Superconducting Magnet R&D

Linear Collider
LHC Accelerator Research Program
Materials R&D
High Field Magnet R&D

Work for Others

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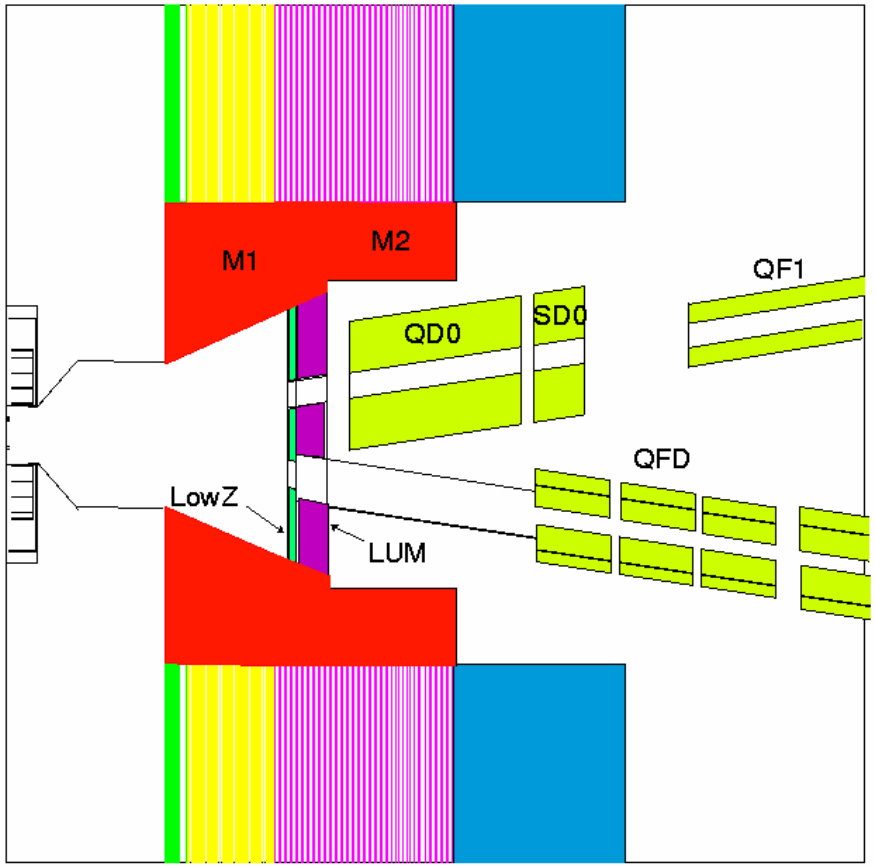
Superconducting Magnet Division

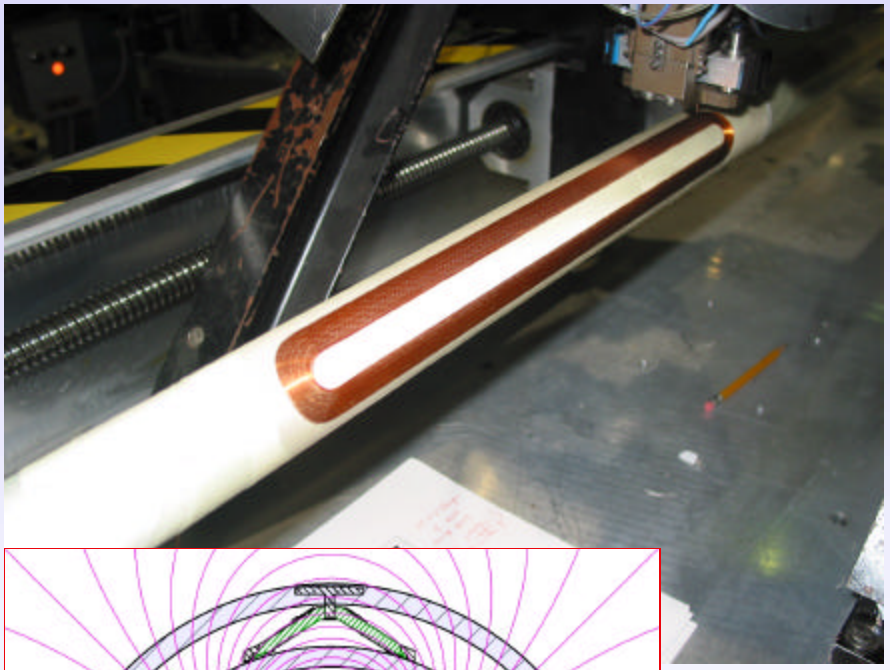
Linear Collider Magnet R&D - Direct wind technology

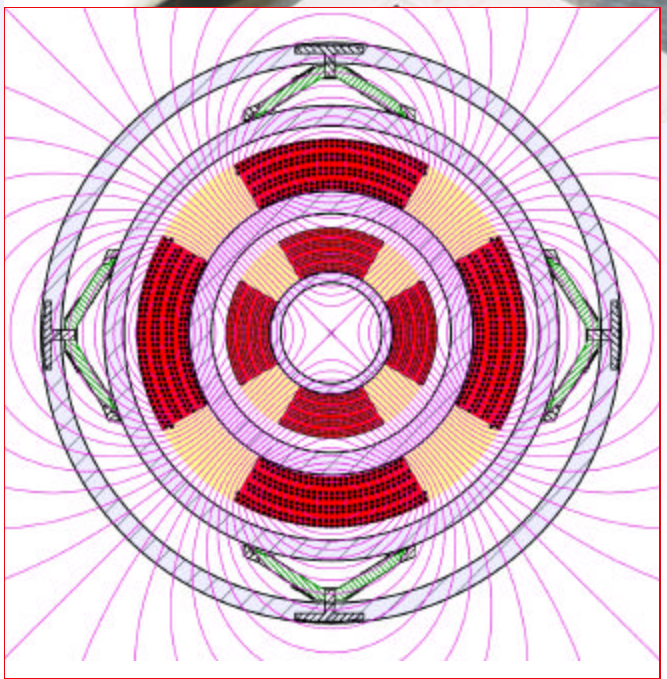
- Why this technical approach to the IP final focus magnets ?
  - Conventional magnets cannot achieve the gradient (144 T/m) and are too large for the available space
  - Permanent magnets are not really permanent and give problems with changing the collision energy (90 -> 500 Gev)
  - “Conventional” superconducting magnets have both beams in the structure and are too large
  - Direct wind produces highly compact multi-element magnets which gives a flexible system



Issues involve mechanical stability (1nm !), optics sensitivity, interaction with the solenoid, field stability (5 ppm), radiation resistance and a 11 (22) MW disrupted beam.

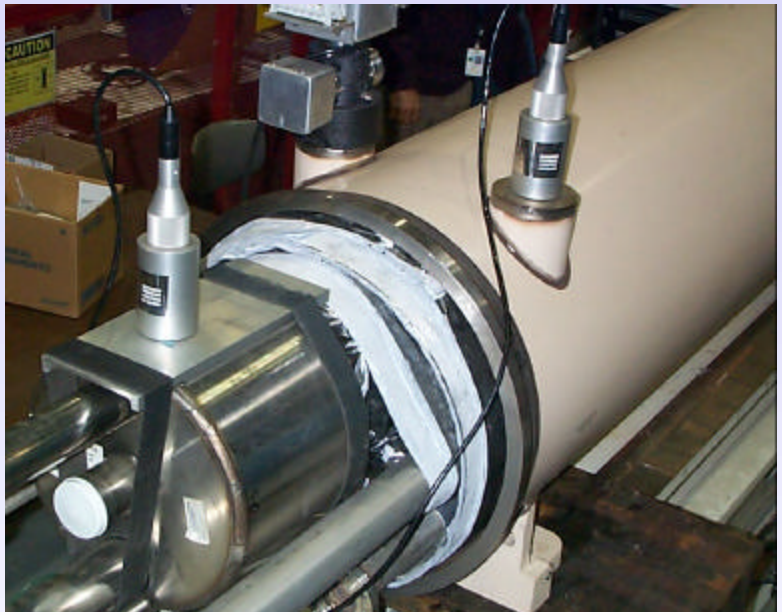
Linear Collider Magnet R&D - Coil Winding Progress

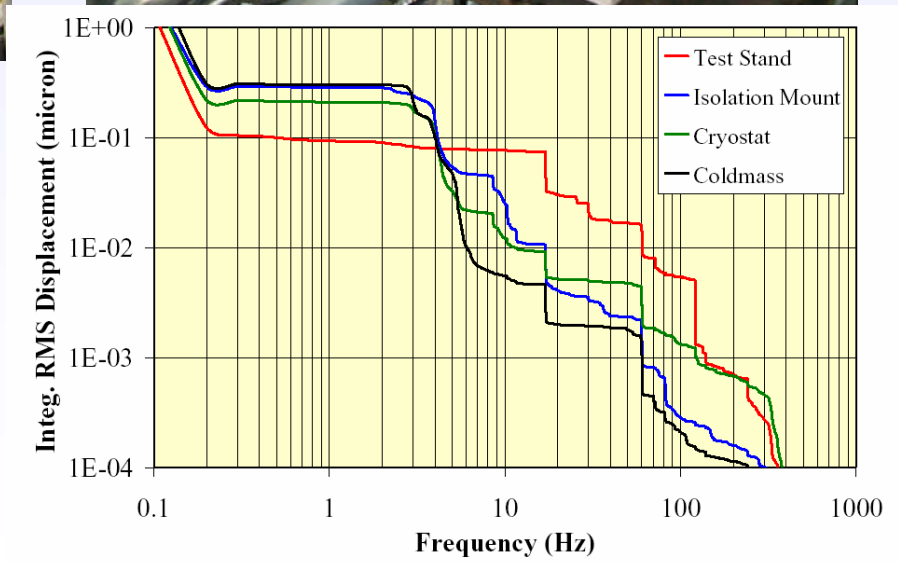




Proof-of-principle/prototype coils have been wound for the inner most layer and the second shell. Coils at SLAC for ITRP visit. Field measurements next.

Linear Collider Magnet R&D - Vibration Measurements

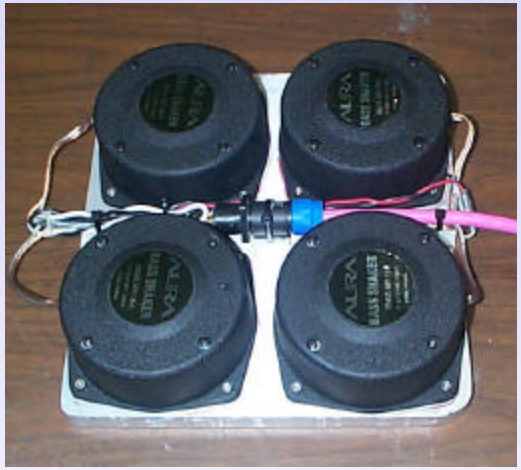




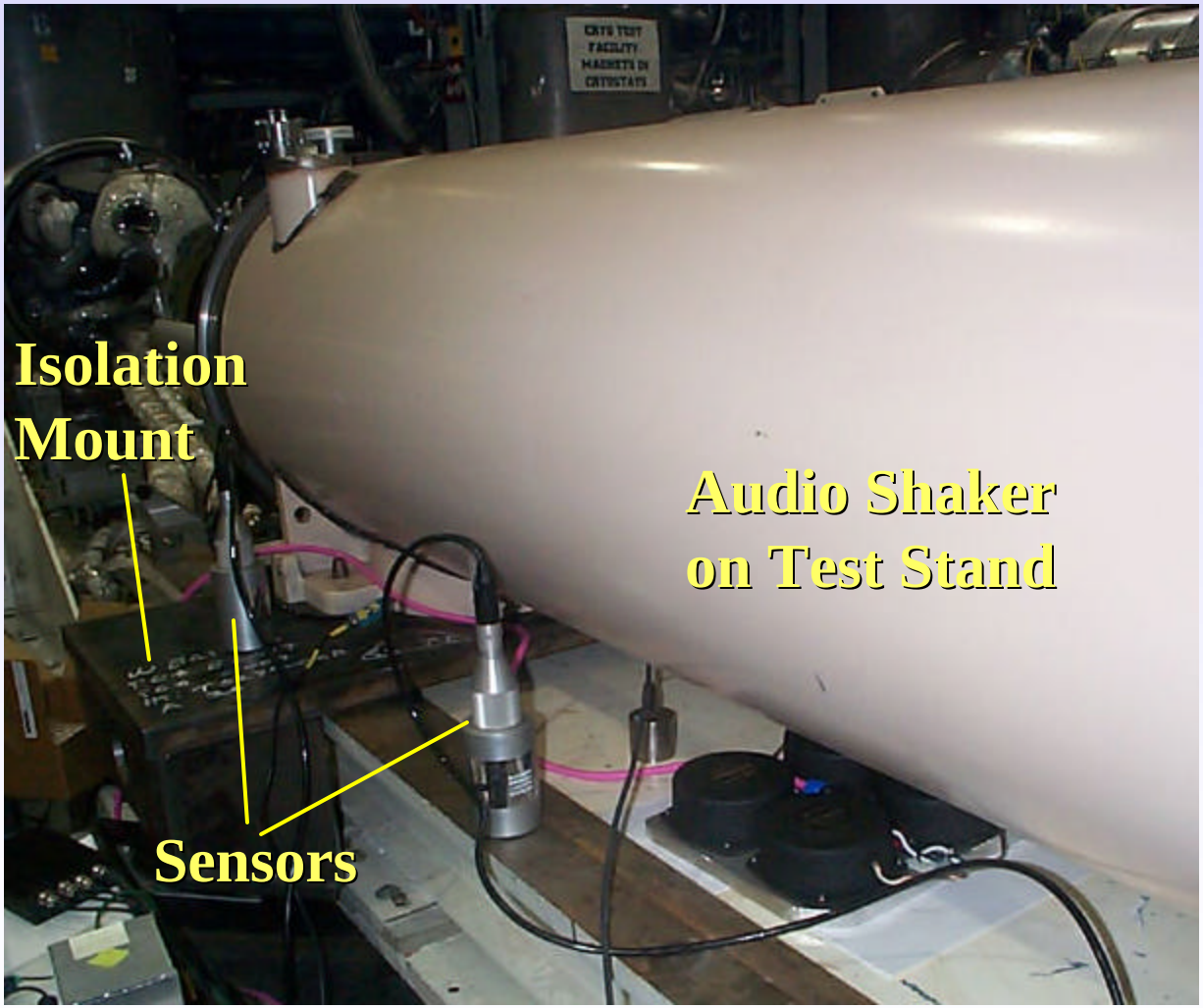
The measuring system is essentially a copy of the one developed at SLAC for their work.

We must develop cold sensors for measurements internal to the cryostat

Linear Collider Magnet R&D - Vibration Measurements



Audio shaker. Effective for > 20Hz



Linear Collider Magnet R&D - Vibration Measurements

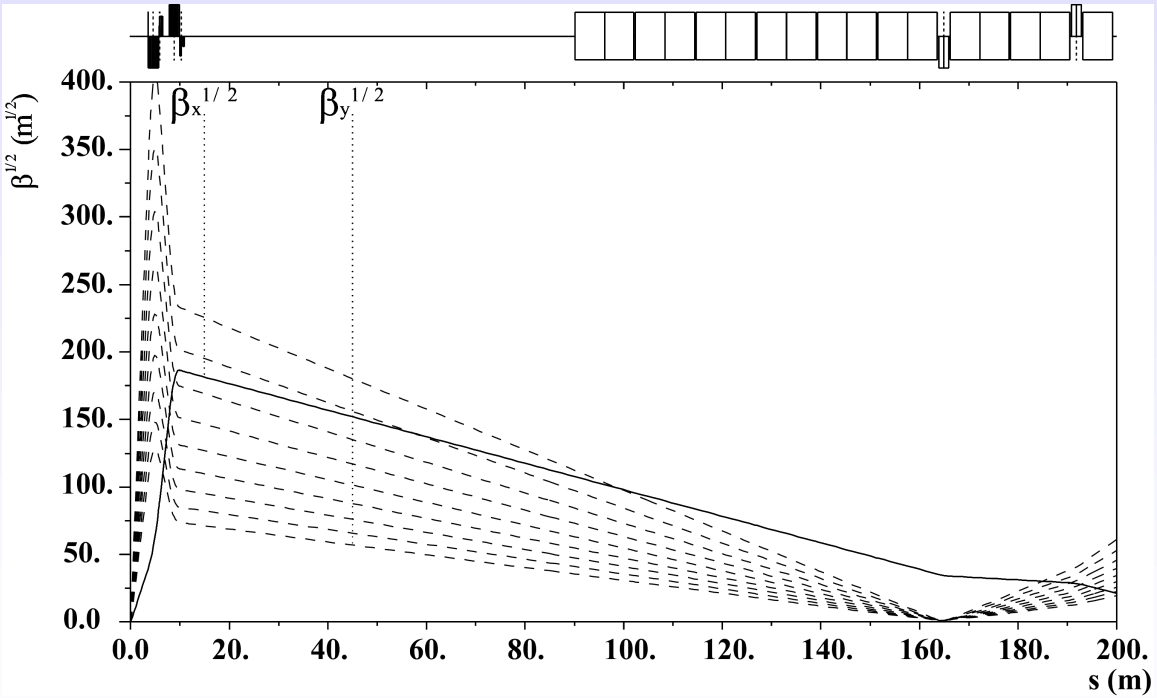
	Vibration RMS Amplitude in nm (Vertial)				
Location	**0.3 to 6 Hz**	**> 6 Hz**	**~17 Hz**	**~60 Hz**	**~120 Hz**
Ground	**80**	**73**	**65**	**8**	**1**
Test Stand	**70**	**77**	**66**	**11**	**5**
Isolation Mount	**283**	**46**	**9**	**1**	**--**
Cryostat	**212**	**22**	**7**	**2**	**--**
Cold Mass	**304**	**10**	**4**	**1**	**--**

The shock mounts are effective for the higher frequency range but enhance low frequencies

It is mildly encouraging that in a noisy environment (compressors, expanders, etc..) we are at the nm scale for >15 Hz vibrations. There may be hope yet.

Linear Collider Magnet R&D - IP Optics

For NLC commissioning it would be nice to take advantage of the focusing strength adjustability of the compact superconducting final doublet to relax the vertical spot size at the IP and thereby reduce tuning sensitivity.



Exercise: Vary β_y^* from 0.11 mm to 1.1 mm in 8 magnification steps while keeping β_x^* constant at its 8 mm nominal value.

Challenge: At BNL we are presently looking for "knobs" to do BDS optics matching that maintain phase advance between critical points. These studies are being done in consultation with NLC optics experts at SLAC.

Linear Collider Magnet R&D - Next Step

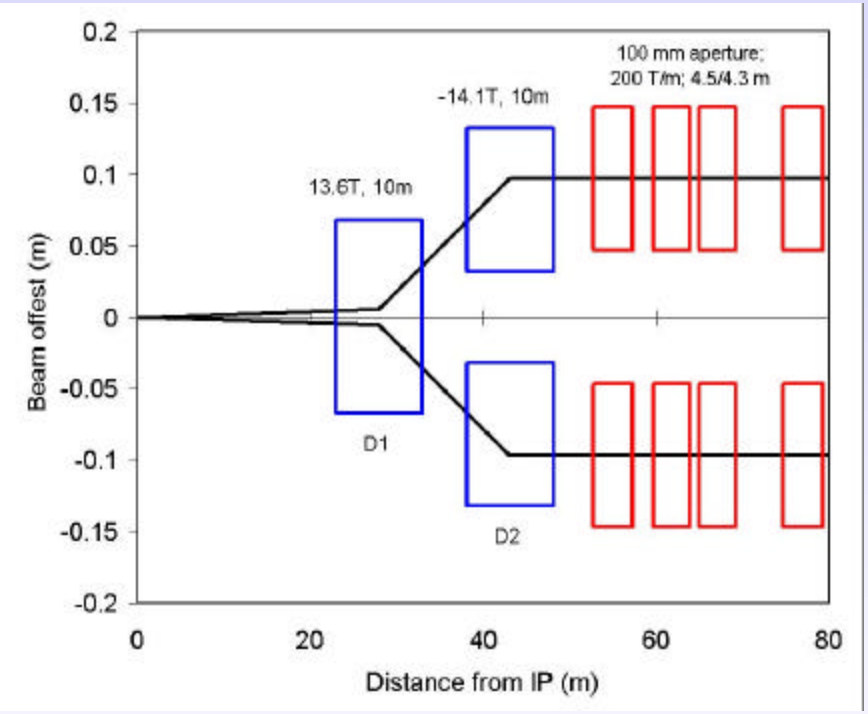
The US LC Accelerator Task Force risk analysis has these final focus magnets are the highest risk hardware category that is not receiving R&D funds.

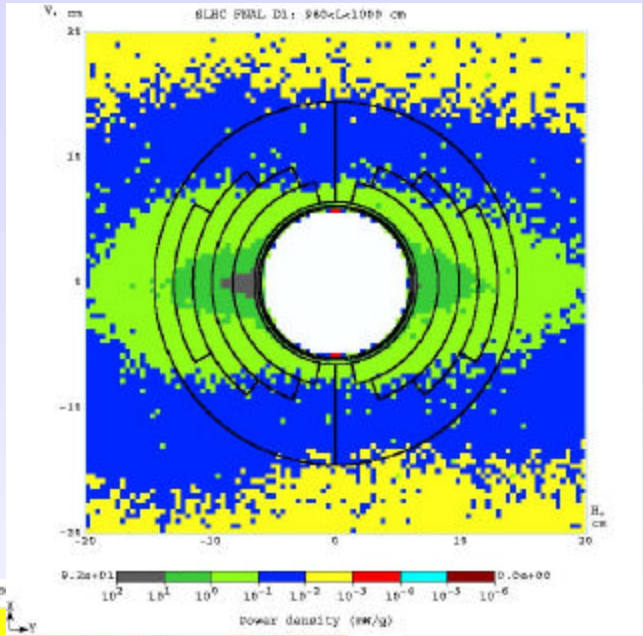
Further progress will require the engineering of a prototype magnet. This can be based on the present coil, but is a several year program.

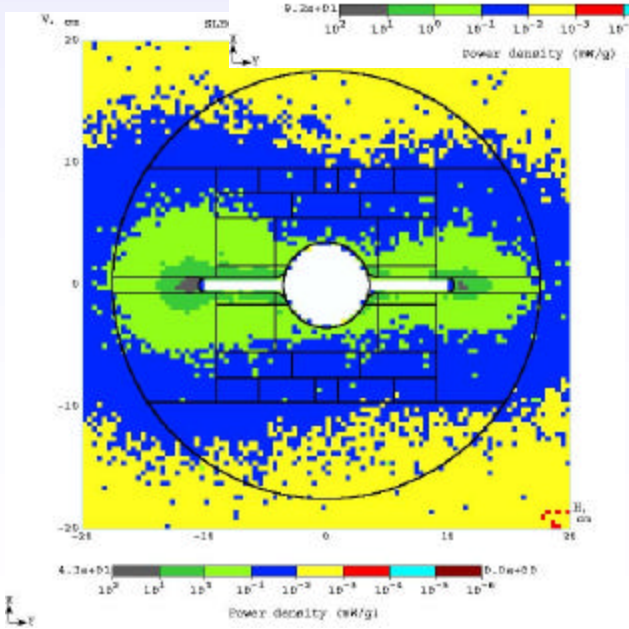
We are actively working with SBIR proposals on vibration issues

The deliberations from the ITRP will influence the future direction of the US effort

LHC Upgrade Magnet R&D - Split Plane Dipole







A approach based on a split plane dipole tacitly assumes that the main technical problem is the heating issue

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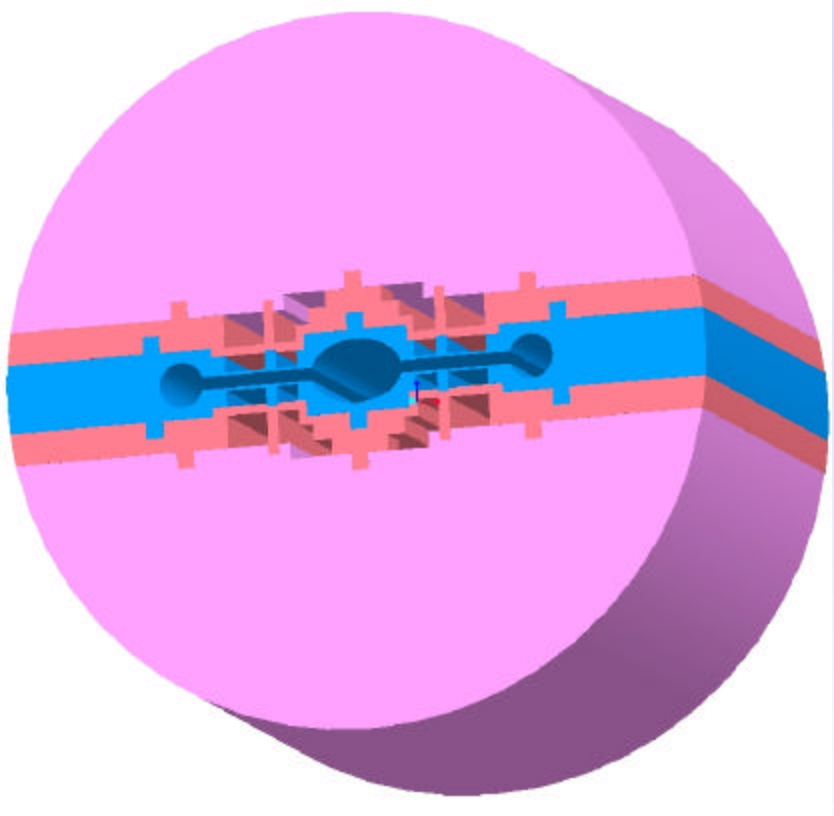
LHC Upgrade Magnet R&D - Split Plane Dipole



Before initiating a thermal analysis we are creating the mechanical model to ensure both magnetic field quality and mechanical stability. There are obviously many issues with a design such as this.
We are starting to get close on paper.

Radiation damage tests at Fermilab

This is obviously a very different kind of design

Flat coils: HTS compatible

LHC Upgrade Magnet R&D - the next step

FY04

- Finalize magnetic design
- Complete mechanical analysis, start thermal analysis (with Fermilab)
- Develop external structure to restrain collars

FY05

- Compete cold mass design
- Complete thermal analysis
- Build R&D coils
- Build 'simplified' cold mass

FY06

- Test magnet in cryostat
- Heat load and temperature tests

Materials R&D: Nb_3Sn Conductor development

Magnet Division / Materials Science Dept. Collaborations

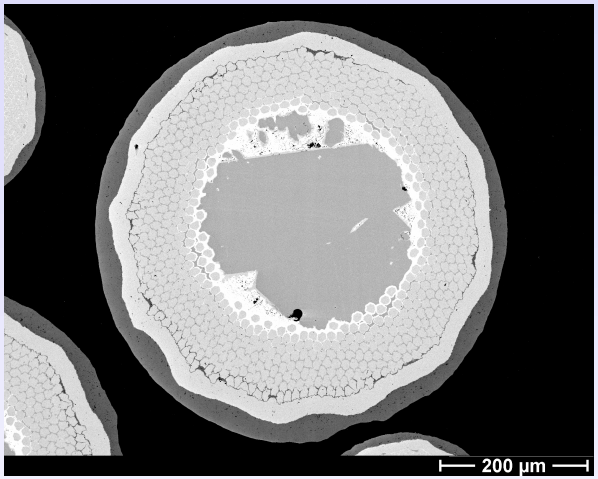
A. Ghosh, W. Sampson, R.Soika / L Cooley, M Suenaga, A Moodenbaugh

- Nb_3Sn strands
  - Facility for heat treatment and testing 0.3 to 1.0 mm strands with integrated fixtures
    - Limited to 1000A and fields up to 11.5 T
  - Electron microscopy studies (also with U. of Wisconsin)
  - Magnetization measurements to 5 T
  - Powder metallurgy / mechanical alloying experiments starting
- Nb_3Sn Cable
  - Facility for heat treatment and testing of Rutherford cables at background fields to 7.5T
  - Flux-Jump Instability Studies

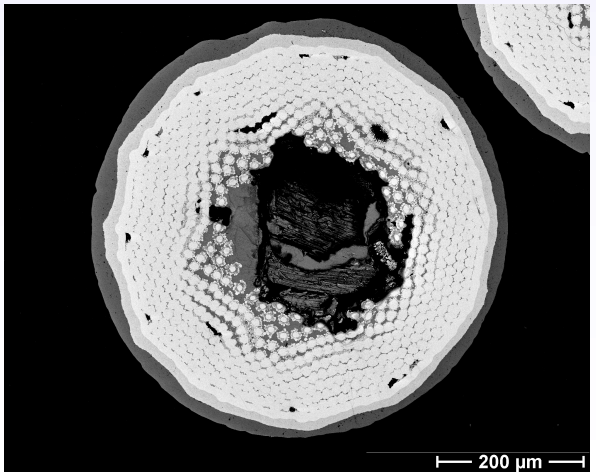
Shorter heat treatments for Nb_3Sn

- SEM analyses in Seth Hynes' senior project (Wisconsin; M Suenaga mentor) implemented separately at BNL and OST
- Standard heat treatment = 328 total hours
  - Ramping at 1°C/min also significant time
- This HT = 198 hrs (OST: 232 h)
  - Notice that intermediate step floods entire filament area with tin, which is converted to Nb_3Sn in short time
- Critical current results for new HT similar to that for standard HT (OST: slightly higher)

217°C/24h +425ºC/150h



217°C/24h + 425ºC/150h +700ºC/24h



Materials R&D: Flux-Jump Instability

The critical state of the superconducting filaments may become unstable because of two inherent properties of high-field high current superconductors:

- Jc decreases with increasing current (-dJc/dT)
- Flux-motion within the superconductor generates heat.

$$\beta = \mu_0 Jc^2 d^2 / (4 \times \gamma C(Tc - T0))$$

The stability parameter

has to be less than 3 to ensure conductor stability from flux-jumps.

Jc is the current density of the filaments

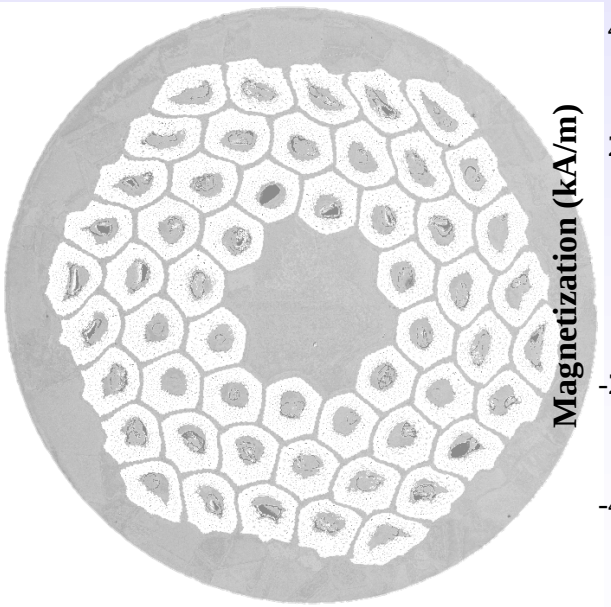
d is the filament diameter

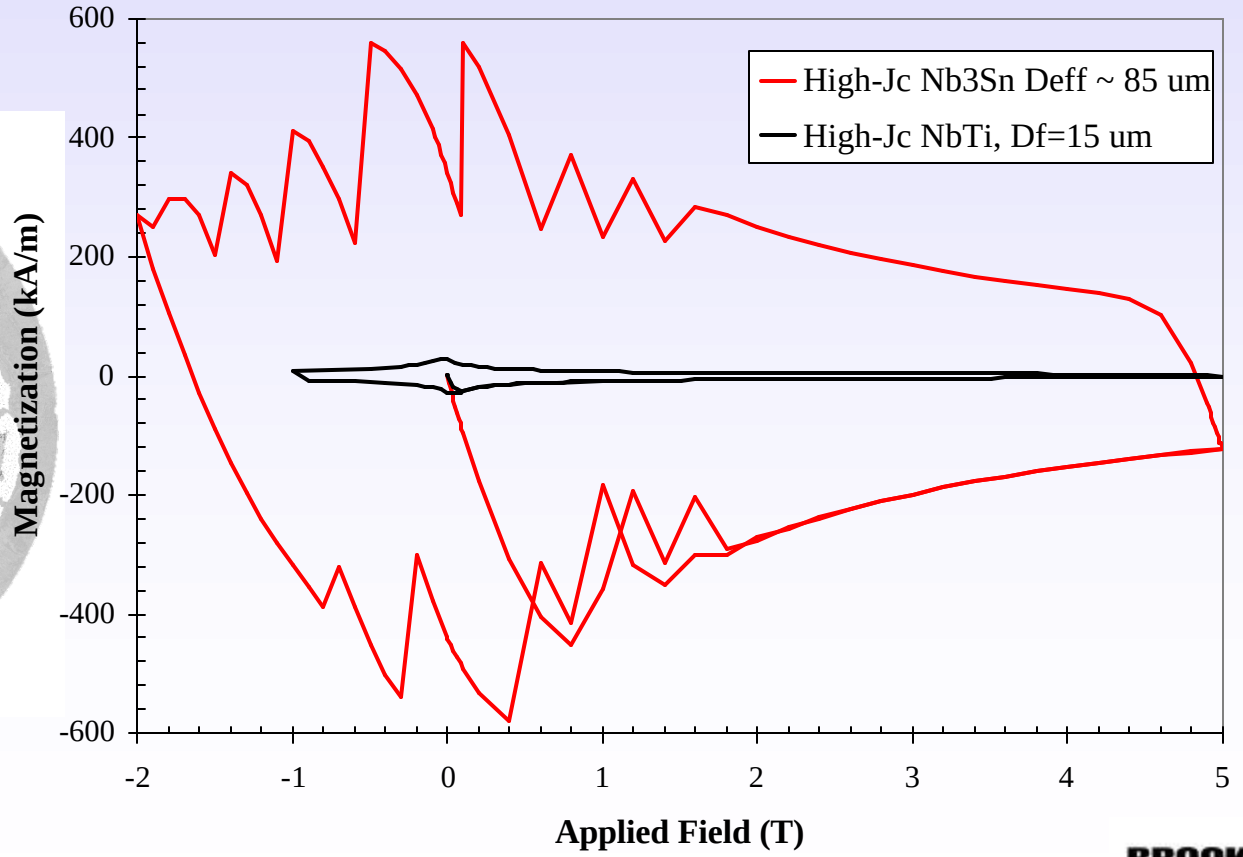
C is the heat-capacity (increases with increasing temperature) and

Tc is the critical temperature (field-dependent)

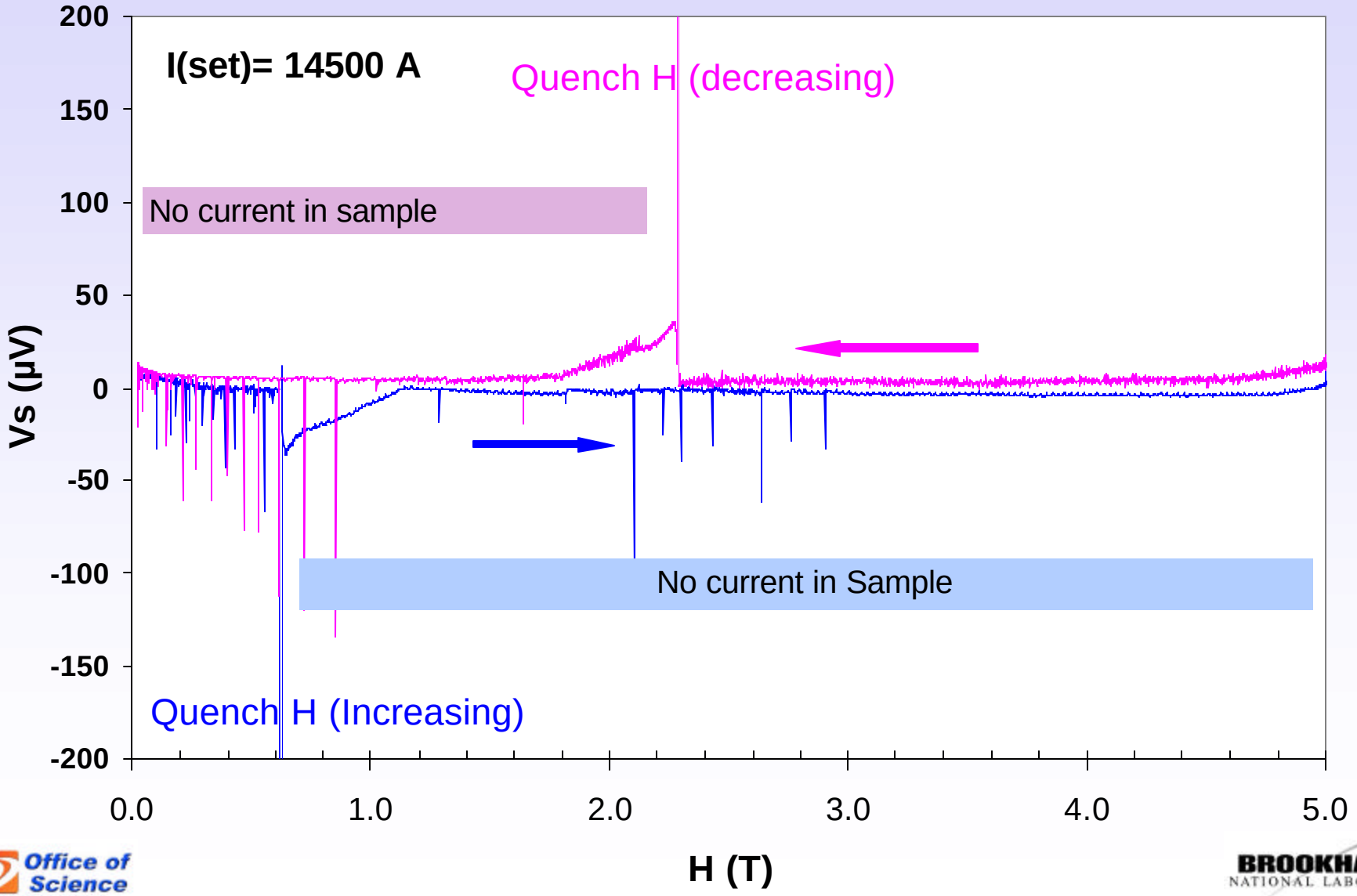
Materials R&D: Flux-Jump Instability

The individual sub-elements of high Jc internal-Sn Nb3Sn multi-filamentary strands behave as a solid tube of superconductor of large diameter ~ 60-100 μm . This leads to magnetic instability at low fields as seen in magnetization measurements.

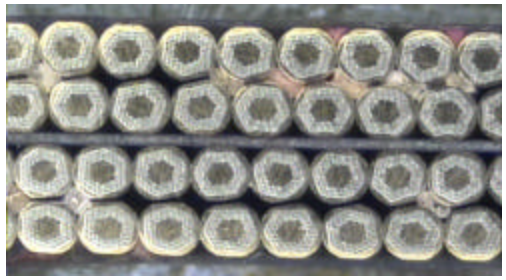




Materials R&D: Field-Sweep quench Measurements
First Direct Observation of Flux-Jump induced Instability in Nb3Sn Cables



Materials R&D: Current Ramp Quenches at Fixed Field 30-Strand cable 0.8mm wire



Cable I_c from Strand Meas.

Unstable Region

Quench Threshold

Stable Region

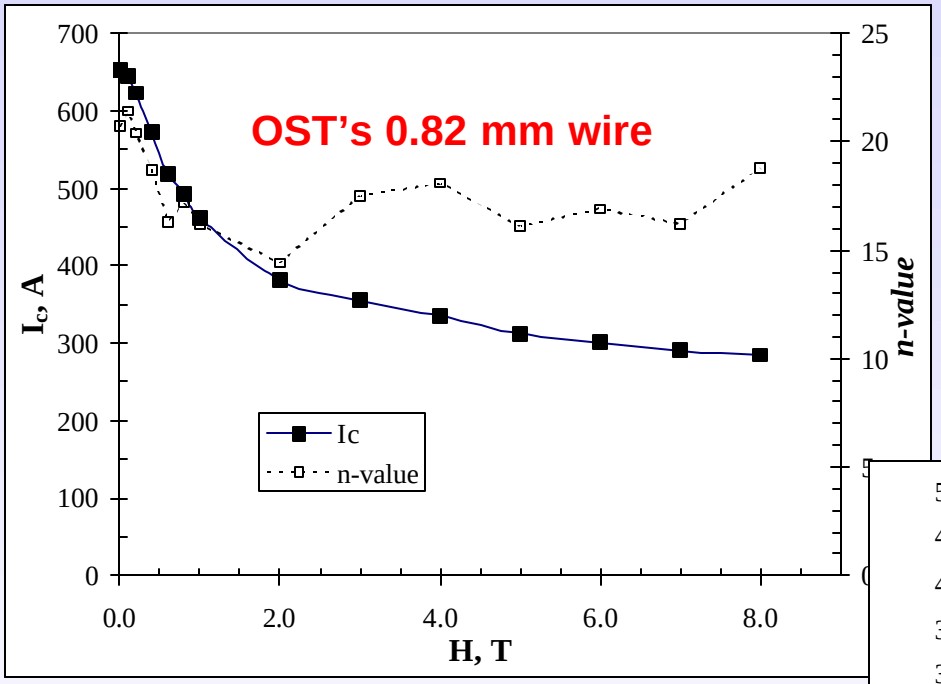
Current [A]

40000
35000
30000
25000
20000
15000
10000
5000
0

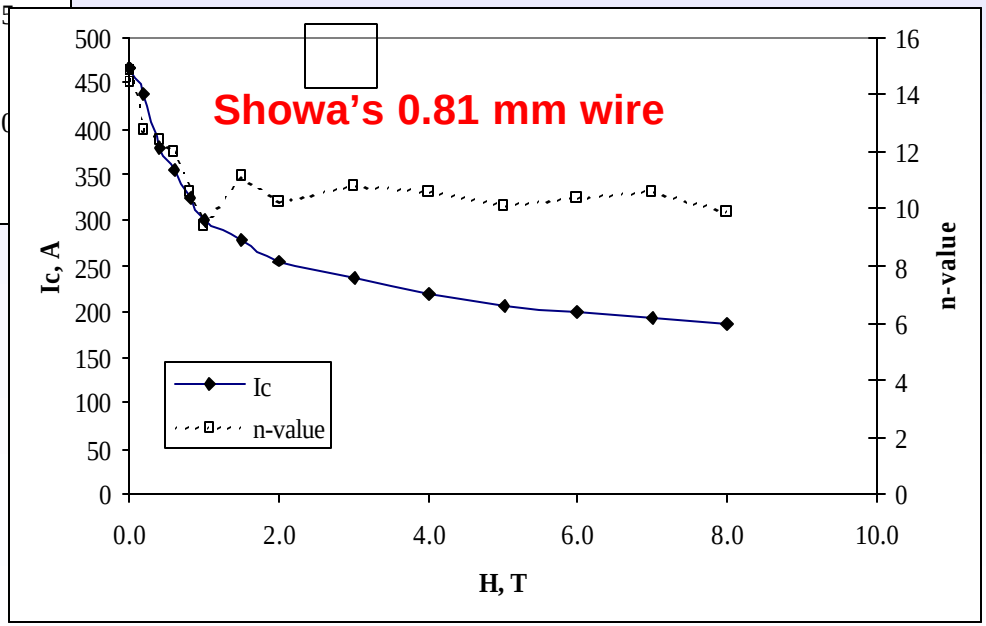
0
2
4
6
8
10
12

H_{SF} [T]

Materials R&D: Multi-Filamentary Bi-2212 (HTS) Wires from Oxford & Showa



These measurements are not for the best wires from OST and Showa. But they are indicative of the fact that both can now achieve comparable performance. A factor of two improvement in Jc would make these conductors interesting for high field application.



Present J_c(5T) ~ 2kA/mm^2

Wire ID	No. of Fils	Diameter	Jc (1T)	Jc (5T)
		mm	*A/mm^2*	*A/mm^2*
B1152	127x7	1.00	2617	1863
PMM030224	85x7	0.82	3076	2080
PMM030224	85x7	0.72	2738	1872

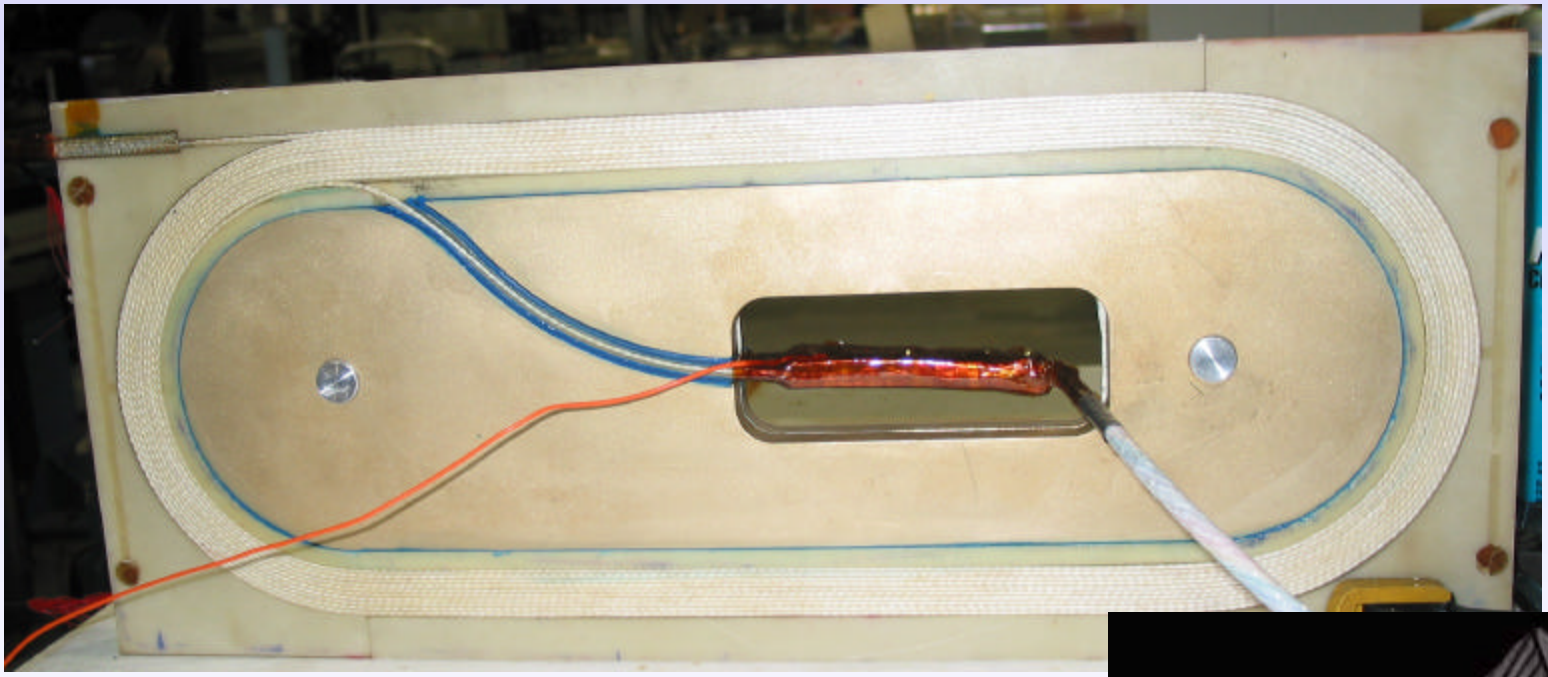
Materials R&D: MgB_2

- Global belief: now capable of 40 T if doped to add electron scattering
  - Substitution of carbon for boron is key for added scattering, high H_{c2}
  - Mechanism just emerging; samples not homogeneous; limits not known
  - BNL: Explore limits, understand mechanisms, make samples to feed unique electron microscopy facilities (with R Klie – BNL CFN)
    - Carbon doping (adds electrons) vs. Alkali metal doping (adds holes)
    - Thermal plasma sprayed coatings (with SUNY-Stony Brook)
- MgB_2 wire development (collaboration with Ohio State and industry) based on power developed from the in-house R&D

High Field Magnet R&D

- Looking at a react-and-wind technical approach
  - Suitable for both Nb3Sn and HTS materials
  - Flat coil designs due to the brittle cable
  - Contrasts with LBL and Fermilab wind-and-react
- Primary development tool is a 10-turn coil program
  - Not much point trying to build magnets until coils work
  - Cheap (er)
  - Rapid turn-around
  - Parametric variation possible
- Short term goal of a ~12T common coil dipole

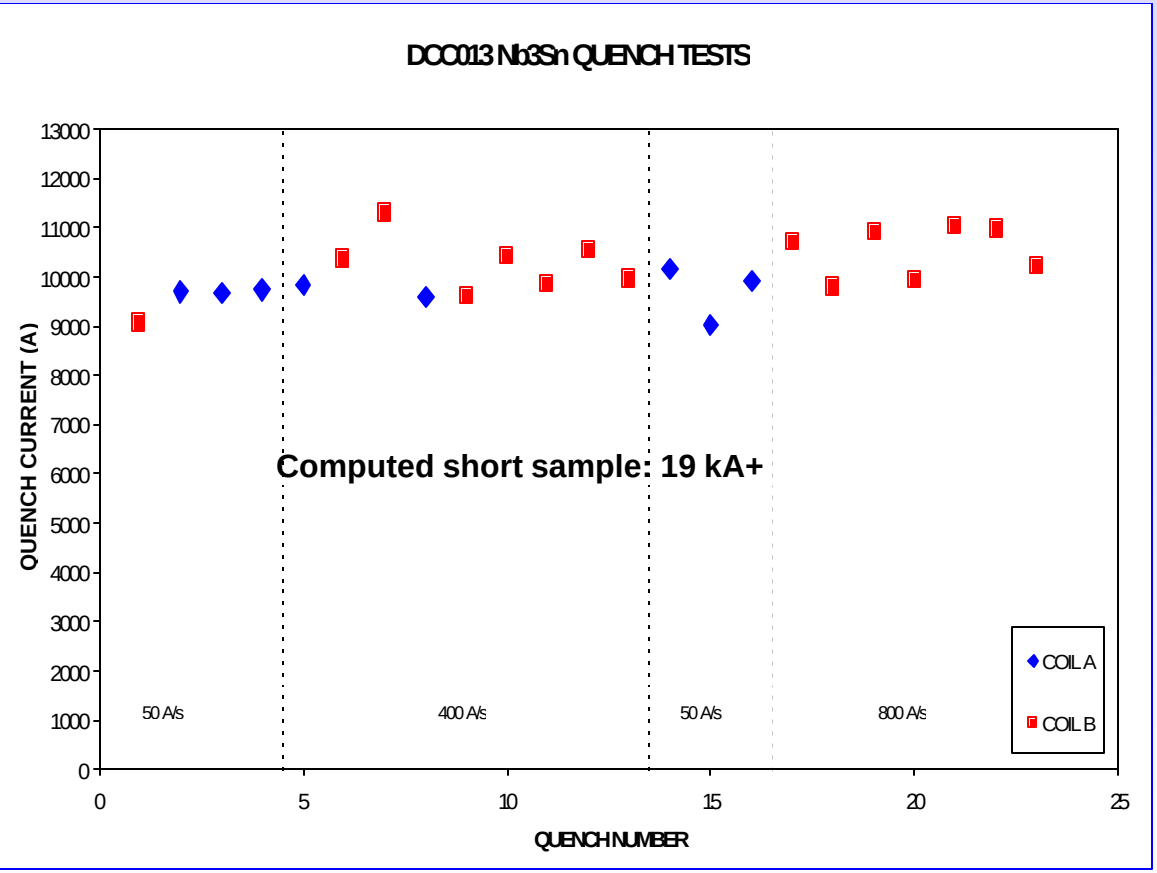
High Field Magnet R&D - HTS Technology development



A 10-turn racetrack R&D coil recently built and tested at BNL.

- Minimum bend radius 70 mm; Cable thickness ~1.6 mm.
- Bending strain 1.4% or 0.7% depending on whether the wires in the cable are sintered or not.

High Field Magnet R&D - Nb3Sn Technology development



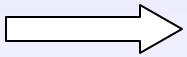
This is a representative coil test using the high performance Nb3Sn from the national conductor effort. The coil was made using react-and-wind techniques.

This result is similar to those obtained at Fermilab using wind-and-react, but not consistent with the LBL results !

The only coils that worked were those made from the low performing ITER cable.

High Field Magnet R&D - Nb3Sn Technology development

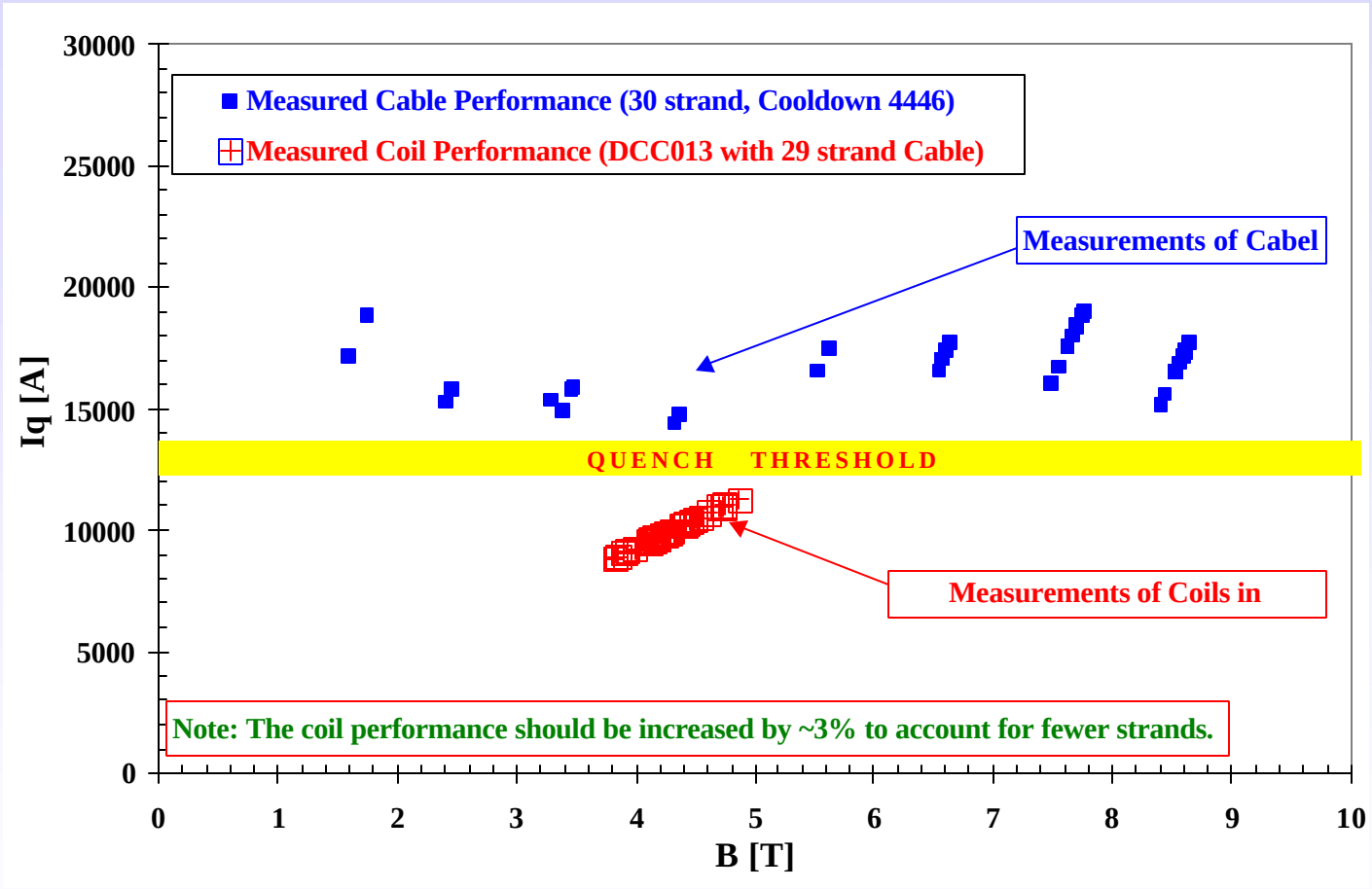
As of last September we were still highly suspicious of the mechanical issues in dealing with react-and-wind



Both coils quenched but all quenches were in the first turn. Possible causes:

- Bending degradation
- Special issues related to first turn (geometry, splice, etc.)
- Kevlar string causing large local strain on the cable
- Bonding between Nomex insulation and turns
- Mechanical (zero pre-stress)
- Practical issues (technicians available keep changing)
- Other fundamental issues: conductor stability, etc.

High Field Magnet R&D - Nb3Sn Technology development

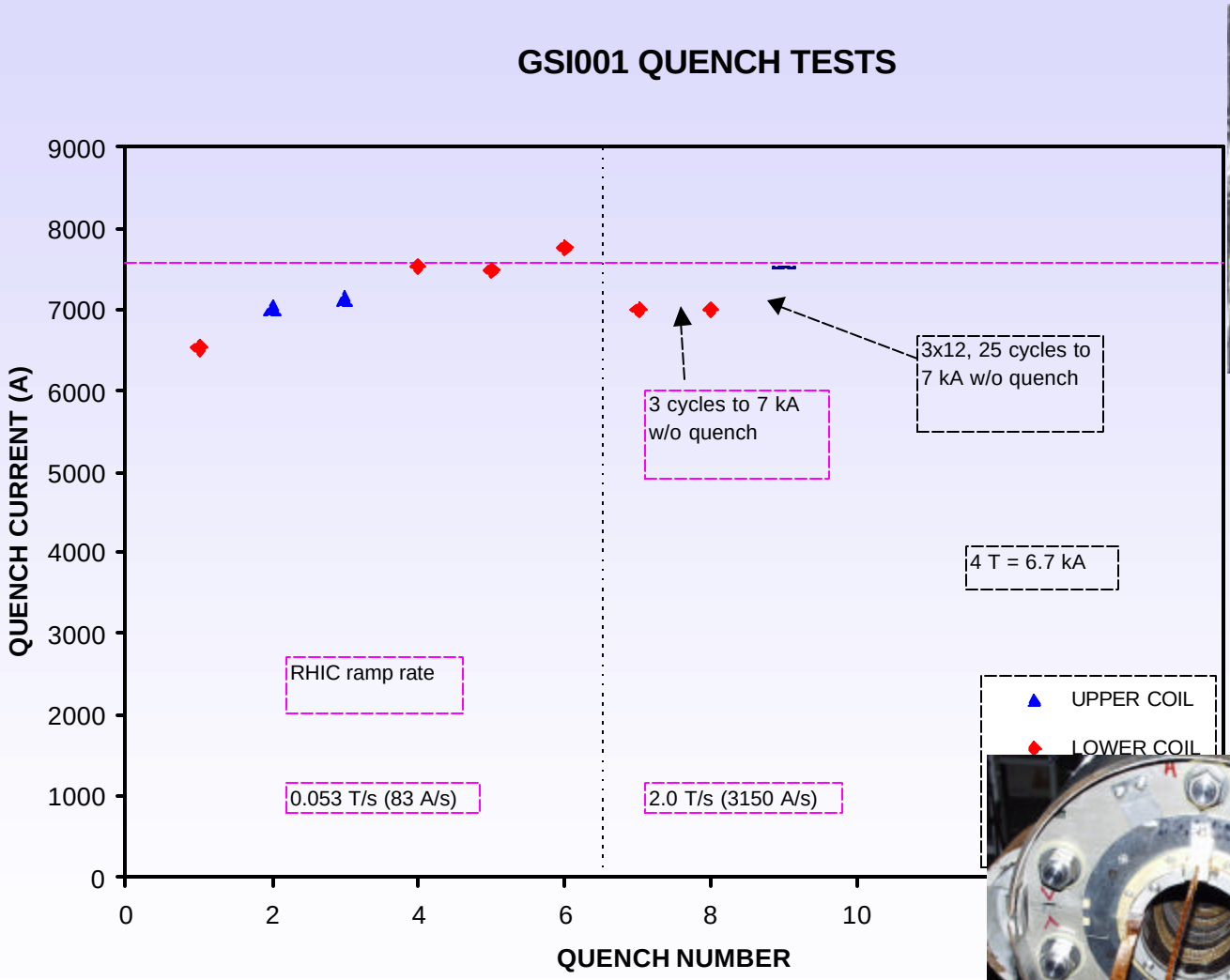


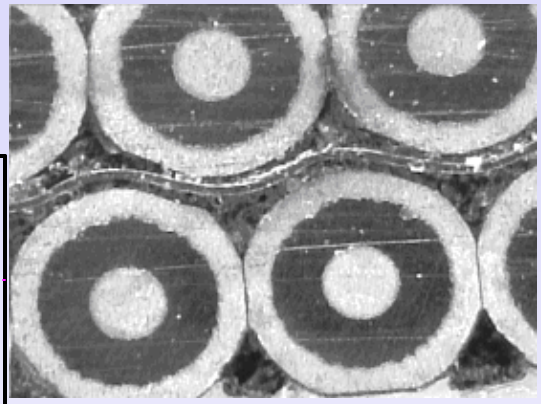
It would appear that we are experiencing some mechanical degradation with react-and-wind coils as well as cable instabilities (but not as bad as we thought)

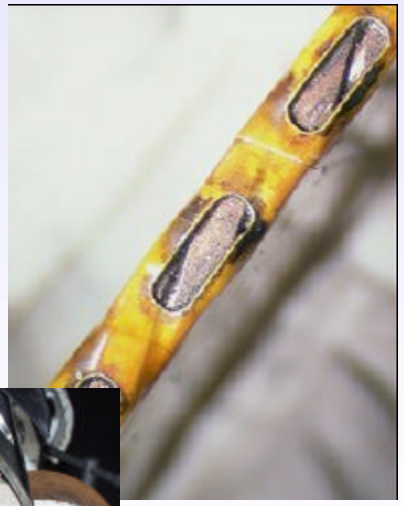
High Field Magnet R&D - Flat Coil Winding machine

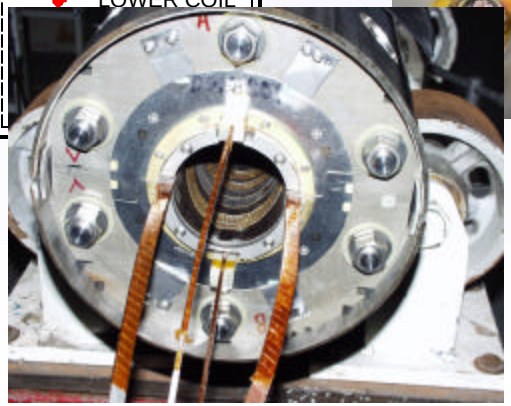
Once the winder is commissioned then we will start to fabricate a 12T (50-turn) common coil magnet. The load line is such that it should hit the flux jump threshold around the short sample current.

Work for Others - r & D: GSI rapid cycling dipoles





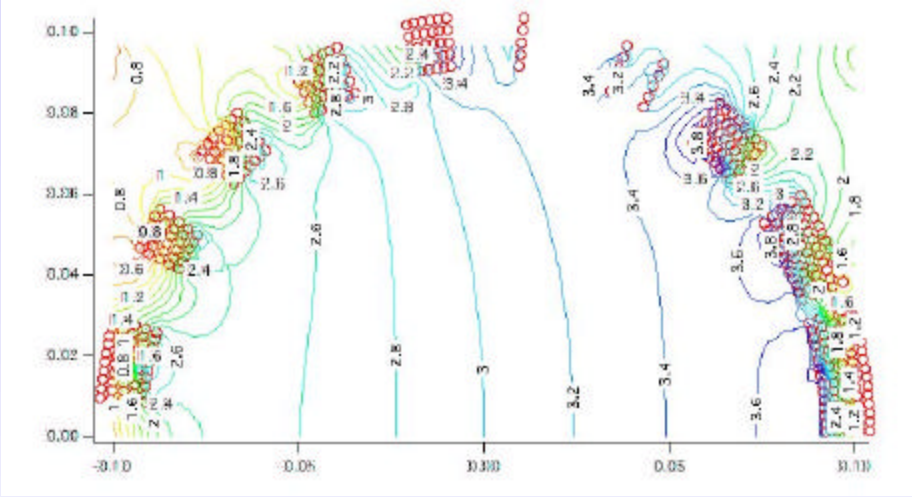


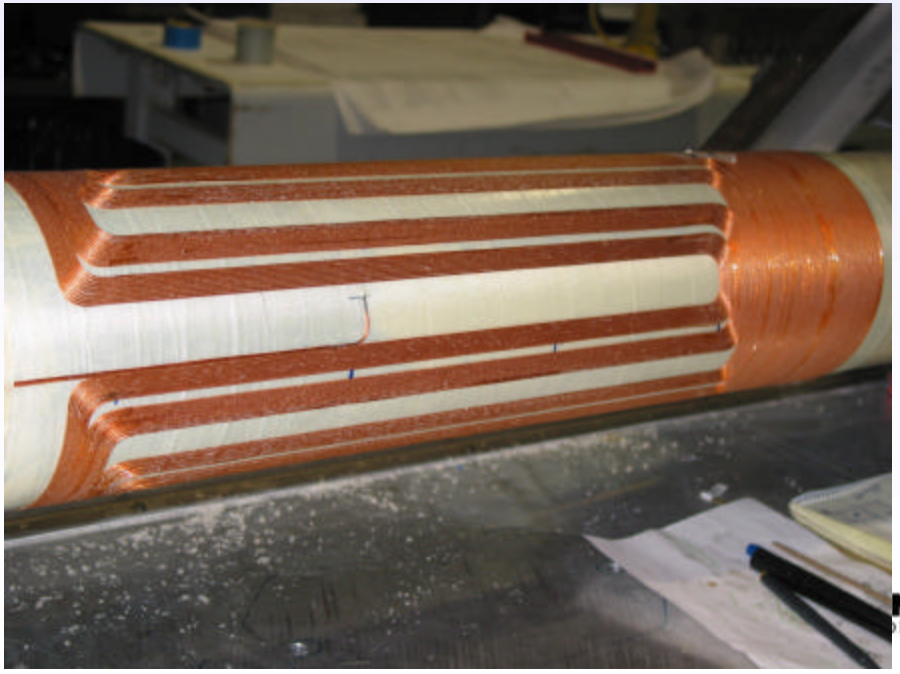


Work for Others - r & D: J-PARC Neutrino Line Combined function magnets with KEK

First time anyone has attempted to built a superconducting magnet of this type.
Certainly useful for beam-lines in other applications - superbeams.

KEK will work on the collared coils, BNL on the corrector system. Both labs on prototype elements (1m long)





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Conclusions

The linear collider quad program shows distinct promise of resulting in the optimum solution. Unless something happens to the budget though all magnet work may have to stop

LARP dipole development in very early stages. A very difficult problem. No major resources until FY06 and competition with LARP quadrupole program.

The materials program has requires continued infrastructure development and has challenges for both Nb3Sn and HTS superconductors. Distinct promise in all areas.

High field magnet work may also fall victim to lack of support in FY05. Hopefully we can demonstrate a ~12T common coil dipole in FY04.

Work for Others continue to provide 'interesting' problems which enhance our overall capabilities