Impact of HTS Magnets on IR Layout and Design

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

Design Considerations

There are two classes of magnets:

- Main ring magnets
  - Large number
  - Design should be driven by cost
    - Cost is determined by material and labor
- Insertion region magnets
  - Small number
  - Design should be driven by performance (we can allow bigger cost per magnet)
    - The material and labor cost of final magnets will be a small fraction of overall cost that includes cost of R&D.

$\Rightarrow$ Different design principles should apply to two!

HTS magnets with brittle conductors and high "labor & material costs" may be too demanding for whole machine but OK for IR's.

HTS Magnets for IR Upgrade

Are we ready to build HTS accelerator magnets?

No, not yet!

Given the time frame of upgrade, the right questions to ask are:

Is there a possibility to demonstrate the viability of HTS magnets in time for making a technology choice for luminosity upgrade?

Based on short HTS coils (yes we have built and tested a few), it's promising. But it's too early to tell without more R&D and proof.

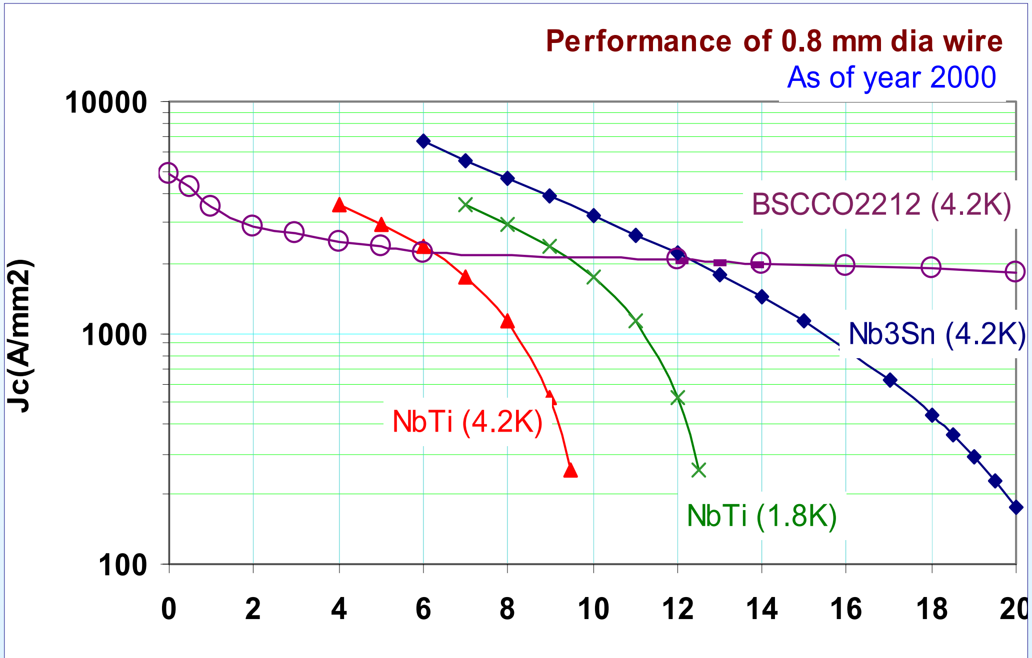
What is the impact of HTS on overall IR upgrade design?

HTS magnets with very high fields may be enabling technology for some designs (layouts). But, the benefits must be examined in all lattices to see how each can benefit. Modification in strategy?

What is the impact of HTS on high luminosity operation?

HTS can tolerate several degrees (even up to 5-10) increase in temperature. That changes many design principles.

HTS: A High Field Superconductor



(~100 meter or longer lengths)

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 today)

Investment in 2212 has been much less than in 2223, there may be room for relatively more improvement.

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

These are quench fields, operating fields may be 10% or more lower.

Cu(Ag)/SC Ratio

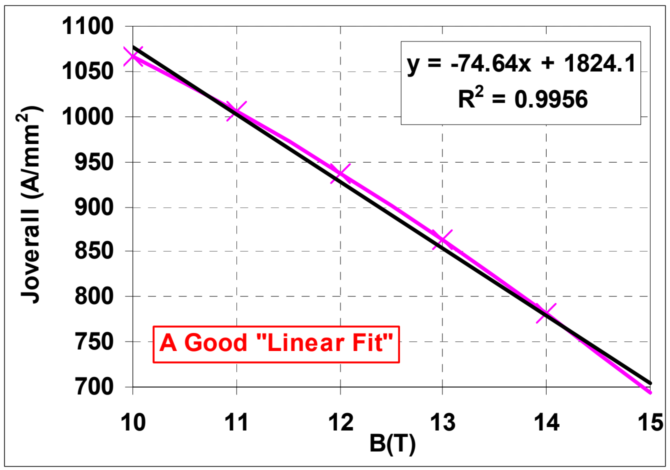
BSCCO: 3:1 (all cases)

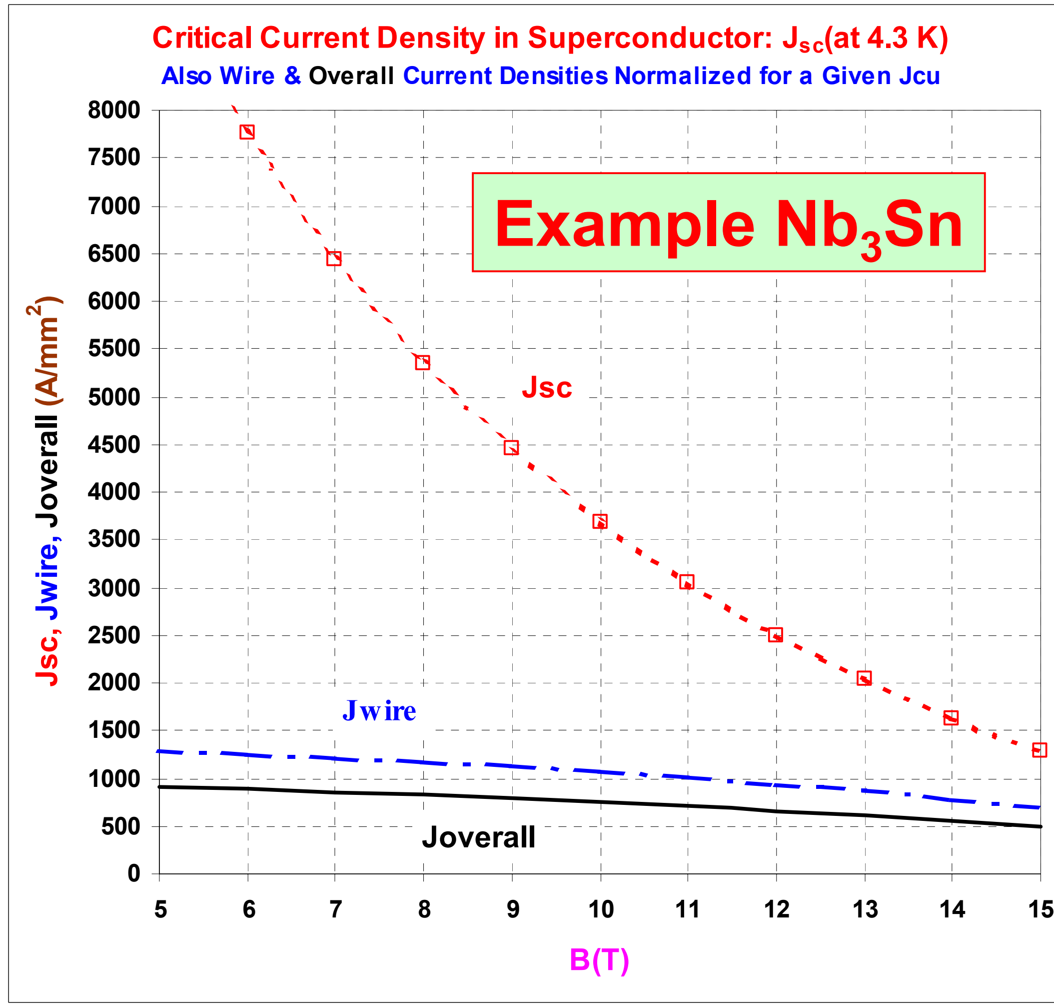
Nb_3Sn: 1:1 or J_{cu}=1500 A/mm^2

Engineering (Operating) Current Density in Magnet Designs

J_{sc}(12T,4.3K)	J_{cu}(A/mm^2)
2500	1500

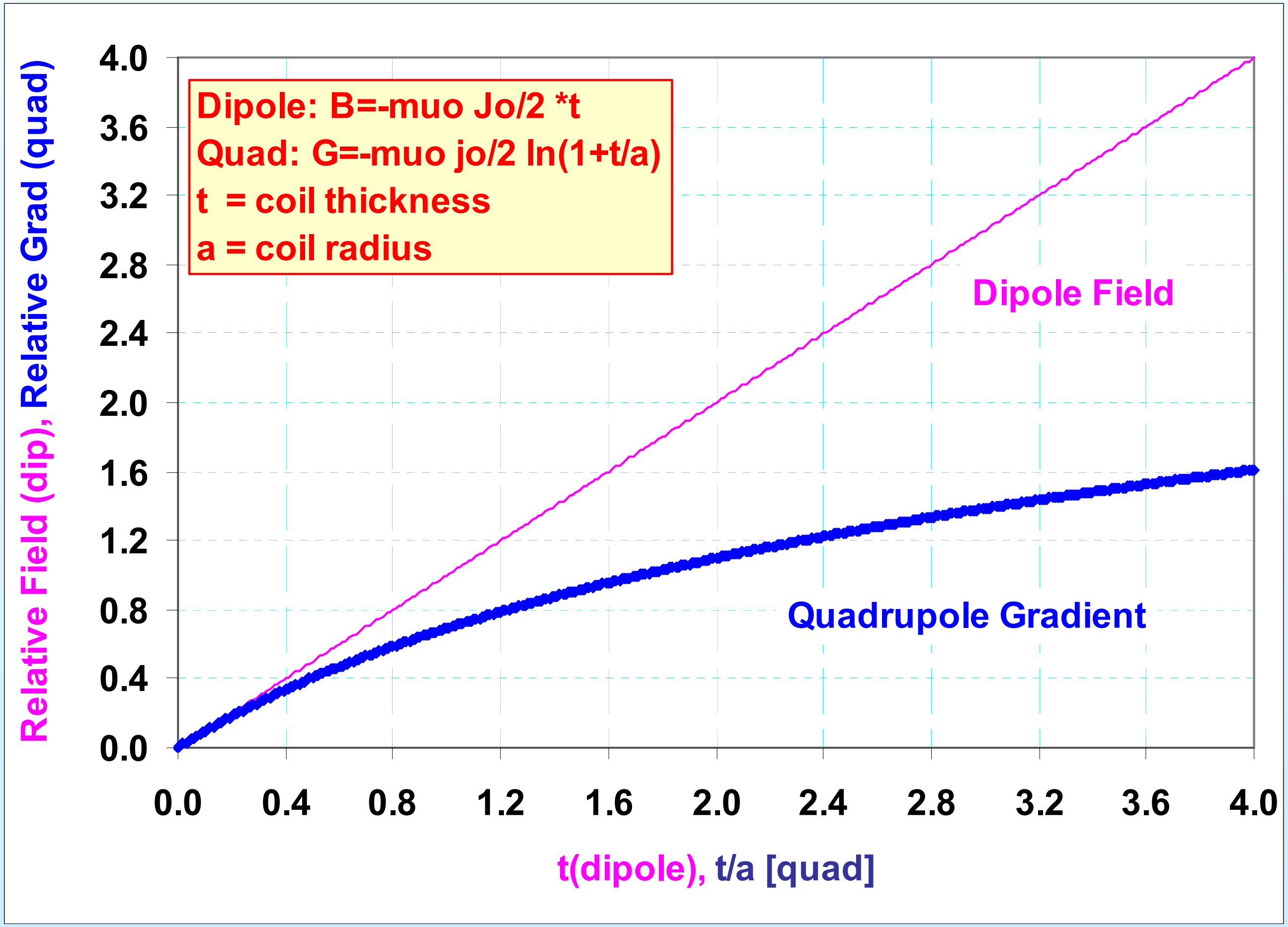
Cu/Sc Ratio	B(T)	J_c(A/mm^2)	J_{wire} (A/mm^2)	Joverall
6.30	5	9454	1295	911
5.18	6	7766	1257	885
4.29	7	6431	1216	856
3.56	8	5347	1171	825
2.96	9	4446	1122	790
2.46	10	3689	1066	751
2.03	11	3048	1005	708
1.67	12	2500	938	660
1.35	13	2031	863	607
1.09	14	1631	781	550
0.86	15	1289	693	488
	Scaled from TWCA			Insulated





High Field Magnet Designs
A Basic Difference between Dipole and Quad

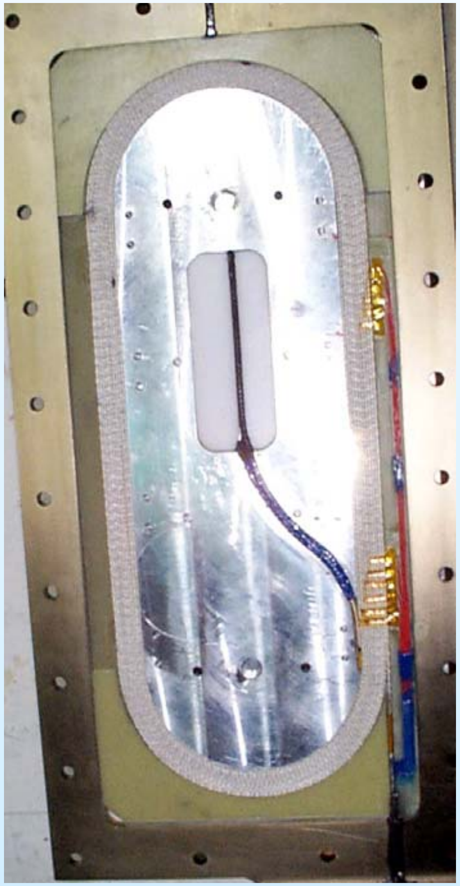
The increase in pole tip field is linear with coil thickness in dipole, but not so in quadrupole. The situation gets worse as we go to high gradients.



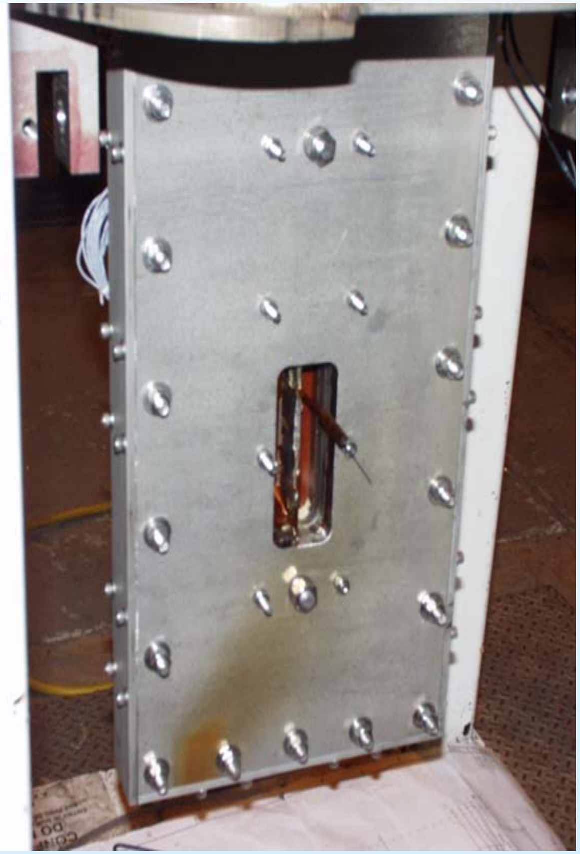
High current density at high fields is much more useful in high gradient quadrupoles than in high field dipoles.

HTS Test Coils and Magnets at BNL

BNL has built many test coils (14) and magnets with HTS cable and tape.



HTS Cable Coil



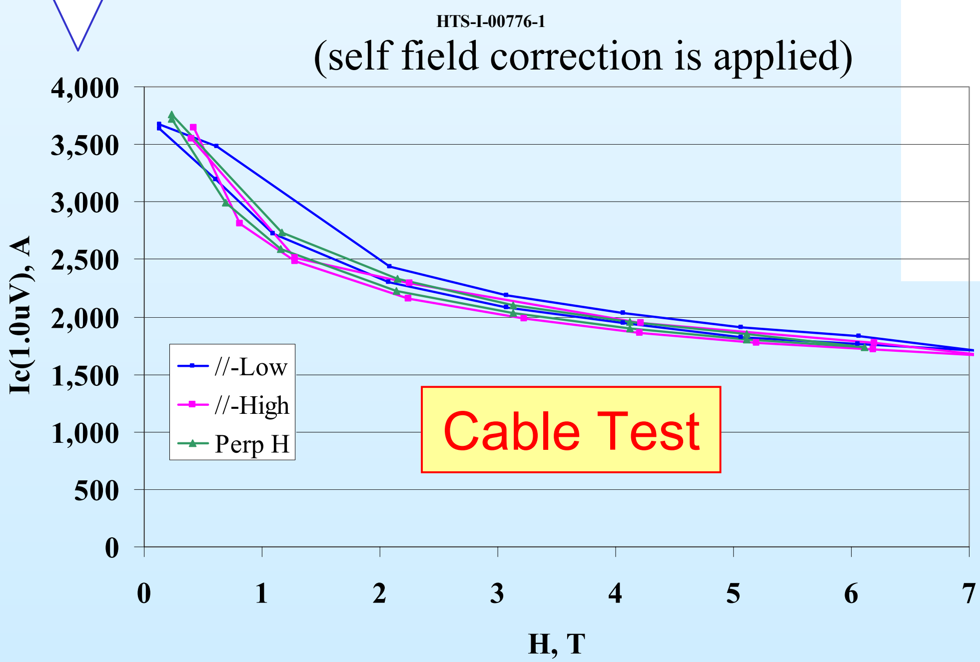
HTS Cable Coils in support structure

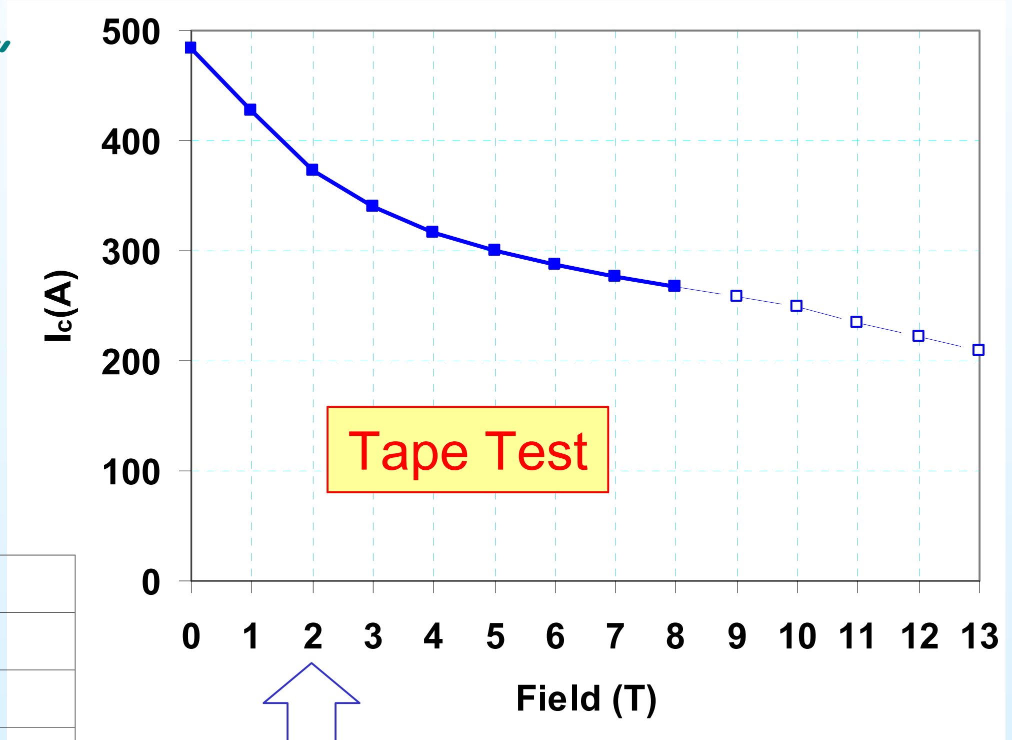
Two HTS tape coils in common coil configuration

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

Measurement of "***BSCCO-2212 cable***"
Showa/LBL/BNL collaboration

Today's HTS cable can carry large currents. This was a narrow cable. LHC size cable will carry much more. Moreover, Ic is better by over a factor of two now.





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

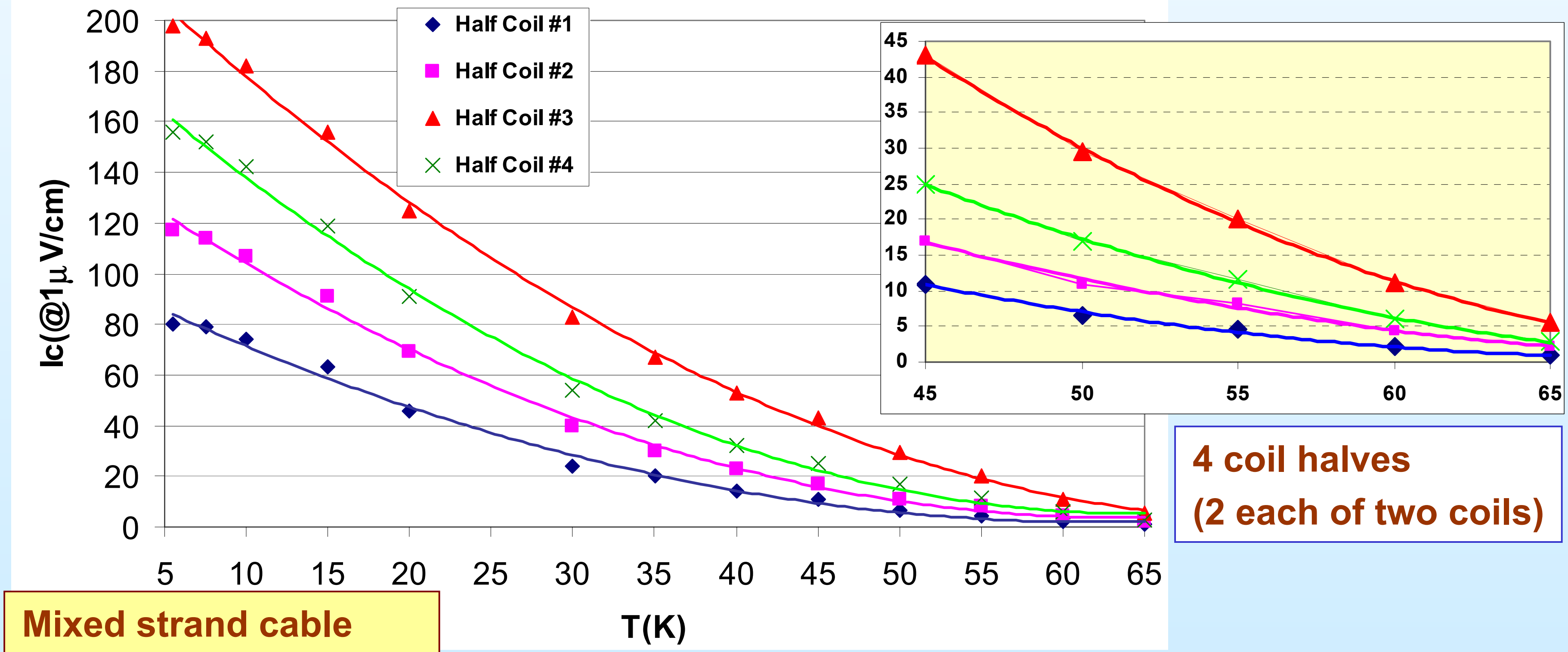
(field perpendicular value is ~60%)

High Temperature Performance of HTS Coils Built at BNL

Remember: HTS is also a High Temperature Superconductor!

A few degree increase in temperature, either from energy deposition of decay particles, or from mechanical motion, has a small effect on critical current.

HTS magnets will not quench easily, they can tolerate much more beating!



4 coil halves
(2 each of two coils)

Mixed strand cable
(2 BSCCO 2212, 16 Ag)

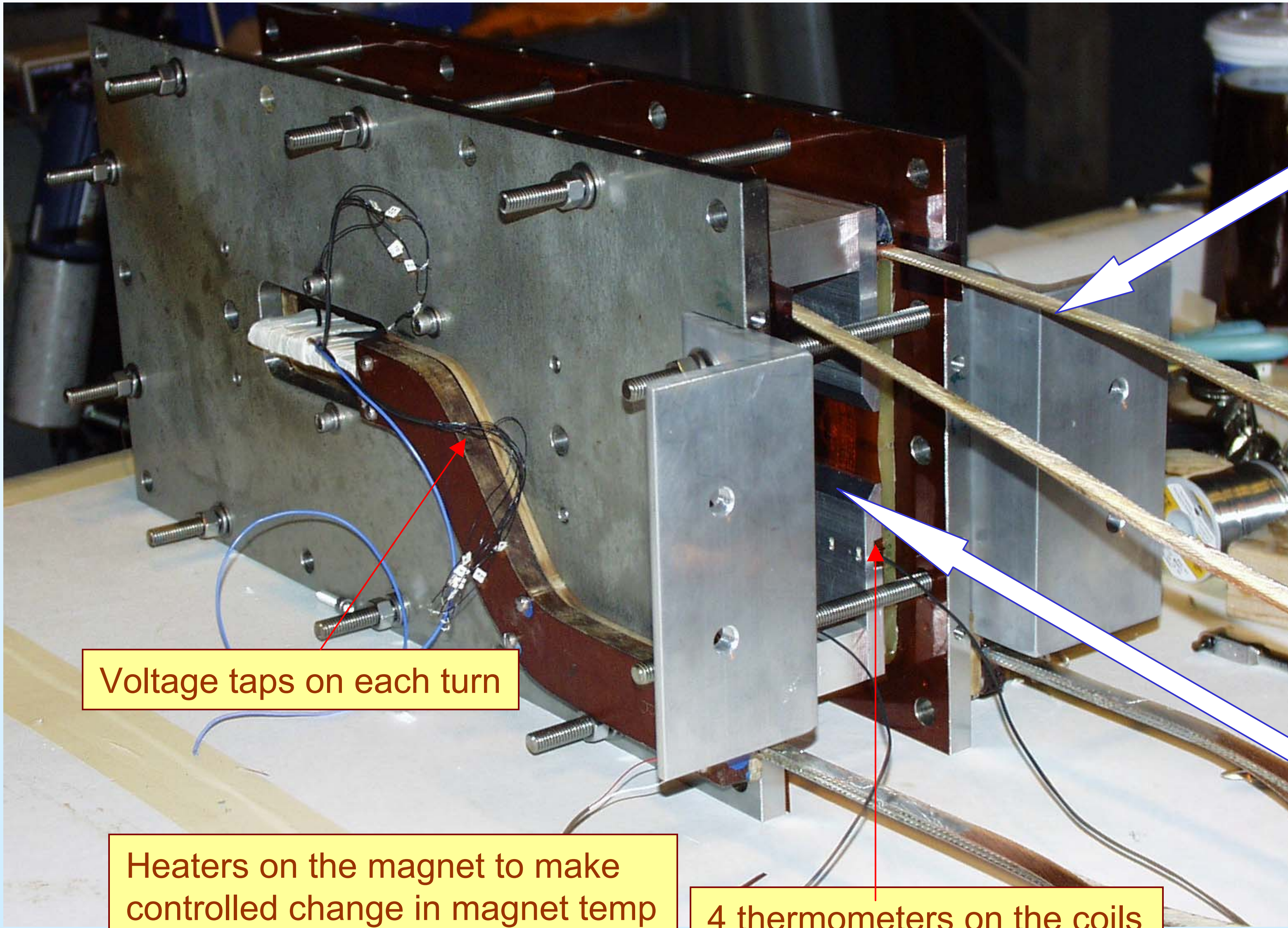
BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

DCC006: 2nd HTS CC Cable Dipole

74 mm Aperture for Field Quality Measurements

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

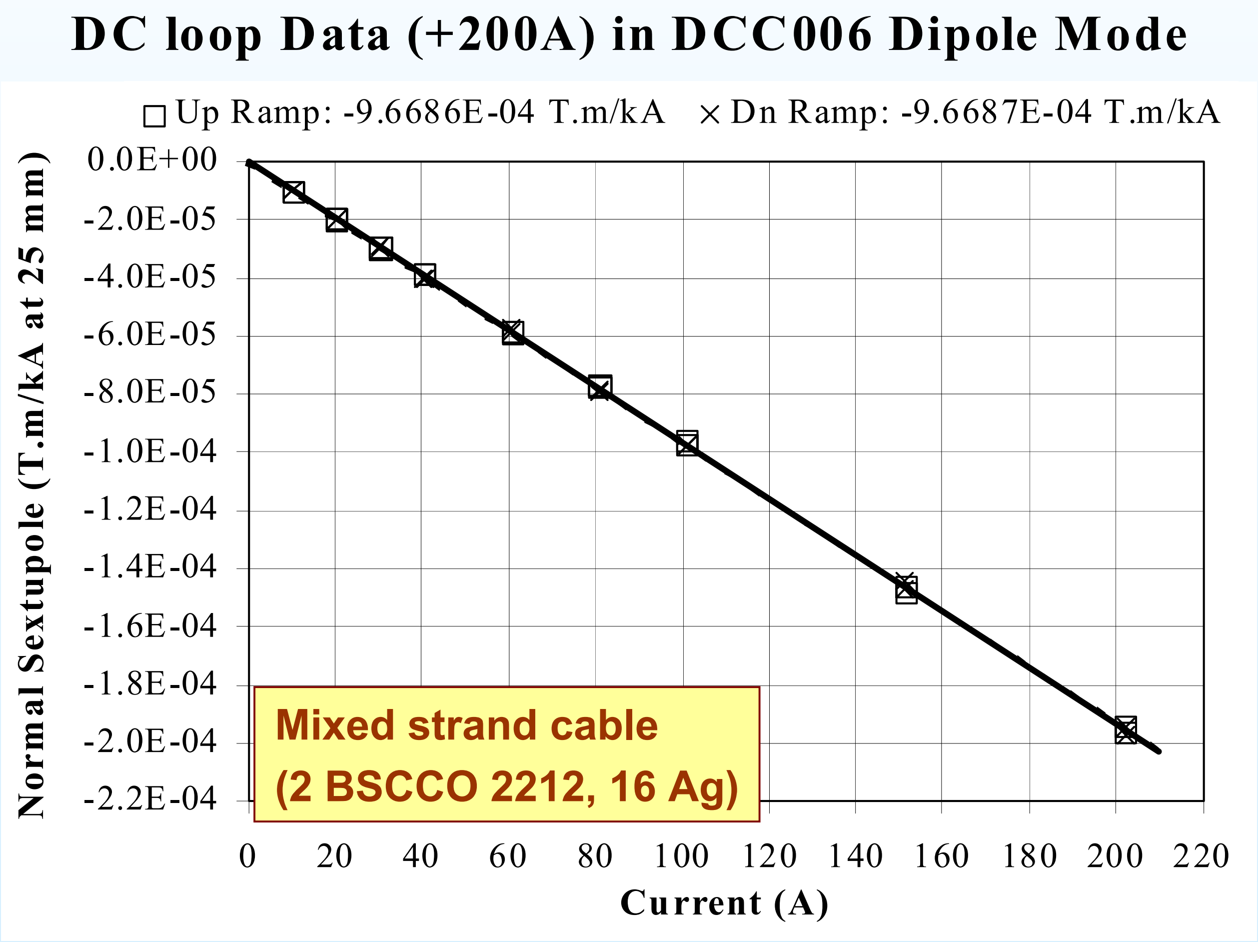


HTS Cable Leads to make high temp measurements

74 mm aperture to measure field quality

Field Quality Measurements

Sextupole Harmonic



Difference between up and down ramp values is within measurement errors.

Max field on conductor was only ~550 Gauss. Expect a relatively smaller measurement error when the total current is high in an all HTS cable.

First Likely Application of HTS: Interaction Region (IR) Magnets

Interaction region magnets for the next generation colliders can benefit a lot from:

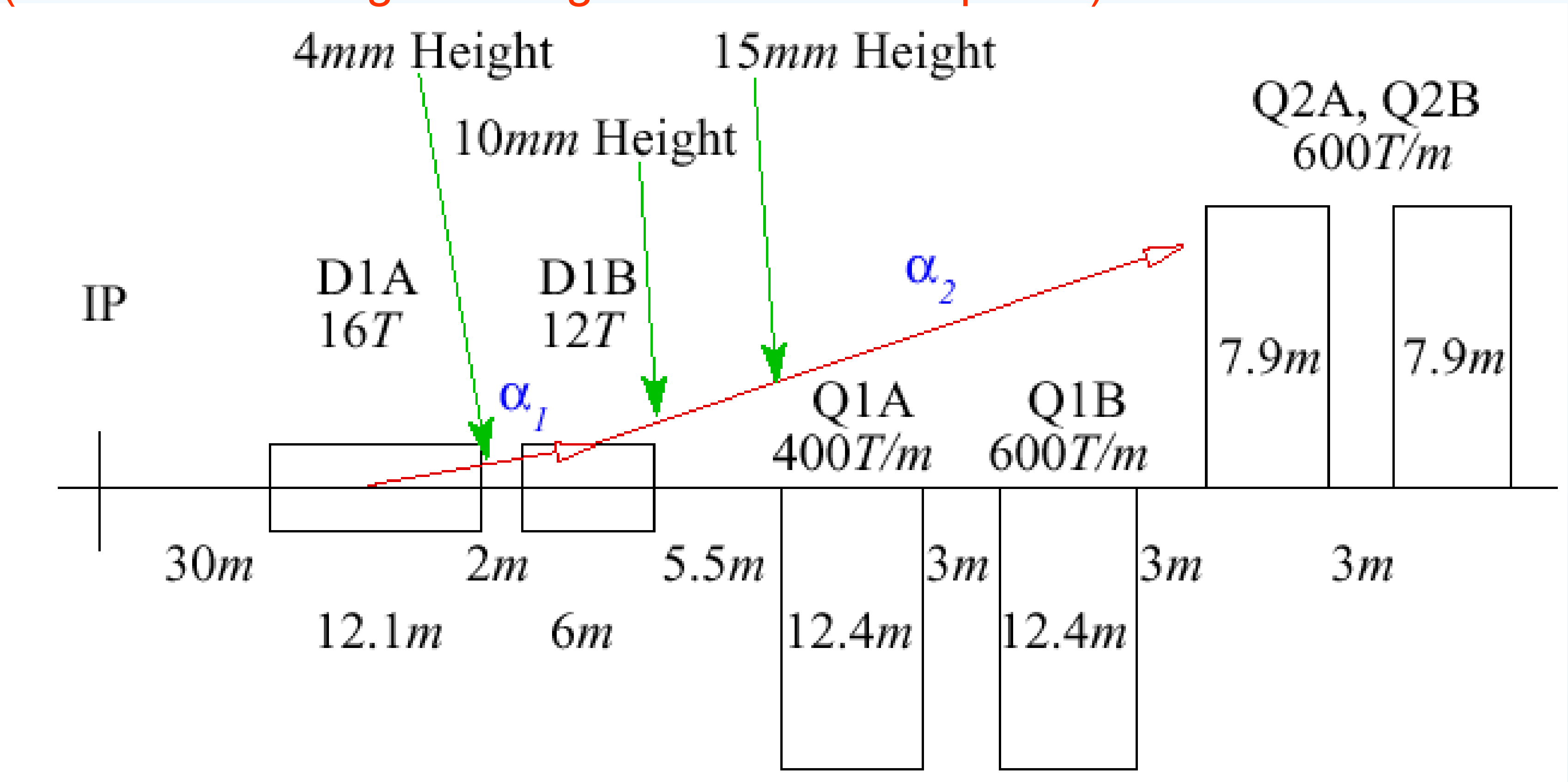
- the ability to produce very high fields
- the ability to deal with large energy deposition
- the ability to operate at elevated temperatures that need not be uniform

→ For these IR magnets, the performance, not the material cost is the issue.

→ IR quadrupoles in LHC may be replaced a few years after first experiment

VLHC-2 IR Layout for Flat Beam Optics

(relevance to magnet designs for "D1 first" optics?)



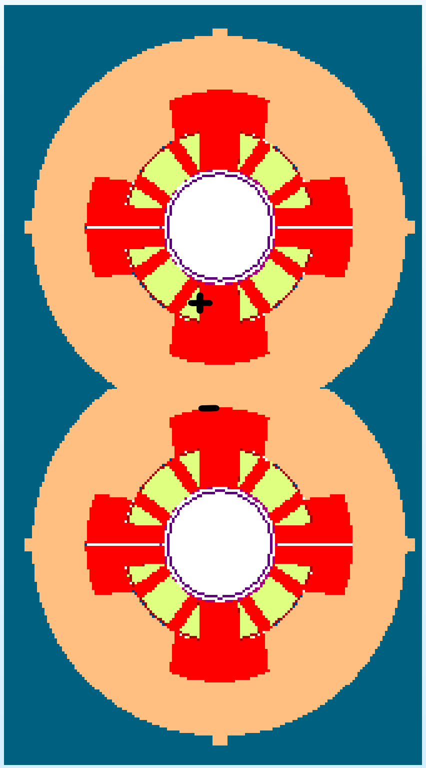
- Optics and magnet requirements (field & aperture) depends crucially on the minimum spacing in the first 2-in-1 IR Quadrupole **(doublet optics)**
- 23KW of beam power radiated from the IP makes this a natural for HTS.

BROOKHAVEN NATIONAL LABORATORY

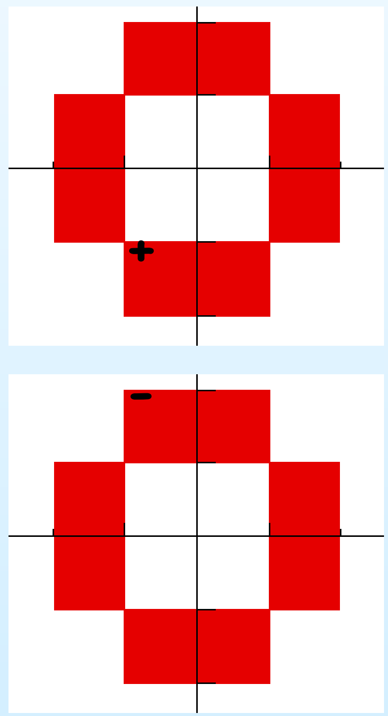
Superconducting Magnet Division

VLHC-2 Interaction Region Magnet Design Concept

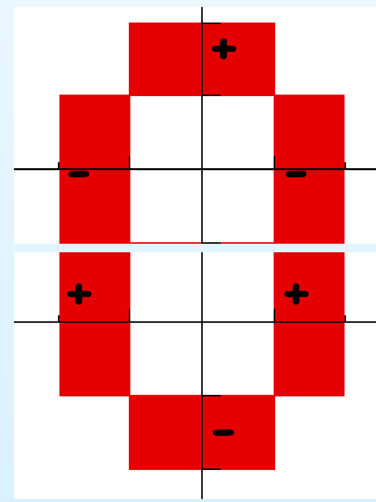
Conventional 2-in-1 cosine theta design



Panofsky 2-in-1 quad design



Modified Panofsky Quad with no spacing



(Bo not zero)

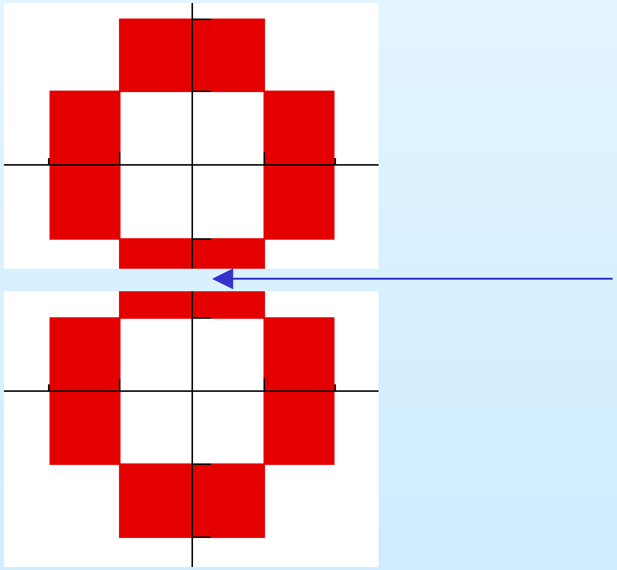
Spacing depends on the conductor and support structure requirements

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

Variations of the Q1 Design

We have investigated several variations of the design shown in previous slide. Expect system optimization between field field strength, field quality and corrector designs.

A design of particular interest (for neutrals) is the case when there is nothing present at the midpoint of two apertures.



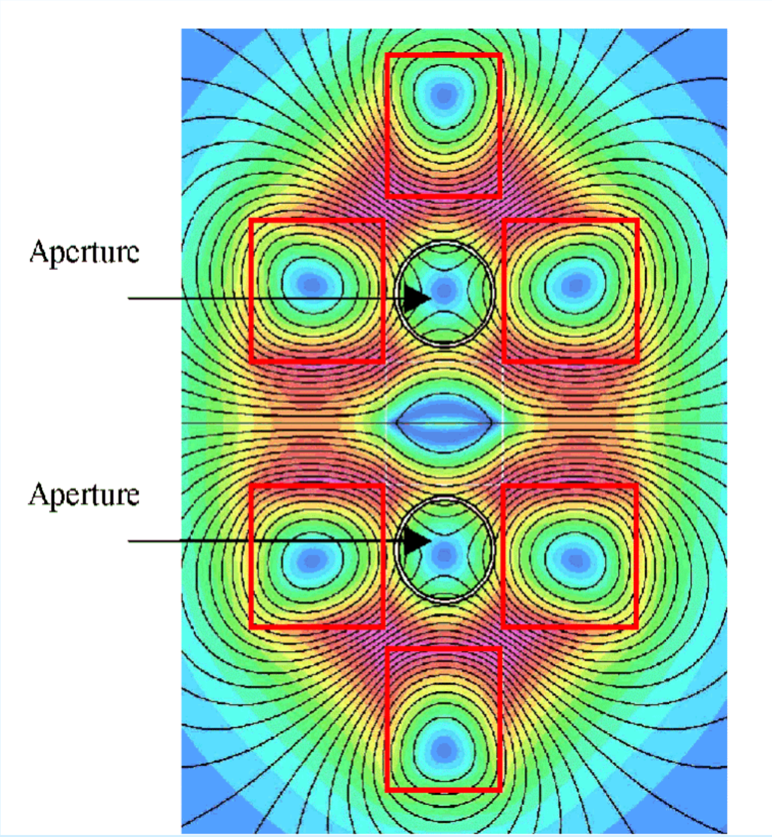
Decay products from IR clear the superconducting coils

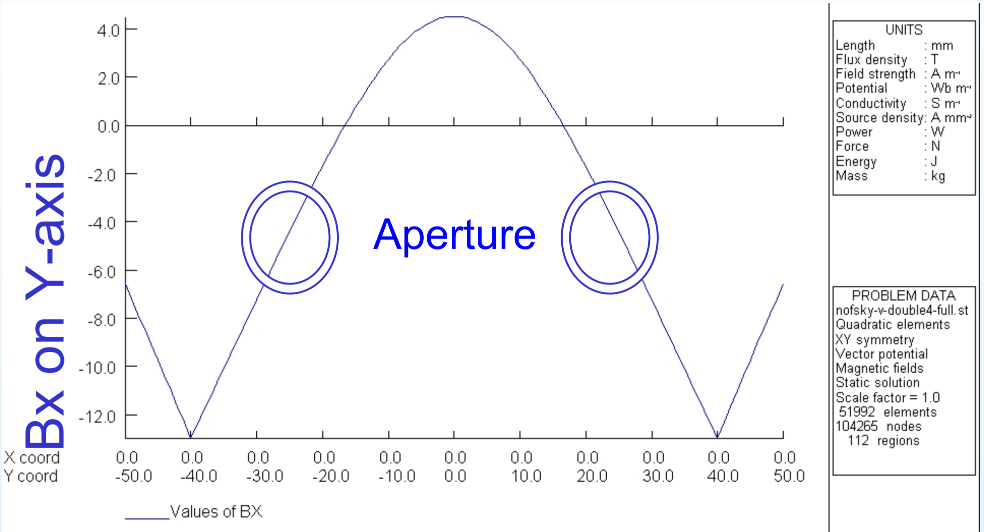
Fields in the Proposed Double-Quad Design

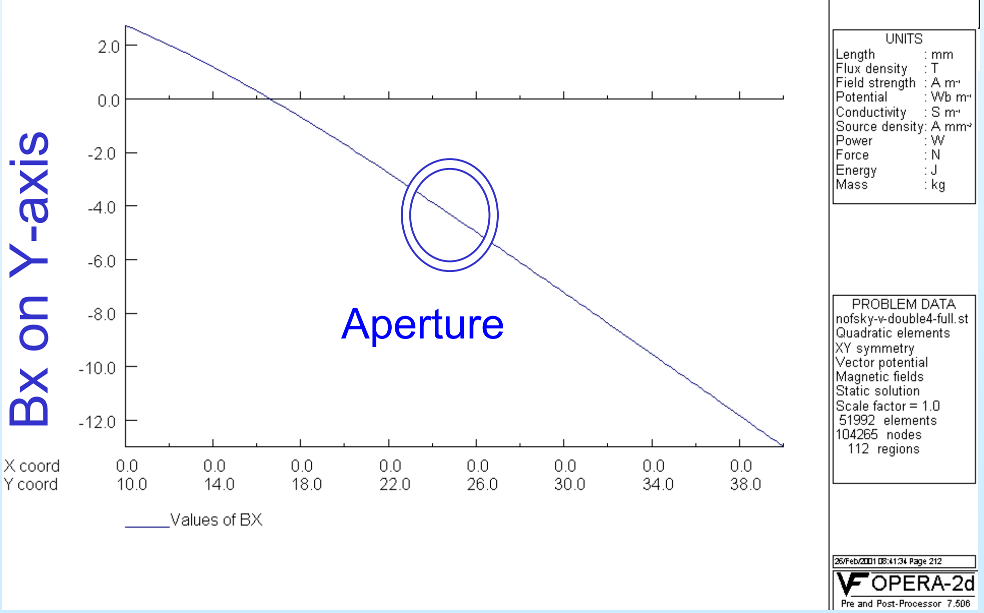
BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Field contours and field lines







PRE-SUMMARY
HTS: Then and Now

Only a decade ago, HTS was treated as a material of curiosity for such applications. Now we are taking it more seriously. Fermilab and CERN use it in HTS leads.

It is available in much more than a few meter length

BNL recently purchased wire from Showa that was 1.5 km long.

LBL has made HTS cable that was ~100 meter long.

It carries much more than a few Ampere current

Even today, LHC size cable should carry ~5 kA current at high field.

… and we have made a number (14) small coils with it

Despite being very brittle, it has been shown that it can be handled.

So far, in the limited test, we have not seen a significant degradation.

However, for making magnets, there is a long way to go!

SUMMARY
HTS: Now and Future

HTS has a potential to make a significant impact on IR Design

- Can generate high fields
- Can work at elevated temperature
- Can simplify cryogenic system

A reasonable effort in HTS magnet R&D should be directed now to make sure that we don't miss out a potential opportunity

- This is a "High Risk, High Reward R&D"
- Machine people are requested to explore all benefits of it.