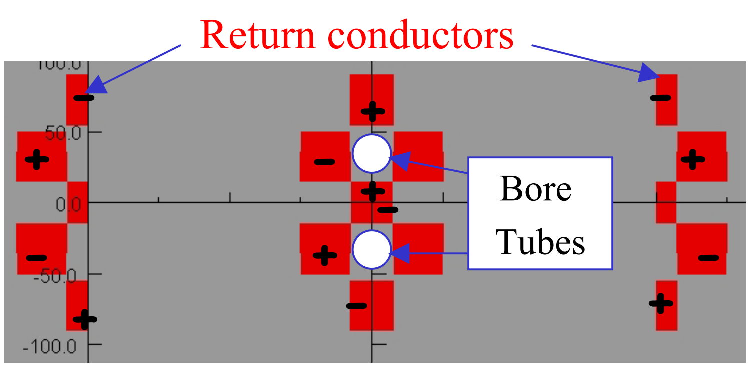


Modified Panofsky Quad



(Bo not zero)

Conductor friendly and better field quality design



Spacing depends on the conductor and support structure requirements

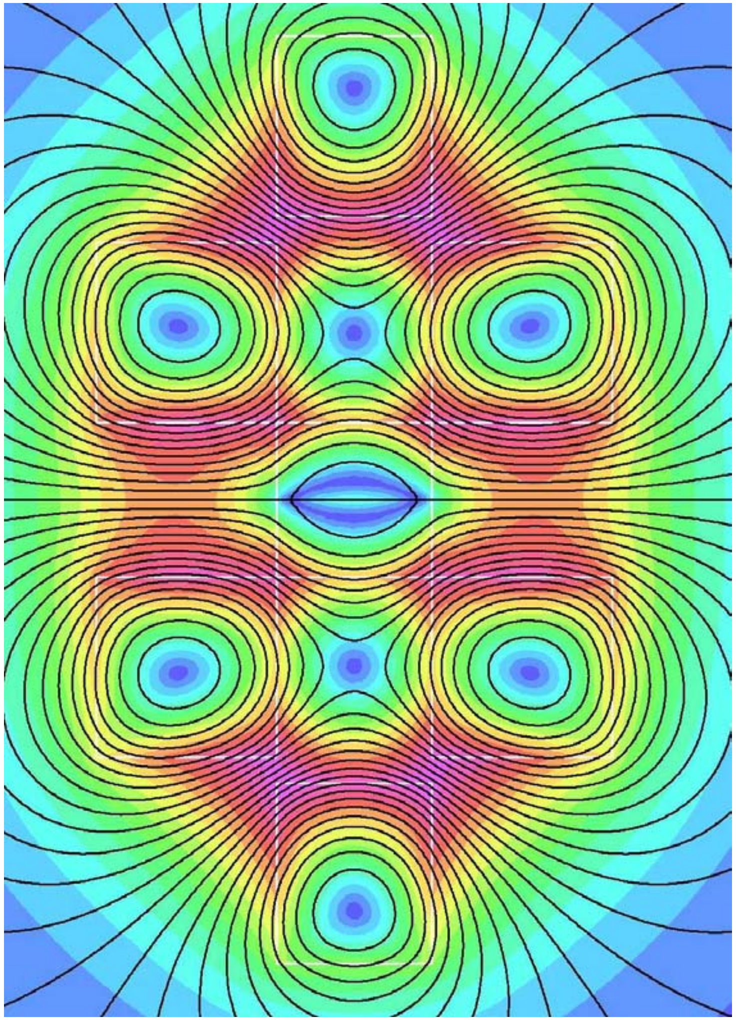
Support structure and middle conductor is removed/reduced. This reduces spacing between two apertures significantly.

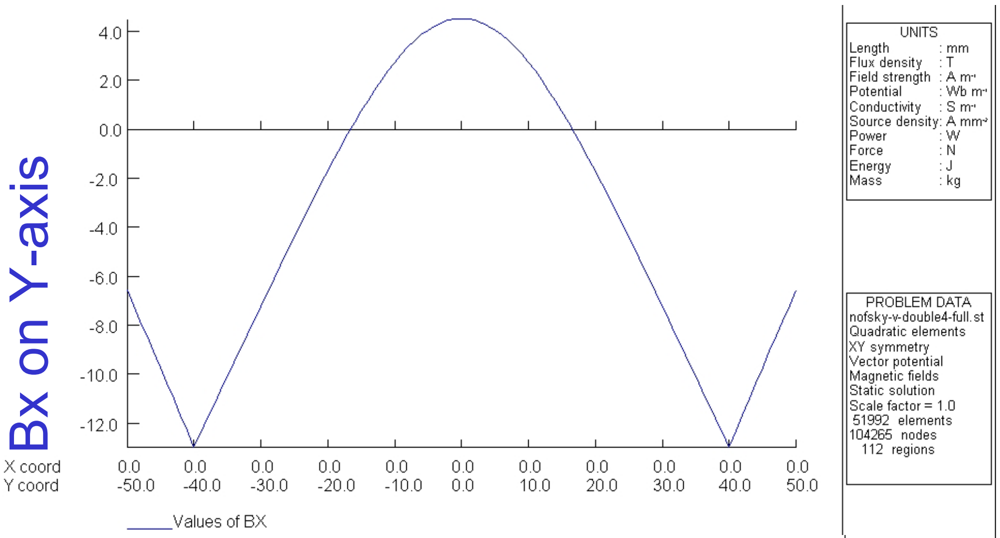
BROOKHAVEN NATIONAL LABORATORY

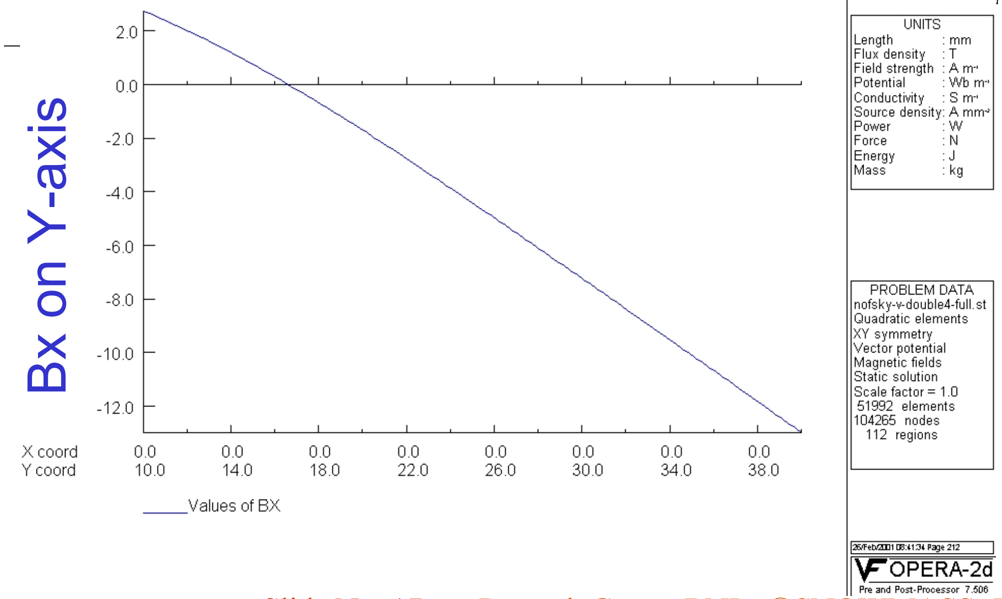
Superconducting Magnet Division

Fields in the Proposed Double-Quad Design

Field contours and field lines







Design Parameters of VLHC-2 Insertion Region Magnets

For doublet optics

Designs based on the Nb_3Sn and other materials available today

Table Irx1: Design parameters of VLHV-2 interaction region magnets

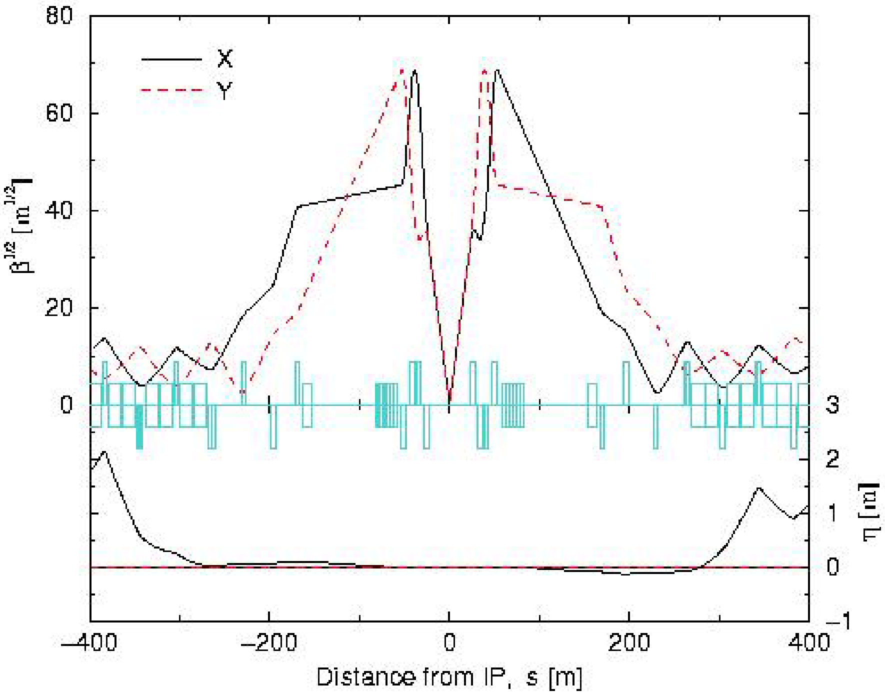
Magnet	Field	Gradient	Peak Field	Aperture	Length	Type
D1A	16 T	---	~16.7 T	25 mm	12.1 m	1-in-1
D1B	12 T	---	~12.5 T	50 mm	6 m	1-in-1
D2	12 T	---	~12.5 T	50 mm	11.1 m	2-in-1
Q1A		400 T/m	~11 T	30 mm	12.4 m	2-in-1
Q1B		600 T/m	~10 T	30 mm	12.4 m	2-in-1
Q2A		600 T/m	~10 T	30 mm	7.9 m	2-in-1
Q2B		600 T/m	~10 T	30 mm	7.9 m	2-in-1

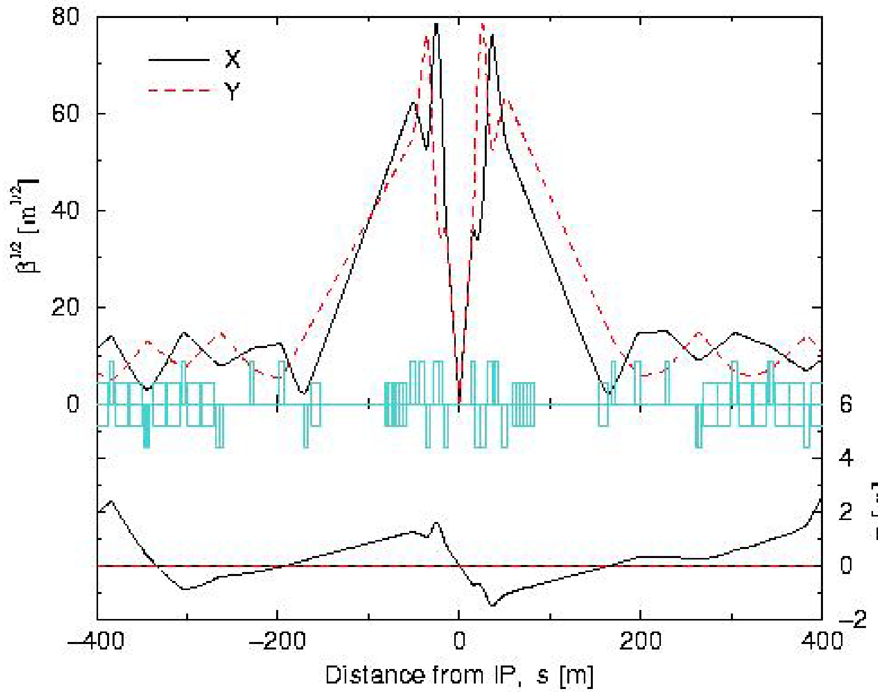
Notes:

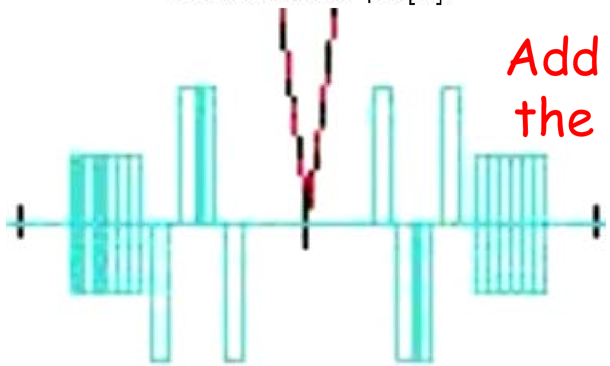
1. D1A has higher field and lower aperture. Lower aperture means less accumulated forces. Can be built with Nb_3Sn or *"BSCCO, Nb_3Sn hybrid".*

2. The gradient in Q1A is lower due to a superimposed non-zero dipole field.

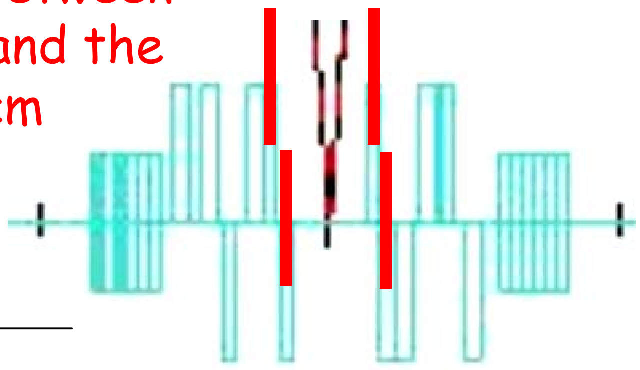
Quadrupoles for LHC IR Upgrade







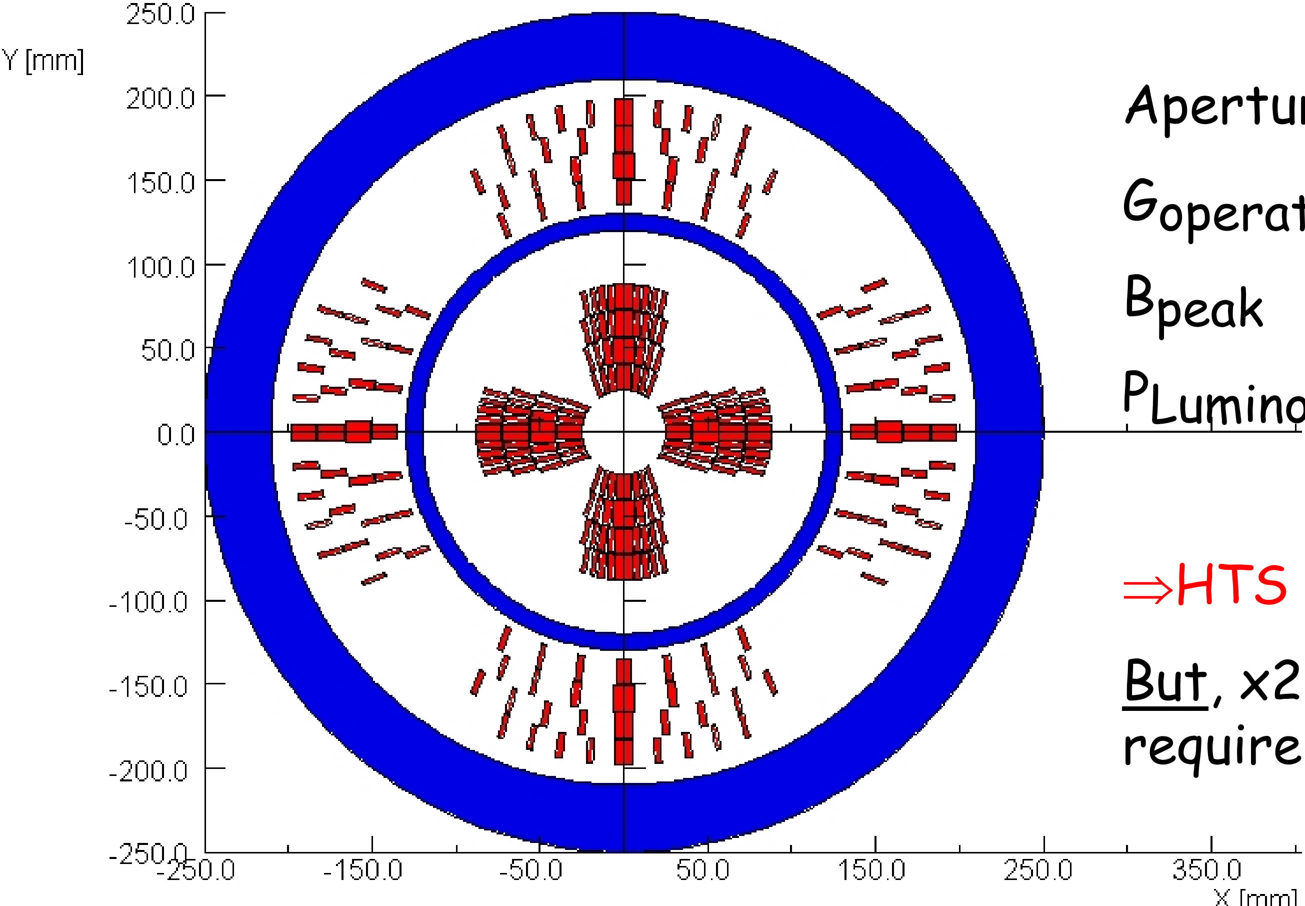
Add a quad doublet between the existing triplet and the IP for $\beta^* \approx 18$ cm



*M Harrison, S. Peggs, R. Gupta, private communication.

** Adapted from Jim Strait's talk at PAC2001

An Initial Concept for HTS based Q0 quads LHC IR Upgrade



	Q0A	Q0B	
Aperture	50	70	mm
$G_{operating}$	540	320	T/m
B_{peak}	16	13	T
$P_{Luminosity}$	>1000		W

⇒HTS for Q0A, at least.

But, x2.5 improvement in J_c required.

Very preliminary concept.

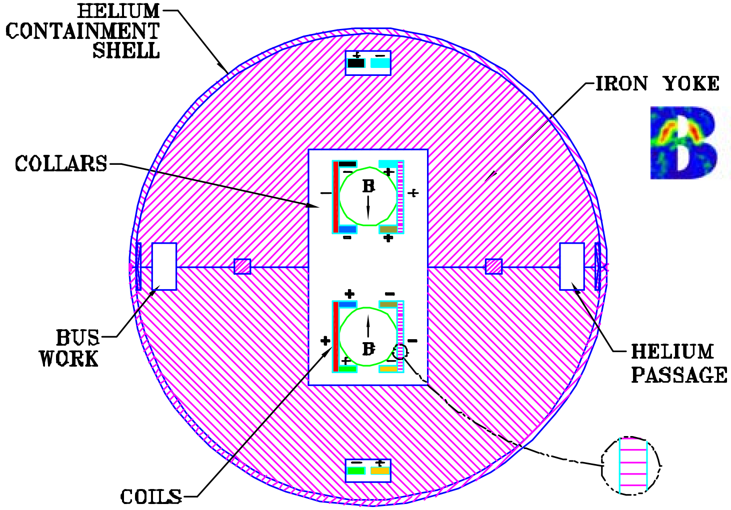
Needs to optimized.

HTS may also be required for inner triplet for 200 TeV VLHC (>25 kW power).

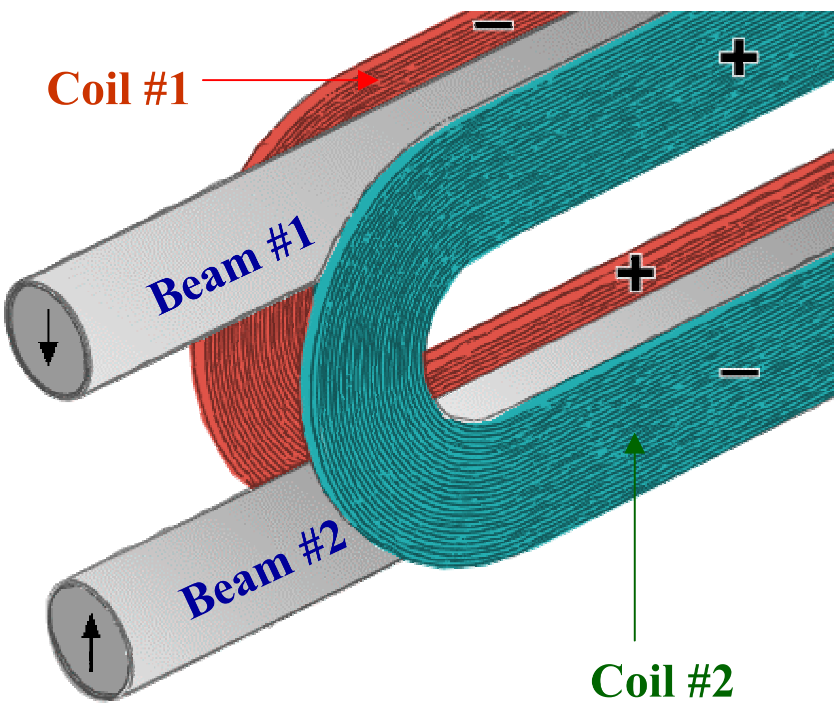
*R. Gupta, et al., to be presented at MT17, September 2001.

** Adapted from Jim Strait's talk at PAC2001

Common Coil Design



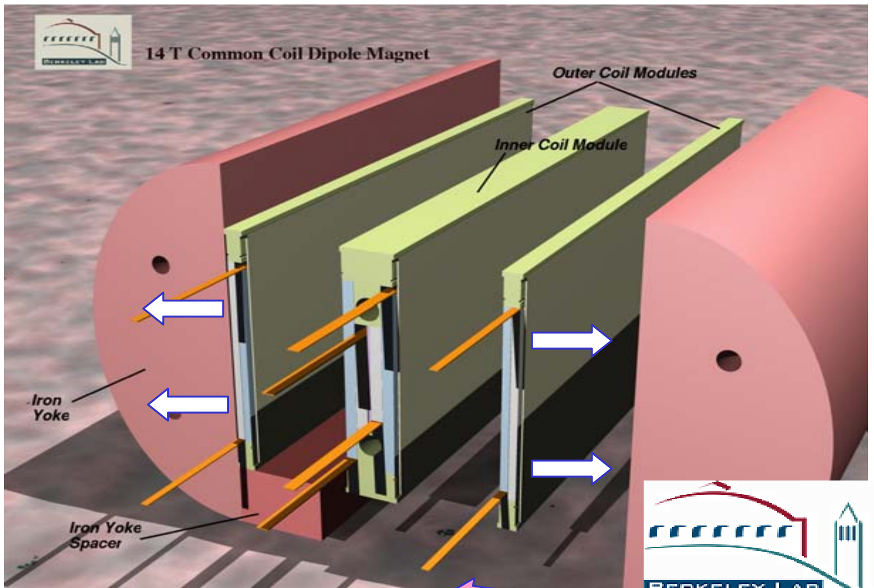
- **Simple 2-d geometry with large bend radius** (determined by spacing between two apertures, rather than aperture itself)
- **Conductor friendly (no complex 3-d ends, suitable for brittle materials - most for H.F. are - Nb_3Sn and HTS)**
- **Compact (compared to single aperture LBL's D20 magnet, half 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**



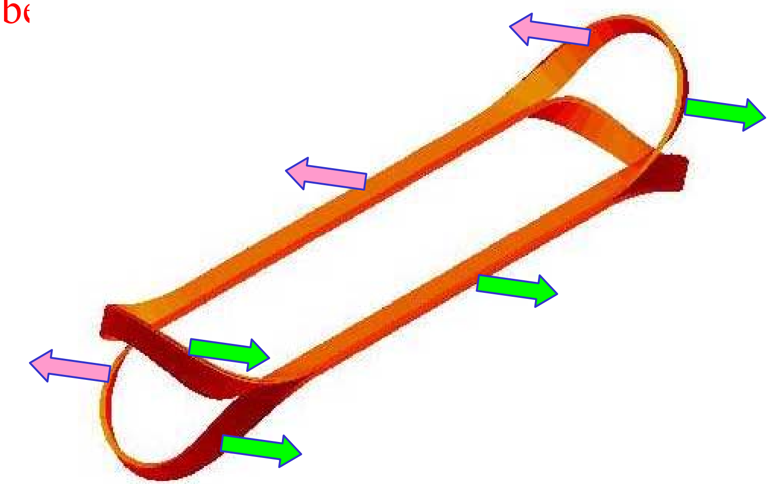
Main Coils of the *Common Coil Design*

Common Coil Design in Handling Large Lorentz Forces in High Field Magnets

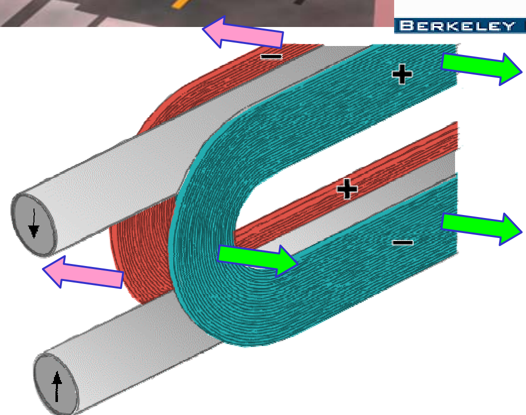
In common coil design, geometry and forces are such that the impregnated solid volume can move as a block without causing quench or damage. Ref.: over 1 mm motion in LBL common coil test configuration).



In cosine theta designs, the geometry is such that coil module cannot move as a block. These forces put strain on the conductor at the ends and may cause premature quench. The situation is somewhat better in single aperture block design, as the conductors don't go through complex be



Horizontal forces are larger



We must check how far we can go in allowing such motions in the body and ends of the magnet. This may significantly reduce the cost of expensive support structure. Field quality optimization should include it (as was done in SSC and RHIC magnet designs).

Magnet Technology Development Program at BNL

Primary goal of the magnet program at BNL is to develop High Field "React & Wind" magnet technology with HTS playing a major role for various applications.

Why HTS now?

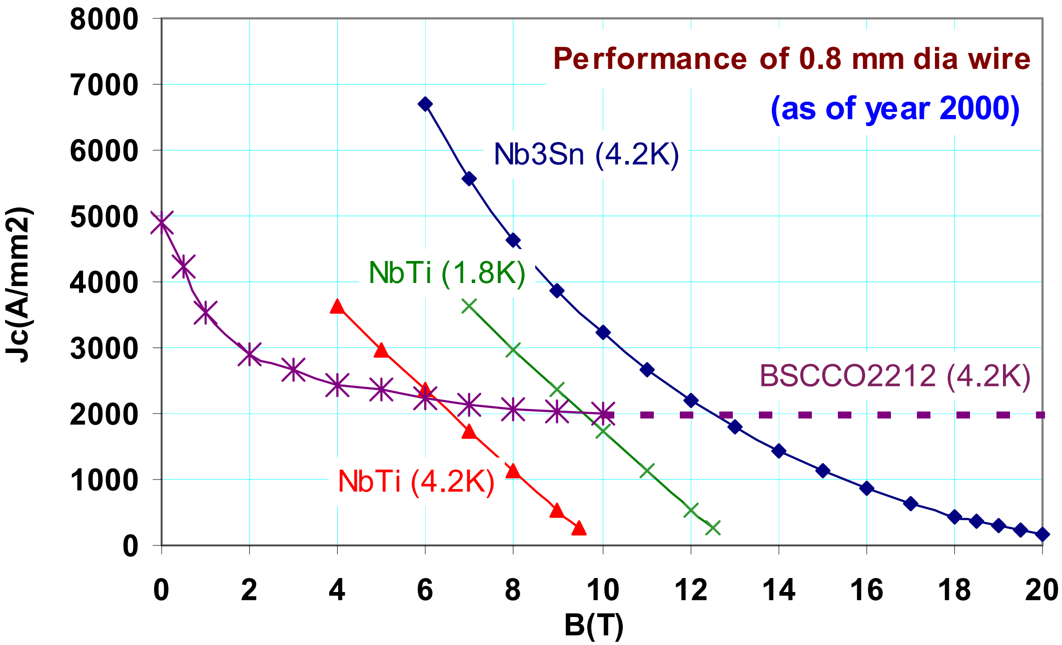
- HTS has now reached a level that one can do meaningful magnet R&D with

  The recent test results from Brookhaven (to be presented later) are encouraging.

- HTS itself yet can not produce the desired field but hybrid magnets almost can

  This for both for testing the HTS technology and in some cases (depending on application) on specialty magnet technology.

Expected Performance of HTS-based Magnets



Year 2000 data for J_c at 12 T, 4.2 K

Nb_3Sn: 2200 A/mm²

BSCCO-2212: 2000 A/mm²

Near future assumptions for J_c at 12 T, 4.2 K

Nb_3Sn: 3000 A/mm² (DOE Goal)

BSCCO-2212: 4000 A/mm² (2X from 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

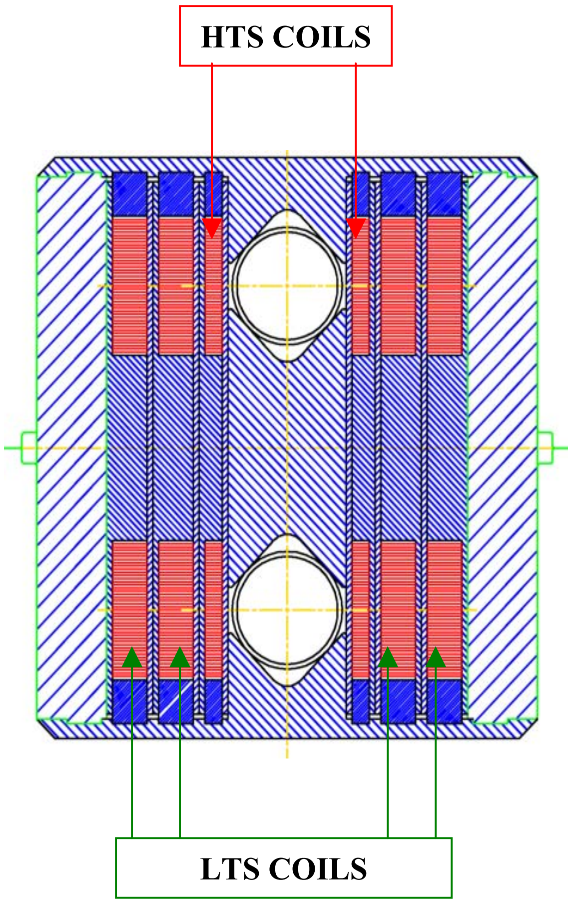
Near Future	
All Nb_3Sn	All HTS
12 T	11 T
15 T	16 T
18 T	22 T

Cu(Ag)/SC Ratio

BSCCO: 3:1 (all cases)

Nb_3Sn: 1:1 or J_{cu}=1500 A/mm²

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).

Technology Development Program

HTS requires about 0.5 C control on reaction temperature. Achieving this temperature uniformity is more likely with “React and Wind” Approach.

The minimum bend radius of our 10-turn coil program is 70 mm for both Nb3Sn and HTS. This is tighter than that is used elsewhere even for Nb3Sn. The goal of our program is not assure a safe success but to see how far we can push the technology. We can change the bend radius easily, if needed.

HTS is a new technology. It should be developed in a systematic and experimental manner. The program must be designed to deal with negative results as an integral part of it. We must determine how and how far we can push the technology and what breaks it. It must have rapid turn-around to allow many such experiments. Those experiments should be inexpensive both in terms of time and in money.

Magnet Program Design Philosophy

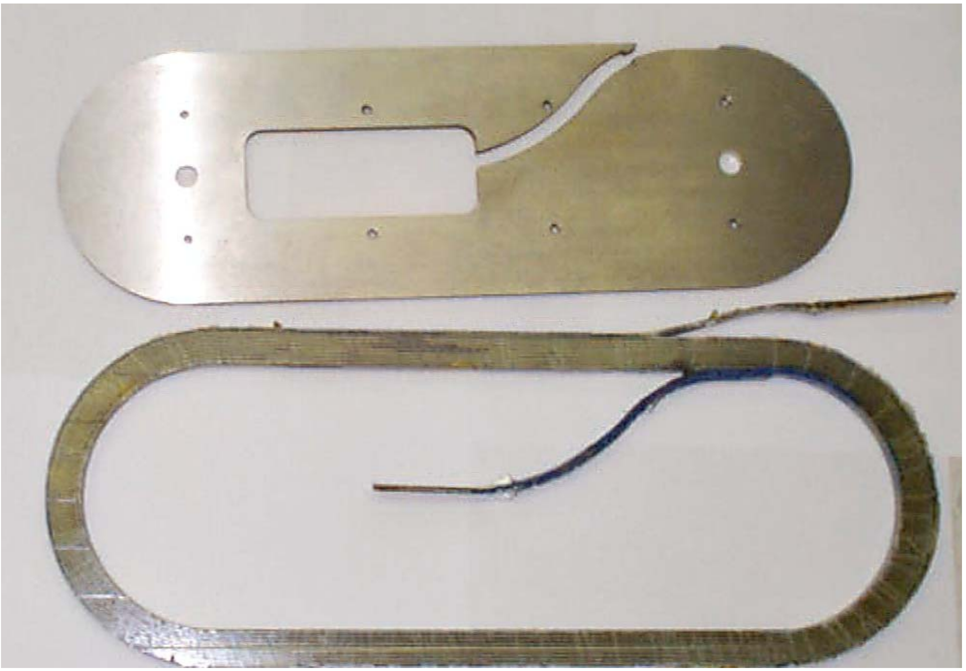
- If it takes well over a year to build and test a product, we tend to become conservative. We tend to stay with the proven technology since so much rides on each test.

- Since significant cost reduction and/or improvements in the performance are unlikely to come with "the comfort zone technology", the magnet program must be designed for rapid throughput so that we can take chances. This will scientifically evaluate the old "comfort zone" issues and test feasibility and profitability of new ideas.

- In an atmosphere of limited funding, "*designing a magnet program*" is just as important as designing a magnet.

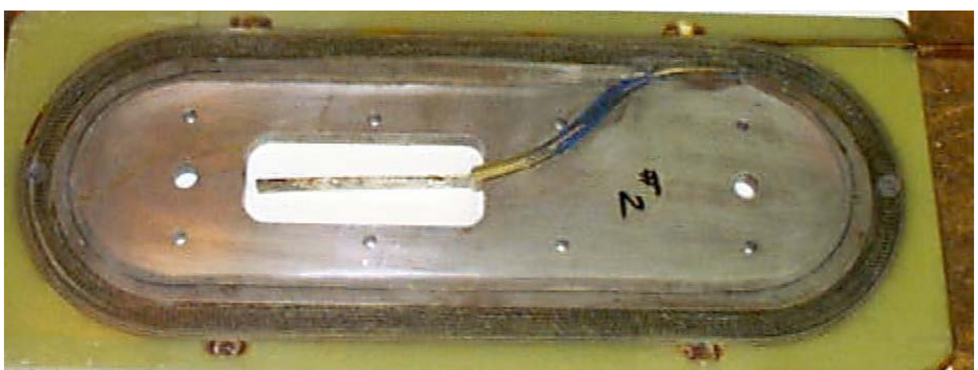
It sets the tone and nature of the magnet R&D.

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)

In the next generation package, bobbin will not be a part of the final product.

Fast Turn Around, Low-cost Magnet Construction

We do most, if not all work, in our local machine shop (when technicians are free from tunnel, etc.). Difficult to compete with other priority jobs at central shops. This also gives us faster throughput and more control.

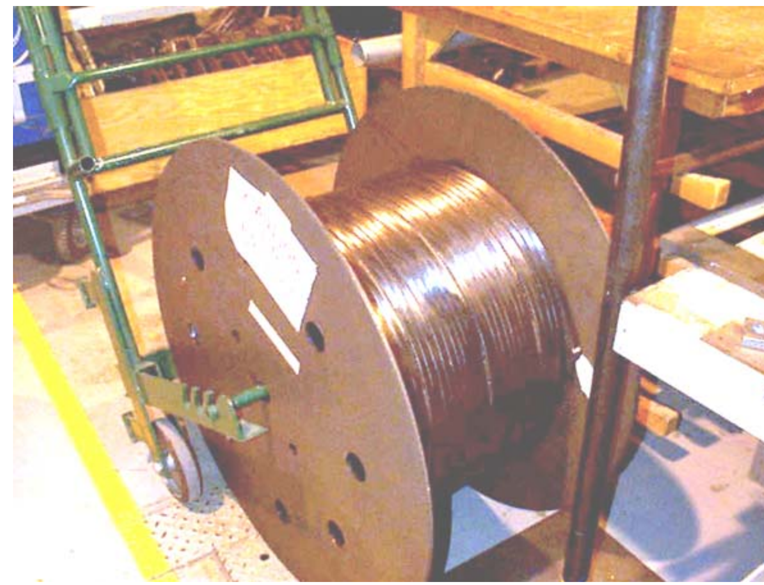
We have developed techniques to deal with less than desired tolerances. For example, we put vacuum impregnated coils on a Nomax sheet that is placed on a high precision Granite table. A thin layer of blue epoxy in between coils and Nomax gives overall final precision when put under some load.

Note “Blue Epoxy” is the 21st century answer to “Green Putty”. It just works a little better.

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.



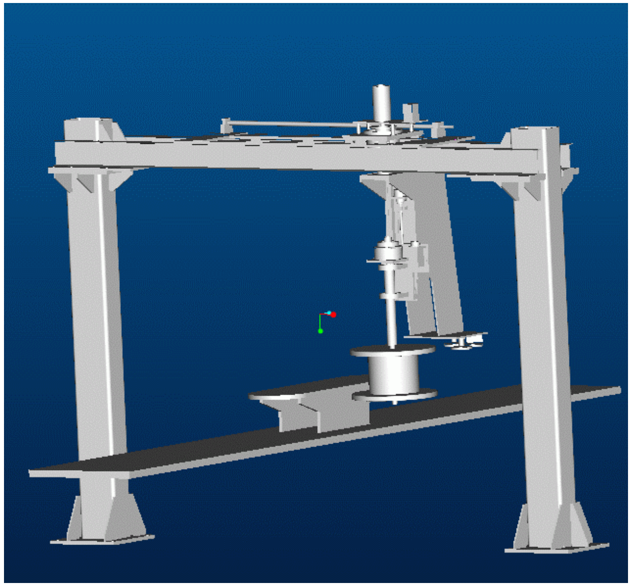
Nb_3Sn cable after reaction.

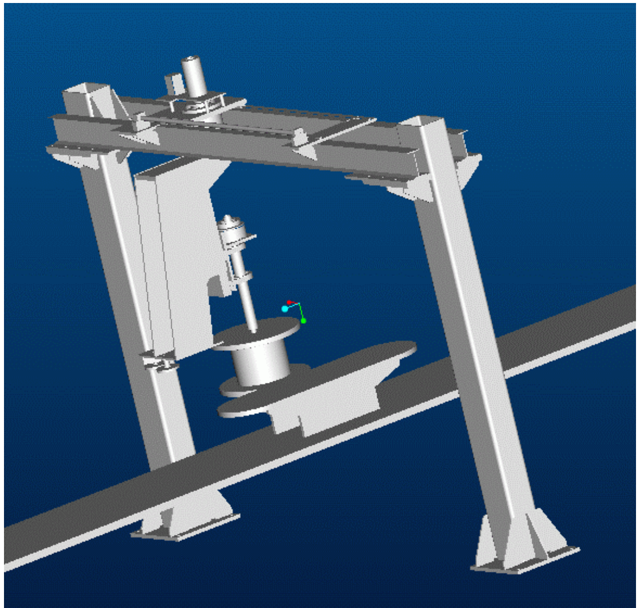
Nb_3Sn Cable Coming Out of Spool

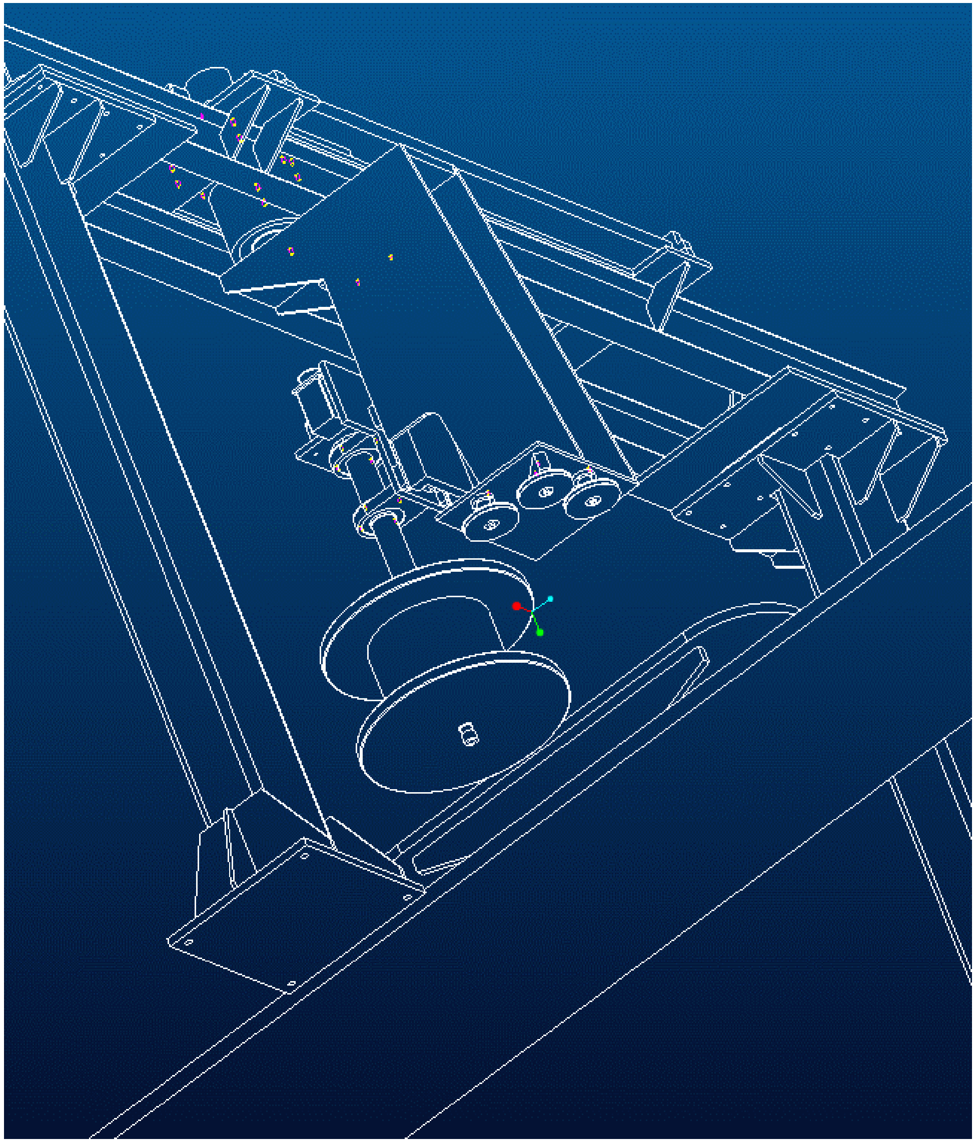
The coil is wound like a regular NbTi coil, of course with proper care (e.g., lower tension). This should help establish procedure, care (cost) required for Nb_3Sn magnets.

- **Reverse bend have been removed from the above tooling.**

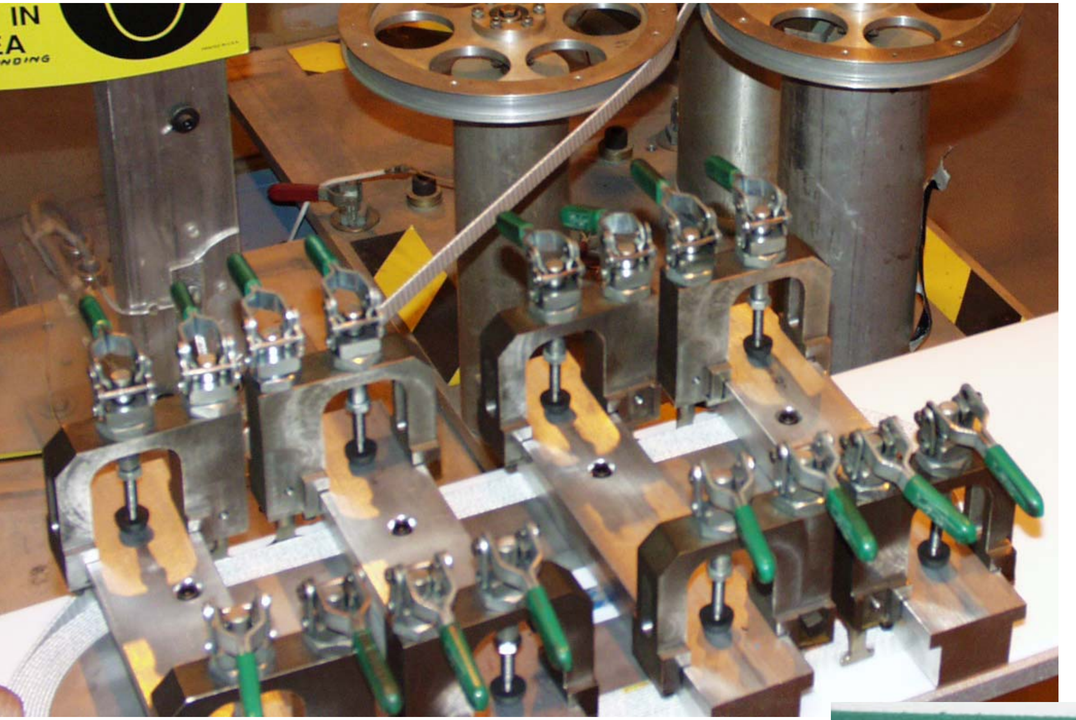
New Versatile Coil Winder Now Under Design







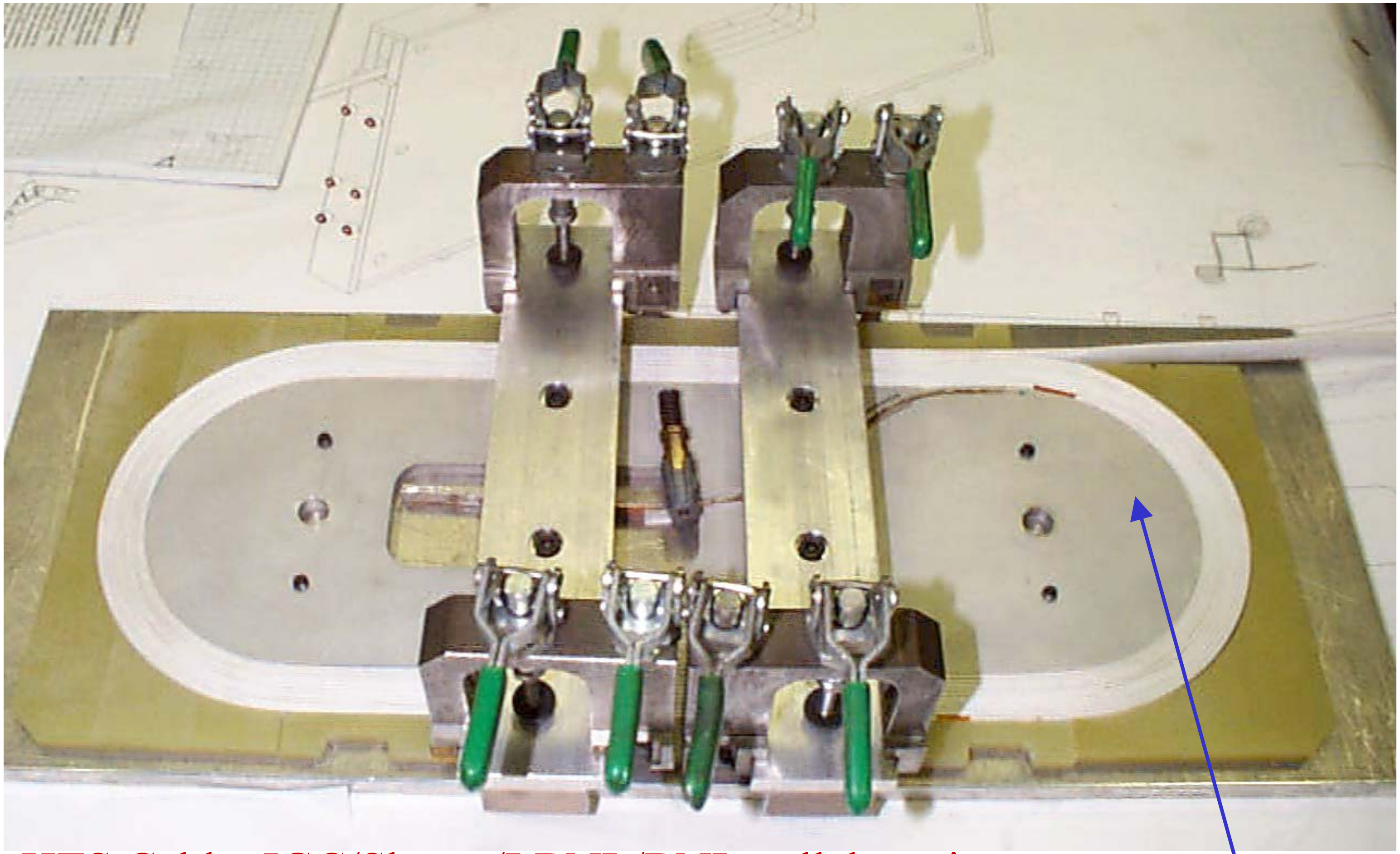
Holding Turns in Place During Winding



Present generation use clamps
(potential for conductor damage?)

Next generation:
Use Kevlar strings

HTS Coil Wound by Hand

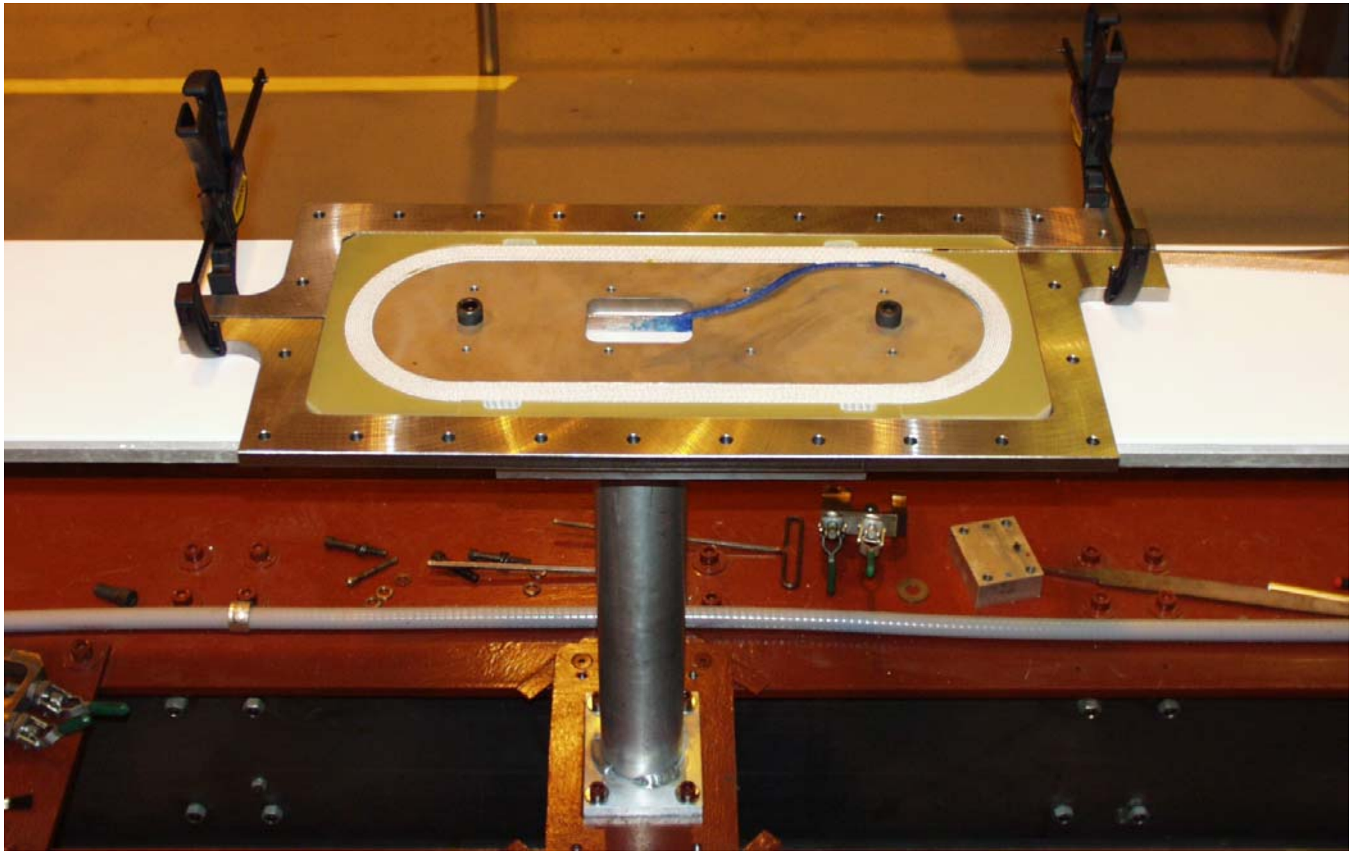


HTS Cable: IGC/Showa/LBNL/BNL collaboration

Al Bobbin

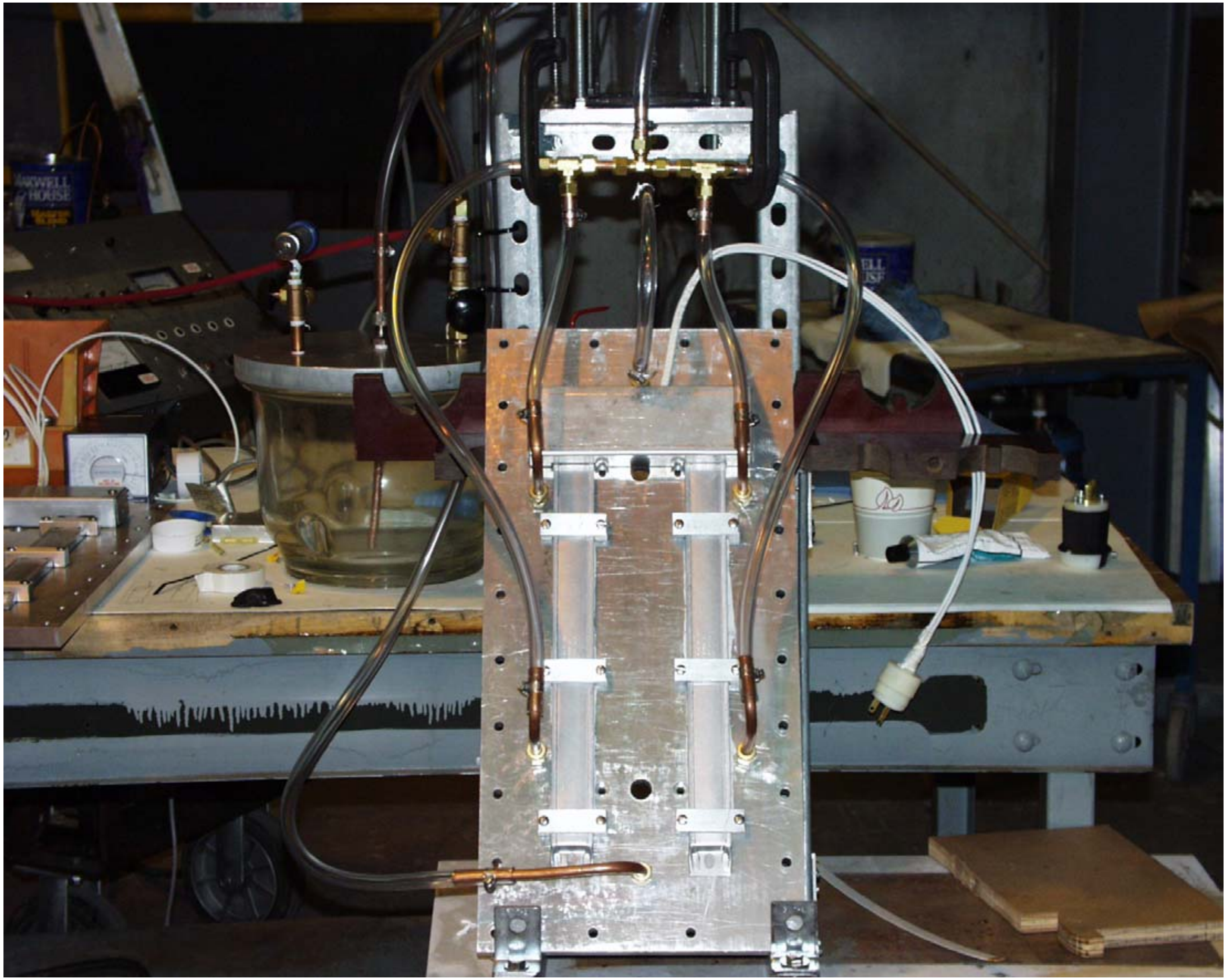
(also used, Fe, SS and brass bobbins)

10-turn Coil Being Prepared for Vacuum Impregnation

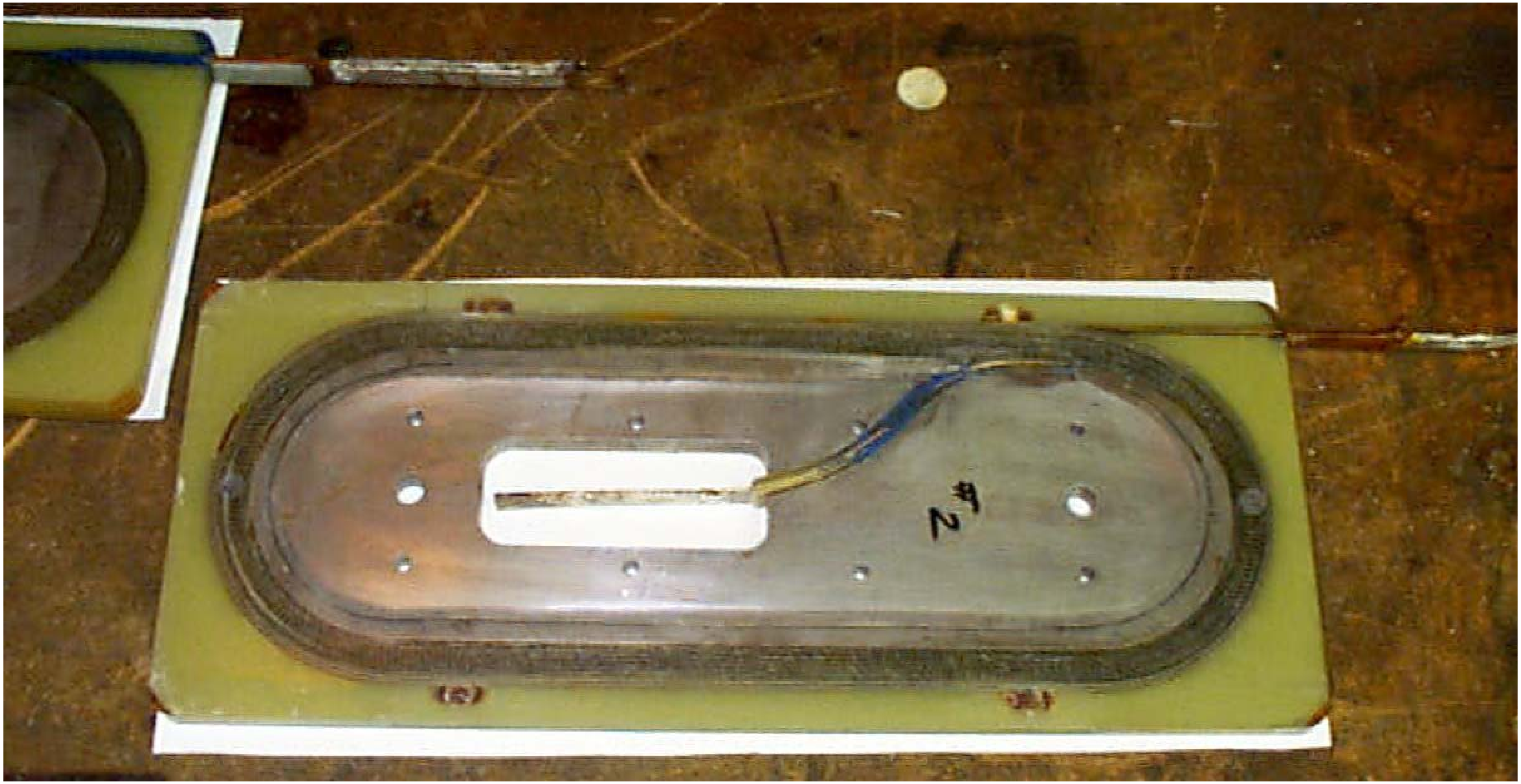


Blue epoxy & G10 to fill larger gaps

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.

Epoxy Issues

- First coil impregnation
  - All ***unreinforced*** epoxy>1/2 mm thick cracked
    - On surface ***and*** between elements

After impregnation (before cooldown)

After liquid nitrogen cooldown

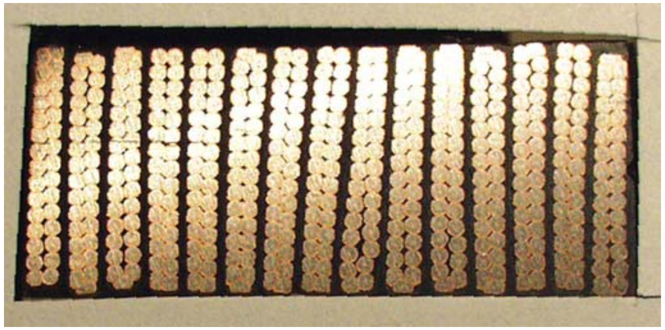
Use blue epoxy, G10, etc. to fill larger gaps

Insulation Test & Development

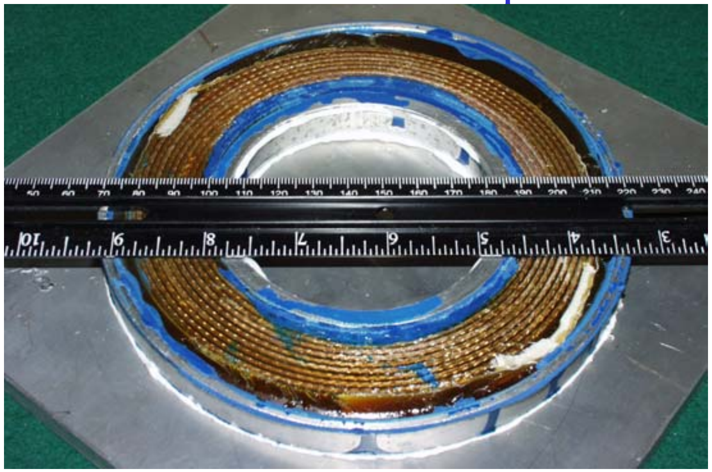
Insulation tapes as thin as 50 microns

Impregnated nomex insulation

10-turn fiberglass insulation test setup

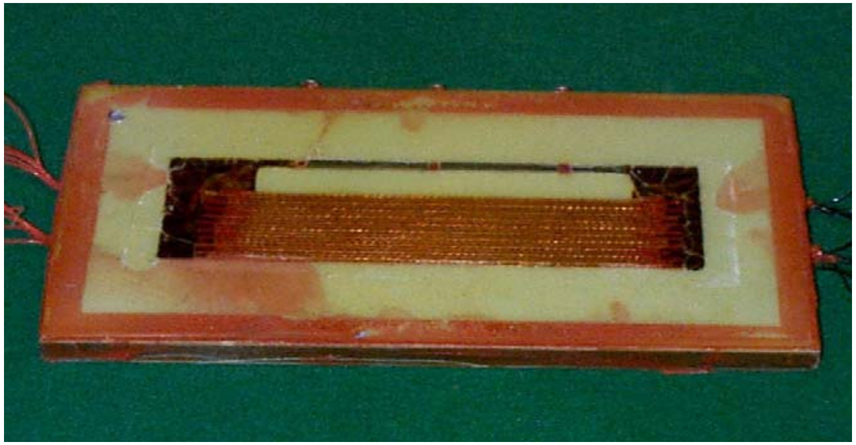


Insulation test setup



Braided insulation on reacted cable

Insulation Hi-pot test sample

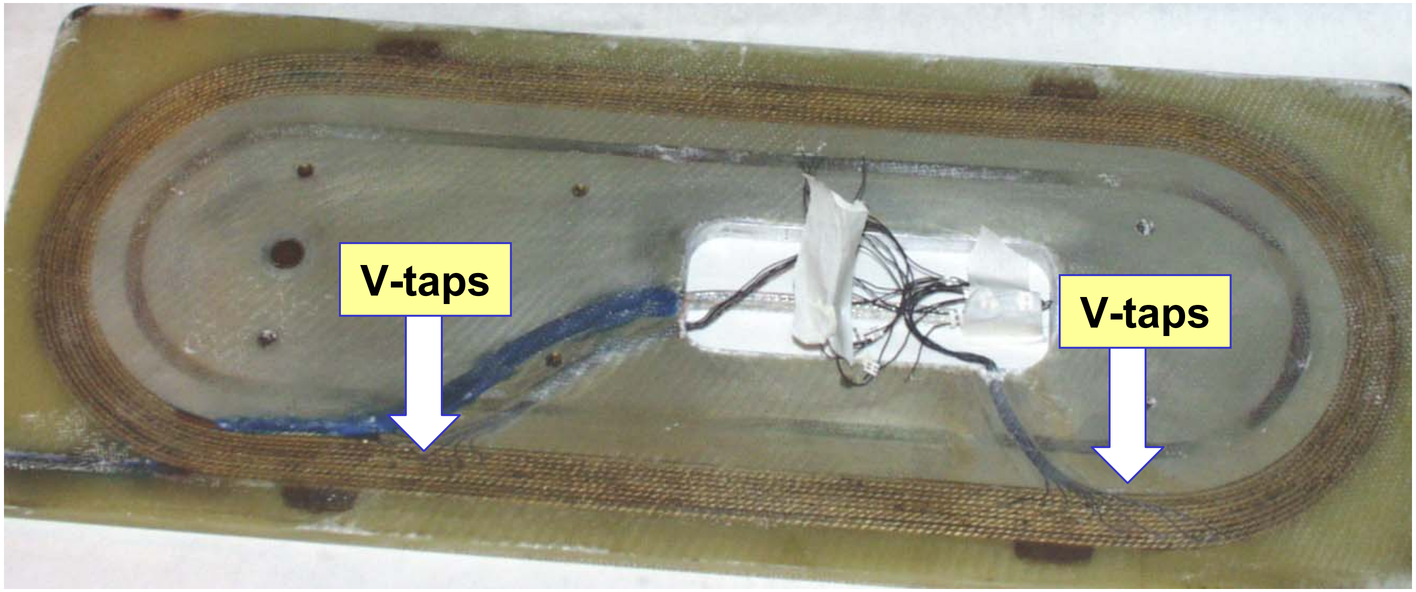


Voltage Taps, etc.

We put at least one voltage taps on each turn

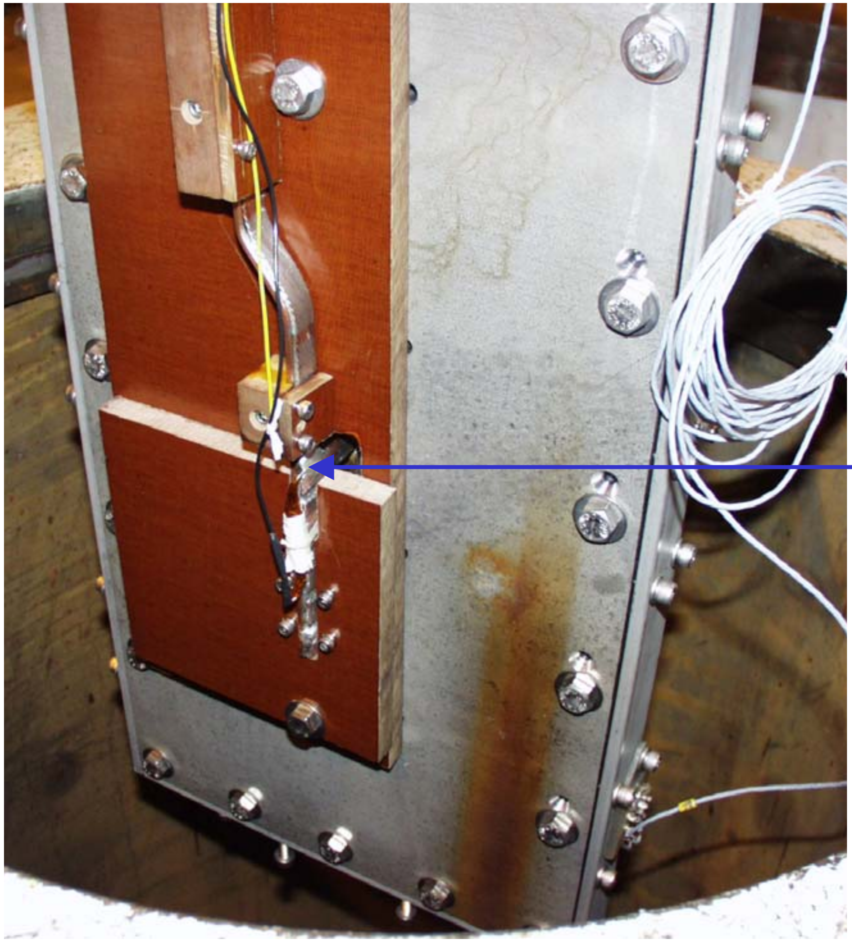
Given the aggressive R&D nature of the program we instrument is as much as we can to locate the weak spot (remember we are pushing beyond the safe limit).

Technicians have done a superb job as they have put hundreds of voltage taps and lost only one so far (open) and we do not believe that they have damaged any coil.



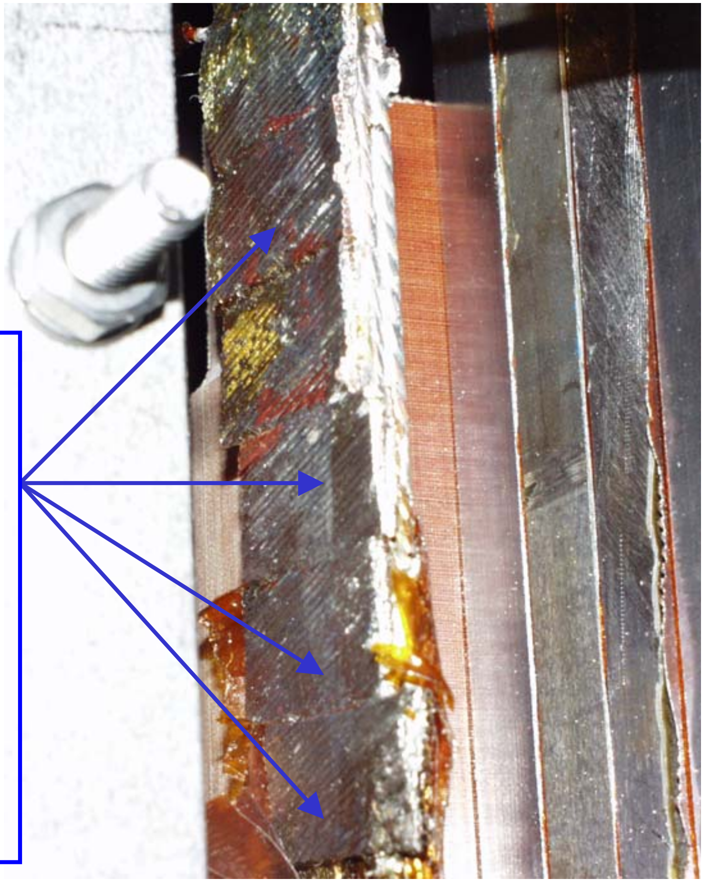
Recently, we have also started putting two quench heaters on each coil.

Internal Splice in Common Coil Design
(splices are perpendicular and are in low field region)



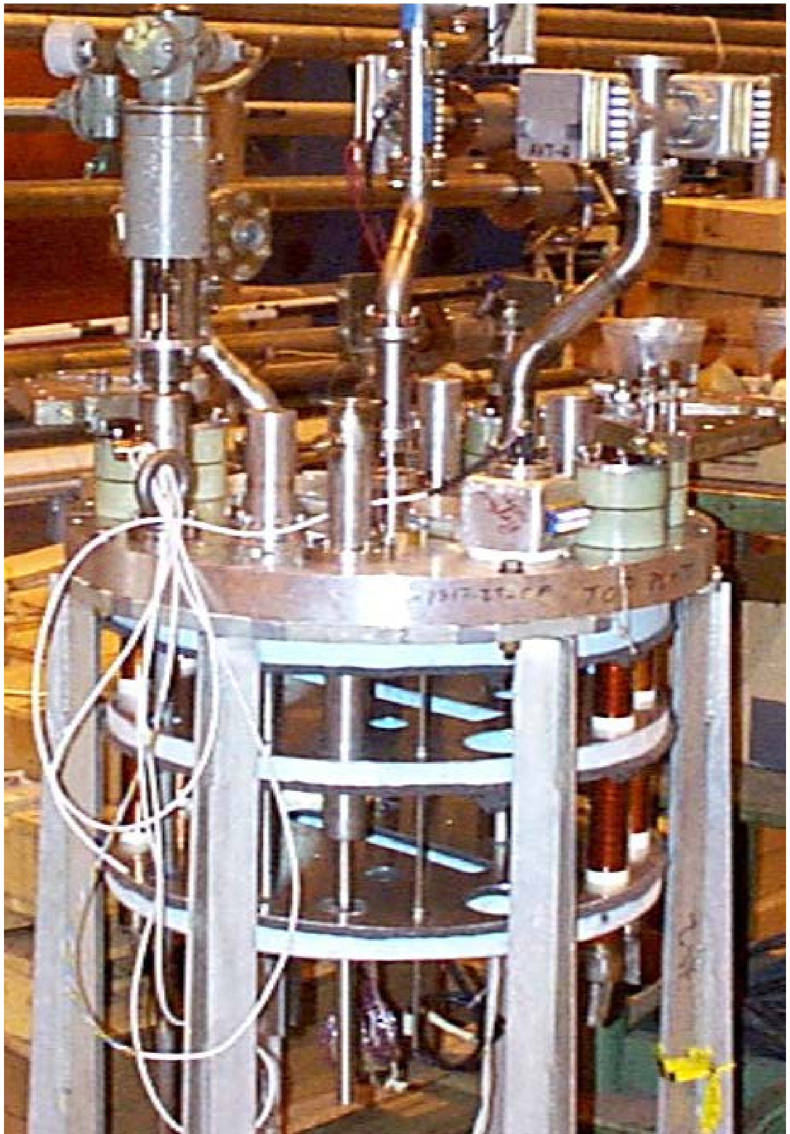
Splice for a single coil test (perpendicular splice take out the current to outside lead)

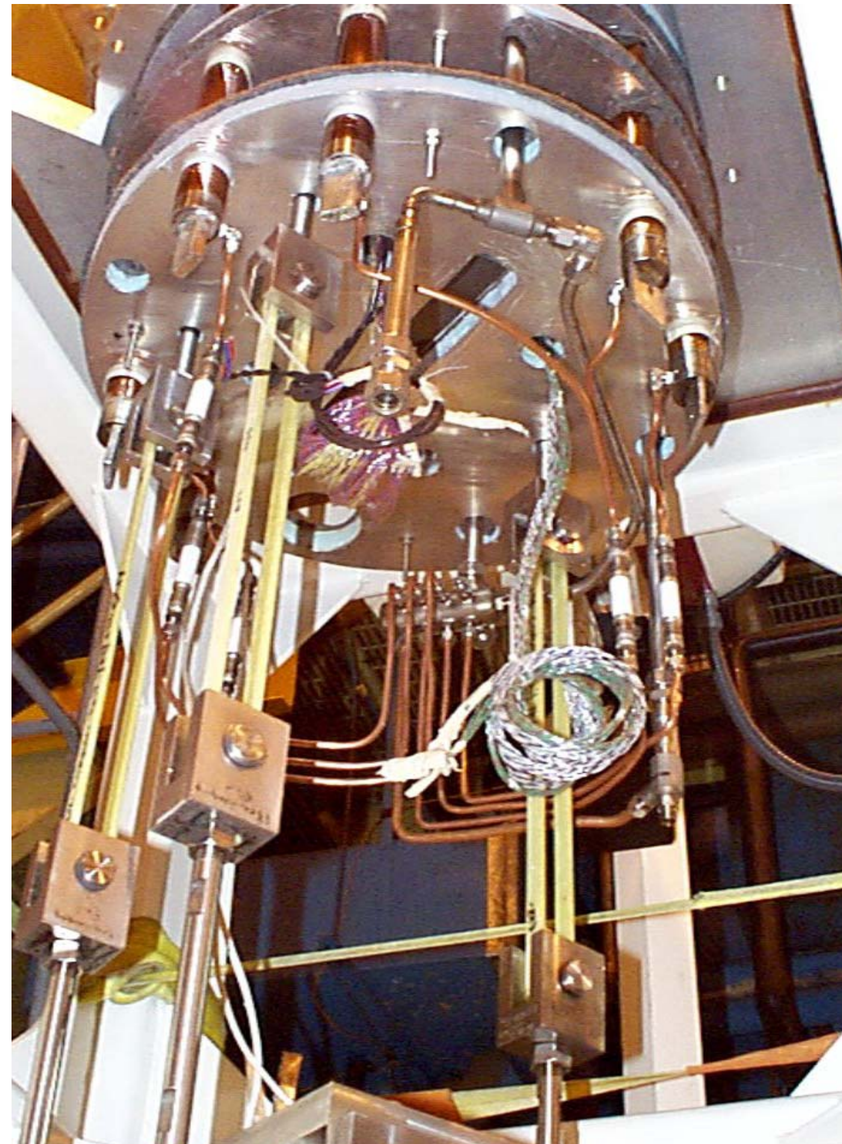
Perpendicular splices



Internal splice between two coils in a common coil configuration (note several perpendicular splices)

New Top Hat and Commissioning of High Current Test Facility





Support Structures (three)

Early Support Structure (4 T)

Simple used in low current testing

New Versatile Support Structure (9T)

Can take one to six coils with multiple power supplies in various configurations

Allows HTS coil testing in background field

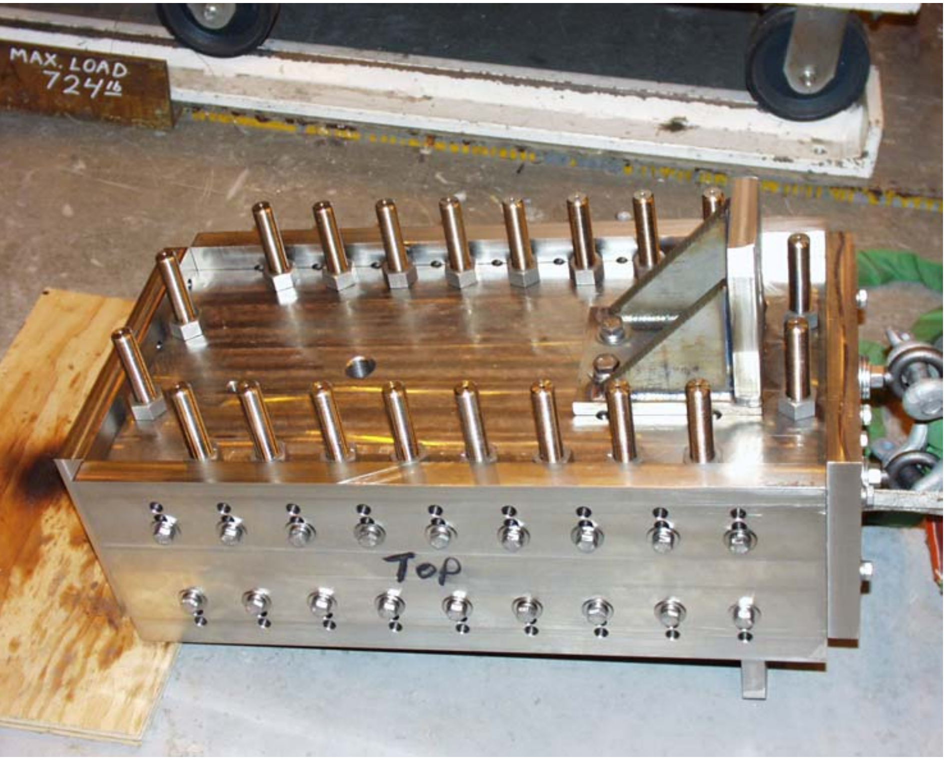
Future Support Structure (12 T)

Still in conceptual stage. Would be versatile and allow HTS coil testing in high background field

4 T Support Structure

Two coils in a support structure

New 9 T Support Structure



Versatile: Can test from one to six coils with three different currents.

Good for testing HTS coils in background field.

Test Results

Nb3Sn Coil Tests

Four rounds completed

HTS Cable Coil (racetrack and solenoid) Tests

Several liquid helium tests

Many liquid nitrogen tests

Time elapsed: A little over one year since starting Phase II

Turn around is reasonable as this also includes setting up the group (of part time people) and assembling the facilities.

We should have a faster turn-around in future for more systematic studies.

Nb_3Sn: Test Number 1

Single Coil Test

Internal splice brought out from one side

Could not get any quench up to 9500 A
(limited by power supply and leads)

This is ~70% of the short sample.

This establishes that **no major** damage was caused in our process of making coils with brittle pre-reacted Nb3Sn (wind & react).

Nb_3Sn: Test Number 2

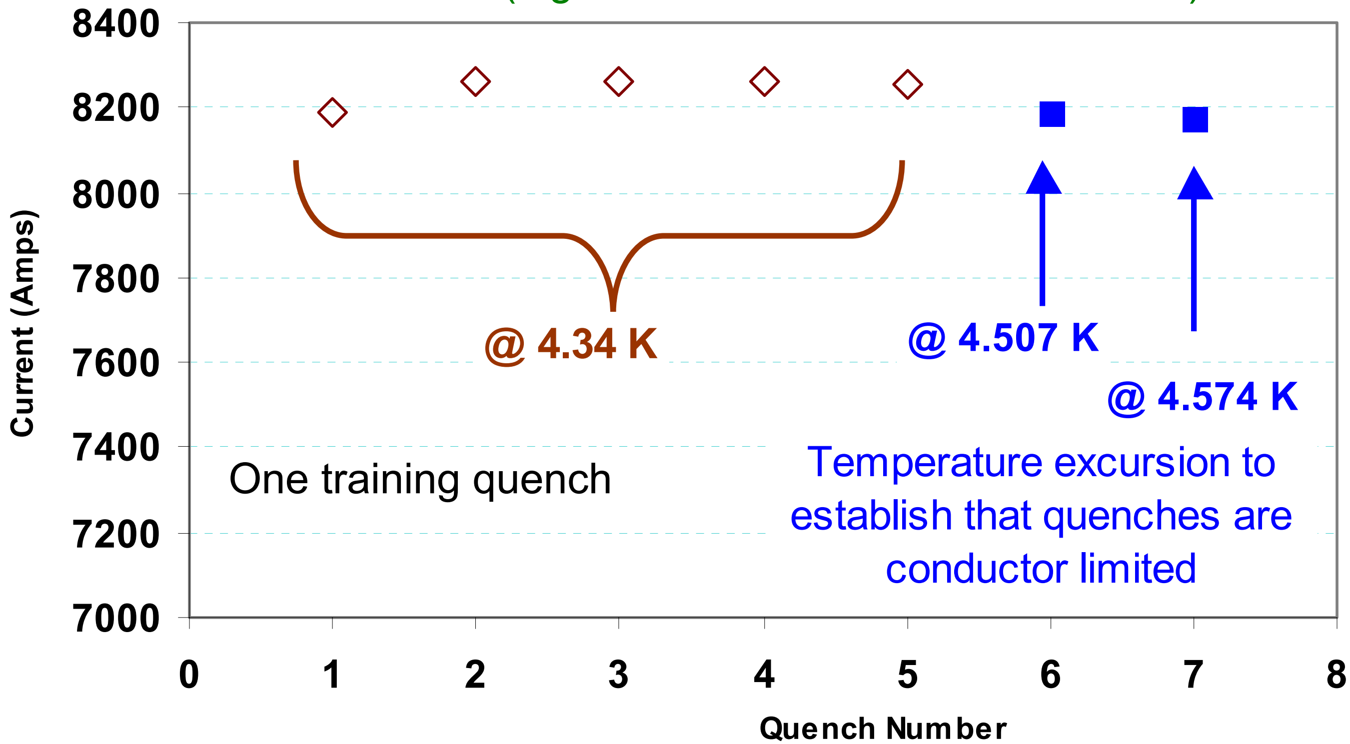
Two coils tested in common coil configurations

(coils very close, almost zero separation)

Plateau after one quench.

Tested only at high ramp rate. Based on ramp rate dependence and cable measurements elsewhere we though we reached ~93%. Subsequent test results at BNL in other magnets show that it was ~80% (higher based on LBL-RD2 numbers).

There were no voltage taps on the coils. Therefore we could not determine where the quenches were (coil or splice, etc.)



Nb_3Sn: Test Number 3

Two coils with at least one voltage tap on each turn

(coil separation and hence computed quench current goes up)

Could not get to quench plateau due to power supply limit.

Ramped to 86% (power supply limit) of cable short sample limit (11kA, measured at BNL, a value higher than other measurements).

One quench at 9.7 kA after staying at flattop (what happened?).

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

Could not get magnet to quench after ~10 ramps, tried various ramp rates.

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

Some people say that presence of voltage taps discouraged the bad guy to quench!

Nb_3Sn: Test Number 4

Common Coil Configuration with High Performance (RD3 outer) Cable

This is expected to carry about ~20 kA at the quench field of ~8+ T

We made new support structure.
Developed techniques to assure good contact between coil & support.
We made new top hat.
We made new leads for 20kA test.
We cobbled-up many other new things for this test.

… and we got a quench plateau at ~3kA.
At this low field, only one out of 26 wires can carry this current.
The cable did not get degraded, it got severely damaged.

Nb_3Sn: Test Number 4 (contd.) What happened?

The magnet was heavily instrumented (usefulness in understanding indicated below).

We have at least one voltage tap at every turn.

All quenches (except the heater induced quenches) were exactly same.

- They have same profile.
- They all occur between voltage tap #9 & #10 (turn #2 & #3 counting from inner)
  - A very unlikely and boring place.
  - One would have suspected it in splice or inner most turn area, where the cable gets handled more.

So what happened?

- There does not seem to be a systematic, design or engineering flaw, as we have made several nb3sn and HTS coils before.
- The same technicians have worked on this project before and they were told, over and over again, to be more careful this time (potential for higher field).

Was it an accident or some thing more?

Nb_3Sn: Test Number 4 (contd.)

Test results in non-electronic transparencies.

We still did a lot of studies.

- Temperature dependence.
- Ramp rate dependence.
- Quench heater induced quenches (there were four heaters) at two currents.

Nb_3Sn: Test Number 4 What happened (contd.)?

We are doing autopsy of the coil. G-10,= and Nomax-sheet has been removed along with blue epoxy.

Good thing about fiberglass-epoxy insulation is that it gets transparent after impregnation so you can see inside. A few interesting things but no smoking guns.

Was it those manual clamps, which inadvertently got over-used (techs say NO).

There is some thing interesting about the cable:

- The previous ITER cables that we used did not get stick. The wires had either chrome-plating or were passed through Mobile-1 by vendor (New England).
- In this case, we spread oil after cabling. Did oil spread on 100% and did it go well inside the cable in between the strand, everywhere?
- This particular cable after reaction had large set and would tend to open up.
- We removed the insulation from the left-over cable and visually checked. Nothing new was found except above. The same tech was asked to put insulation back.
- He came back and said he had to wrap it by hand. What does it imply?

While the investigation continues, we test the other coil by itself and make more coils.

Importance of Rapid Turn around Program

What happened, here could perhaps have happened any where

In short or long magnet.

In a magnet with more or fewer turn turns.

This is a kind of learning/”dealing with accident” thing that must be allowed in a program that is intended to develop in new technology or push the existing beyond comfort zone.

We can make new coil(s) and do another test in a month

no major setback only a learning experience.

It not only validates our magnet program philosophy but proves the importance of it in a true magnet R&D program.

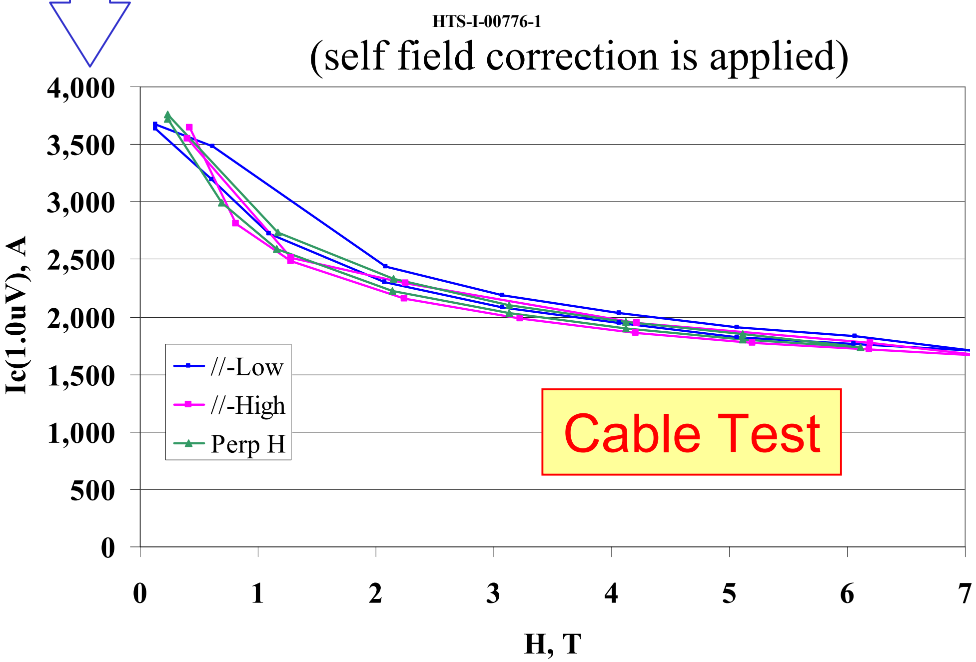
Measured Performance of HTS Cable and Tape As A Function of Field at BNL

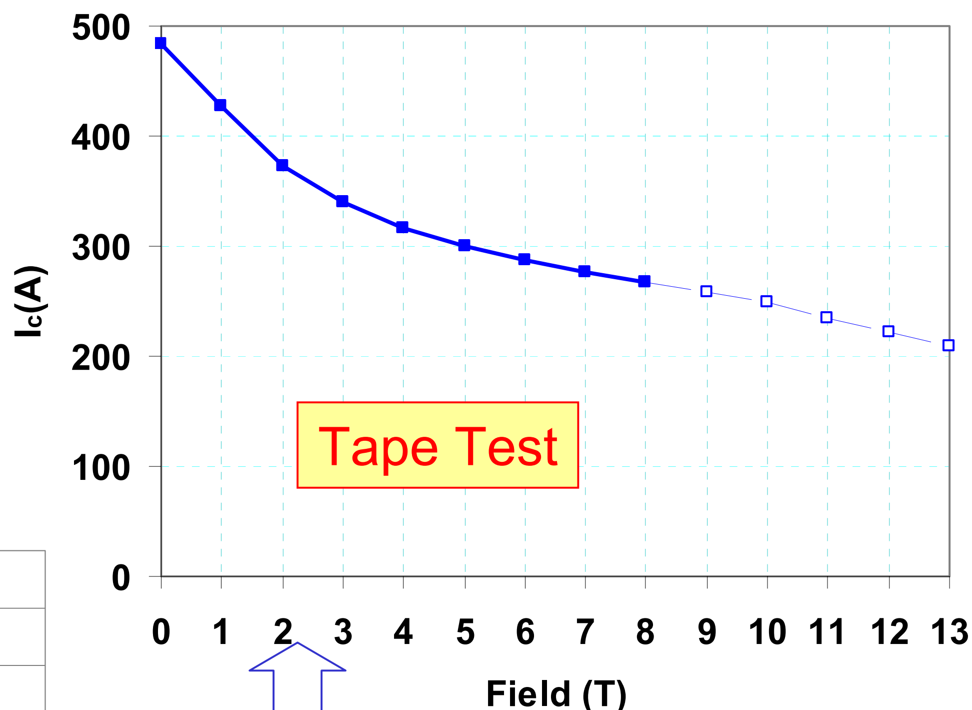
Note: Tape and wire have about the same area.

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

Ic is better by over a factor of 2 now.

This was a narrow (18 strand) cable.
Standard cable will carry much more.





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

(field perpendicular value is ~60%)

HTS Coil Tests

Test Configurations

Single coil test

Racetrack coils

Solenoidal Coils

Two coil Tests

Common coil configuration

Muon collider configuration

HTS Cable Coil Tests

Several liquid helium tests

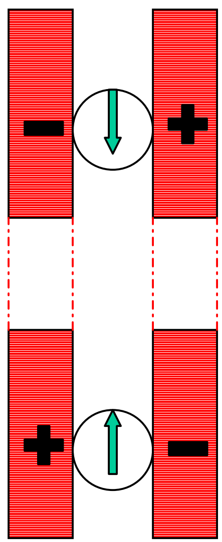
Many liquid nitrogen tests

BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

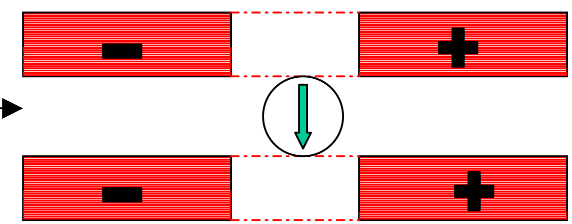
Common Coil and Muon Collider Test Configurations

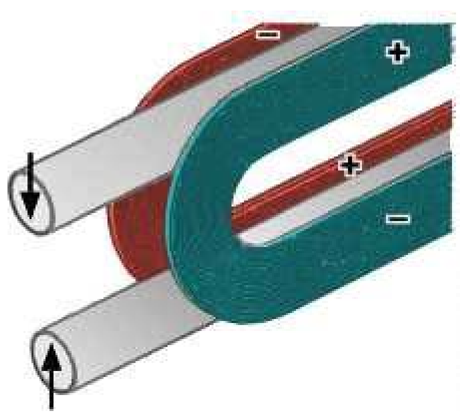
Common Coil configuration

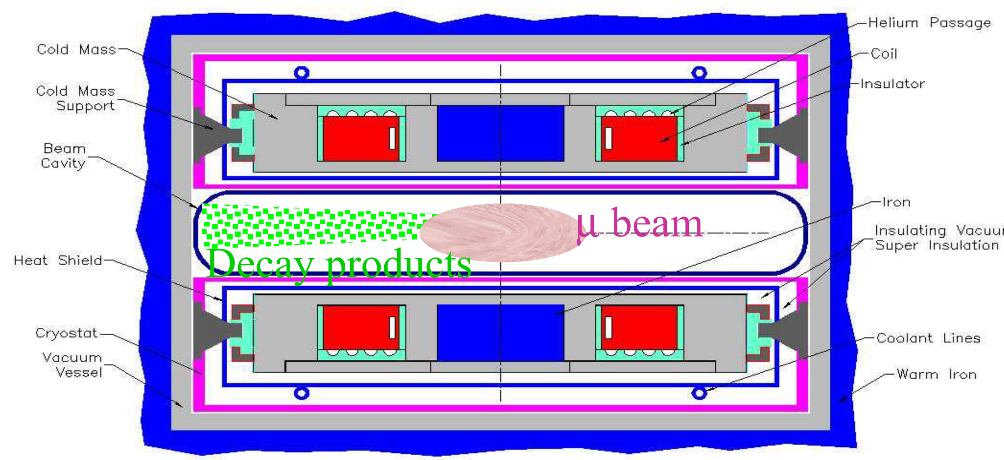


Powering differently changes common coil design test to muon collider design test

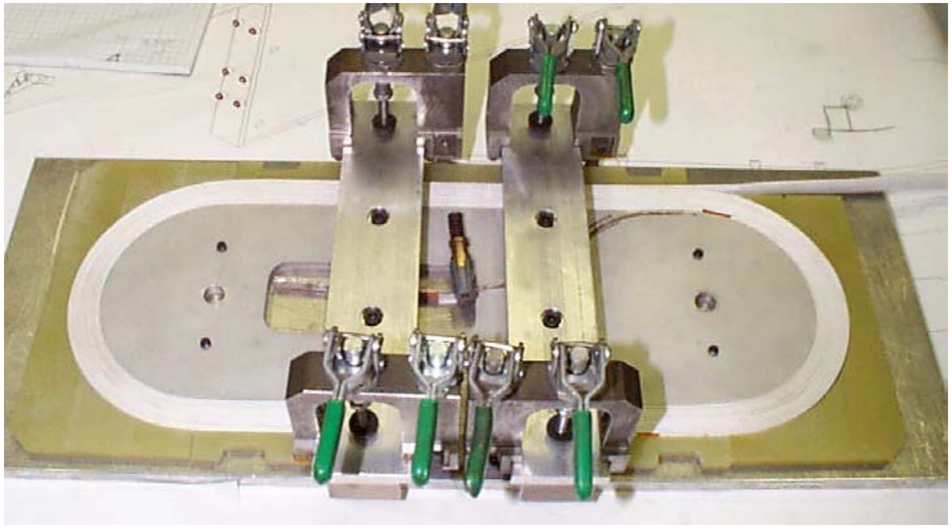
muon collider configuration





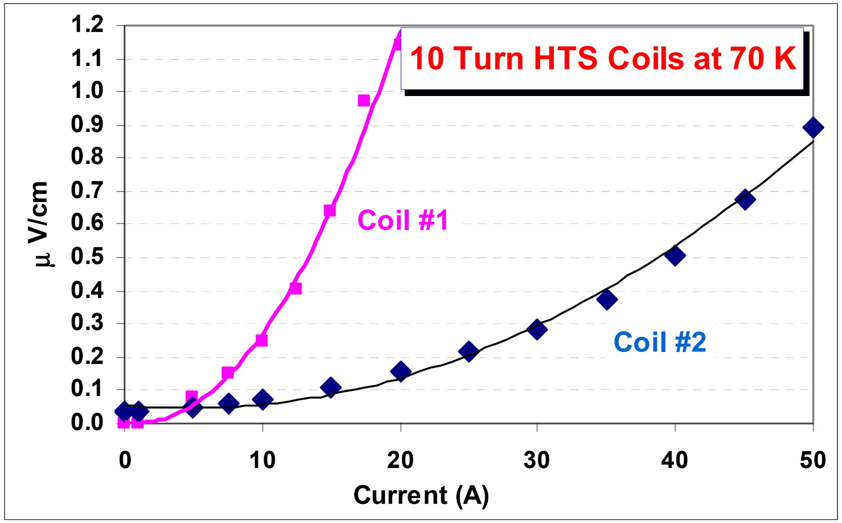


Common Coil Magnets With HTS Cable



HTS cable coil prior to vacuum impregnation

Two coils were tested in Liquid Nitrogen



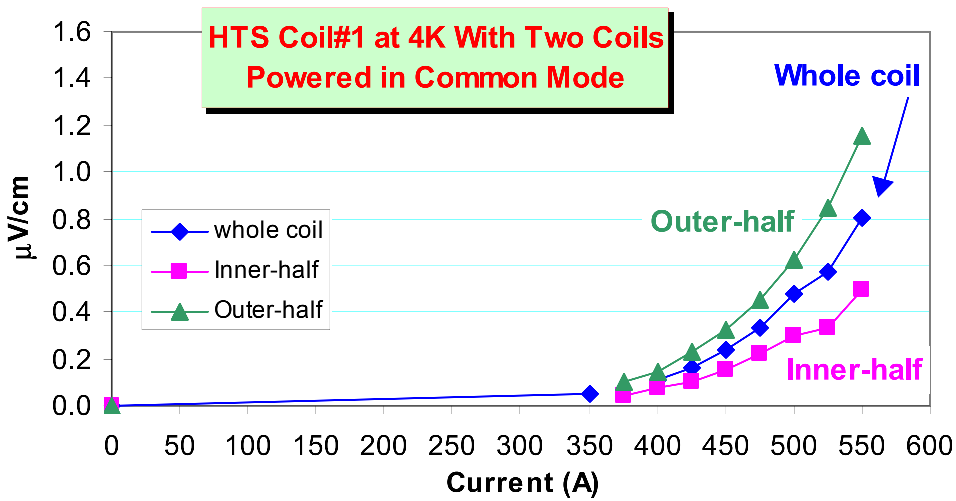
A coil cassette made with HTS cable after vacuum impregnation and instrumentation

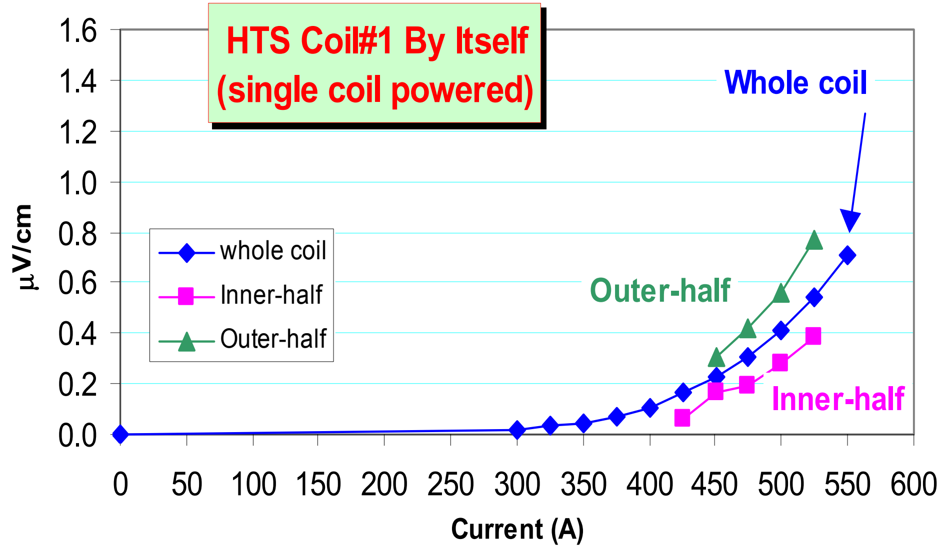
The HTS cables were from two different batches. They behaved differently:

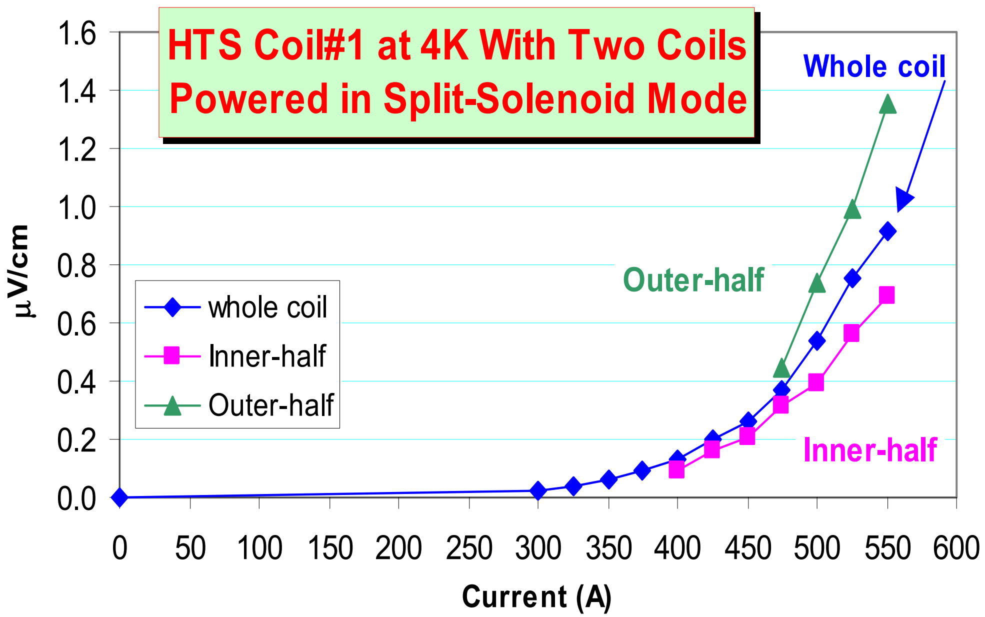
- Different Ic
- Different Tc

Based on preliminary analysis, no large degradation has been observed.

4K Performance of 1st Common Coil HTS Magnet







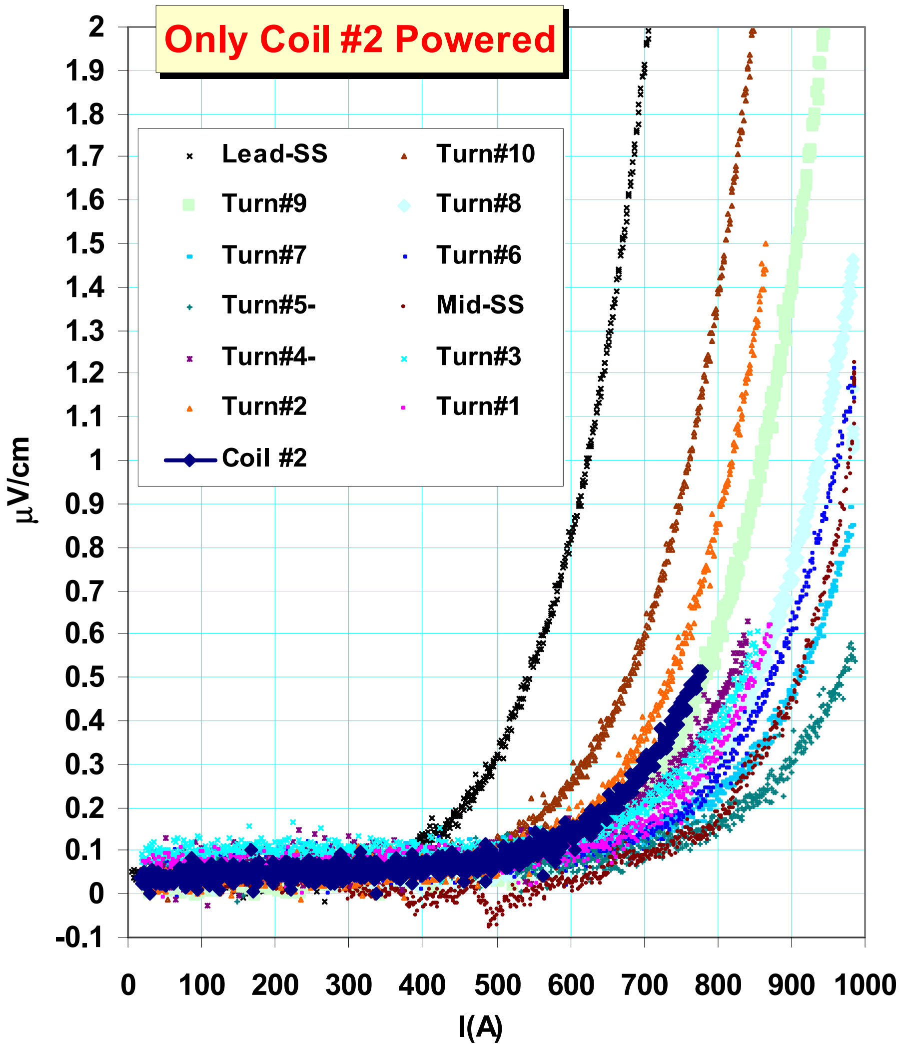
Notes:

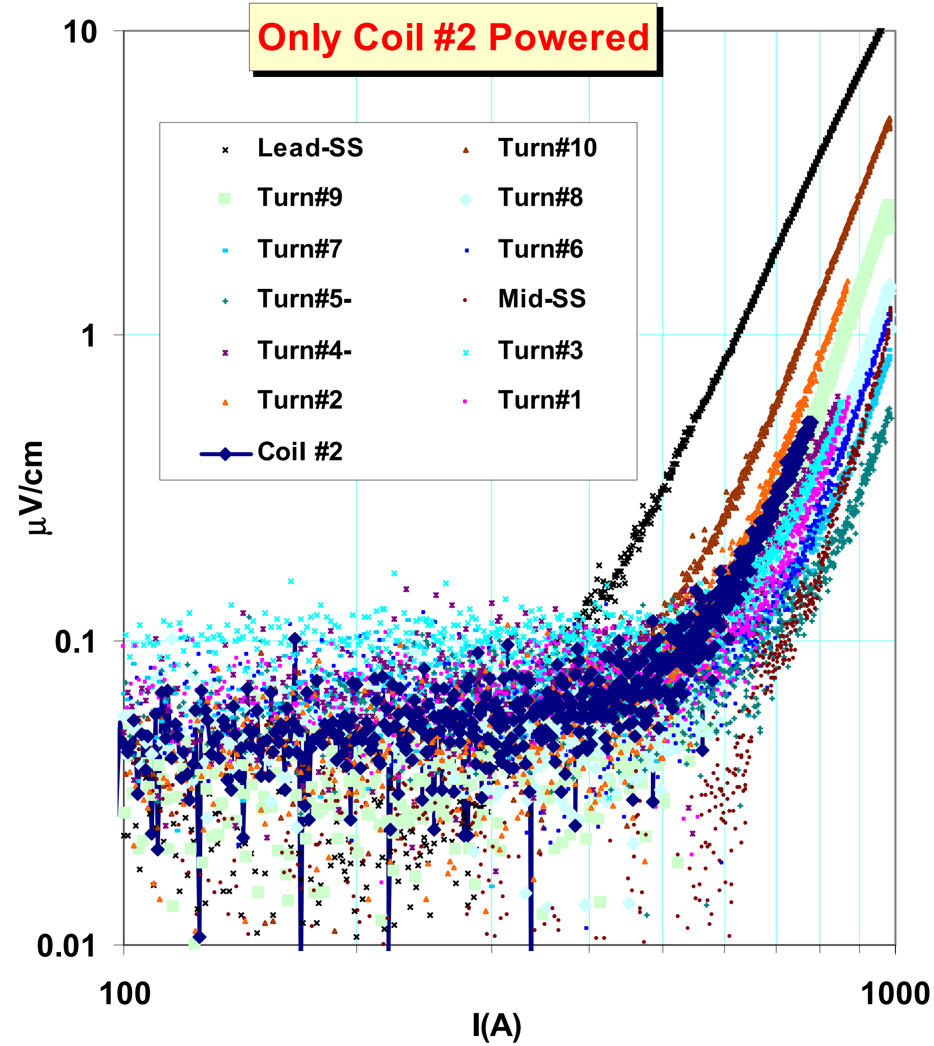
- The cable in coil#2 was better than that used in coil #1; no clear onset of resistive state was observed up to 550 A. See results of next tests at higher current.
- Observed performance of coil#1 is line with expectation (no large/significant degradation was observed).
- The inner coil half (smaller bend radius) has better performance. It was made with the better part of cable - as per LN2 measurements. This means that the cable performance rather than degradation during manufacturing is determining the performance --- an encouraging result indeed.

BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Performance of Coil #2 Powered Alone (Coil #1 off)

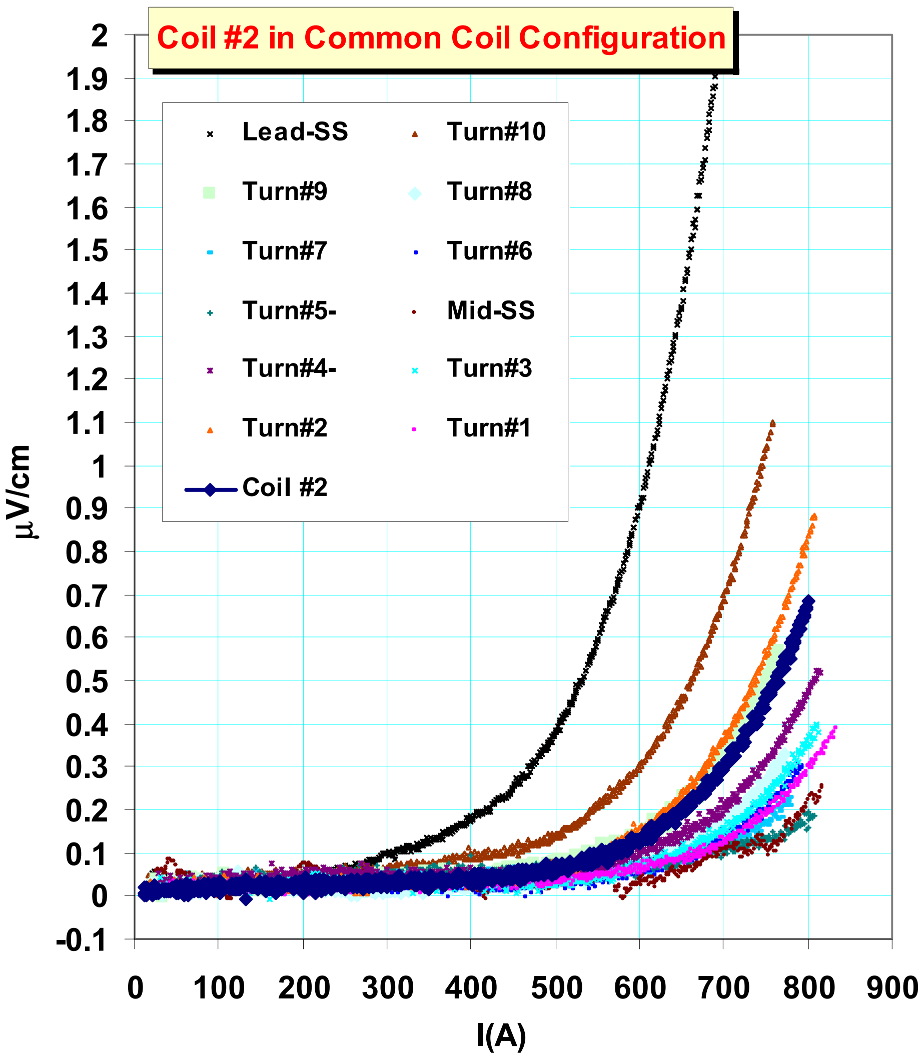


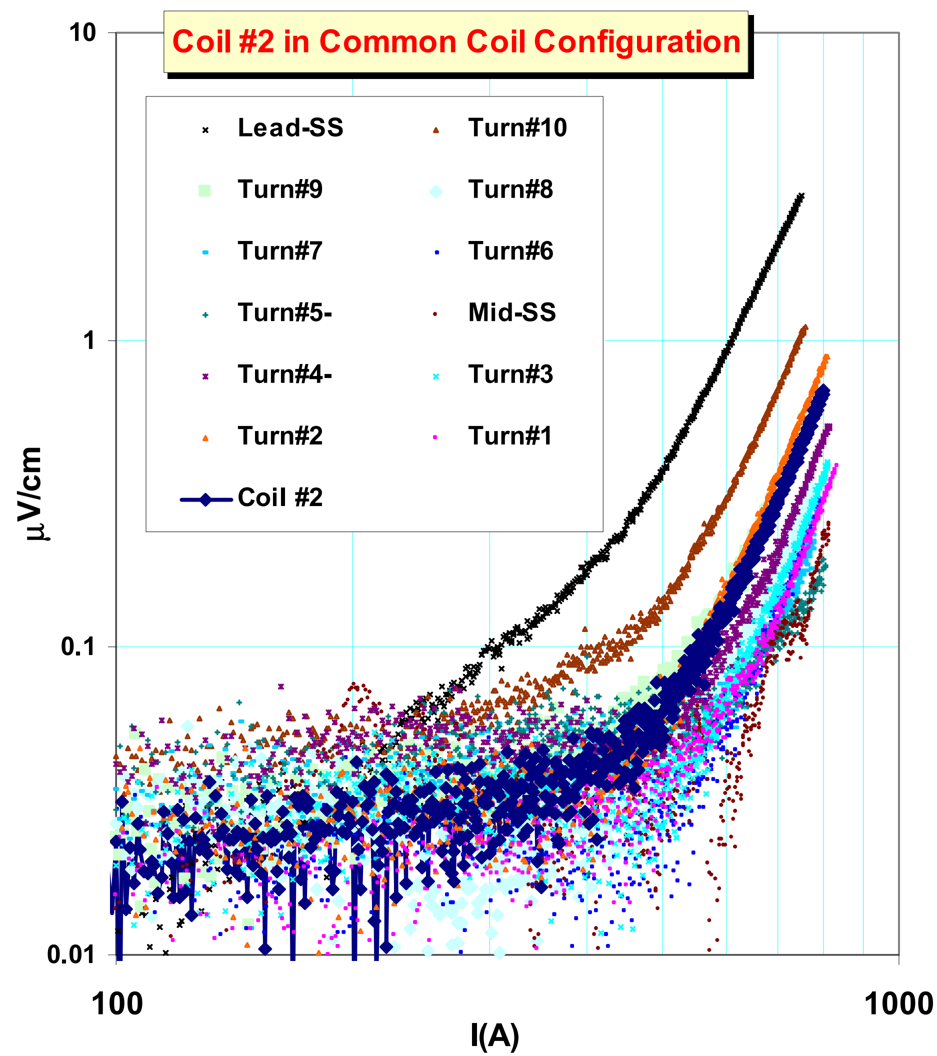


BROOKHAVEN NATIONAL LABORATORY

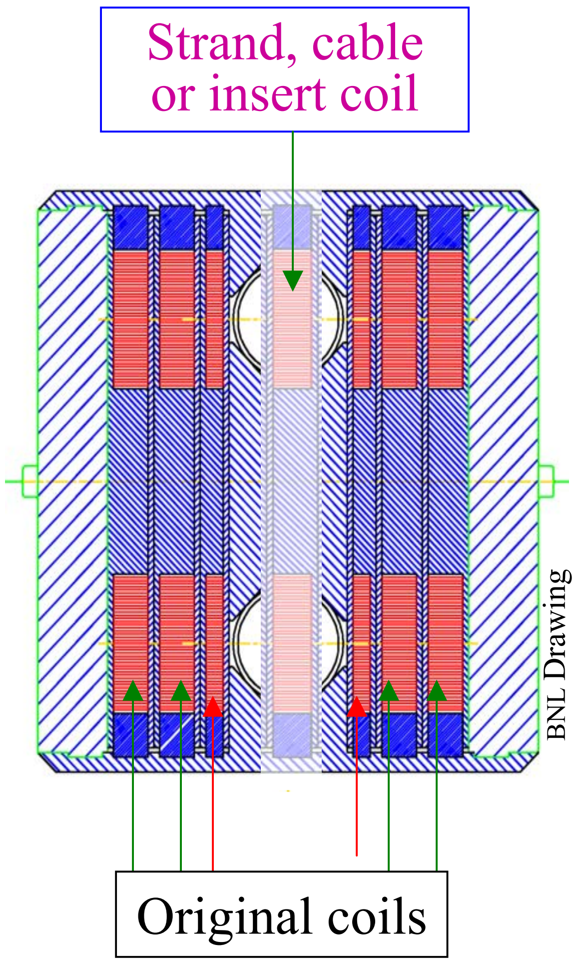
Superconducting Magnet Division

Performance of Coil #2 in Common Coil Configuration





Common Coil Magnet As A Test Facility

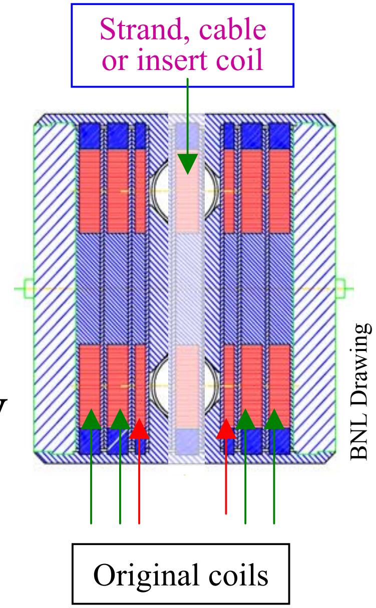


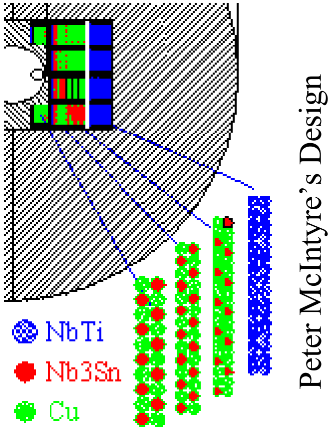
- **A Modular Design with a significant flexibility.**
- **Coil geometry is vertical and flat. That means a new coil module having even a different cable width can be accommodated by changing only few parts in the internal support structure.**
- **The central field can be increased by reducing the separation 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





Conclusion and Status of Magnet R&D Program at BNL

Several new design concept developed in line of "think outside the box".

- **A new way of doing magnet R&D (rapid turn around) established.**

Phase 2 status and progress in ~1+ year (a partial list)

- New engineering design and construction techniques developed
  - "React & Wind" HTS and Nb_3Sn coil
- Rapid turn-around demonstrated
  - 9 racetrack 10-turn coils are built and 3 more are underway (5 HTS and 7 Nb_3Sn coils)
- Five 4.2 K and a number of LN_2 tests of common coil design performed
- HTS and Nb_3Sn cable tested as a function of field (a lot more testing on HTS)
- New top hat for ~25 kA testing complete
- Two support structures built; third 12 T is in conceptual state.
- New thinner fiberglass insulation in collaboration with industries
  - 3 varieties with 50% less thickness (equivalent gain in conductor J_c is ~10%)
- Magnetic design of 12 T background field magnet completed; conductor ordered.

Significant output with a limited resources !