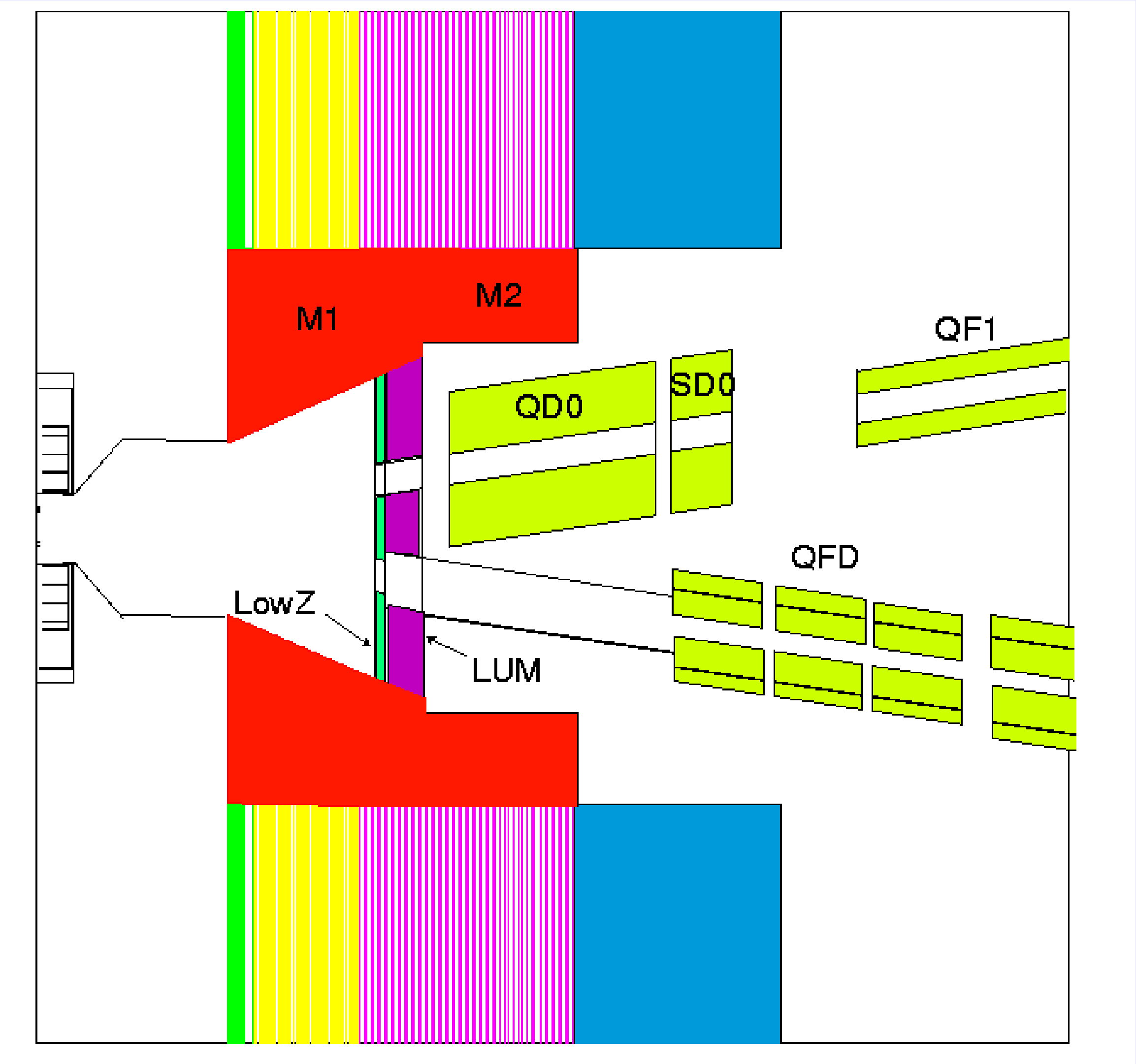
# Superconducting Magnet R&D

Linear Collider Beam Delivery System
Superconducting Materials development
High Field Magnet R&D - generic, LARP
Rapid Cycling Magnet R&D

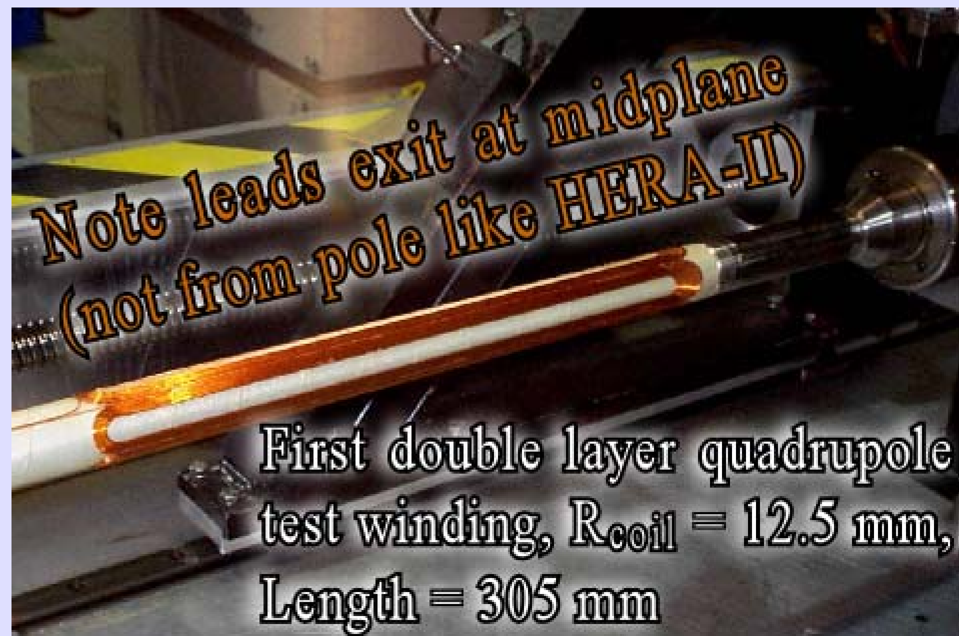
# Linear Collider Final Focus - concept



# Short Test Coils (BNL-LDRD)


Demonstrate the ability to wind small Diameter coils

Double layer coils



# Long Coil Test (BNL-LDRD)

Test Coil winding: 36” long, 1 double layer, full quadrupole pattern

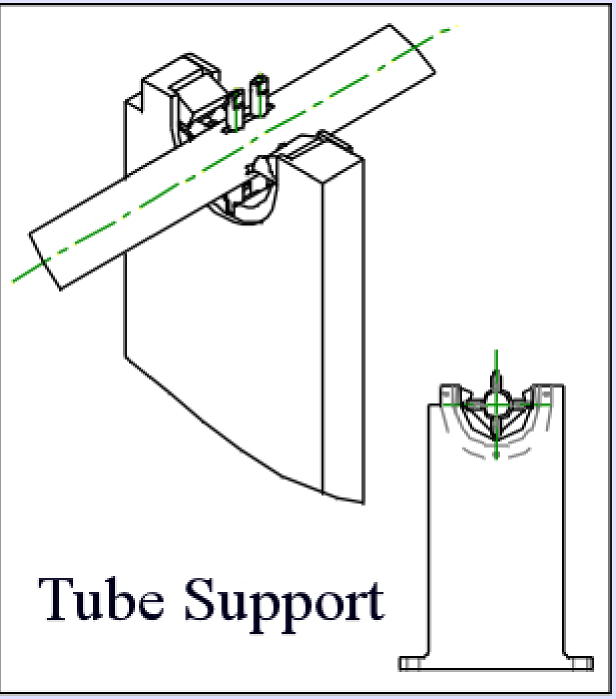
Successes:

- Minimum wire radius O.K. for 20 mm tube
- Wire interleaving for a 2-layer coil worked well
- Good field quality in the ends

Problems:

- Tube bows under stylus pressure
- Substrate (from the DESY program ) is too thick producing minimum spacing issues
- 2nd layer bonding problem (substrate ?)
- Wire coating exceeds shelf life (greatly). Wire is 10 years old (RHIC program).

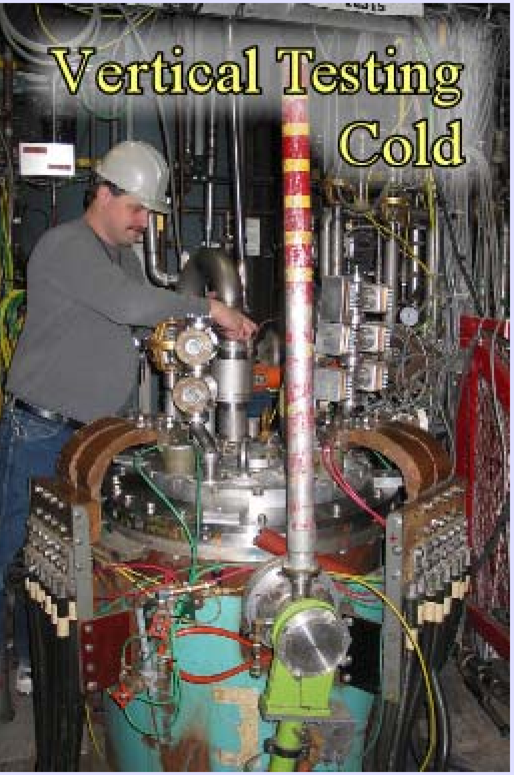
# Ongoing Development FY03 (BNL-LDRD)



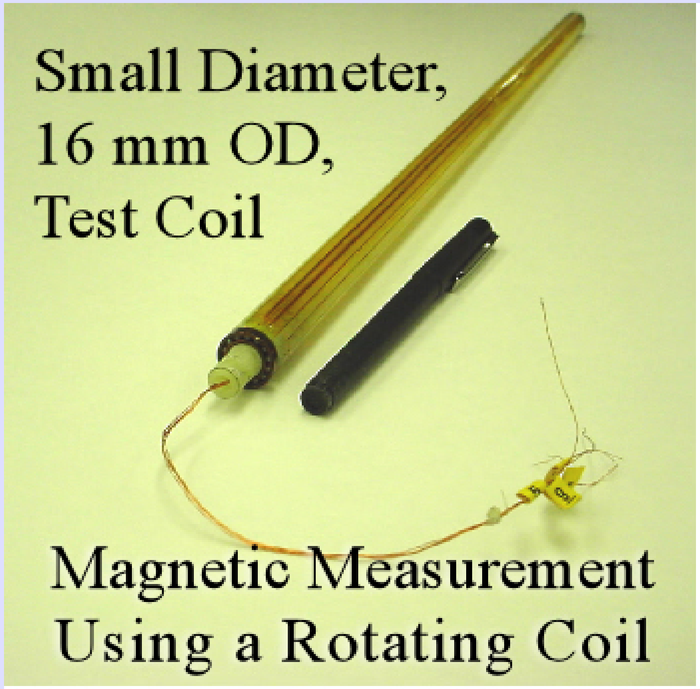

- We are working to produce a tube support system for both winding and wrapping

FY03 goal: demonstrate final winding and wrapping techniques for the first coil layer

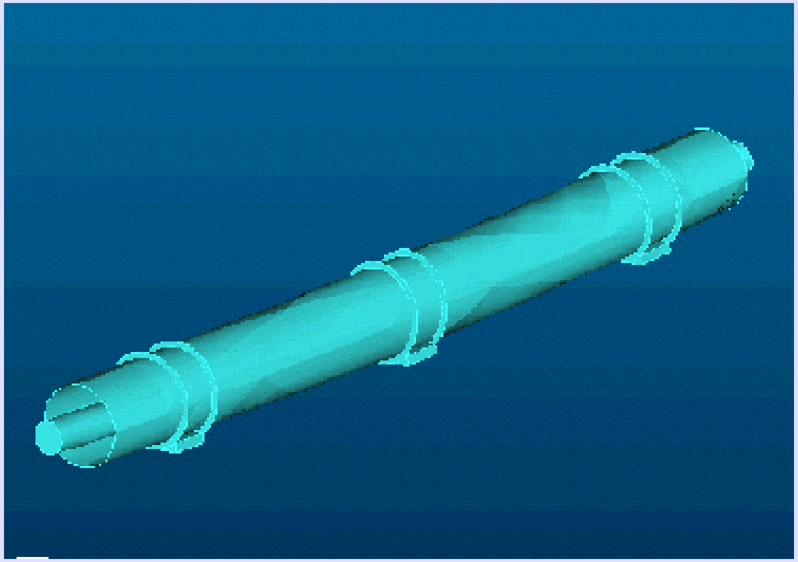
# Ongoing Development FY03




Resuscitate the small bore measuring equipment (curtsey of the APT project)

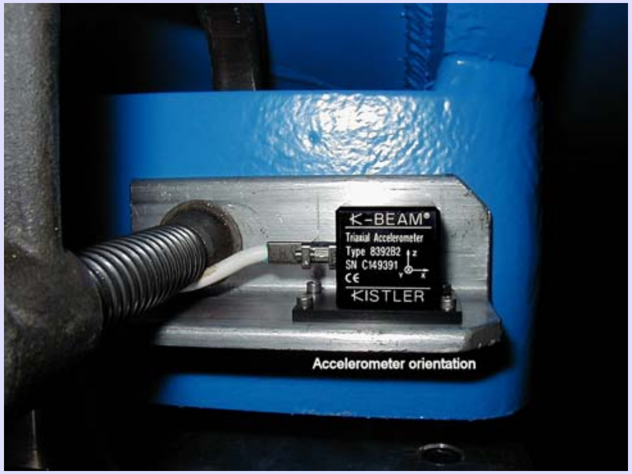



# Vibration studies




LHC D2 magnet modeled in pro-engineer: 14 modes Below 60 Hz

Test measurements on the measuring stand

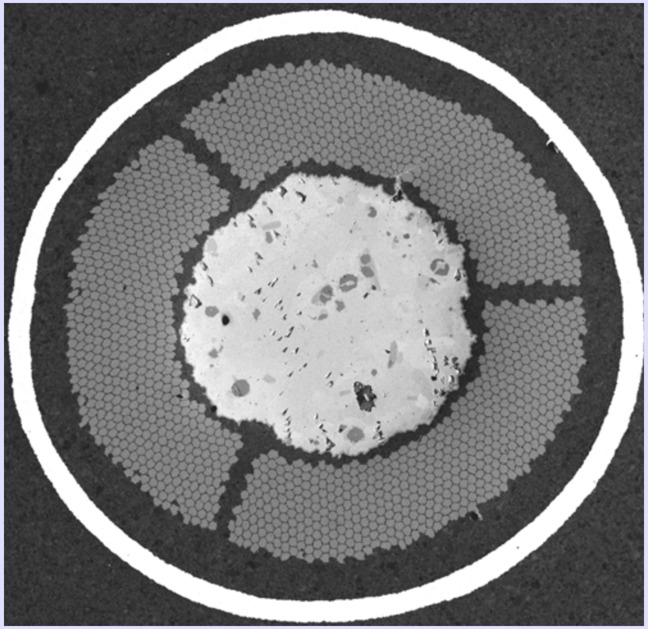


# Superconductor Development and Testing

- $Nb_3Sn$ Conductor development
  - Reaction-kinetics of $Nb_3Sn$ formation in high Sn conductors
  - Flexible cable
  - Rutherford Cable testing
- HTS Conductor development
  - Bi-2212 Wire
  - Cable Testing at 77K and 4.2K

# Reaction-kinetics of Nb3Sn formation in high Sn conductors

- Does Sn diffusion in the limited space between highly packed Nb filaments cause any problems to achieve uniform $Nb_3Sn$ ?
- Collaboration with the University of Wisconsin



Using single sub-element wire from Outokumpu-AS. Three diameters 0.8, 0.6 and 0.4mm were used in the study.

# Conclusions of this study

- The inter-filamentary spacing strongly influences the rate of Sn diffusion, as well as the formation of high-Sn compounds of Nb-Sn
- Ti in the Sn core segregates to the filament/core interfacial region and forms a high-Sn Sn-Ti-Nb-Cu compound.  This makes Ti difficult to diffuse uniformly through the filament region.
- The next step is to study the uniformity of Ti through-out the filament region when $Nb_3Sn$ is formed.  This study is underway.
- Also, a similar study is planned for a wire without Ti in the Sn core with a OST wire which uses Nb-Ta rods.

# Flexible cable

Requires small diameter wires 0.2-0.3 mm.

Procedure: is to fabricate cable, Heat-Treat ~ 650C, insulate using Kapton tape and use to wind coils for "slotted-magnets" (BNL LDRD).

After some trial attempts, cable was made which remains quite flexible after HT.

This accomplished by dip coating the wires with Mobil1 (a synthetic lubricant) and also using a drip of it during the cabling process.

# Flexible cable status

Using ITER strand from *IGC (now OKAS*) achieved good performance in a 6 x 1 cable at a bend diameter of 50mm, Jc ~ 1600 A/mm$^2$ @8T (650 A/mm$^2$ @12T)

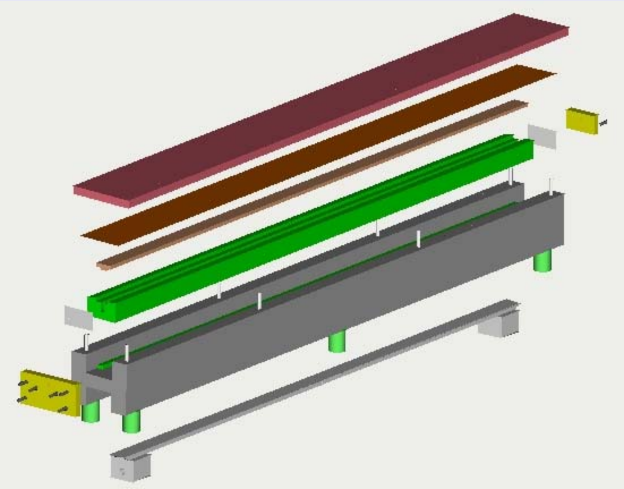
Plan to make similar cable using powder-in-tube(PIT) wire from *Supercon* Jc ~ 1200 A/mm$^2$ @12T. Preliminary attempts of such a cable shows Jc ~ 1950 A/mm$^2$ @8T

Mono Element Internal Tin wire from *Supergenics* has been drawn successfully to 0.33mm. This wire has the potential of ~ 2000 A/mm$^2$ @12T (SBIR related support)

High performance wires using 19 or 37 sub-elements have been difficult to draw to small diameters.

# Cable testing

- Testing $Nb_3Sn$ Cable sample is far more challenging than NbTi cable.
- Samples are assembled similar to coil fabrication.
  - Epoxy impregnation
  - careful sizing of the sample composite
  - uniform application of transverse pressure



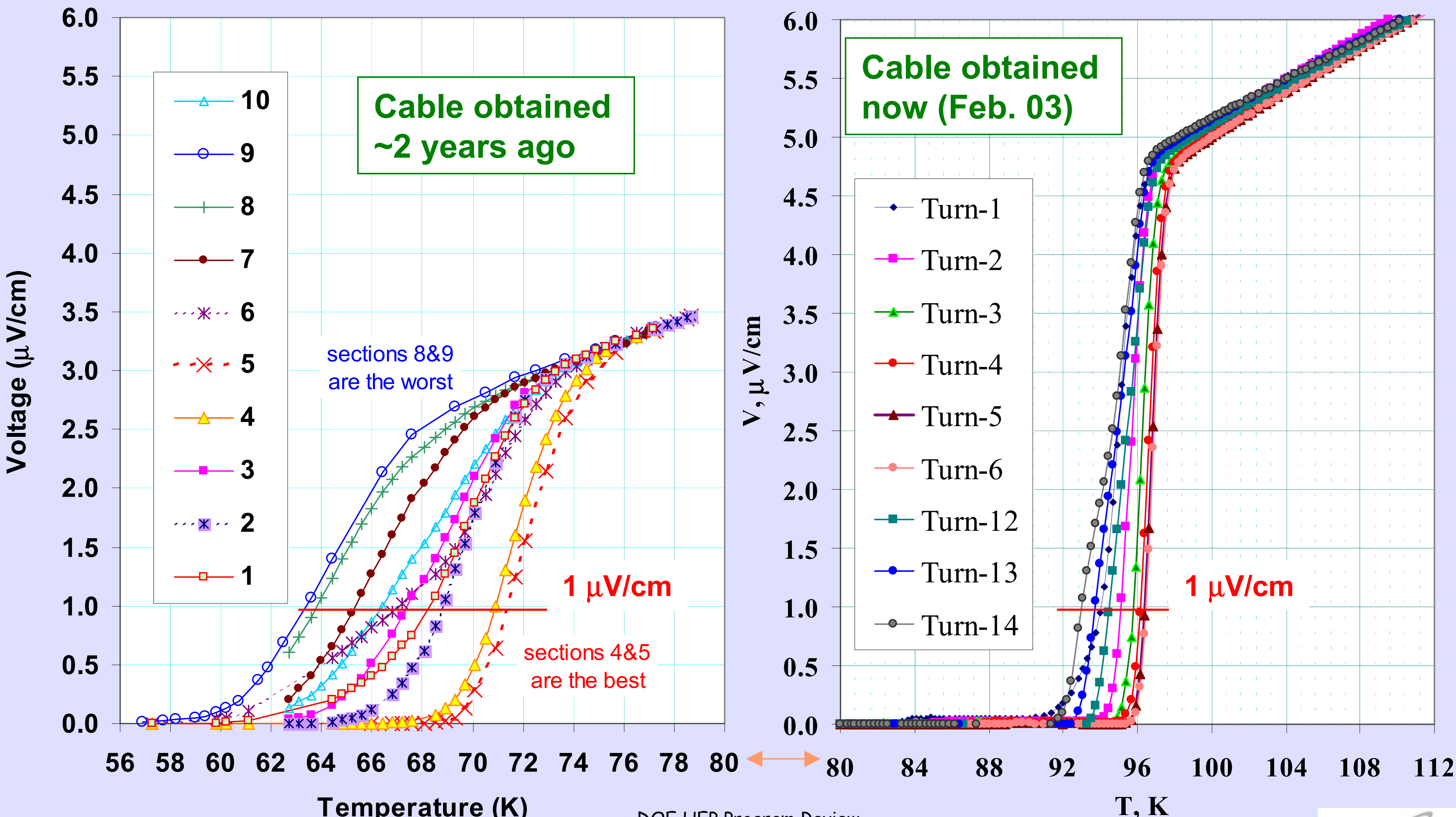
Cable test station: 75mm bore dipole magnet with field to 7.5T(4.2K) , test currents to 25kA

# Status of cable testing

- 12.3mm wide cables using ITER strand ($J_c \sim 450\text{-}750\ A/mm^2$ @12T) have been successfully tested in the 5-7T applied field range.
- Similar cable with high $J_c \sim 2000\ A/mm^2$ @12T have reached 85% of the expected $I_c$ after considerable training.
- These cables would likely reach $I_c$ at applied fields of 10-12T.
- A 12T magnet is under development at BNL

# Improvement in Tc of Bi 2212 Cable from Showa

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

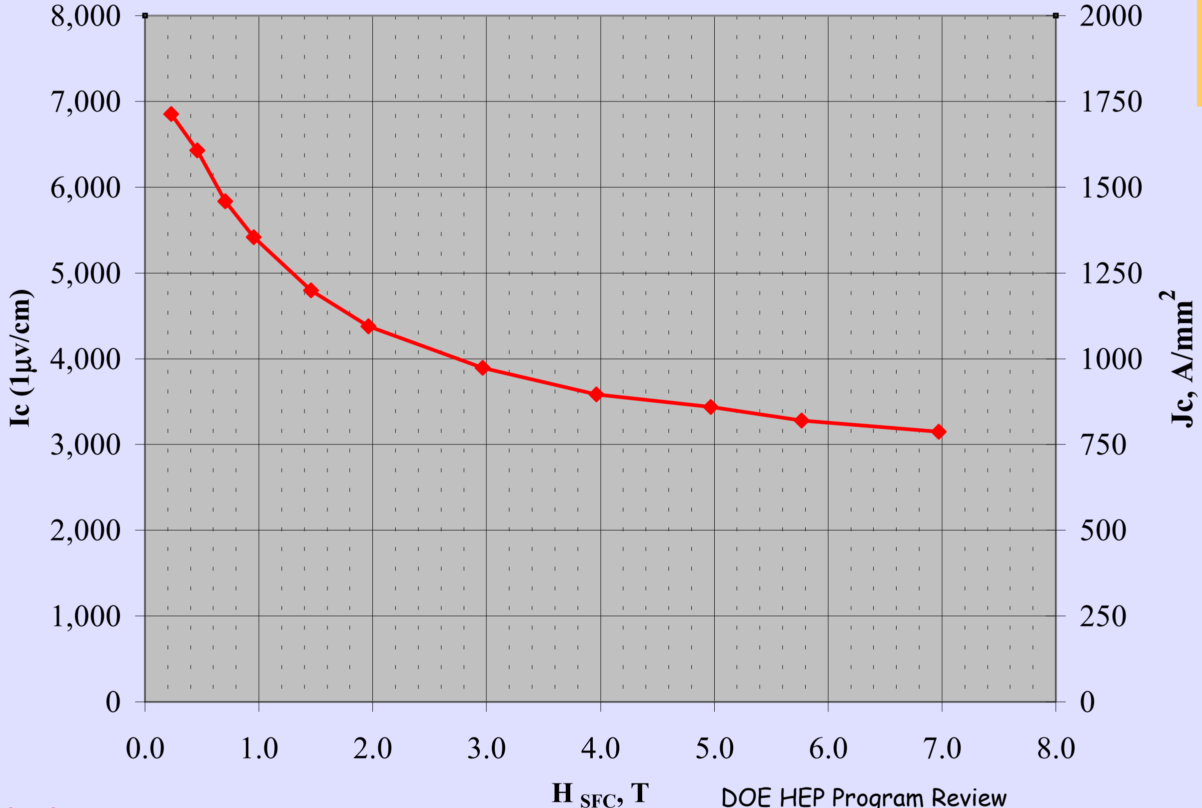


# HTS Development: Bi-2212

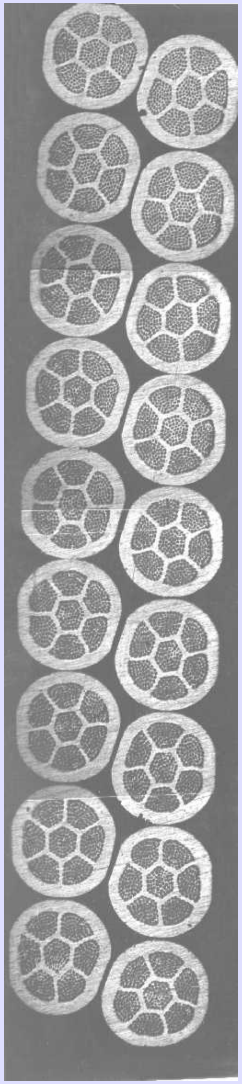
Collaboration with Showa (Japan) + LBNL, & OST (US)

Strand Jc ~ 3000-4000 A/mm² in zero field.

Cable Jc is degraded to ~ 1800 A/mm² (the problem !)




61x7 stack
Ag/Ag-Mg



# High Field Magnet R&D

R&D based on both Nb3Sn and HTS (BSCCO 2212)

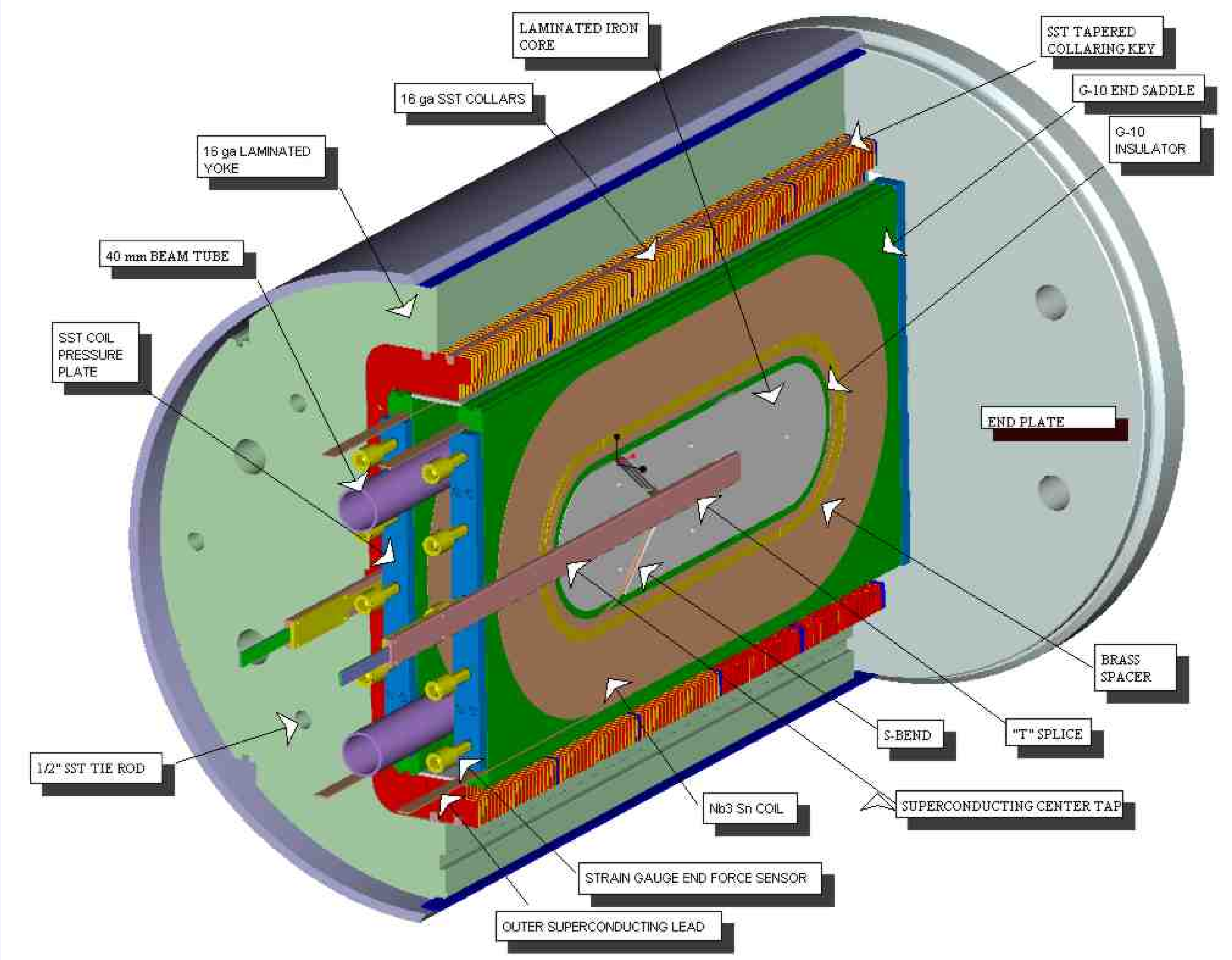
React-and-wind superconductors, hence brittle, fragile materials.

Flat coils to minimize stress

Results to date based on the a 10-turn test coil program

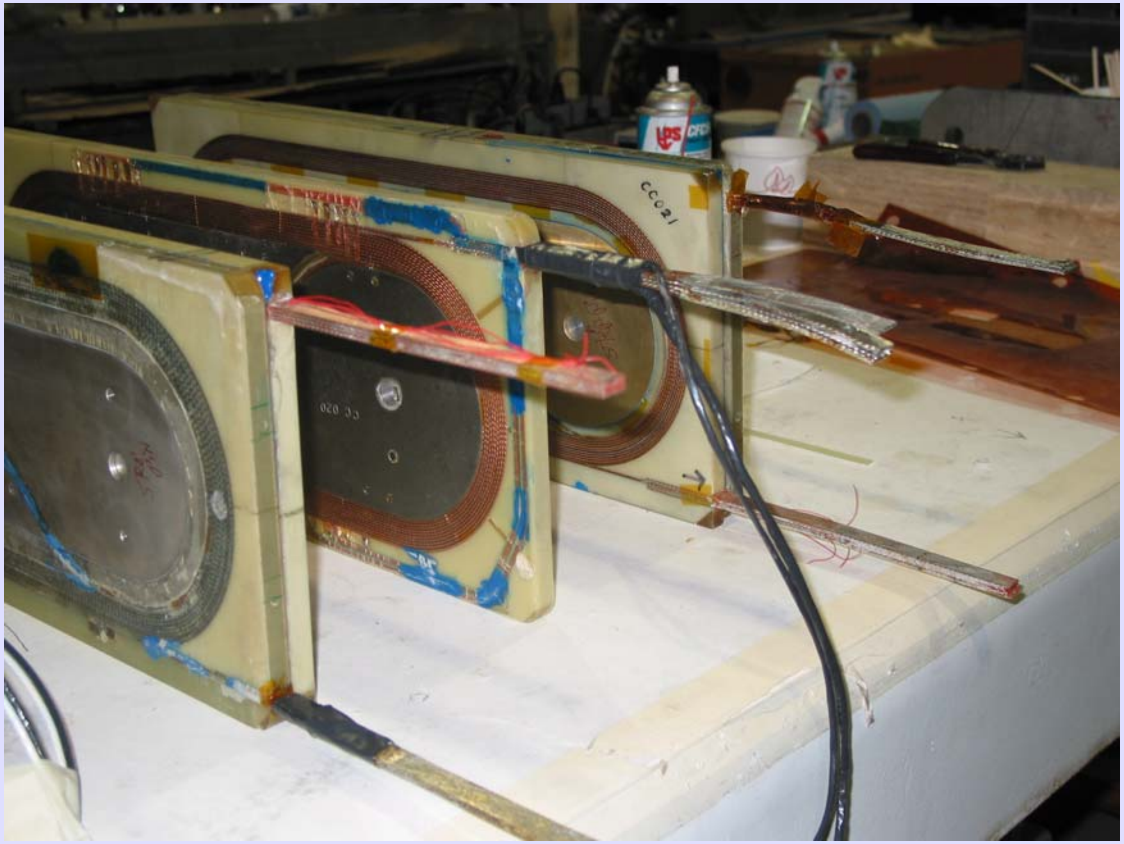
- Low performance Nb3Sn (from the ITER program) gave good results
- High performance Nb3Sn from the national conductor development program gave poor results
- We are analysing the coil production process for problem areas
- HTS coils have operated close to short sample
- HTS conductor: ~factor of 2 further improvement needed

# BNL 12 T $Nb_3Sn$ Common Coil Background Field Dipole




The near term goal of the program. If successful it will be used in materials testing program

# Racetrack Coil Cassettes for Rapid Turn Around Magnet R&D Facility

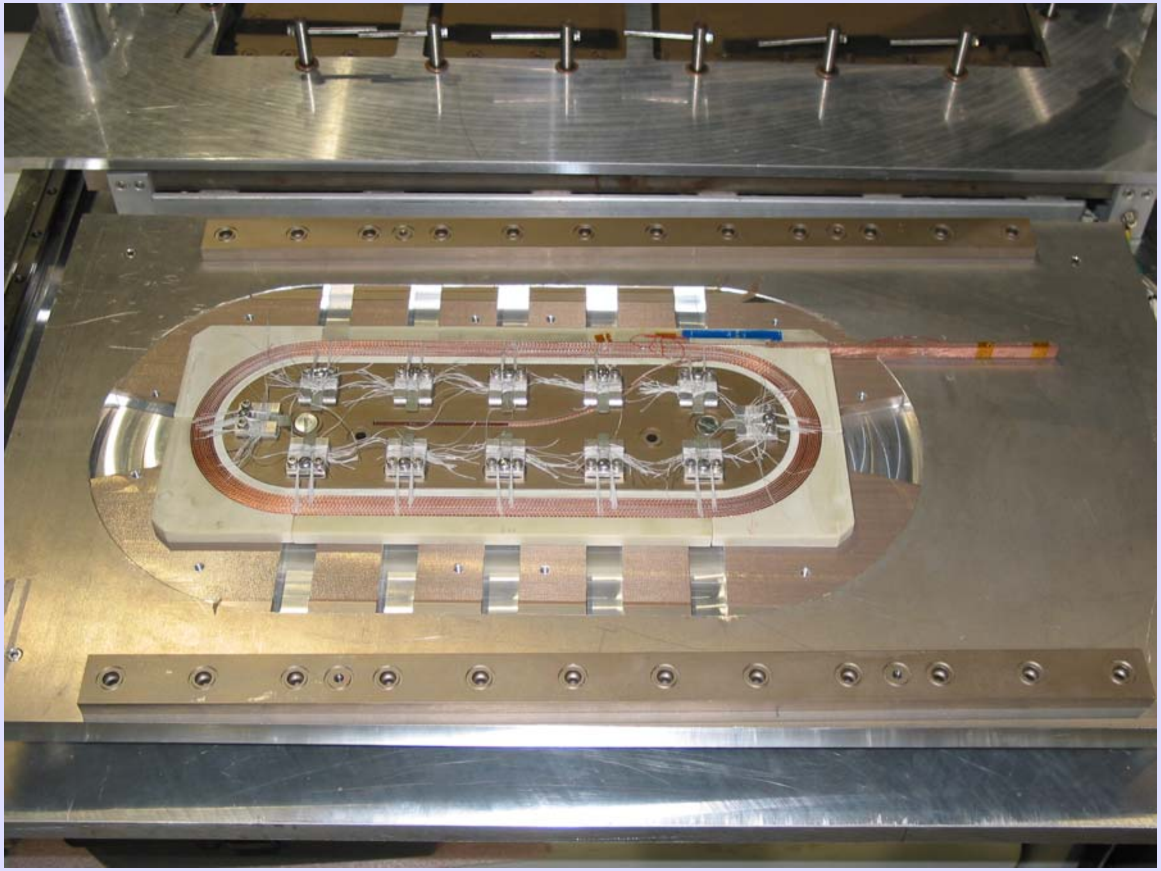


BNL makes 10-turn racetrack coils in modular structure. These modules (cassettes) can be mixed and matched for a variety of experiments in a rapid turn around fashion.

For example, one can easily change aperture, number of layers, type of magnet, etc.

# New Tooling and Techniques for Making Coils

Kevlar strings allow compact coils. The coils can be made in any shape.



These tooling and techniques are being developed for 12 T magnet and are being currently tested in 10-turn coil program.

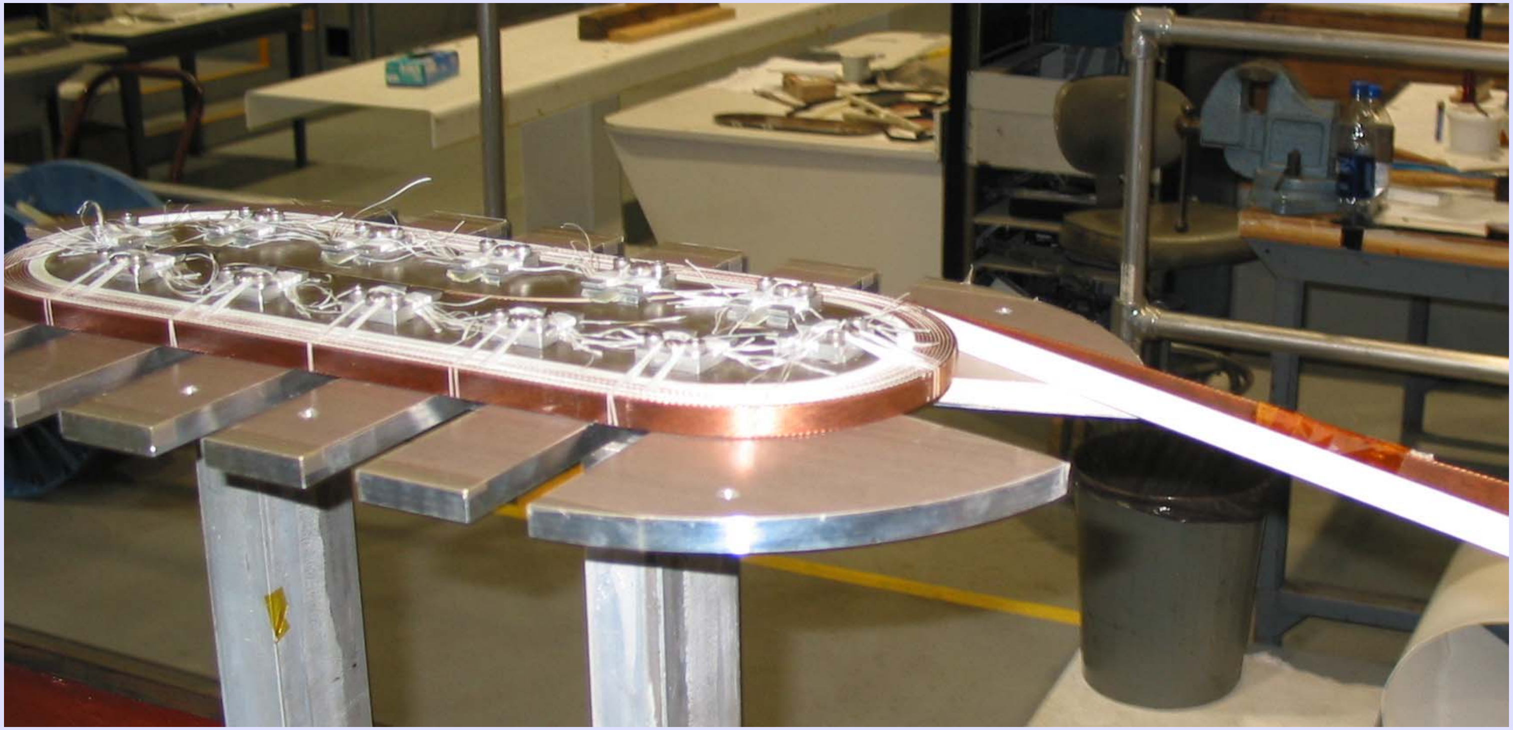
# $Nb_3Sn$ Reaction Process at BNL

The bending radii of reaction spool is about twice the minimum bend radius of our common coil design. This splits bend strain between straight section and ends. Computed bend strain ~0.3% (considered acceptable) if the wires in cable are not sintered; strain becomes ~0.6% if the wires are sintered.


New oil impregnation fixture to vacuum impregnate the cable. Mobile-1 coating on the surface of wire inside the cable should eliminate sintering, if any, during reaction process.

In an attempt to push technology BNL program has been deliberately aggressive. BNL uses 0.8 mm wire and 70 mm bend radius as compared to Fermilab 0.7 mm wire 90 mm bend radius. The bending strain in BNL program is ~50% more.

# Use of Nomex Tape Insulation

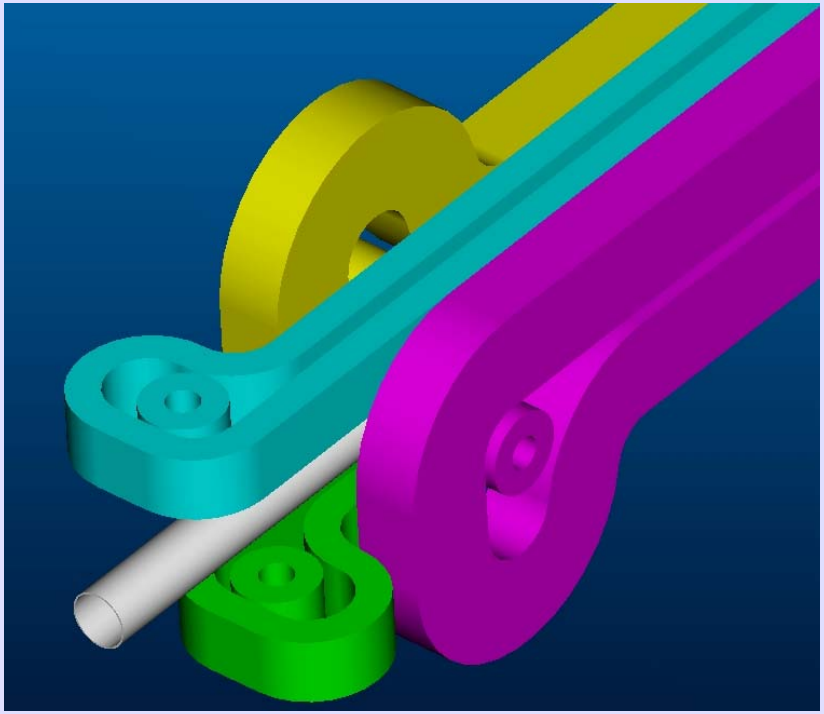


Nomex tape insulation, co-wound with cable. This is the first time Nomex insulation is being used in cable magnet – a robust insulation which also reduce turn-to-turn spacing (~4 mil, 0.1 mm, turn-to-turn).

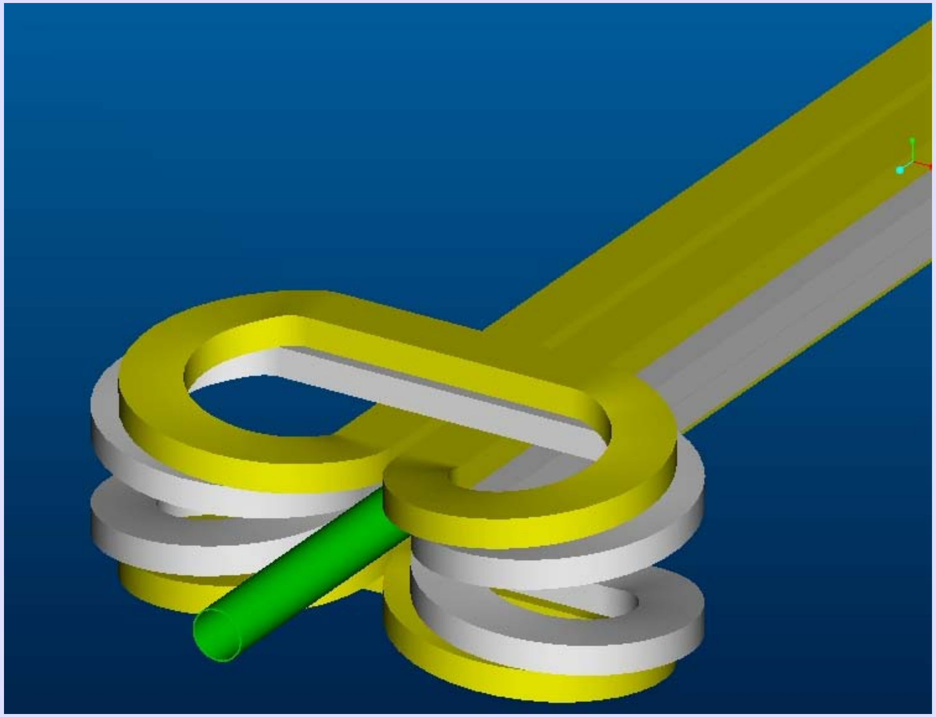
Earlier we used fiberglass, spiral-wrapped over reacted cable.

# New Coil Winder for Brittle Materials

# Low Strain End Design Concepts

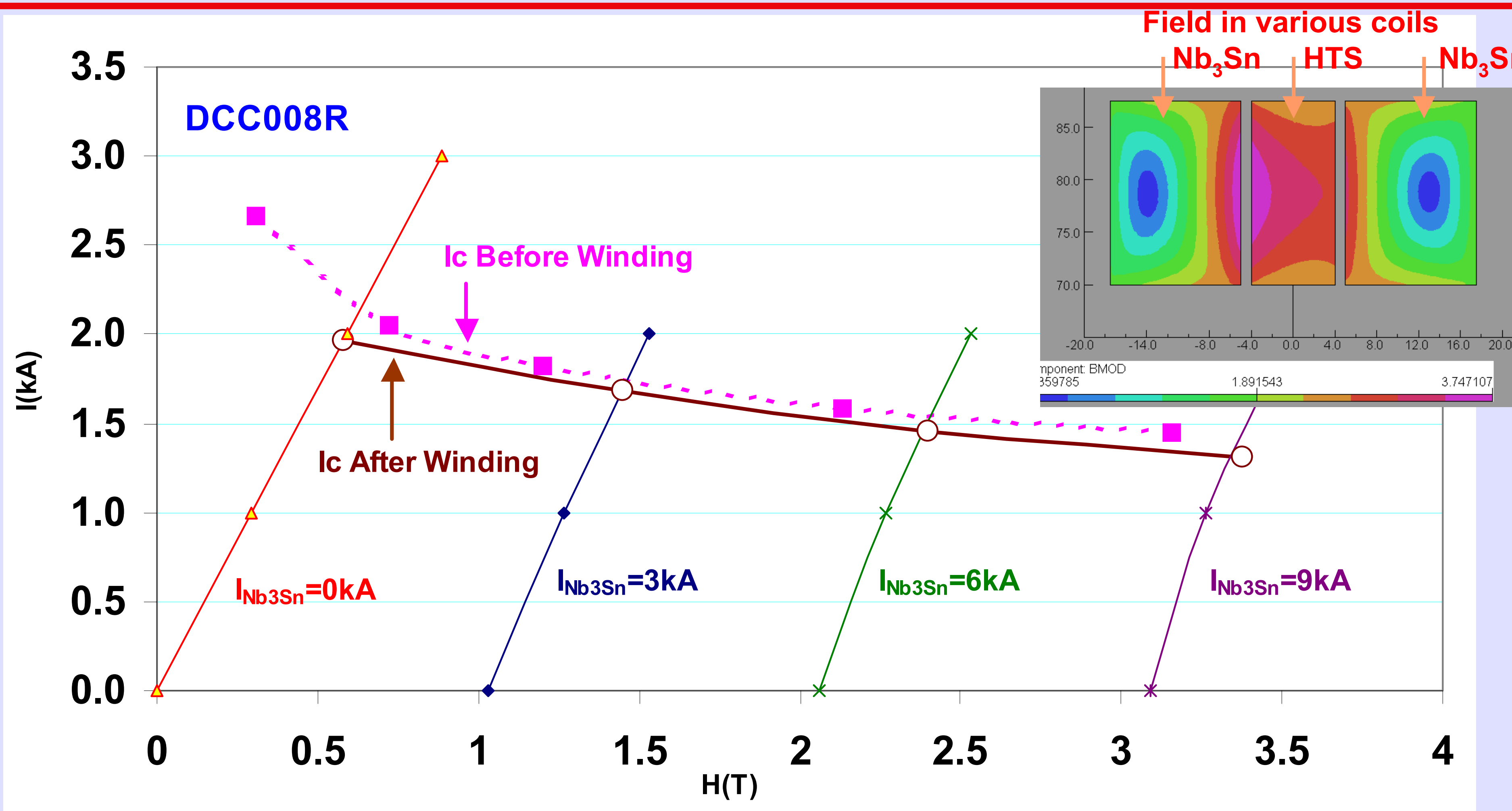


Flat Coil Ends: Sideway Overlap



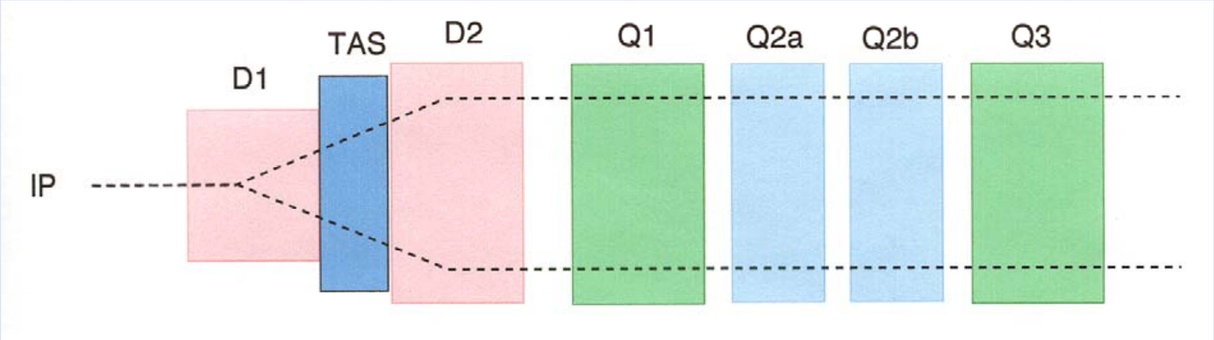
Overpass/Underpass (Clover Leaf) Ends:
NO Reverse bend needed

# Performance of HTS Coil in the Background Field of $Nb_3SN$ Coils




HTS coil was subjected to various background field by changing current in "React & Wind" $Nb_3Sn$ coils (HTS coil in the middle and $Nb_3Sn$ on either side)

# LARP (LHC Accelerator Research Program) - Building on the generic magnet R&D for LHC upgrades



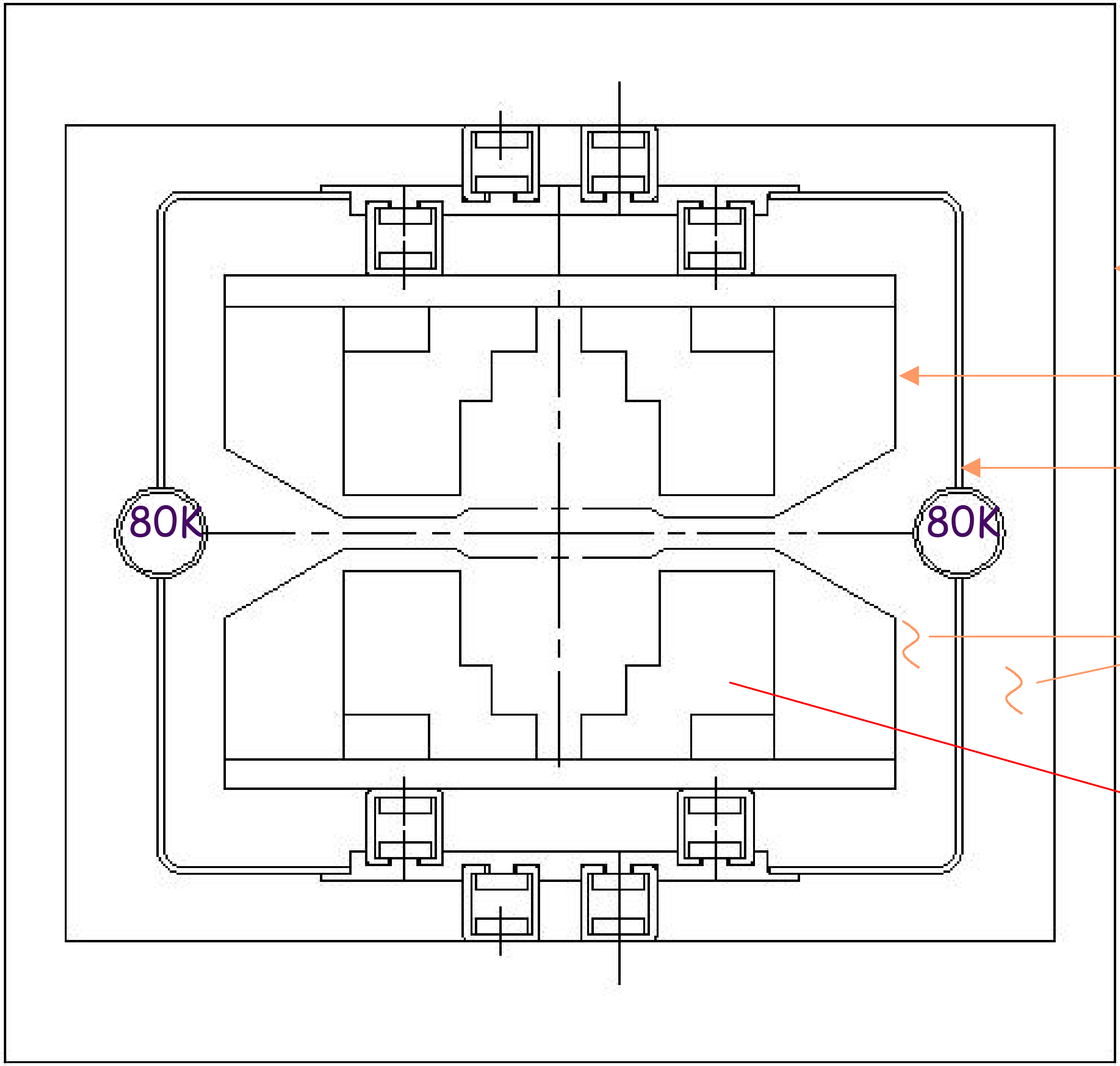

Dipole first IR option helps if the luminosity is limited by the long range beam-beam interaction.  BNL is indicating interest in the D1 dipole.

Technical Issues:

- High Fields (12-15T)
- Large Aperture (84 mm beam separation)
- Significant energy deposition from the IP (~1KW)
- Radiation damage

Note: no-one has built an Nb3Sn (or HTS) magnet of this (any ?) kind

# LHC IR Dipole: Efficient heat removal concept




Absorb the particle losses in a 80K structure. Cryogenic efficiency v's mechanical complexity

Cryostat (300K)

**Coldmass (4K)**

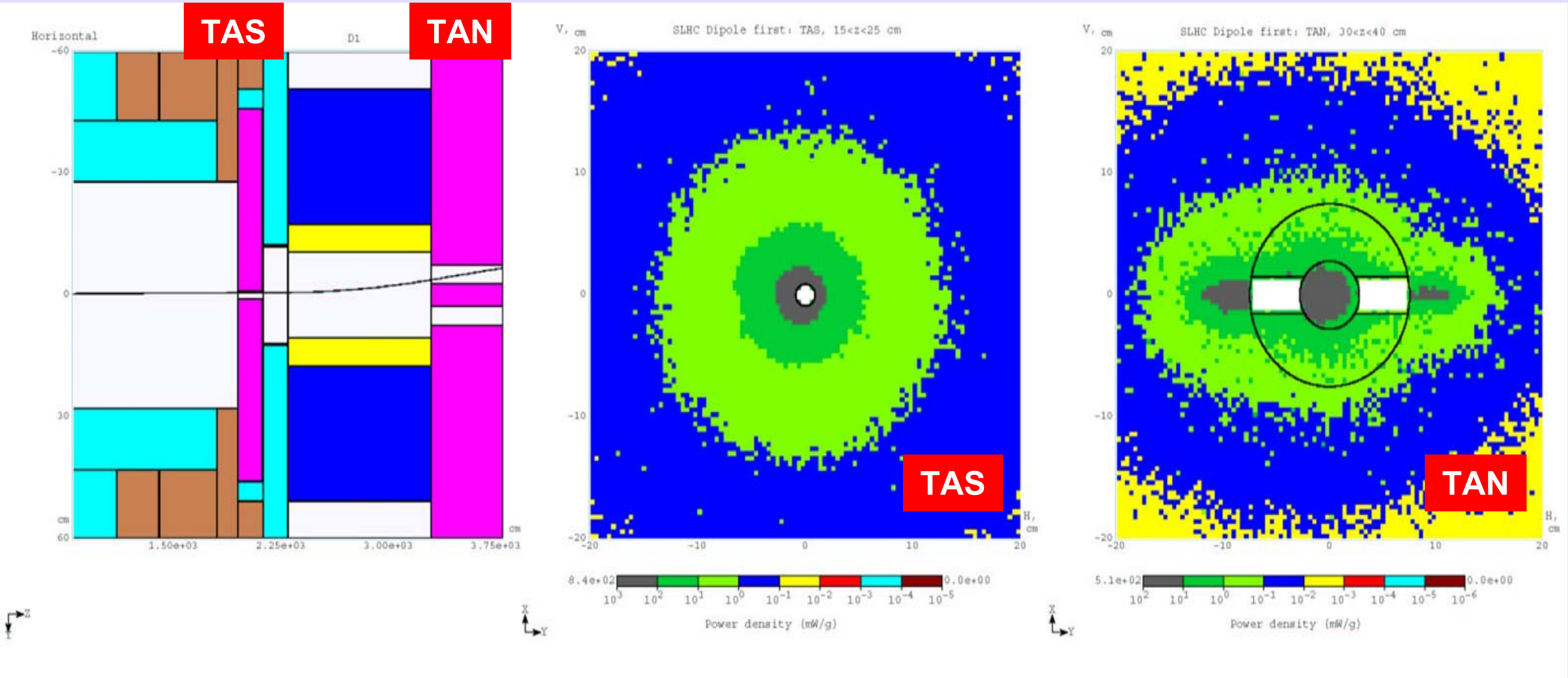
Heat Shield (80K)

Vacuum Space

Superconducting coils

Warm Iron Design

# Energy Deposition in TAS & TAN




**Total power dissipation at 10E35:**

**TAS: 3.17 kW, D1: 0.90 kW, TAN: 2.45 kW.**

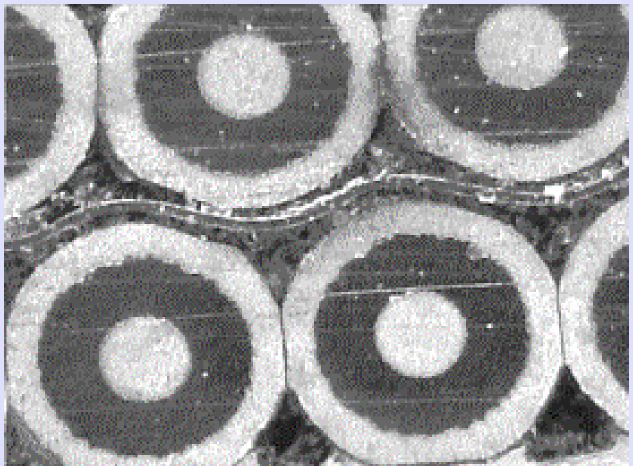
# BNL + GSI Collaboration on Rapid Cycling SC Magnets

- Why ?
  - GSI (Germany) has an approved new facility that includes rapid cycling accelerators with superconducting magnets. - their interest
    - Dipoles: $B_0$ = 4T, dB/dt = 1-2T/sec, low loss
  - Large Hadron Machines of the future will require rapid cycling high-energy injectors - our interest

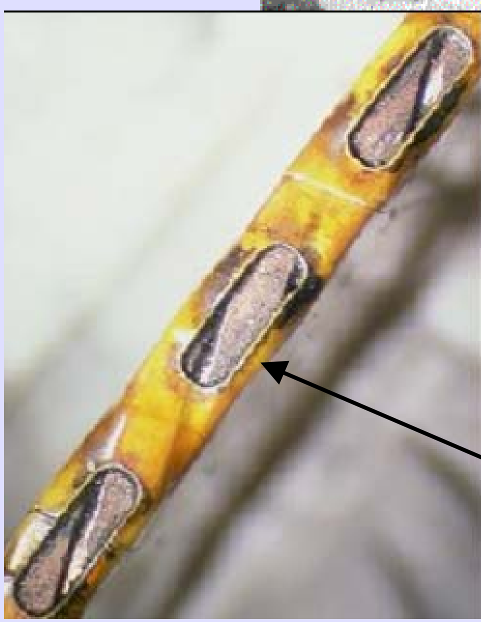
- Dipole features similar to RHIC $\Rightarrow$ joint R&D to modify RHIC conductor & other magnet components
  - Eddy currents, heating mechanisms, field quality, mechanical stability, cooling mechanisms

- GSI funding + a little BNL LDRD

# Features of Modified Dipole

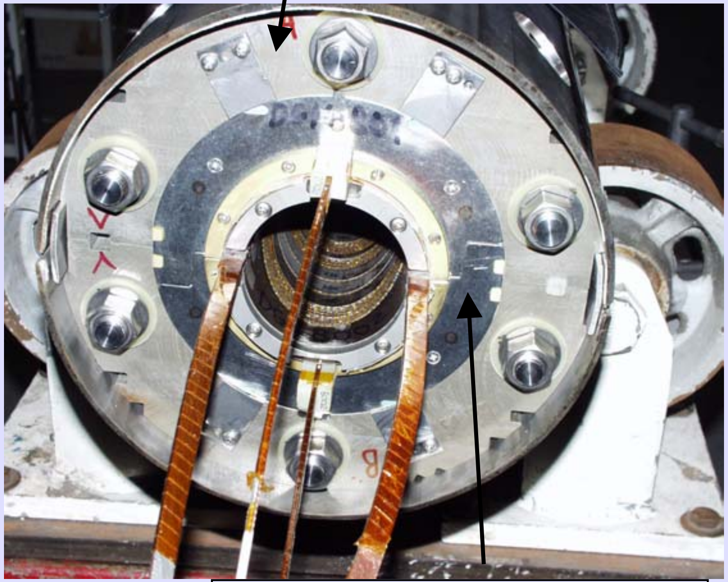


Two 1-mil ss foils



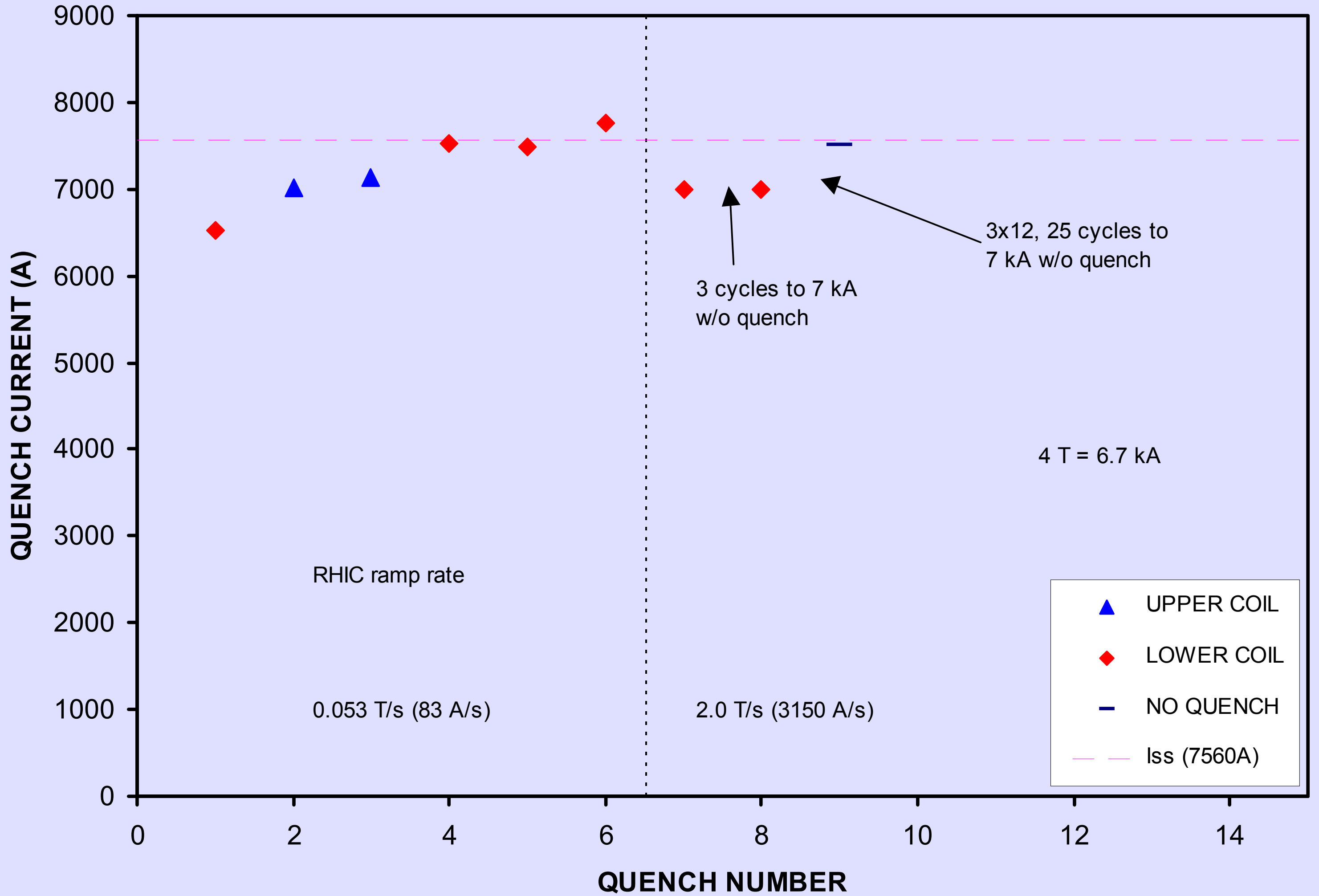
Vented insulation

Thin Si steel yoke lams.

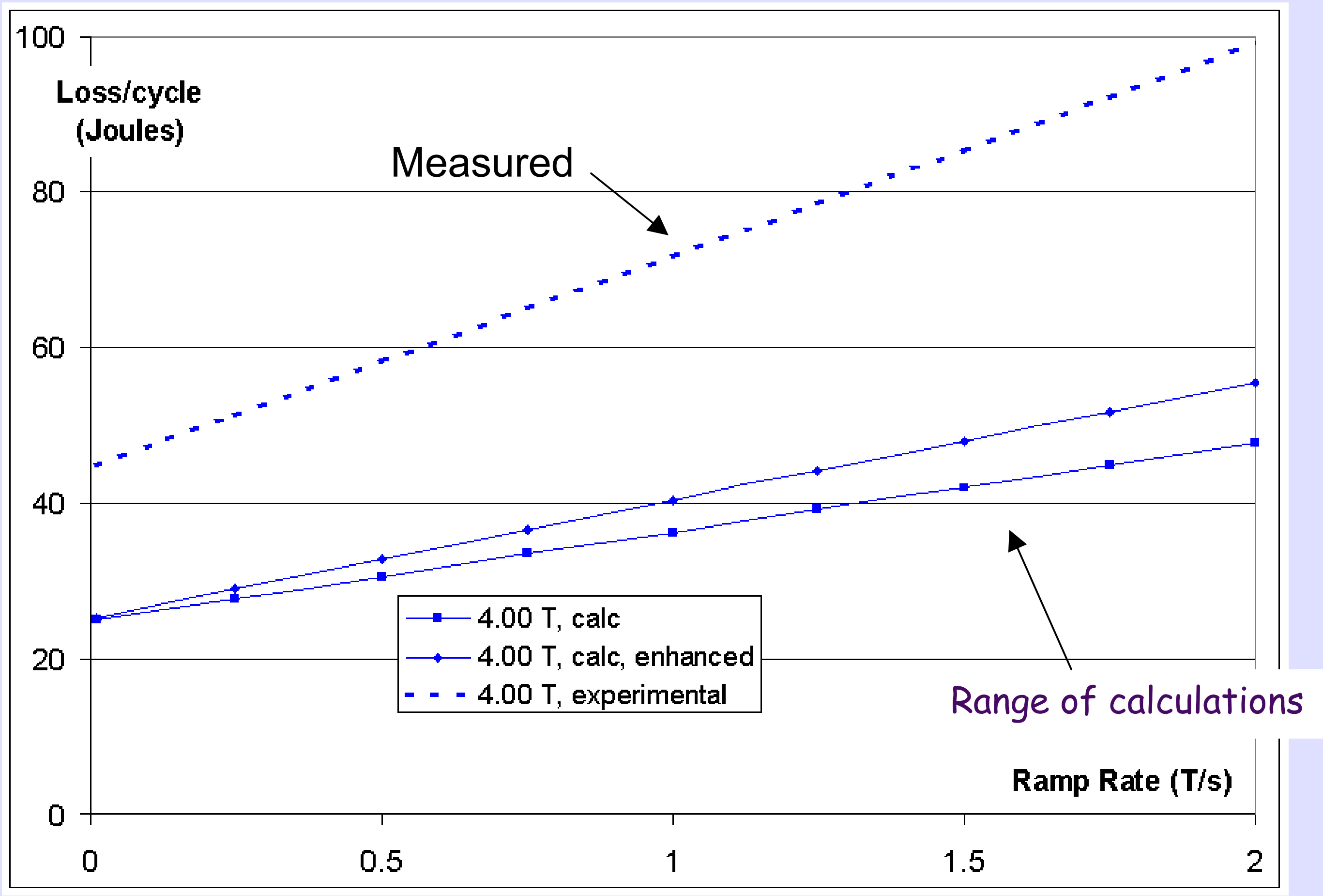


ss collars

# GSI001 QUENCH TESTS



# GSI Rapid Cycling Magnet - Energy Loss Measurement



# BNL + GSI Collaboration on Rapid Cycling SC Magnets

- Next Step
  - Verify field quality in the rapid cycling environment
  - A technically difficult meaurement

At this point then the program is completed

# Superconducting Magnet R&D - Summary

- Compact quad development for a Linear Collider (warm or cold) needs significantly more resources and several years to demonstrate feasibility. Since this is now the US baseline design there is some urgency to get started.
- High field $Nb_3Sn$ magnets are not demonstrated yet but we are making progress slowly. BNL plays a significant role in the national superconductor development program
- High temperature superconductors continue to make improvement in performance. We are close to being able to use these materials for real magnets, primarily in hostile environments, possibly in hybrid schemes.
- We have demonstrated very fast ramping possibilities with SC magnets.
- Funding continues to decline and support for new initiatives non-existent to date.