Alternate Magnet Options
for
Muon Collider

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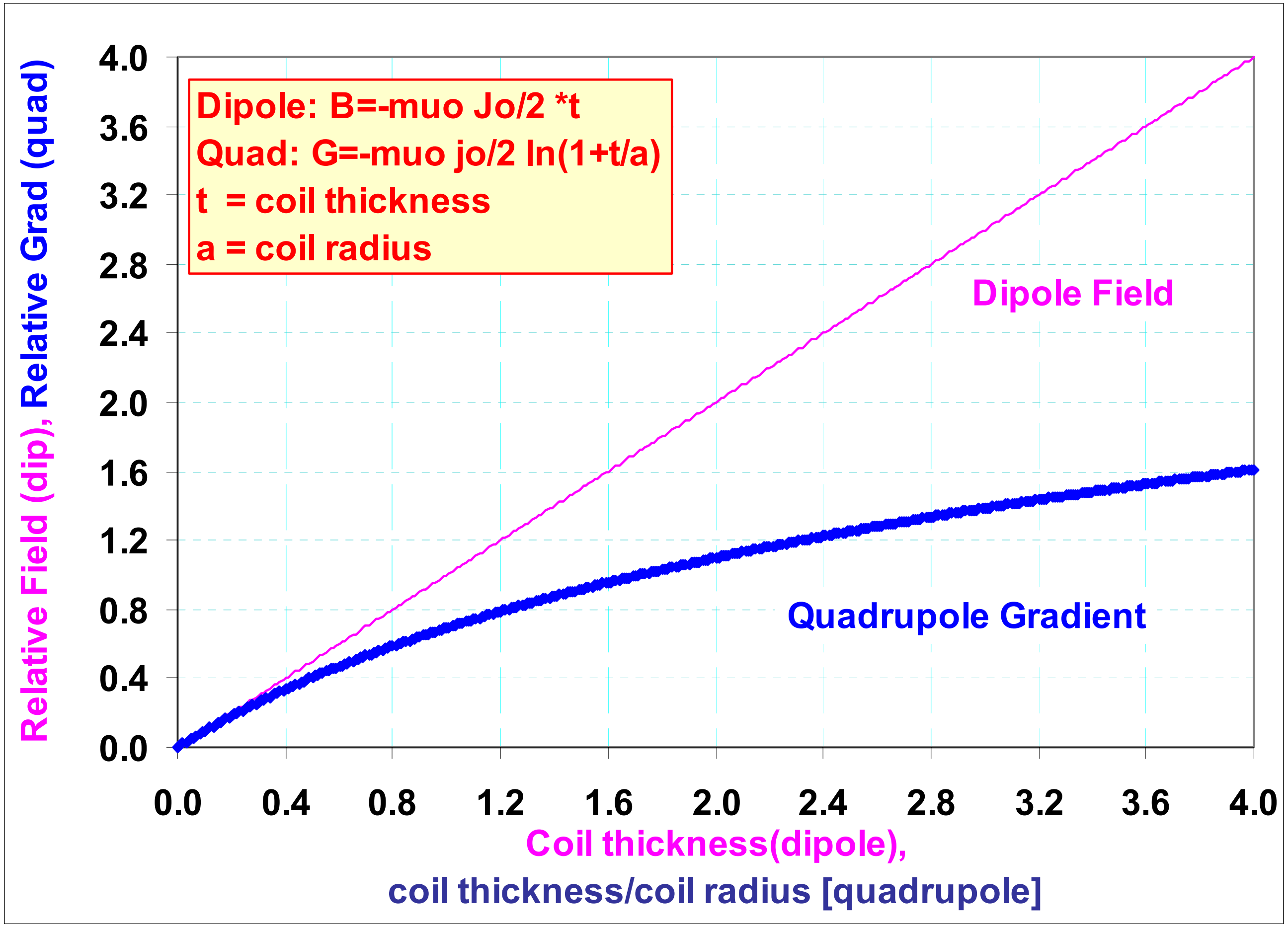
Outline of Presentation

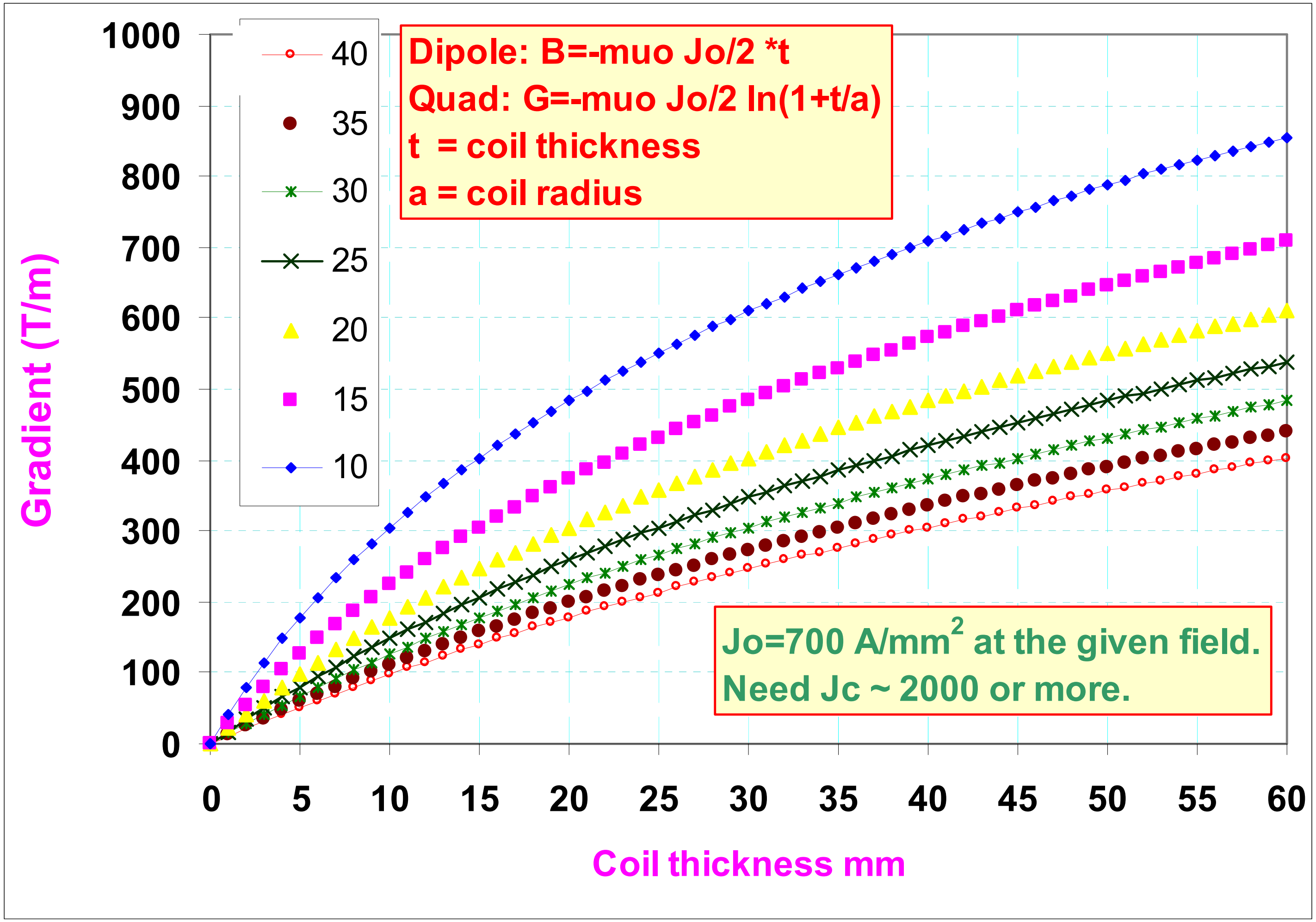
- A quick recipe for help choosing reasonable magnet design parameters
- Alternate design options for muon collider

A Guide to Choosing the Maximum Field in Superconducting Magnets



To get maximum field keep increasing coil thickness (within practical limit) till you reach the maximum field in the coil where magnet quenches

Quadrupole Gradient for various coil radius



Dipole: B=-muo Jo/2 *t
Quad: G=-muo Jo/2 ln(1+t/a)
t = coil thickness
a = coil radius

Jo=700 A/mm^2 at the given field.
Need Jc ~ 2000 or more.

Note: Legends are coil radius, not aperture

The plot scale linearly with Jo (current density in coil).

A reasonable range of Jc is 400-1000 A/mm^2

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

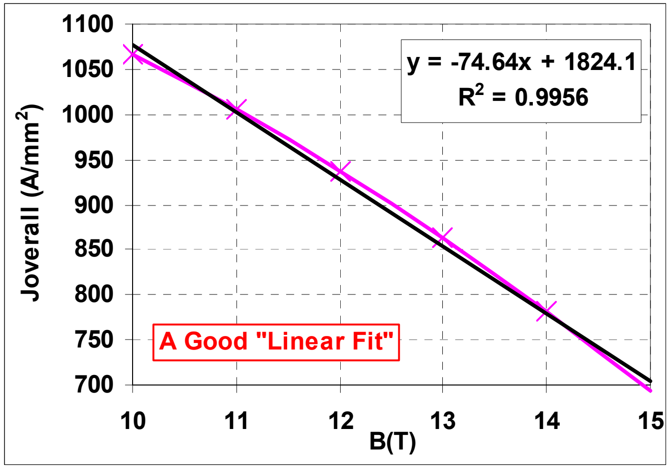
In large aperture magnets, forces become large.

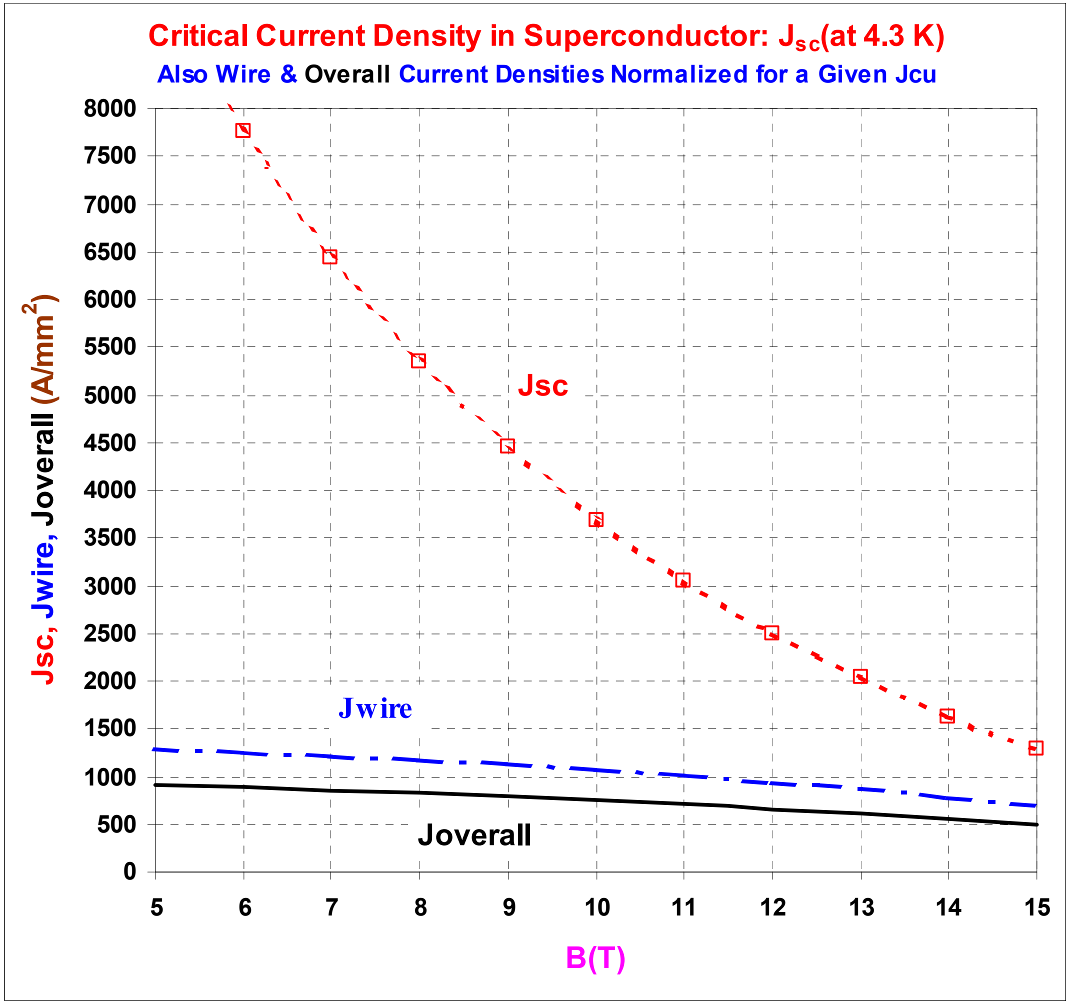
Usable current Density in Magnet Design

A case study of Nb3Sn Superconductor

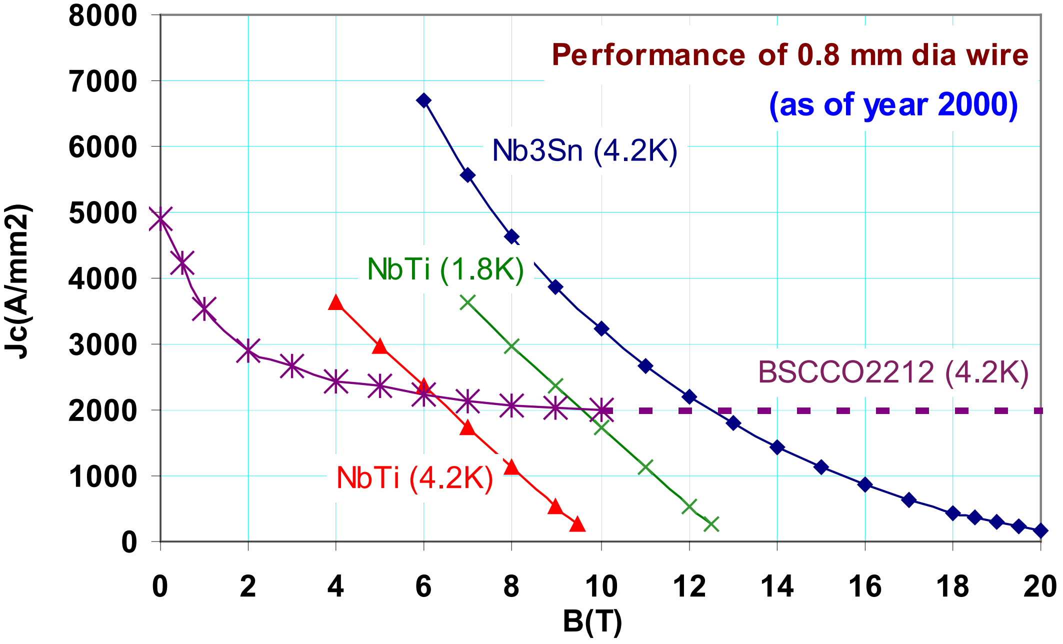
J_{sc}(12T,4.3K)	J_{cu}(A/mm^2)
2500	1500

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





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 15 T 18 T	5 T 13 T 19 T*

*20 T for Hybrid

Near Future	
All Nb_3Sn	All HTS
12 T 15 T 18 T	11 T 16 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 muon collider and IR region magnets where a large energy is deposited from the decay products.
- Has potential for producing very high magnetic fields.

Challenges:

- Large quantities are not available yet

  But enough to make test coils and the length of wire available are increasing continuously. Remember HTS is support by other program.

- Unknown field quality issues

  We will be measuring them soon.

- High cost

  Needs to come down by the time these magnets are needed. Also compare the overall system cost. Consider special applications where cost matters less.

Status:

The performance has reached a level to consider them as a promising candidiate.

BNL has started magnet R&D with this challenging material. Results are encouraging.

Consider HTS option for magnets that are not required immediately.

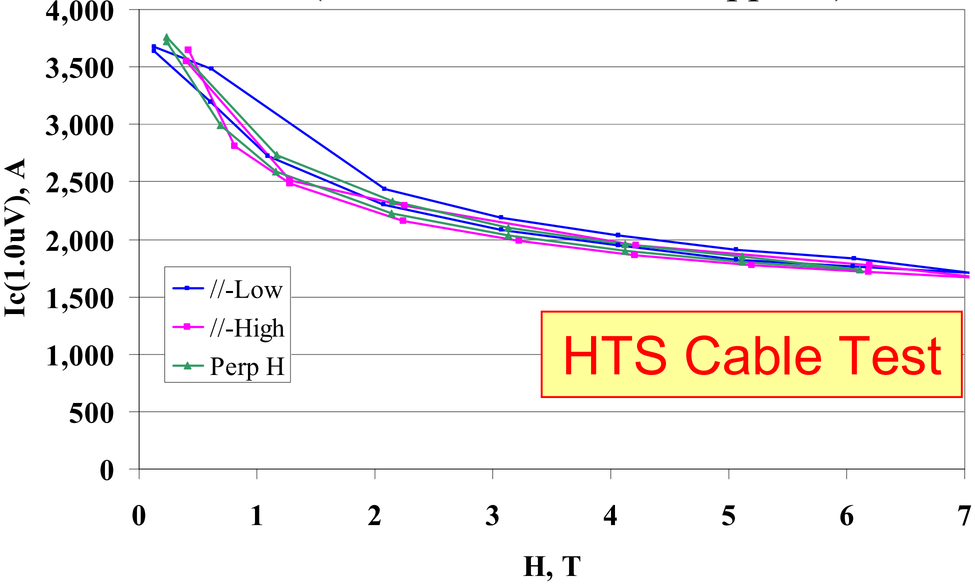
Measured Performance of HTS Cable and Tape As A Function of Field at BNL

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

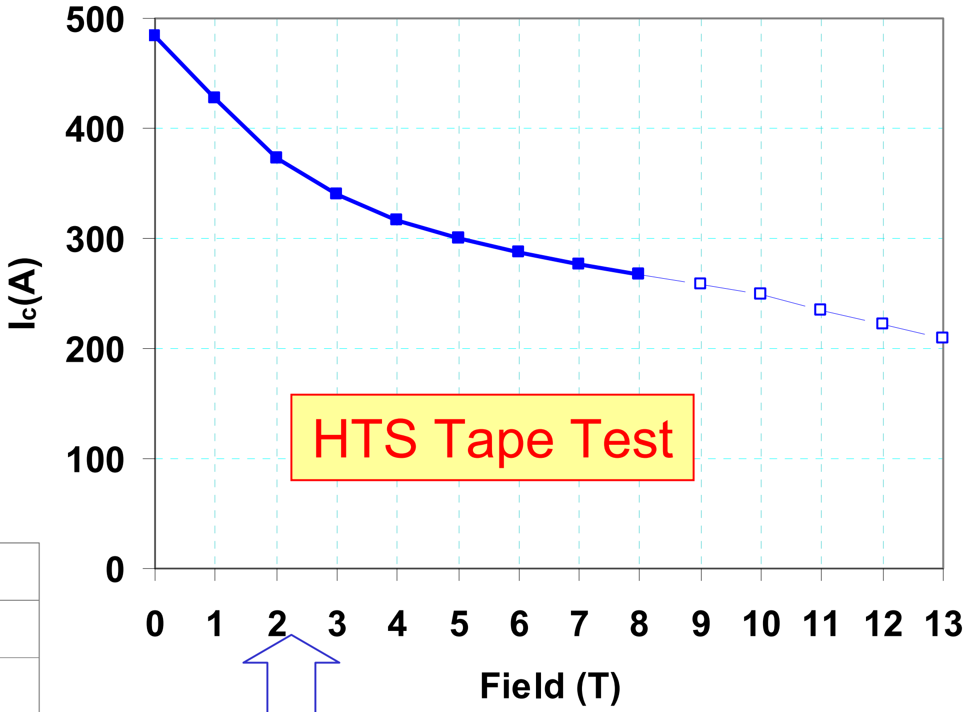
Ic is better by over a factor of 2 now. This was a narrow (18 strand) cable. Standard cable will carry much more. Expect 5000 A up to a high field.

HTS-I-00776-1

(self field correction is applied)



HTS Cable Test

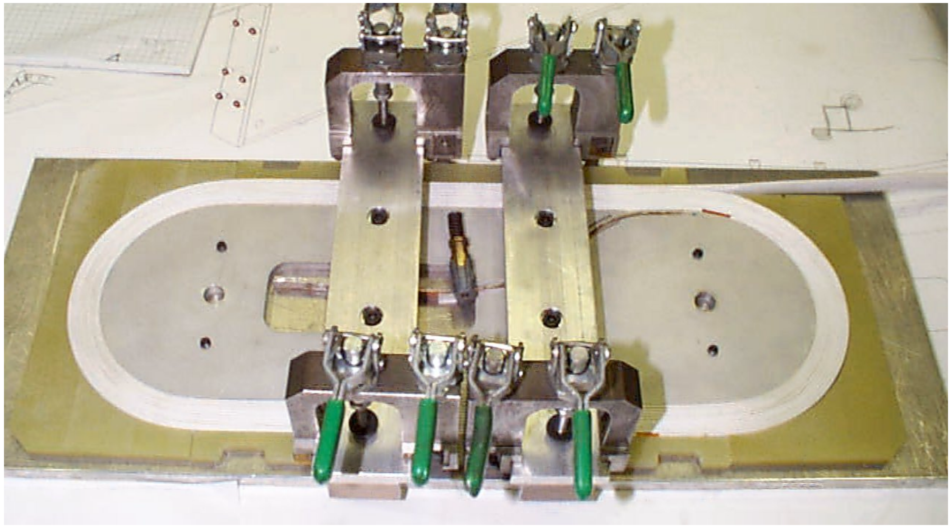


HTS Tape Test

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

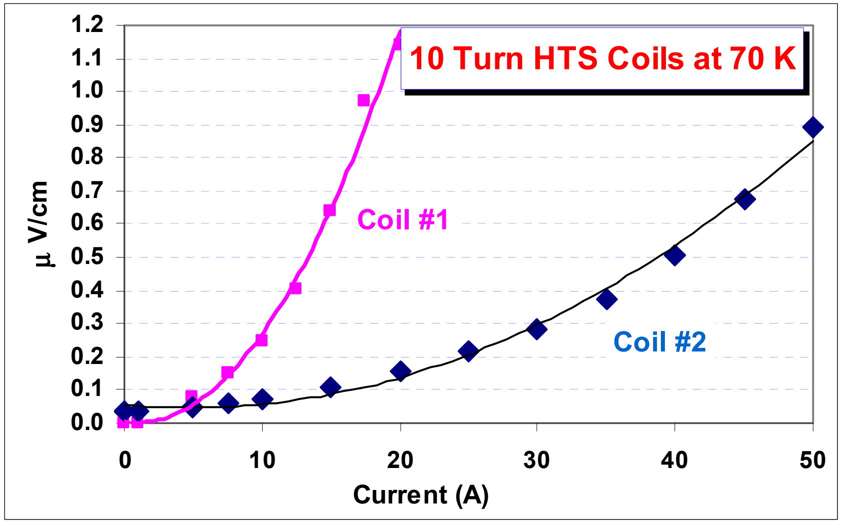
(field perpendicular value is ~60%)

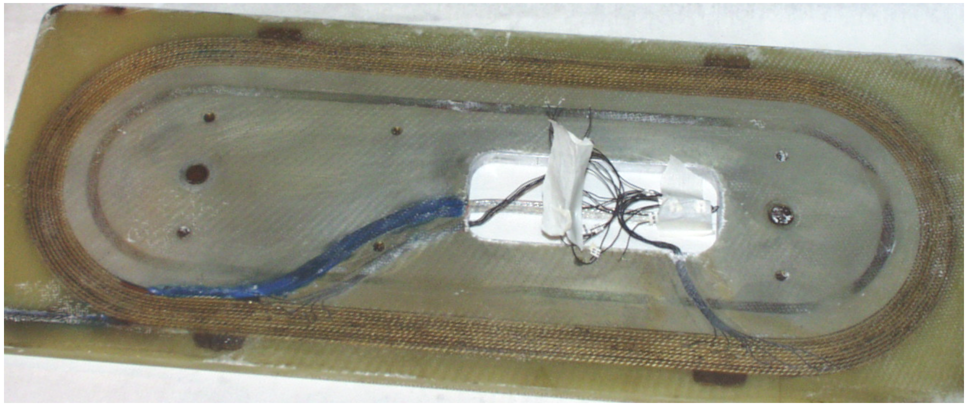
Common Coil Magnets With HTS Cable



HTS cable coil prior to vacuum impregnation

Two coils were tested in Liquid Nitrogen





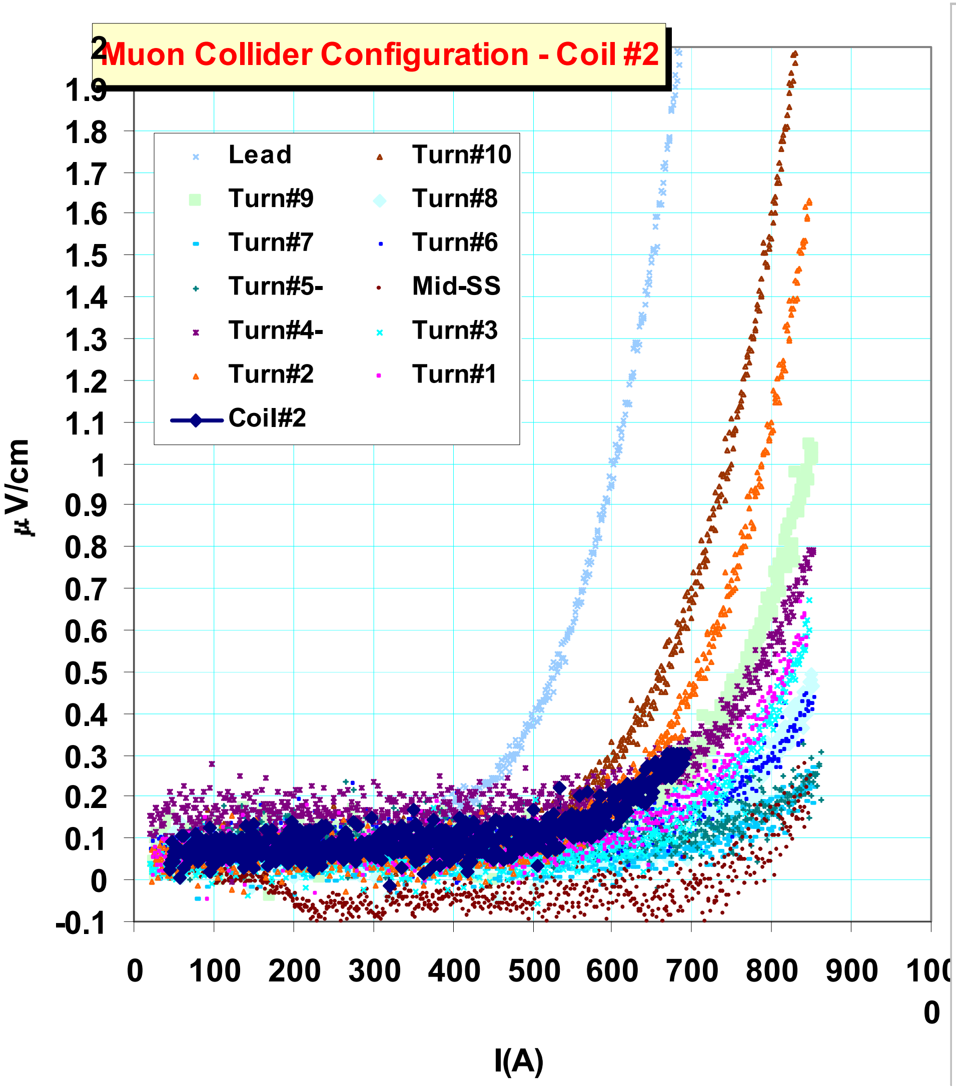
A coil cassette made with HTS cable after vacuum impregnation and instrumentation

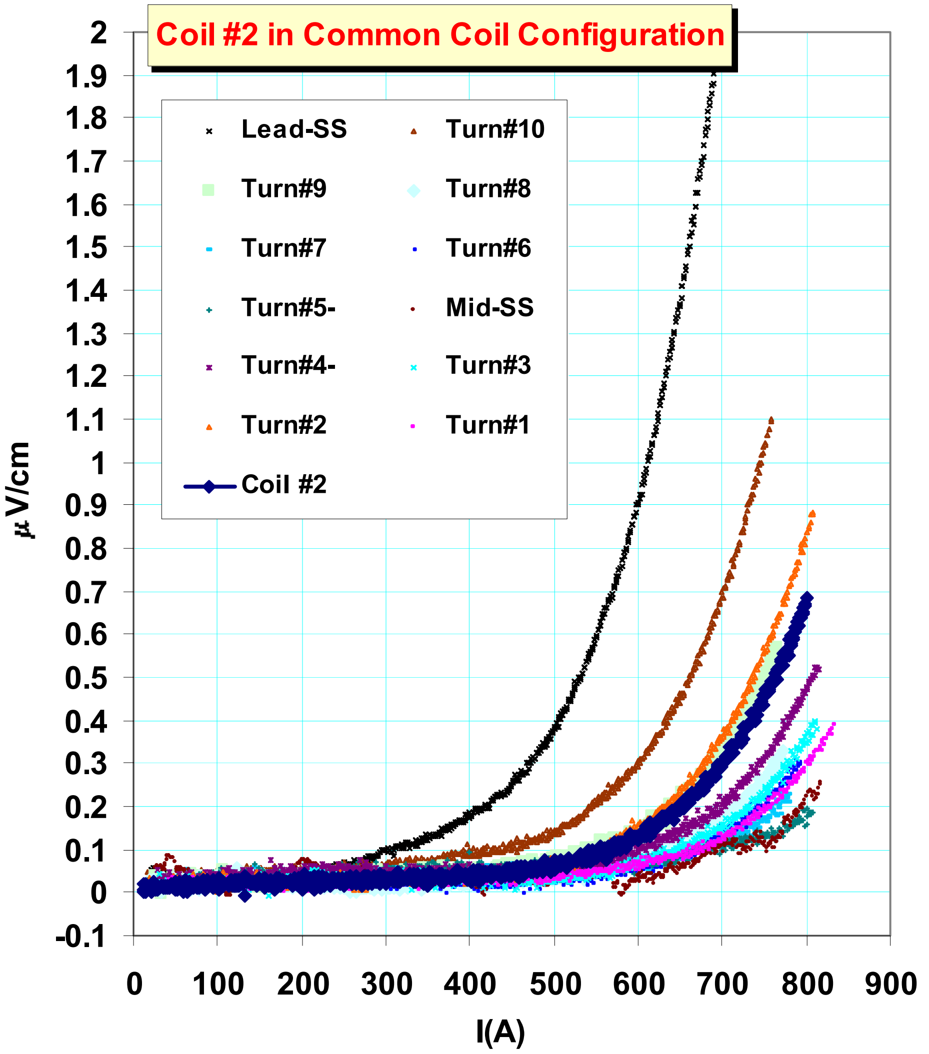
The HTS cables were from two different batches. They behaved differently:

- Different Ic
- Different Tc

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

Results of Coil #2 Tested in Muon Collider and Common Coil Configuration



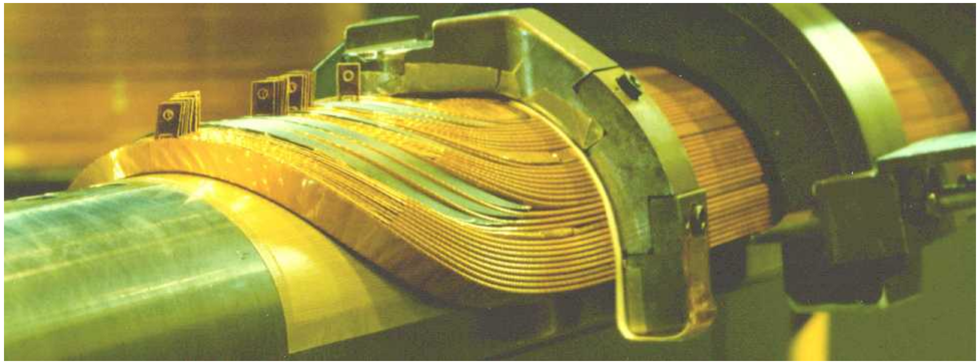


High Field Magnets for Muon Collider and ν Factory Storage Ring

Design Issues:

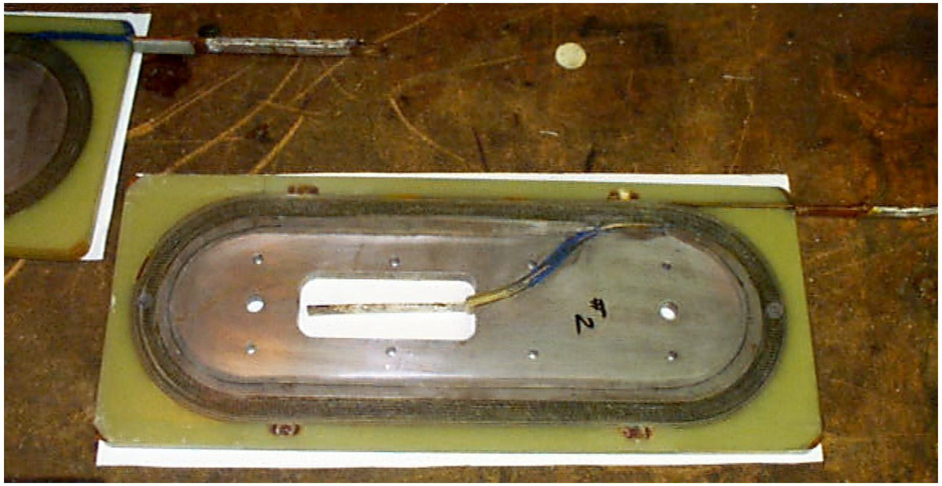
- Must use brittle superconductors

  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

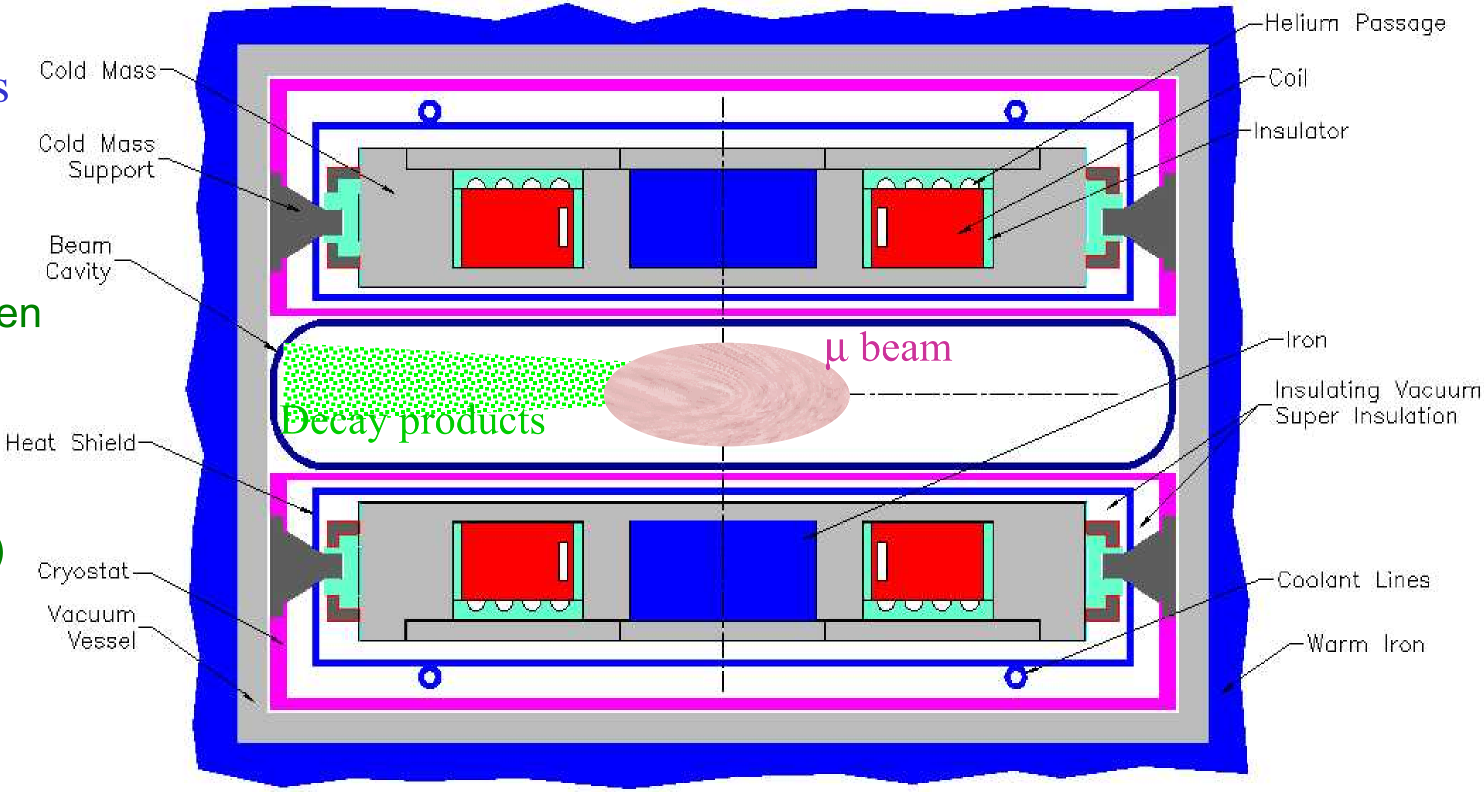
Magnet Design for ν Factory Storage Ring Study II

Simple racetrack coils with open midplane (does not require Tungsten liner)*

The following design is for ν Factory but the principles are relevant to muon collider also

Decay products clear superconducting coils

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

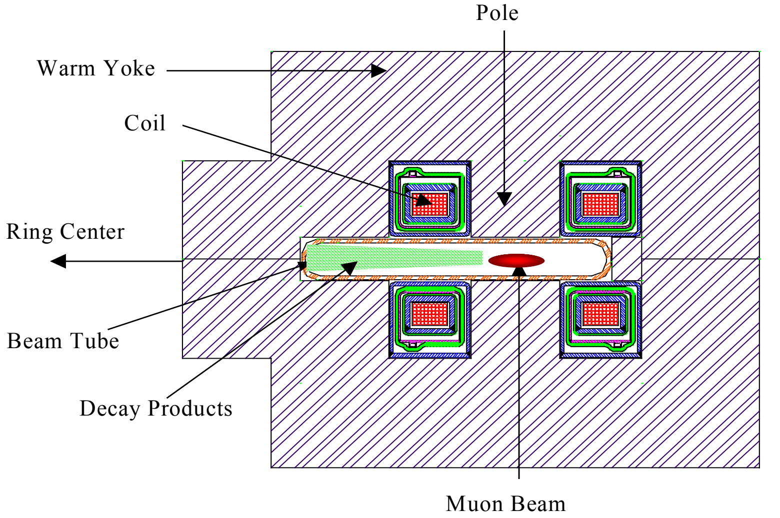


HTS is an interesting possibilities in such magnets.

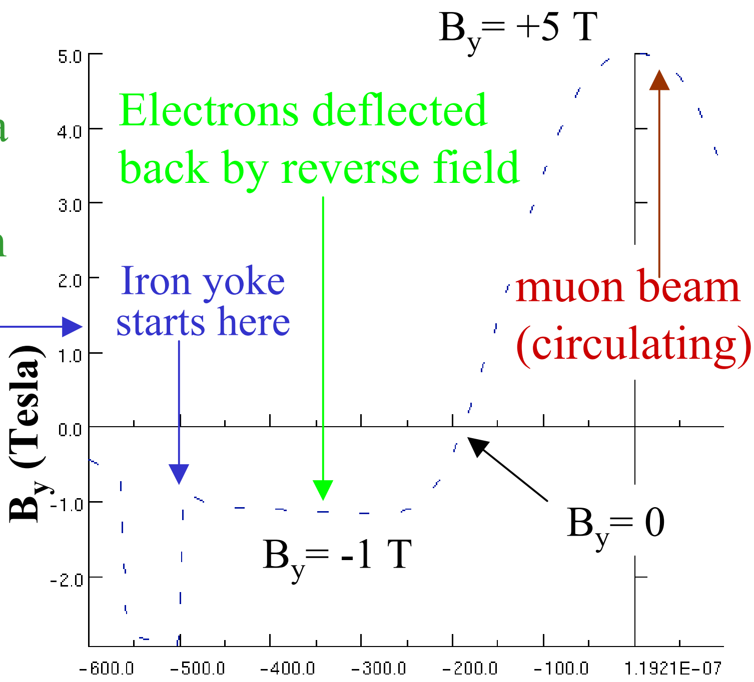
5 T Dipole for ν Storage Ring

5 T central field can be achieved by NbTi

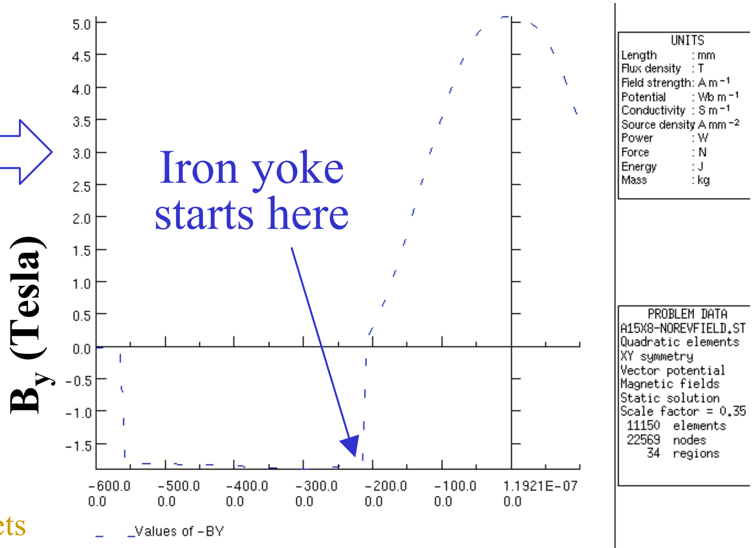
Decay electrons get back towards main aperture by
(a) Reverse field and (b) Magnet saggitta
which knob to use how much may depend on E & B



Design with a reverse field region in Iron



A dipole with no cutout in yoke for a reverse field region. Electrons will hit yoke and create shower



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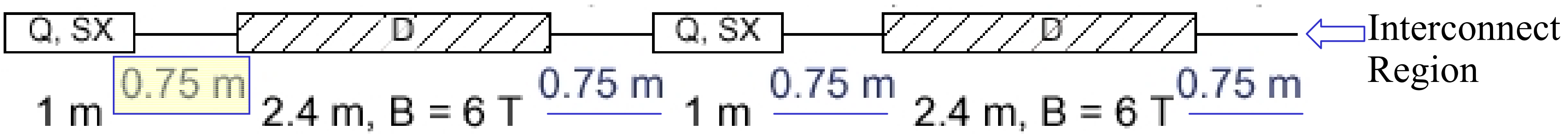
UNITS
Length          : mm
Flux density    : T
Field strength: A m⁻¹
Potential       : Wb m⁻¹
Conductivity  : S m⁻¹
Source density A mm⁻²
Power           : W
Force           : N
Energy          : J
Mass            : kg
```

```
PROBLEM DATA
A15X8-NOREVFIELD.ST
Quadratic elements
XY symmetry
Vector potential
Magnetic fields
Static solution
Scale factor = 0.35
 11150  elements
 22569  nodes
    34  regions
```

In neutrino storage ring, is ~10% energy deposition acceptable?

Lattice & Magnet Designs for a Compact Ring

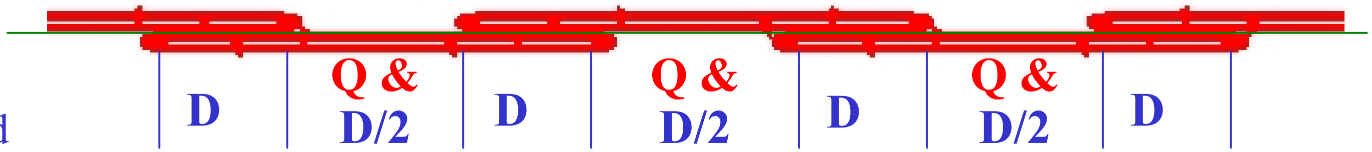
- **Skew quadrupole needs <u>NO</u> conductor at midplane (B. Parker)**
- In study 1 (50 GeV), ~1/3 space was taken by inter-connect regions



Interconnect
Region

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

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



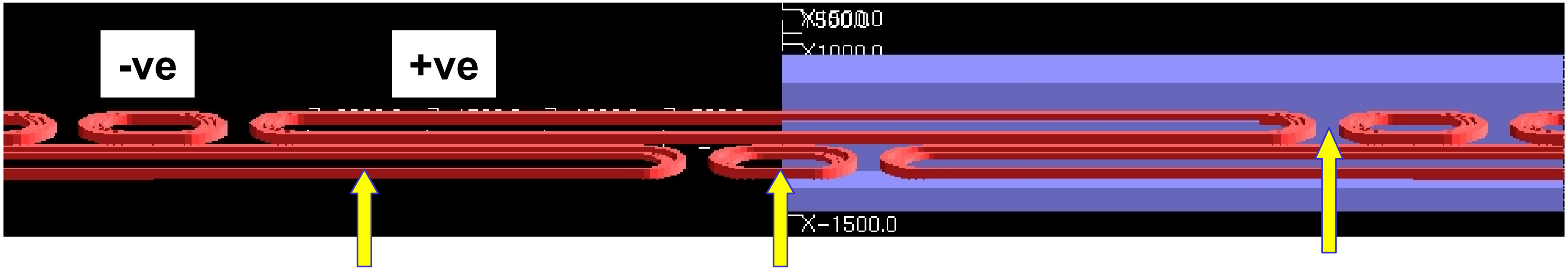
Quadrupole(Q):
Field Gradient
Dipole(D): Field

No space is
wasted for
interconnect

Shorter cells ⇨ smaller aperture, improved beam dynamics

Alternate End Design Concept

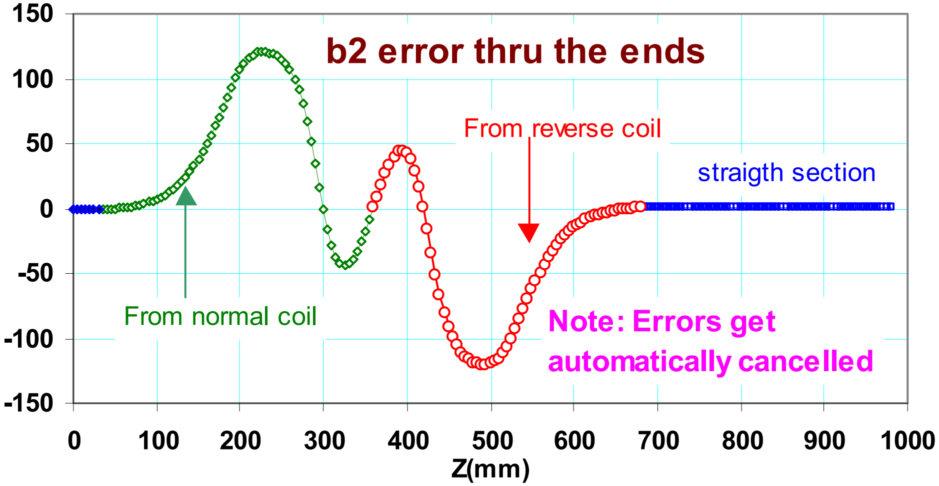
- Reverse coils to cancel field harmonics in ends (also generate skew quad)



Normal Coils
Dipole

Reverse Coils
Skew Quad

One Coil
1/2 & 1/2



Note: Errors get automatically cancelled

New Magnet System Design

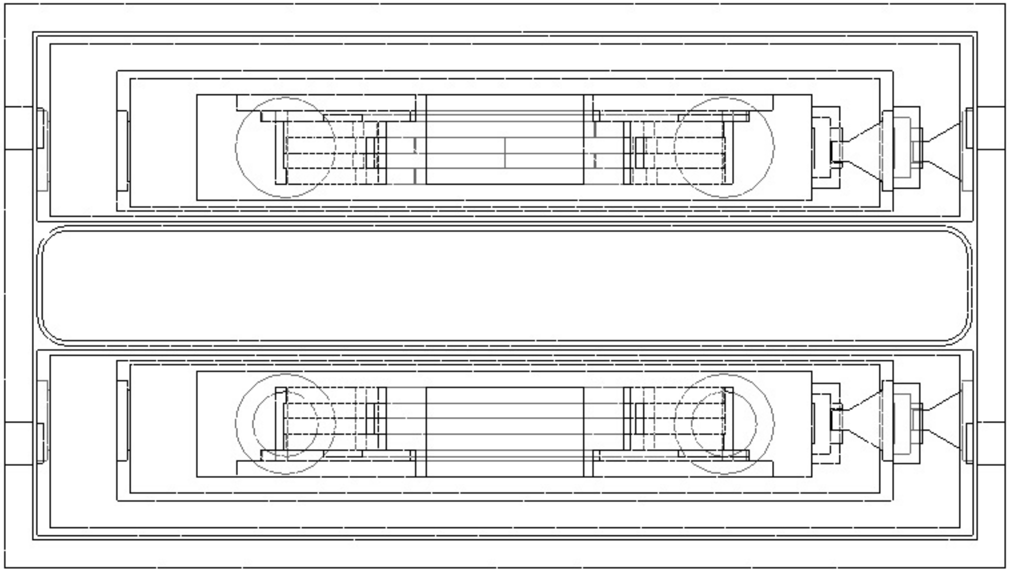
> Good field quality

> Makes ring small

Important for BNL site

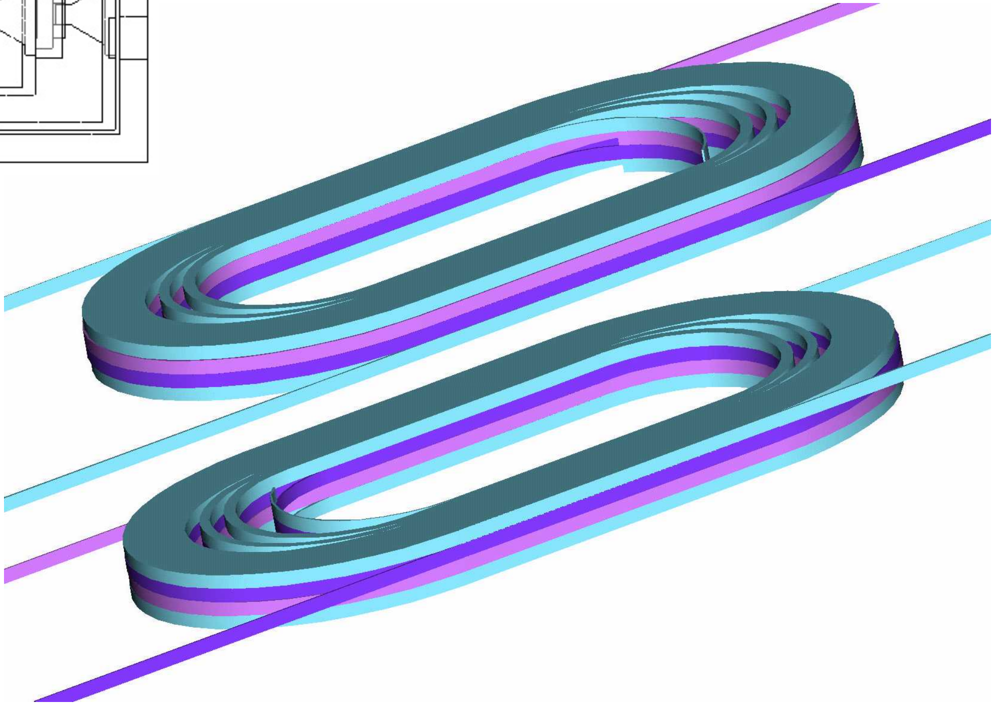
Note: Bx & By (normal and skew harmonics) are cancelled but Bz (axial field) is not.

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.

SUMMARY

Racetrack coil magnet designs with open midplane offers an interesting possibility of making high field magnets that can deal with large energy deposition.

HTS is a promising technology for muon collider magnets.