IR Magnets for VLHC

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Disclaimers

A very limited amount of work has been done on VLHC Interaction Region (IR) magnets.

Consider all designs preliminary and/or conceptual.

All Cosine theta IR quad designs are from Fermilab.

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)

        Material and labor cost does not matter

        Magnet R&D would determine the cost

♠ Perhaps different design principles should apply to two.

Energy Deposition Issues

Consider energy deposition issue as an integral part of the magnet design. Need feedback before going too far.

Do we need liner? If yes how big?

Does open midplane magnet design help? If yes, how much?

We considered open midplane in an early days of LHC quad design. However, preliminary energy deposition calculations suggested that the secondary bombardment was also serious. Revisit the issue again.

If open midplane helps then how much do we compromise in gradient (specially if significant number of turns are removed from midplane)?

What is the impact of that on IR design (optics, geometry and magnets)?

IR Magnets for Stage 1 and Stage 2

Stage 1

Use present conductor technology for determining magnet design except for some small projected improvements (for example, 3000 A/mm^2 J_c in Nb3Sn).

But feel free to be innovative in magnet design.

Stage 2

Stage 2 is 25 years away!

Expect major improvements in superconductor and magnet technology.

For example, consider HTS based magnets.

It is not realistic not to assume progress in this period.

Design IR accordingly.

But if designs and expected performance are too aggressive; please have a fall back solution, just in case!

Stage 1 Low β IR Quad

The following information is from VLHC Design Study Report.

Main features/requirements of the quadrupole design:

- Design gradient: 300 T/m
- Aperture: ~80 mm
- Maximum beam separation within quad: 12.5 mm

- Design gradient: 300 T/m with two layers
- Aperture: 85 mm
- Nb3Sn Jc: 3000 A/mm2
- Mechanical Design: An upgraded version of LHC IR quad design by FNAL

IR Magnets for Stage 2

Two type of optics:

Flat beam and round beam.

IR design depends significantly with the optics chosen.

In round beam optics, the magnetic polarity of the first quad must be the same for the two counter-rotating beams.

Beam can pass through the same quadrupole, but allow beam to separate.

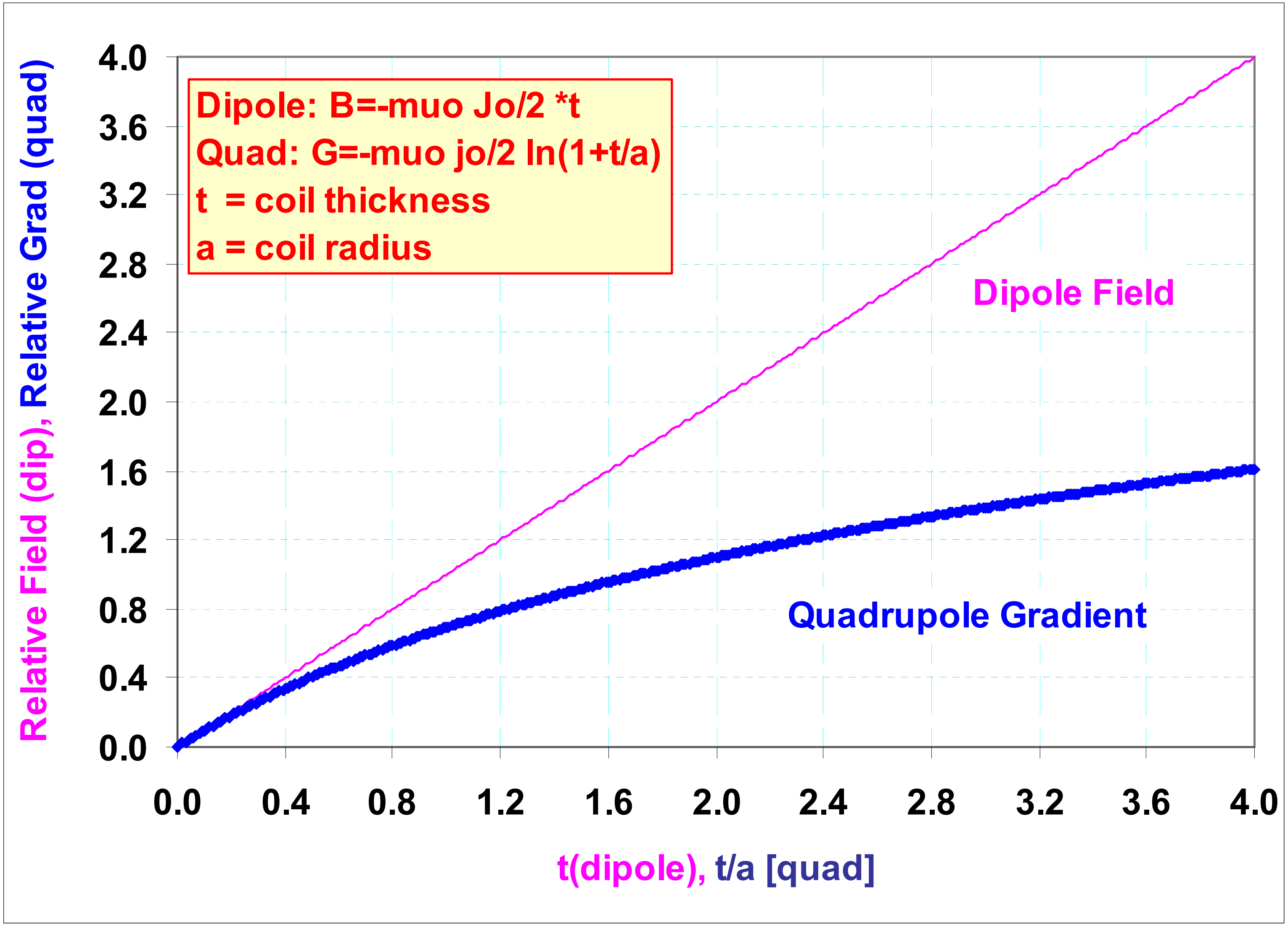
In flat beam optics, the magnetic polarity of the first quad must be opposite for counter-rotating beam.

This means that we need separate quadrupoles for the two beams.

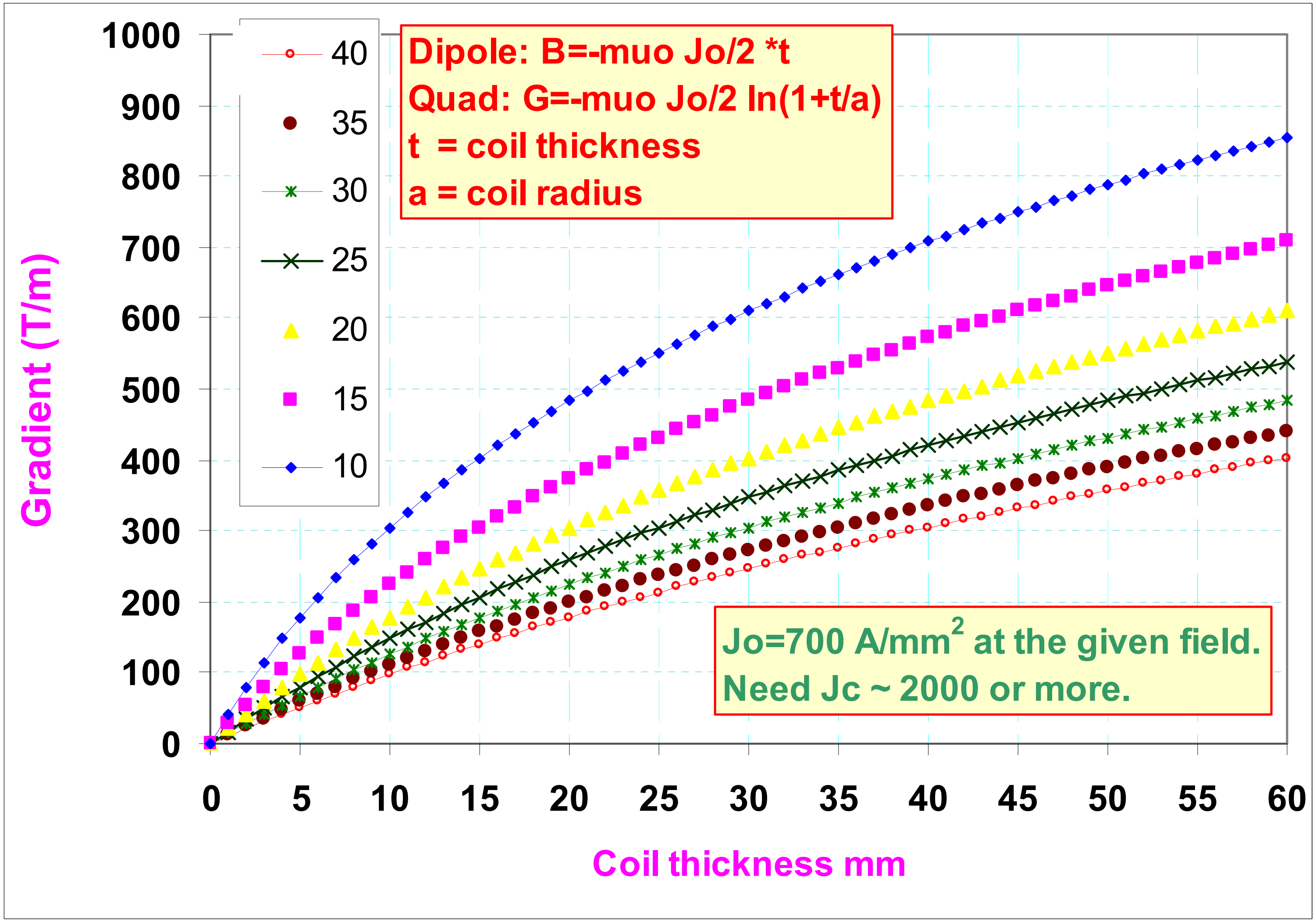
Separation between the two magnets is an important parameter

- Determines the field in the first beam splitting dipole
- Determines the increase in beta function and influences the beam size
- Determines the field strength needed for all IR dipoles
  - Worthwhile to look for alternate magnet designs

A Guide to the Maximum Field in the Magnets



Quadrupole Gradient for various coil radius



Note: Legends are coil radius, not aperture

Important number is field: Gradient * coil radius = pole-tip field

IR Magnets for Round Beam Optics

Stage 2 Interaction Region Magnets

The following information is from VLHC Design Study Report.

IR quadrupoles are double bore magnets with the same cross section as arc quads. Length of the magnet is adjusted to get the desired integral strength.

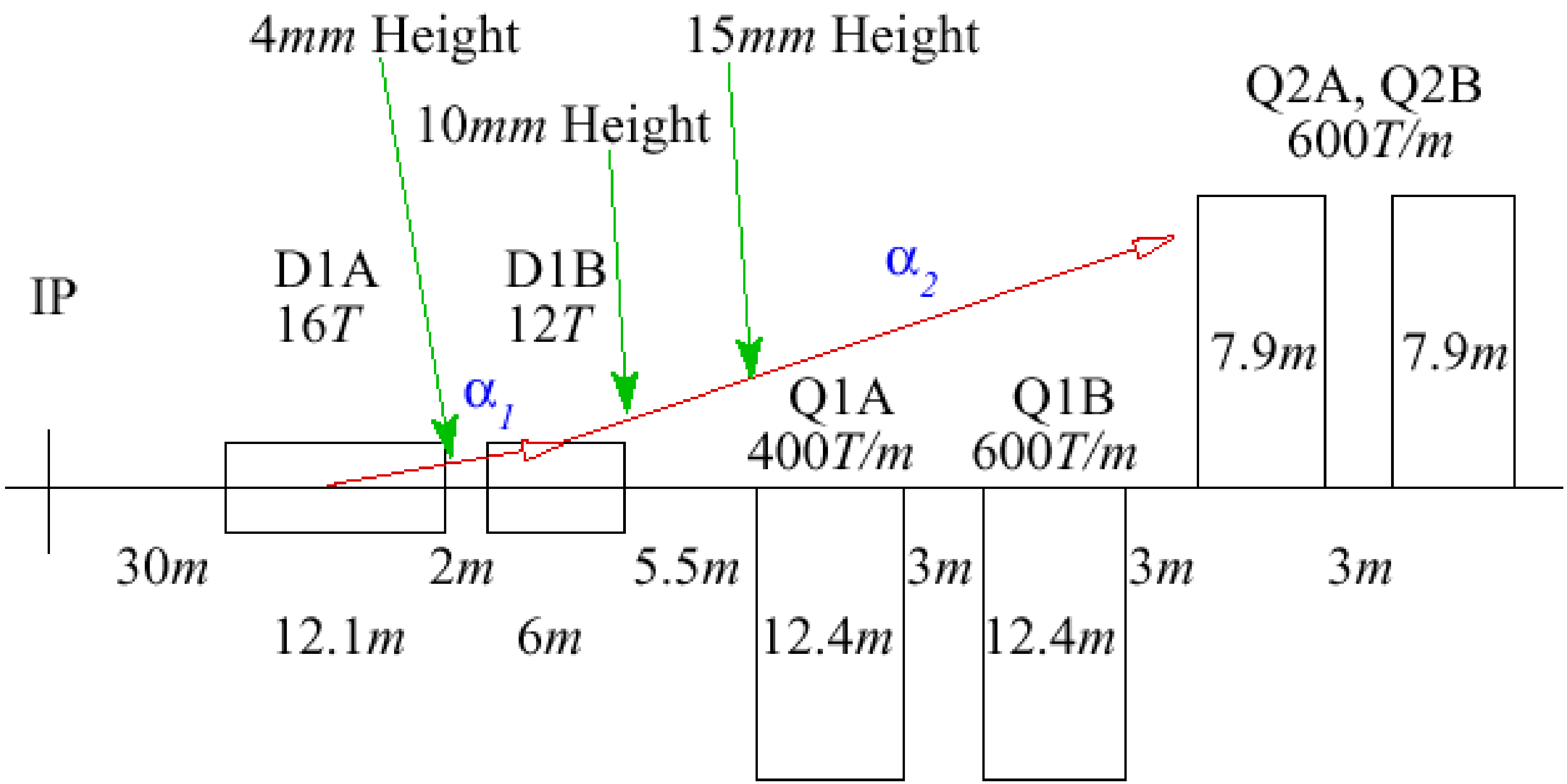
Design gradient: 400 T/m

Aperture: 60 mm

Note: These may not be the final parameters.

First beam splitting dipole (D1) is similar to the second generation IR 80 mm aperture 10 T dipole being built at the University of Twente.

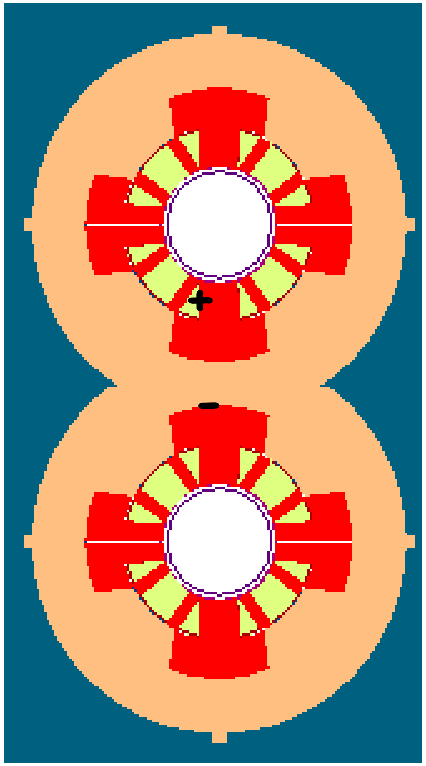
VLHC-2 IR Layout for Flat Beam Optics



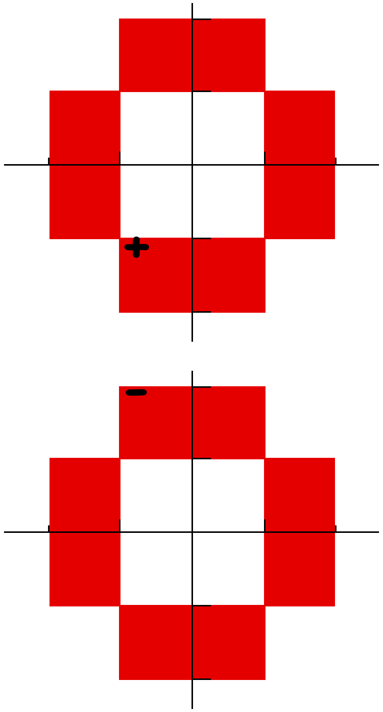
- Optics and magnet requirements (field & aperture) depends crucially on the minimum spacing in the first 2-in-1 IR Quadrupole **(doublet optics)**
- 23KW of beam power radiated from the IP makes this a natural for HTS.

VLHC-2 Interaction Region Magnet Design Concept

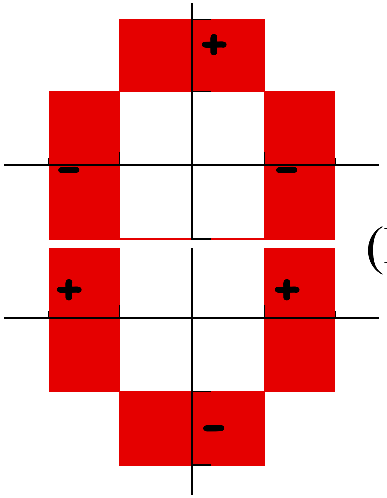
Conventional 2-in-1 cosine theta design



Panofsky 2-in-1 quad design



Modified Panofsky Quad with no spacing



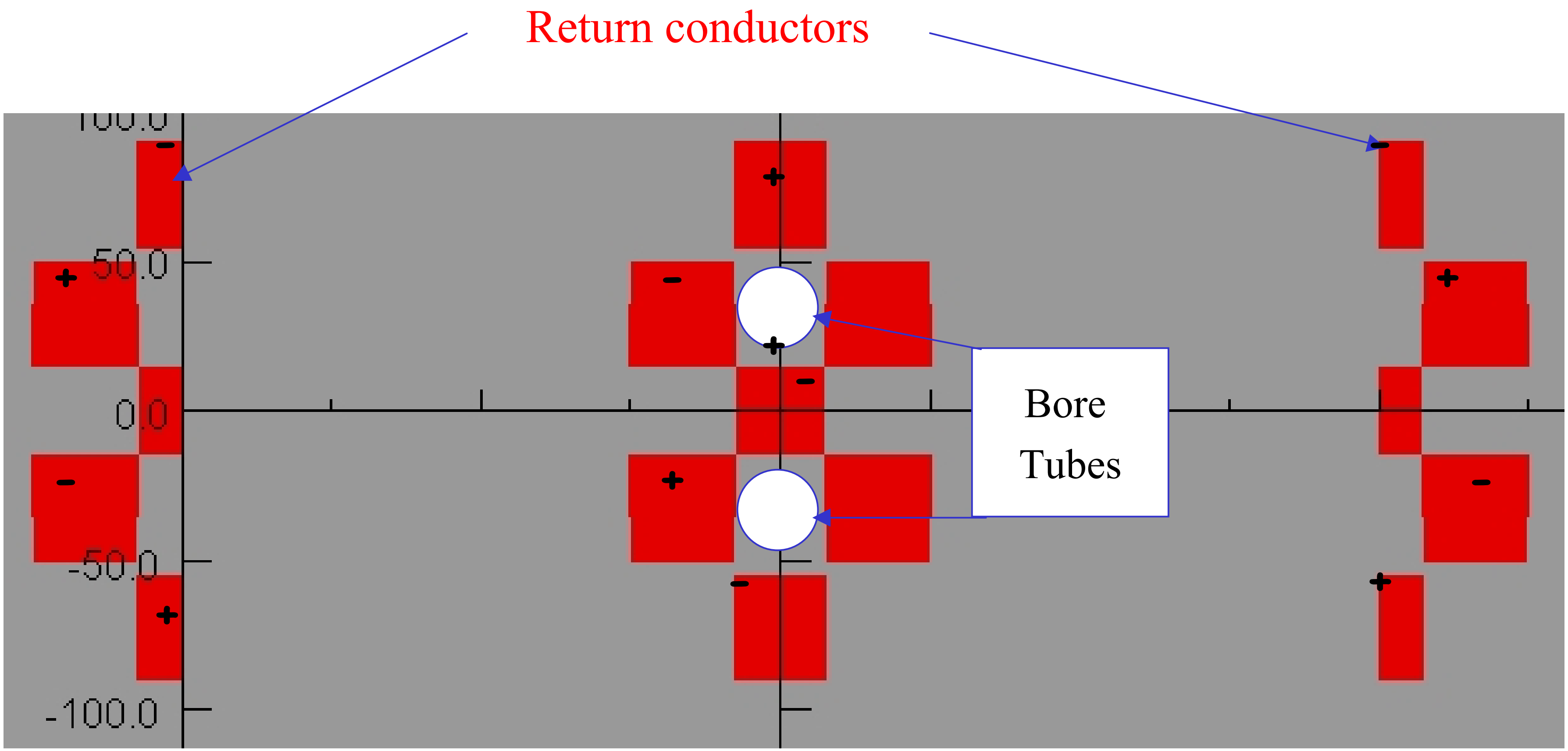
(Bo not zero)

Spacing depends on the conductor and support structure requirements

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

VLHC-2 Interaction Region Magnet Design (Preliminary)

Conductor friendly and better field quality design

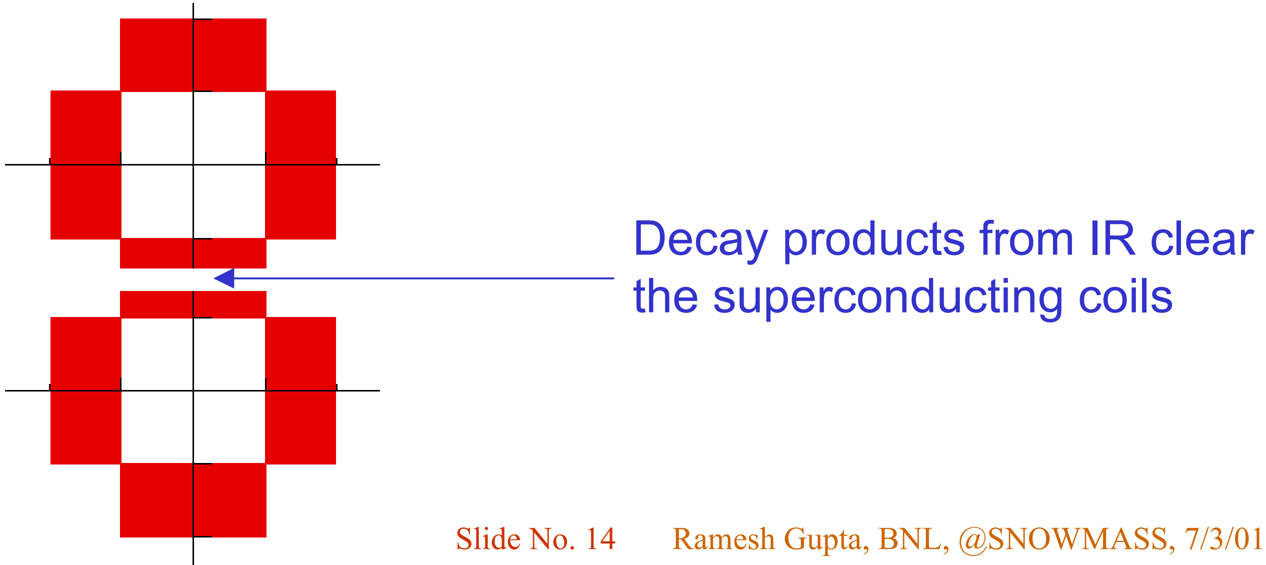


Support structure and middle conductor is removed/reduced. This reduces spacing between two apertures significantly.

Variations of the Q1 Design

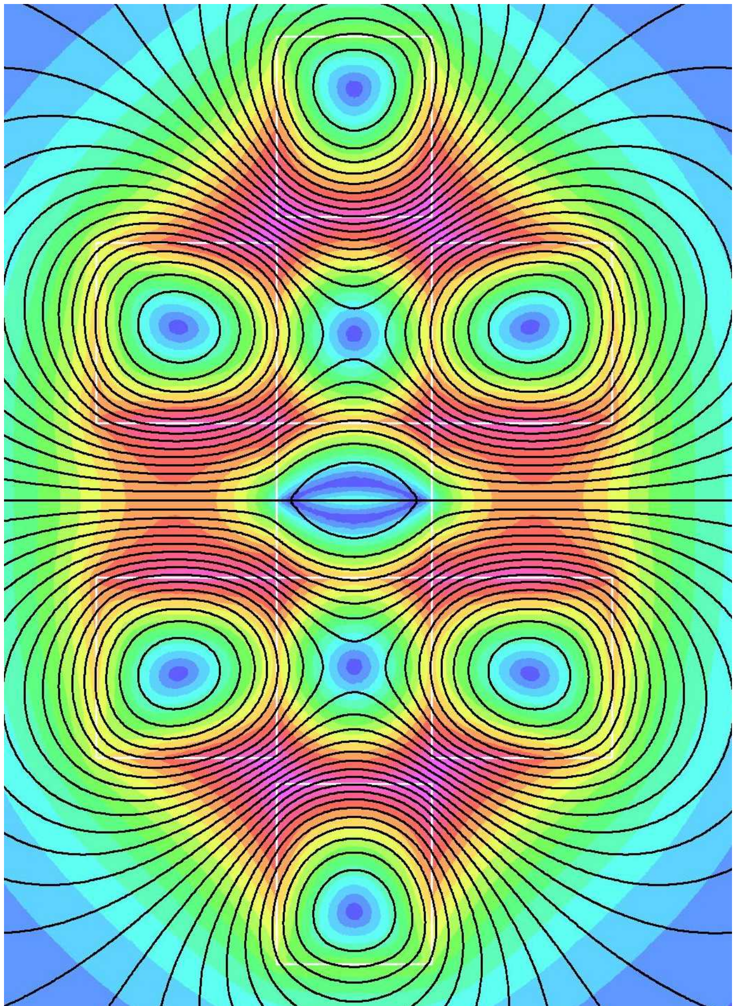
We have investigated several variations of the design shown in previous slide. The conductor configuration (consisted of several blocks) is changed significantly to improve the field quality. Expect system optimization between field field strength, field quality and corrector design.

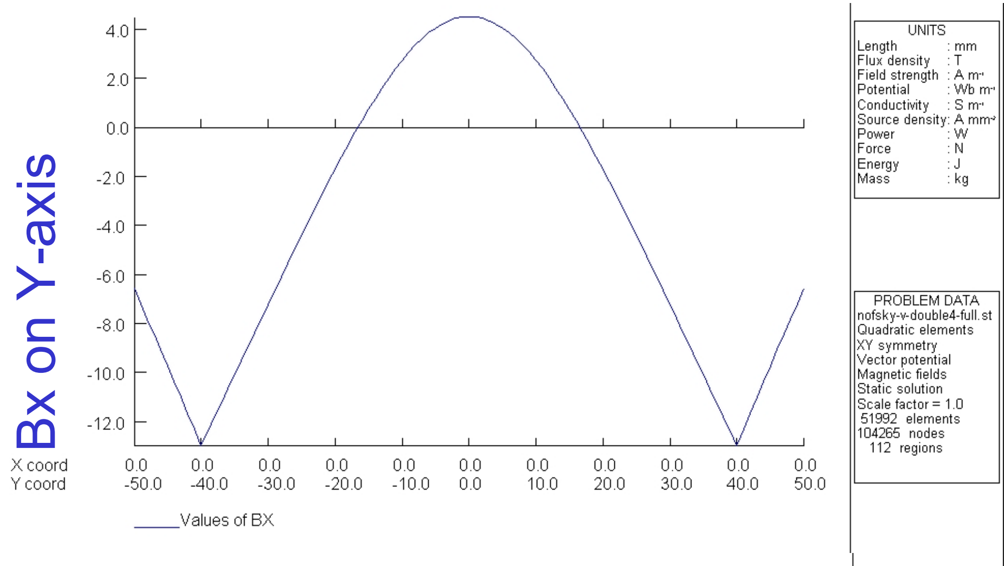
One design of particular interest is the case when no conductor is present at the midpoint of two apertures.

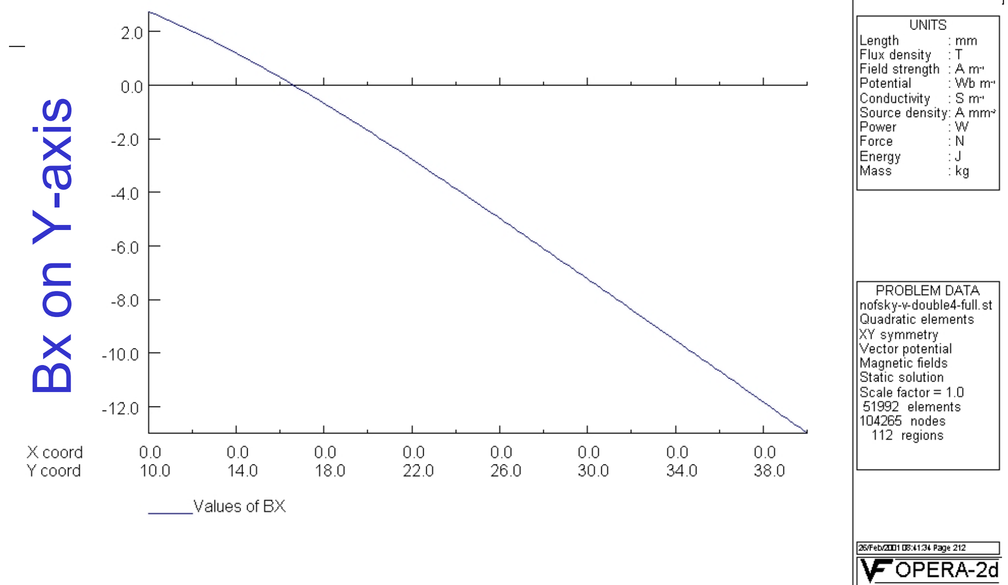


Fields in the Proposed Double-Quad Design

Field contours and field lines







Design Parameters of Insertion Region Magnets for VLHC-2 Flat Beam 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

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.

Design Parameters of VLHC-2 Insertion Region Magnets

For doublet optics

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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.

Design Parameters of Insertion Region Magnets for VLHC-2 Round Beam Optics

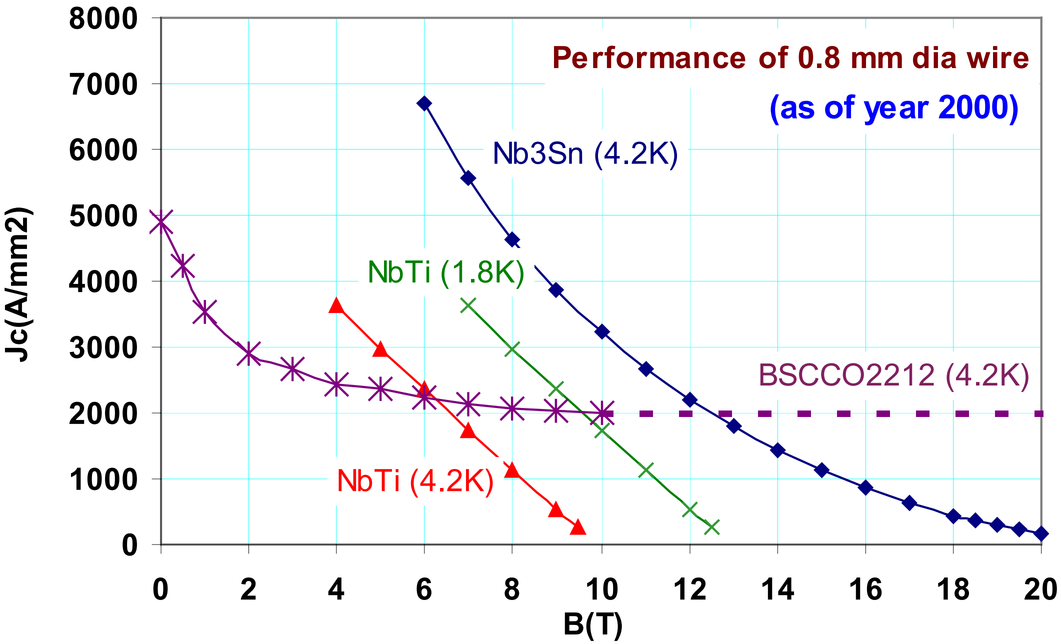
One may like to consider alternate designs for round beam optics as well.

I believe that the magnet parameters can be pushed upward to help beam optics (Please see the maximum fields on the conductor in the previous table).

- Higher field/gradient?
- Larger aperture?
- Remove a few turns from the midplane?

In particular, a large radiated beam power from IP makes these magnets a natural candidate for HTS.

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

Issues with HTS

Advantages:

• Can work at elevated temperature, for example, in IR region where large energy is deposited from the decay products.

• Has potential to produce very high magnetic fields.

Challenges:

•Large quantities are not available yet

But enough to make test coils. The current trends show that longer and longer length are going to be available in future.

• Unknown field quality issues

We will be measuring them soon.

One point of view: The performance has reached a level that we can do serious R&D. If short coils/magnets are built and results are promising, it would have a significant impact on IR region design. So far results are encouraging. Consider this option future magnets, but not near future.

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

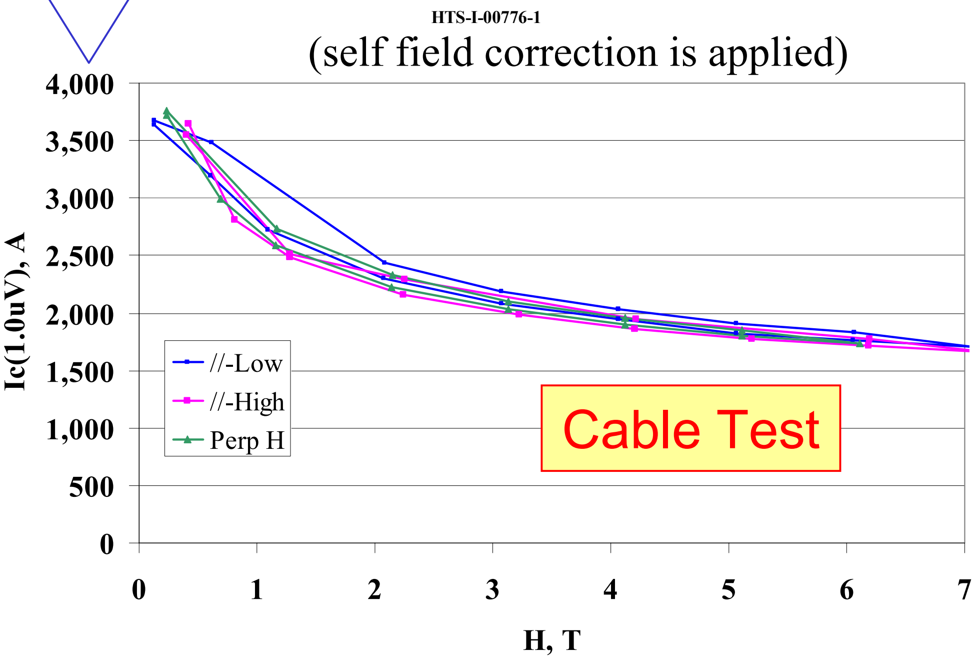
Note: Tape and wire have about the same area.

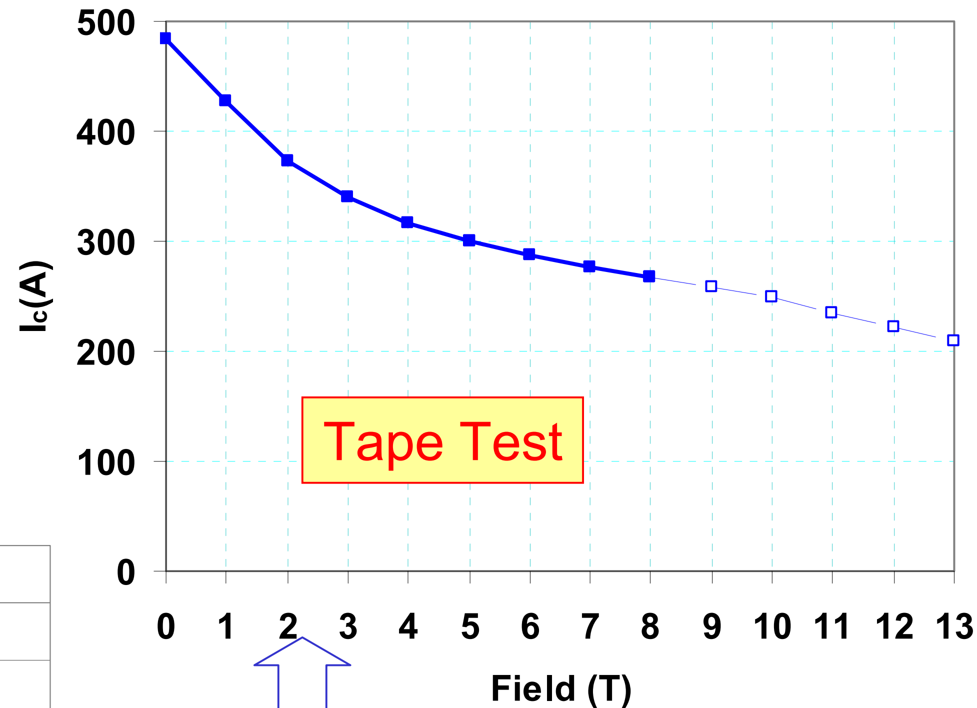
Measurement of "***BSCCO-2212 cable***" at BNL test facility

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%)

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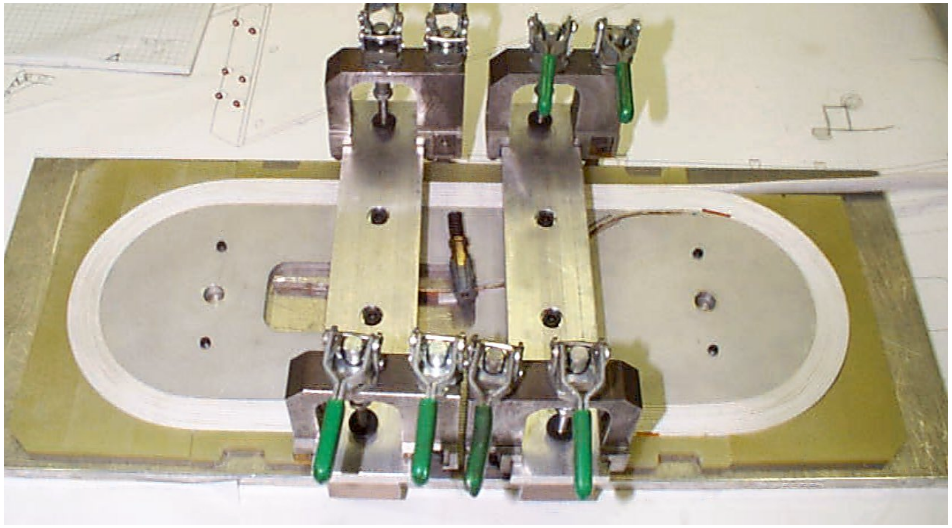
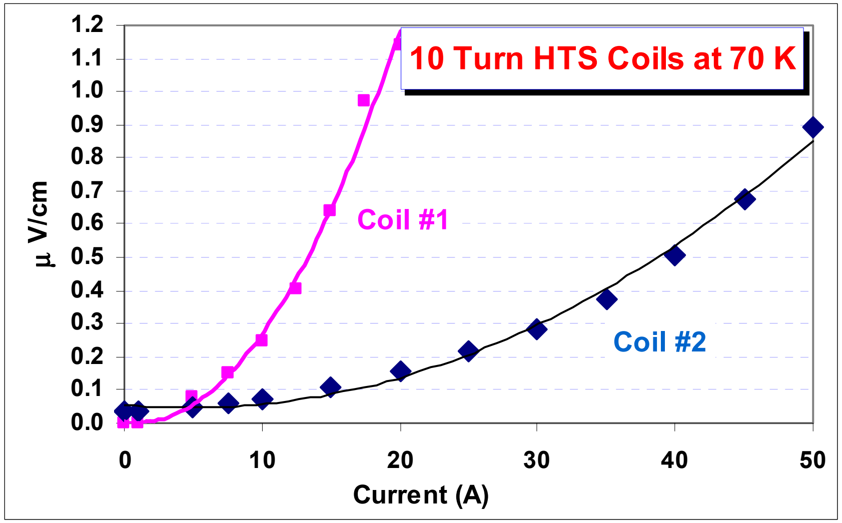
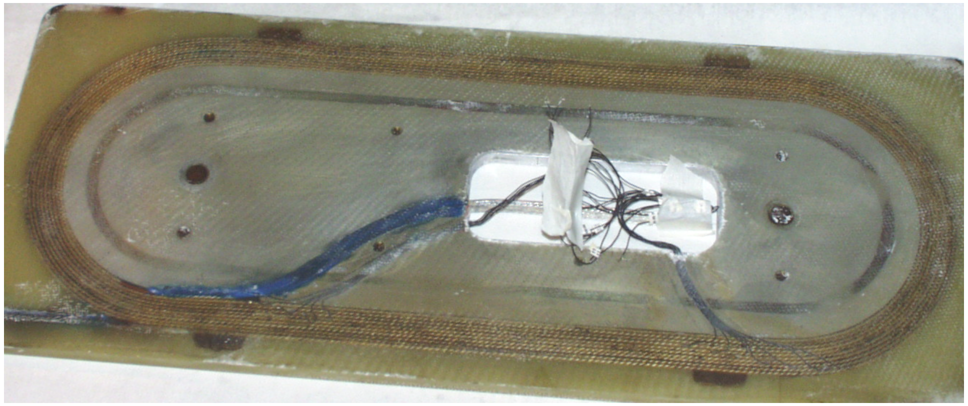
Common Coil Magnets With HTS Cable



HTS cable coil prior to vacuum impregnation

Two coils were tested in Liquid Nitrogen





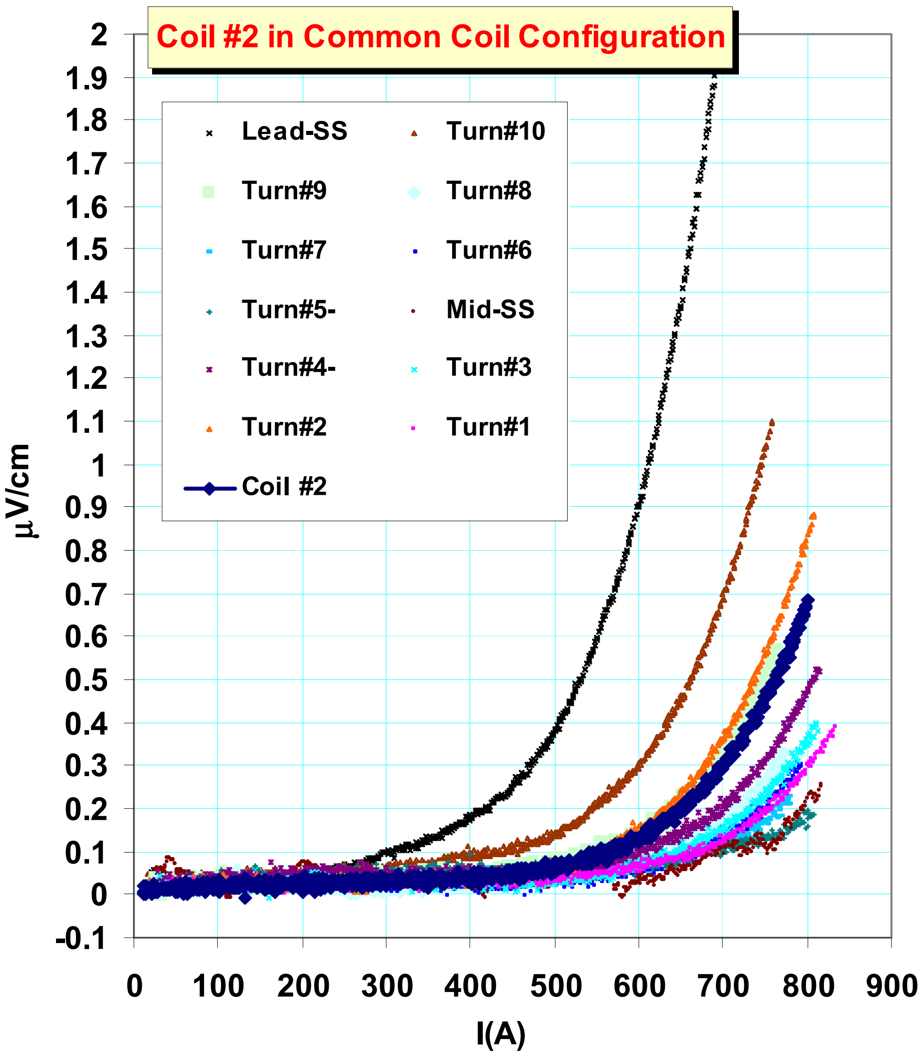
A coil cassette made with HTS cable after vacuum impregnation and instrumentation

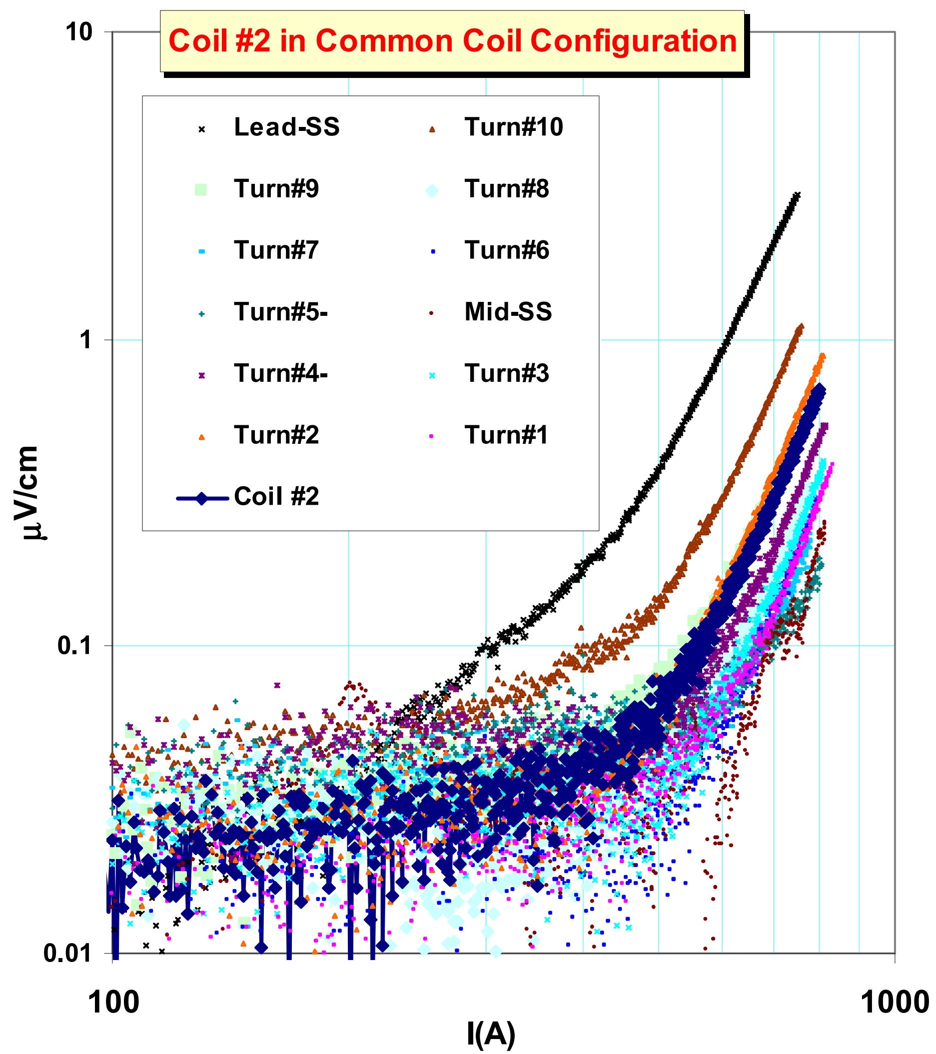
The HTS cables were from two different batches. They behaved differently:

- Different Ic
- Different Tc

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

Performance of Coil #2 in Common Coil Configuration





Summary

A conceptual magnet design and layout has been developed.

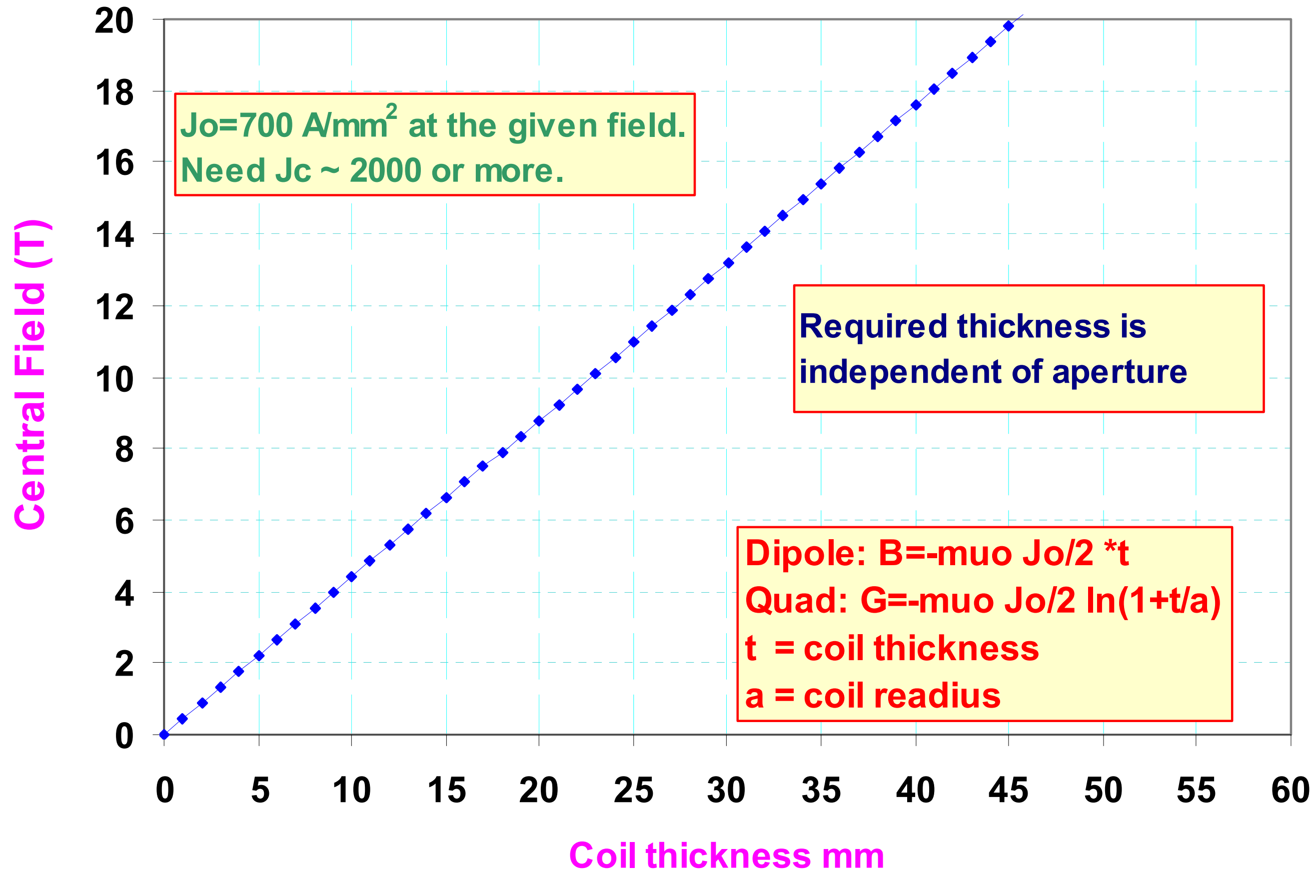
Consider this a classical example of close interaction between magnet designers and accelerator physicists.

Most details are yet to be sorted out.

A significant magnet R&D is needed.

Dipole Field Vs Coil Thickness (for any coil radius)

In dipoles, conductor amount is proportional to the aperture size (linear).



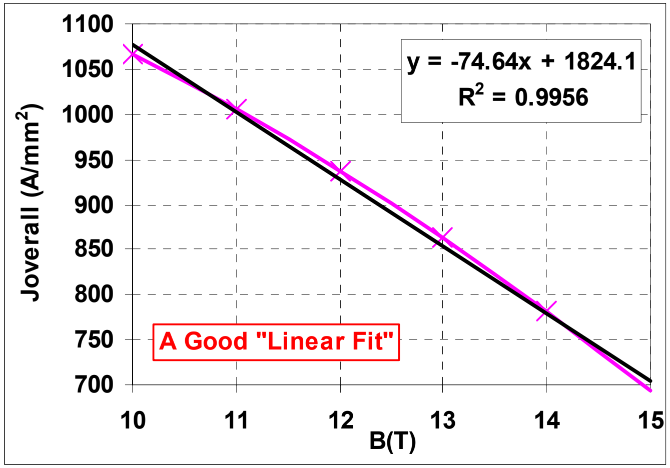
The curve is computed for Jo=700 A/mm2. However, Jo is a function of the field. The curve scales as Jo.

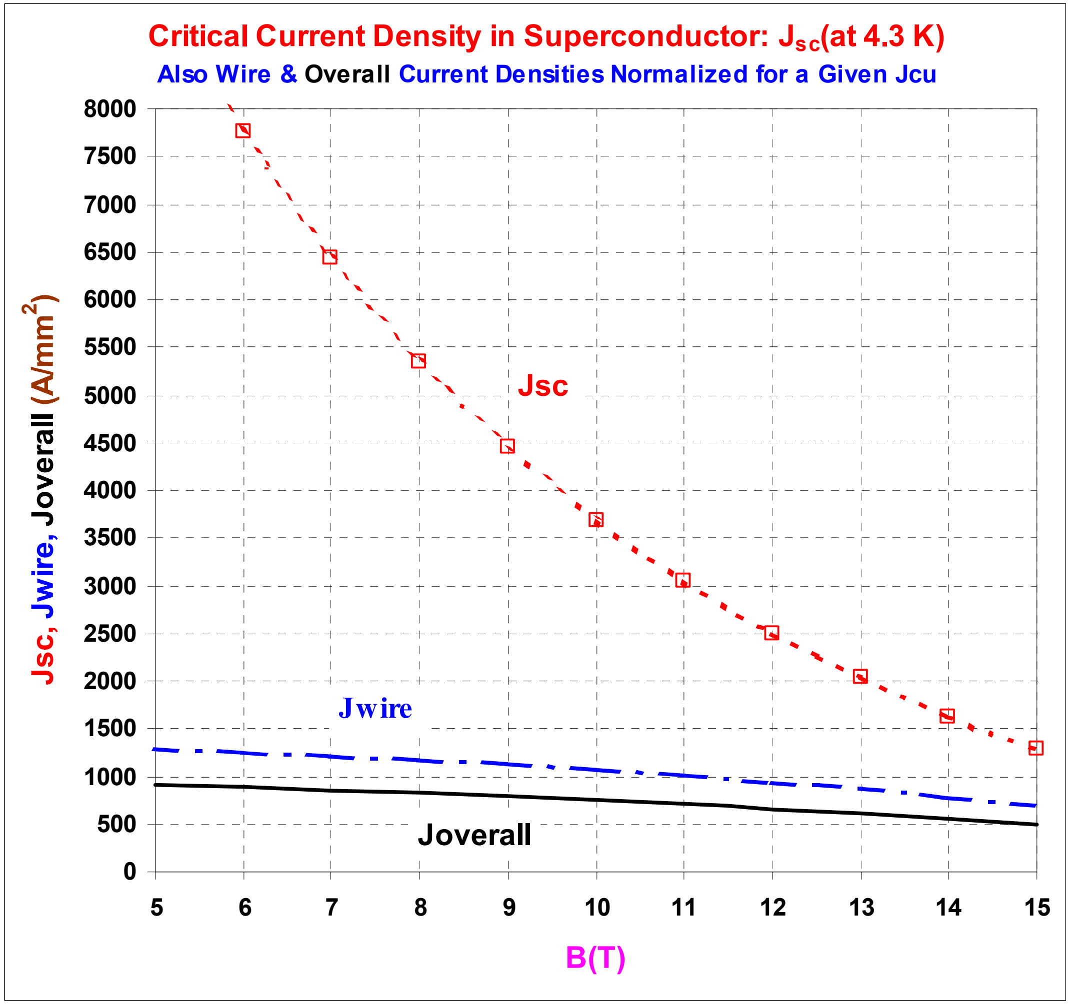
Note: The coil thickness is proportional to the field, but the conductor amount is not proportional to the field. The conductor amount is computed/optimized differently.

Usable current Density in Magnet Design

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

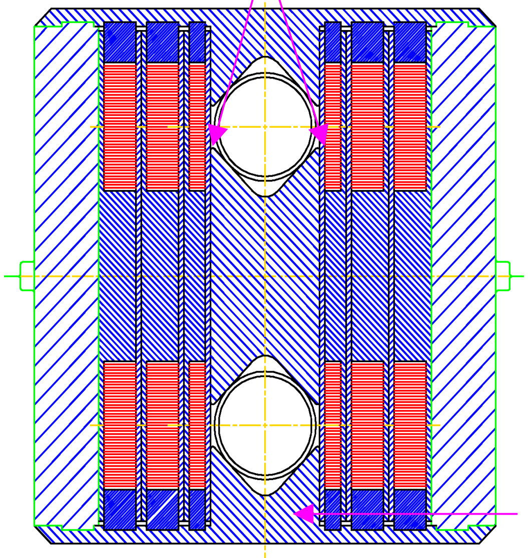
Cu/Sc Ratio	B(T)	J_c(A/mm^2)	J_{wire} (A/mm^2)	Joverall
6.30	5	9454	1295	911
5.18	6	7766	1257	885
4.29	7	6431	1216	856
3.56	8	5347	1171	825
2.96	9	4446	1122	790
2.46	10	3689	1066	751
2.03	11	3048	1005	708
1.67	12	2500	938	660
1.35	13	2031	863	607
1.09	14	1631	781	550
0.86	15	1289	693	488
	Scaled from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





Support Structure Consuming Expensive Space

Internal support at midplane



Is this adequate

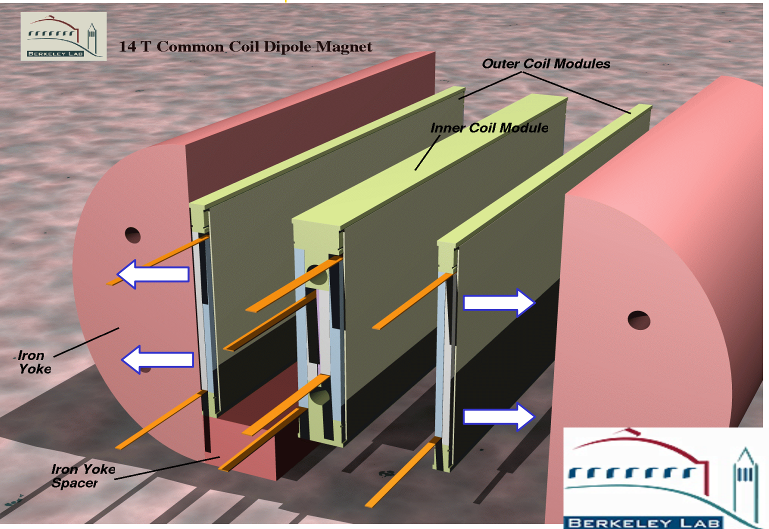
Used in early BNL conceptual design.

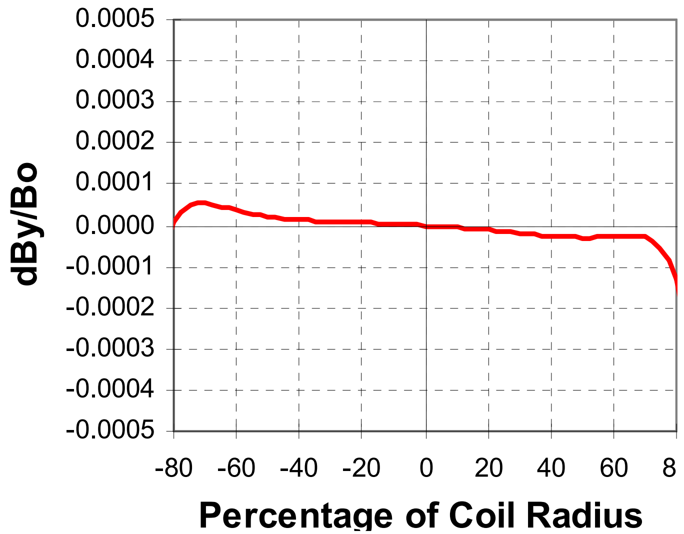
Mechanical designs of other common coil magnets are different; but this ugly feature did not disappear.

Investigate alternate mechanical designs.

Do we need it for field quality purpose?

See 80% good field aperture in RHIC D0.





Average Field errors ~10^{-4} up to 80% of the coil radius