Superconducting Magnets for RIA's Fragment Separator

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

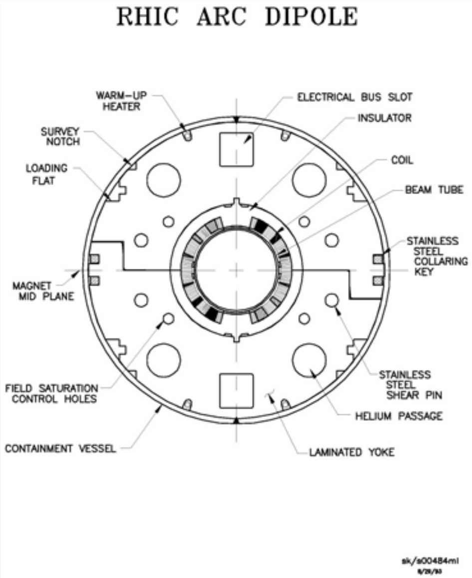
Overview

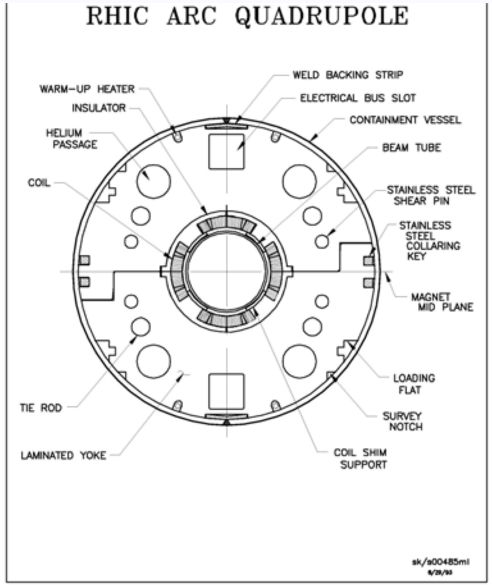
- Magnet Technology at the Superconducting Magnet Division, BNL that may be relevant to RIA

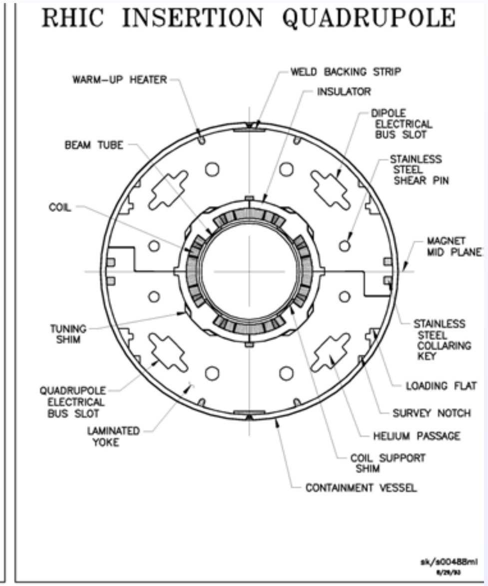
- Some initial work and thoughts on magnets for fragment separator region

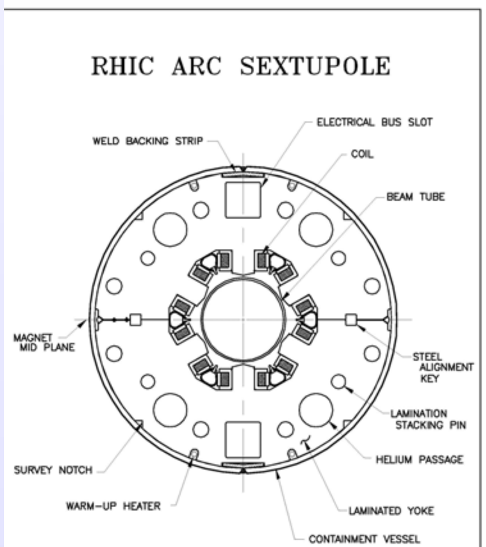
A Few Examples of Variety of Superconducting Magnets in RHIC

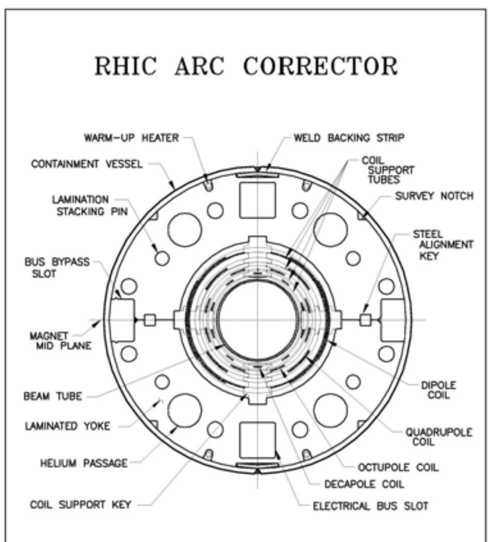
Conductor dominated and iron dominated SC magnets











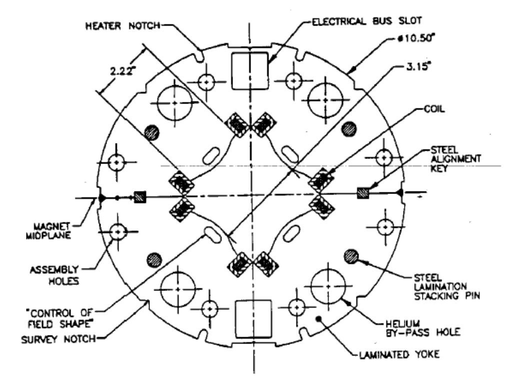
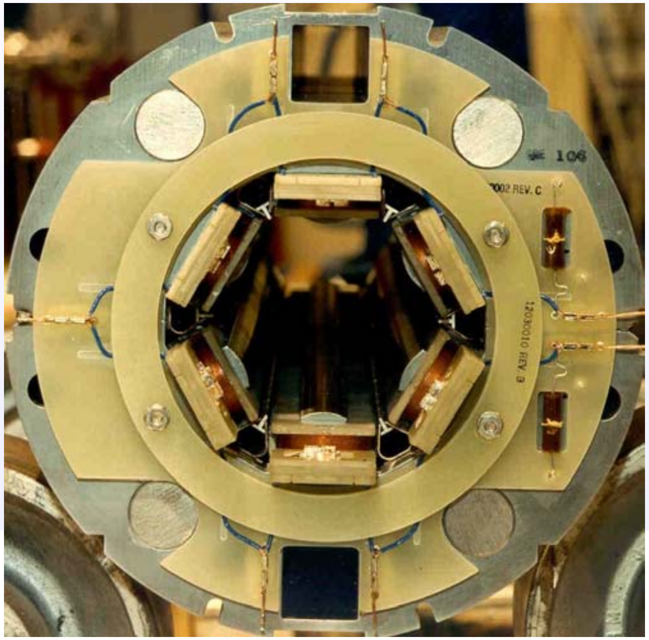


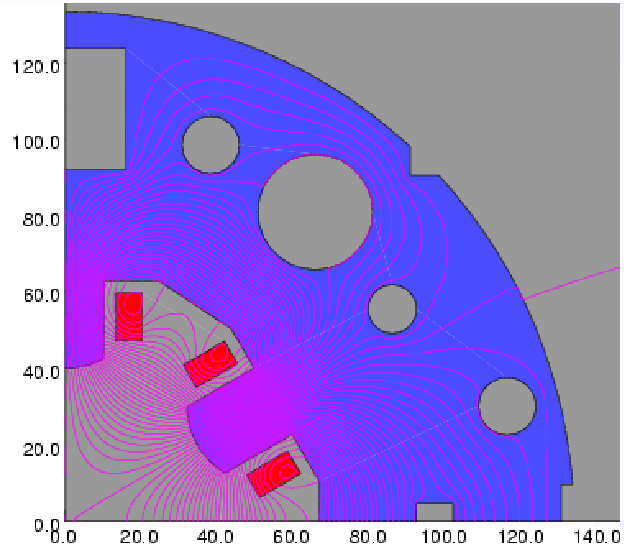
Fig. 1-16. Cross section of the trim quadrupole cold mass. All lamination dimensions outside the pole area are identical to those in the sextupole lamination.

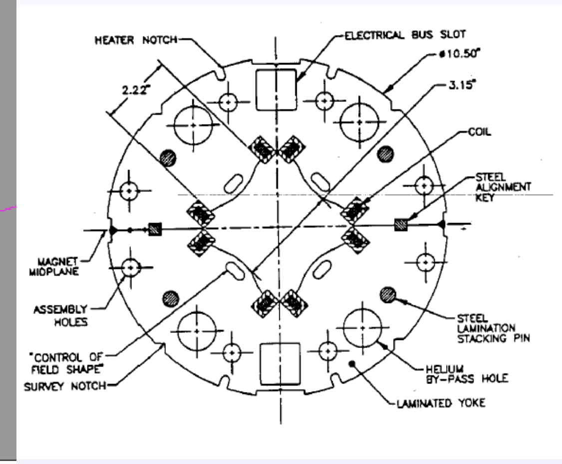
Large Cosine Theta Magnets for RHIC, SSC and LHC

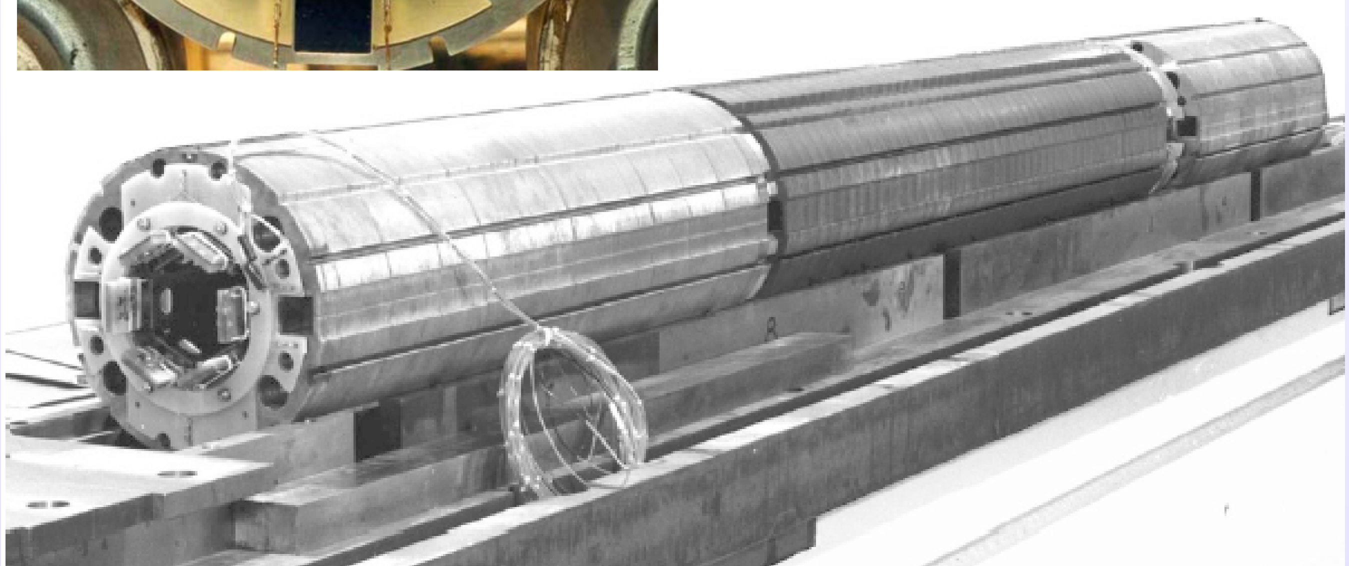
RHIC dipole coldmass during assembly

Examples of Super-ferric Magnets in RHIC



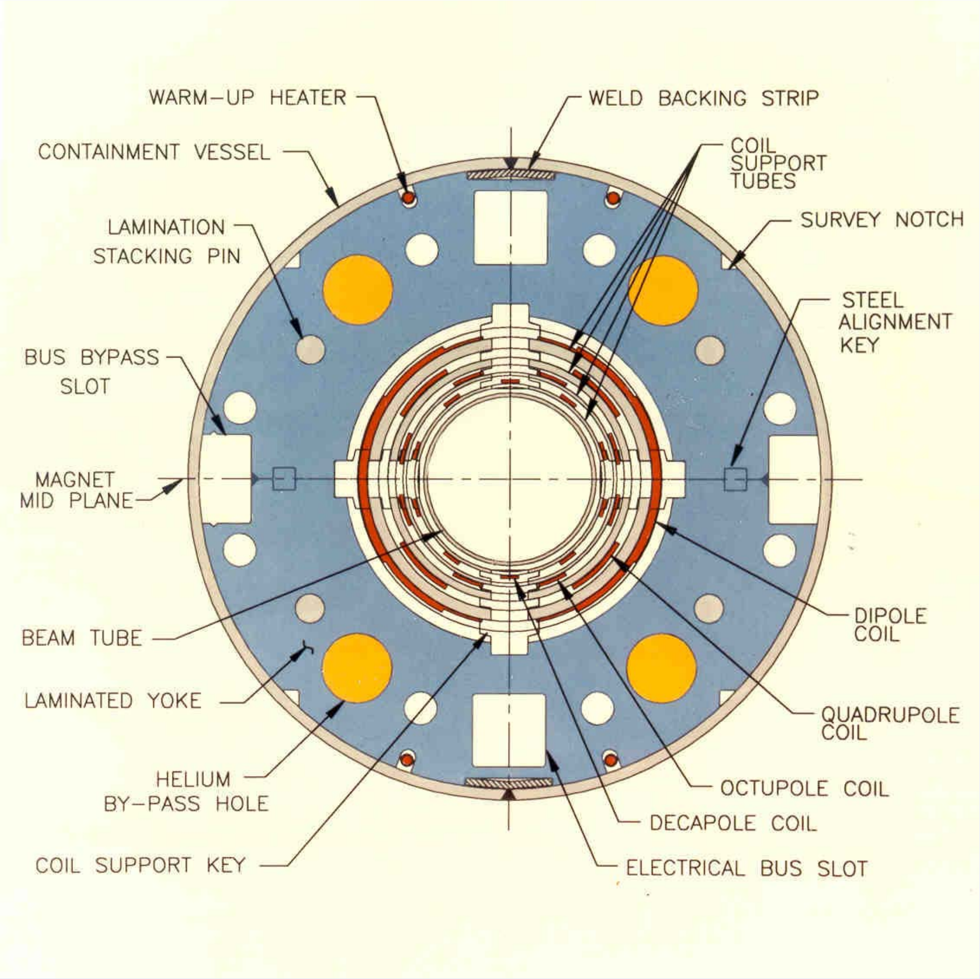






RHIC uses Super-ferric Trim Quadrupole and Sextupole Magnets

An Example of Multi-layer Corrector Magnet for RHIC



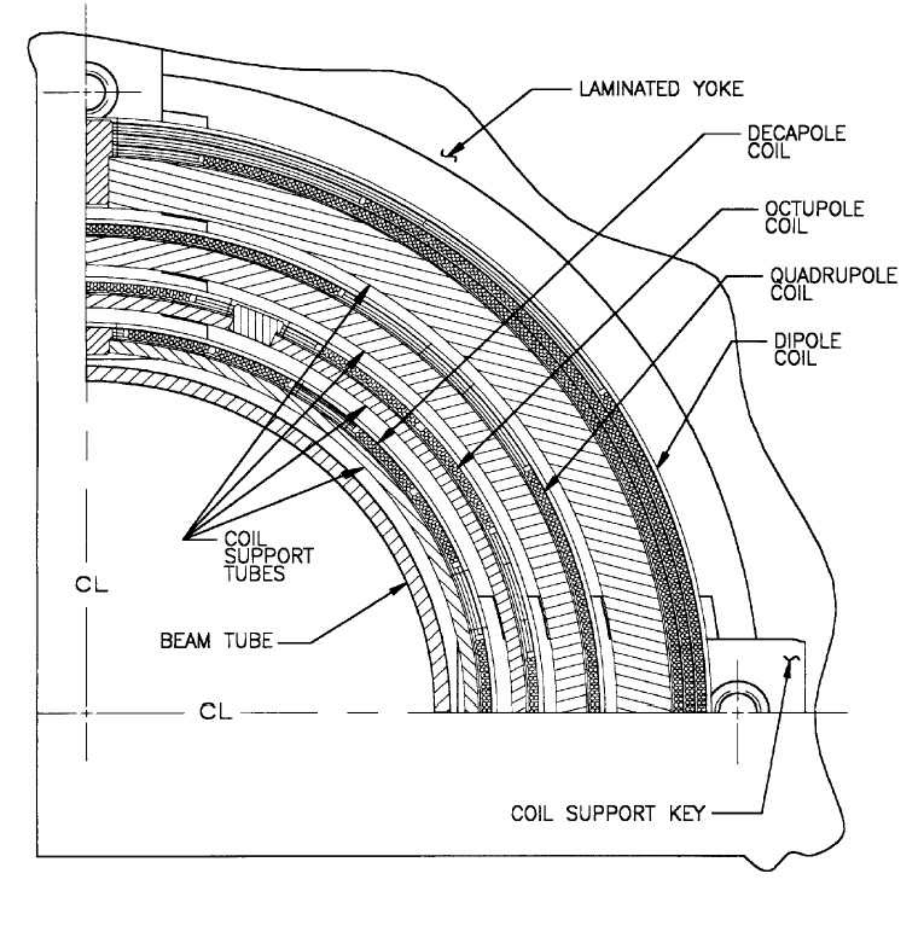
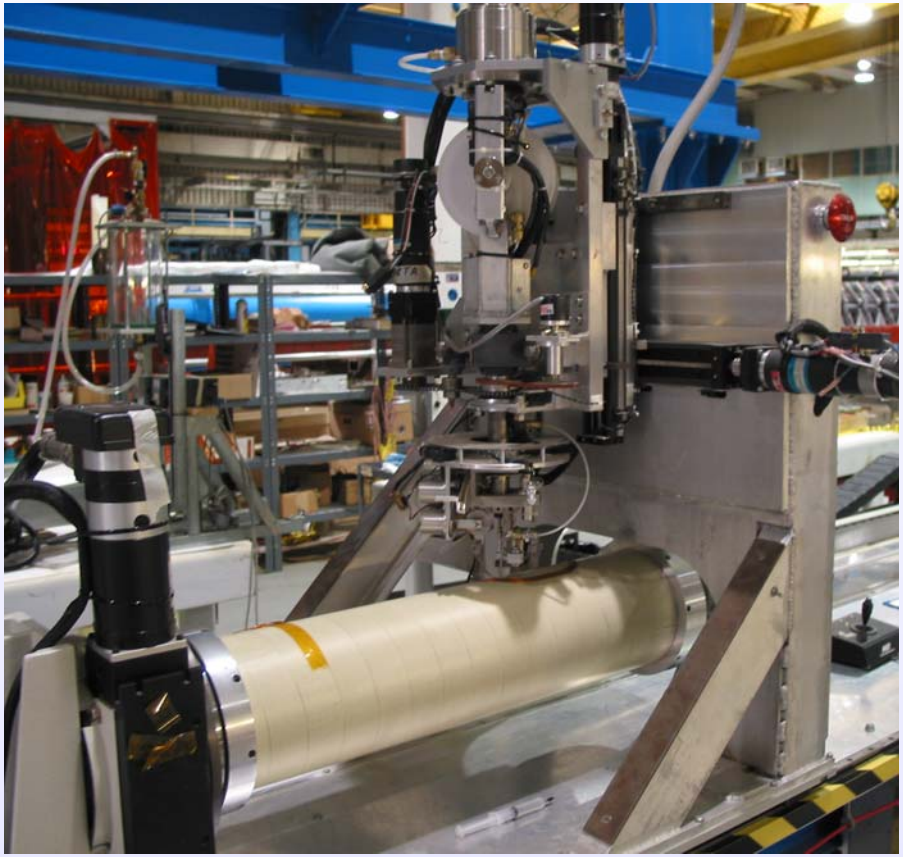


Fig. 1-11. Arc corrector coil cross-section (beam tube i.d. = 69 mm).

Direct Winding on the Tube



A unique technology that is being used for variety of applications worldwide.

Superconducting wires are directly wound on the tube

(One can, instead put copper wires on the tube, if desired)

New designs have been developed for short magnets (length comparable to diameter)

Room Temperature Magnets for SNS

Half Cell – A BNL contribution to SNS

Possible BNL Participation in RIA

• *Radiation Resistant HTS magnets for the first triplet in Fragment Separator*.

• Other magnets in RIA (particularly superconducting magnets in fragment separator region).

• We hope to contribute to RIA proposal with our experience in developing magnet designs, estimating costs, thinking about construction plans, carrying out necessary R&D, and magnetic measurements.

Advantages of using HTS in Magnets for Fragment Separator

- As compared to the conventional Low Temperature Superconductor (LTS), the critical current density (J_c) of High Temperature Superconductor (HTS) falls slowly as a function of temperature.

- The magnet system benefits enormously from the possibility of magnets operating at elevated temperature (20-40 K instead of conventional ~4K).

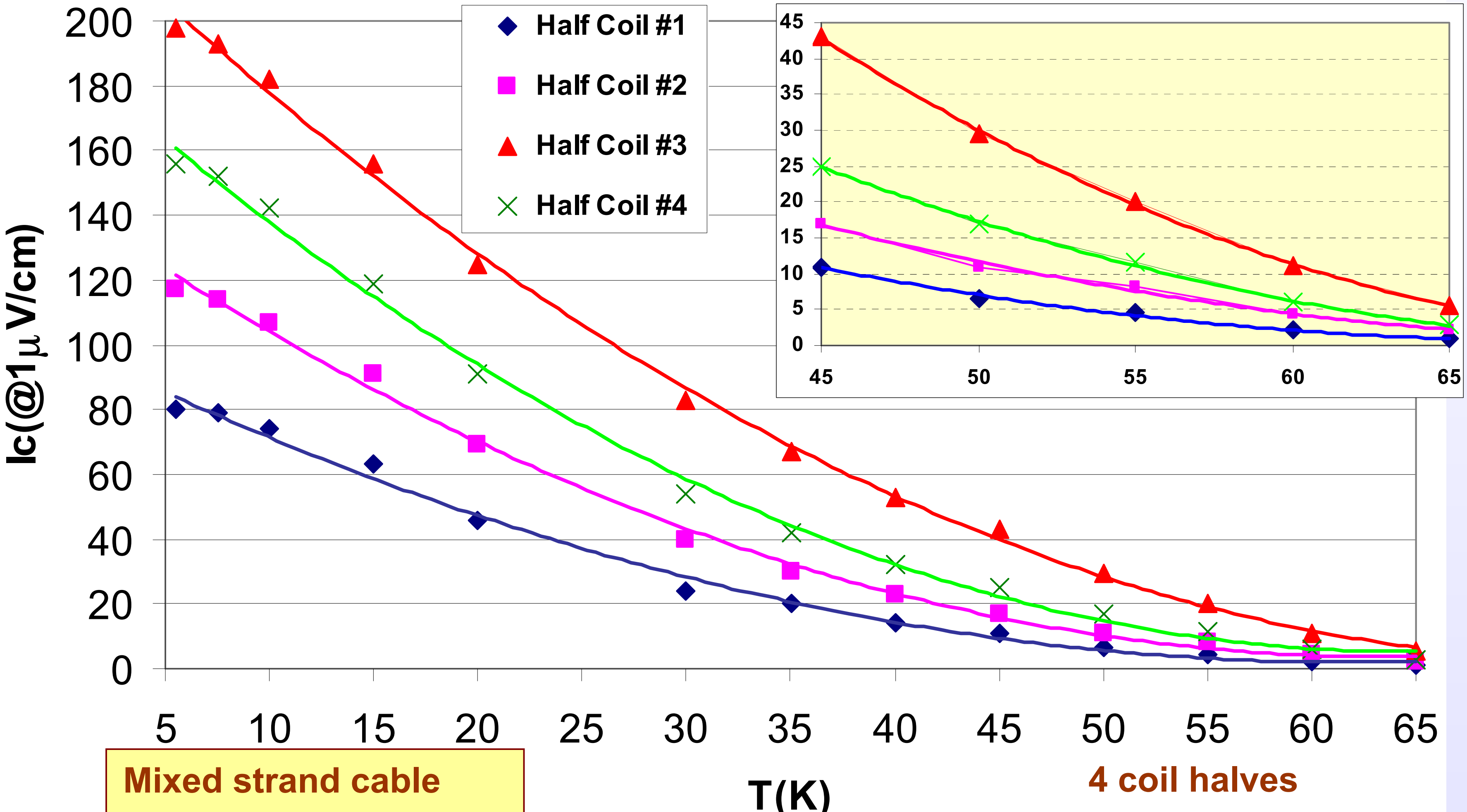
- HTS can tolerate a large local increase in temperature in superconducting coils caused by large energy deposition.

- Moreover, the temperature need not be controlled precisely. The temperature control can be relaxed by over an order of magnitude as compared to that for present superconducting accelerator magnets.

In addition, we plan to use stainless steel tape as a radiation resistant insulation.

Measured Critical Current as a Function of Temperature

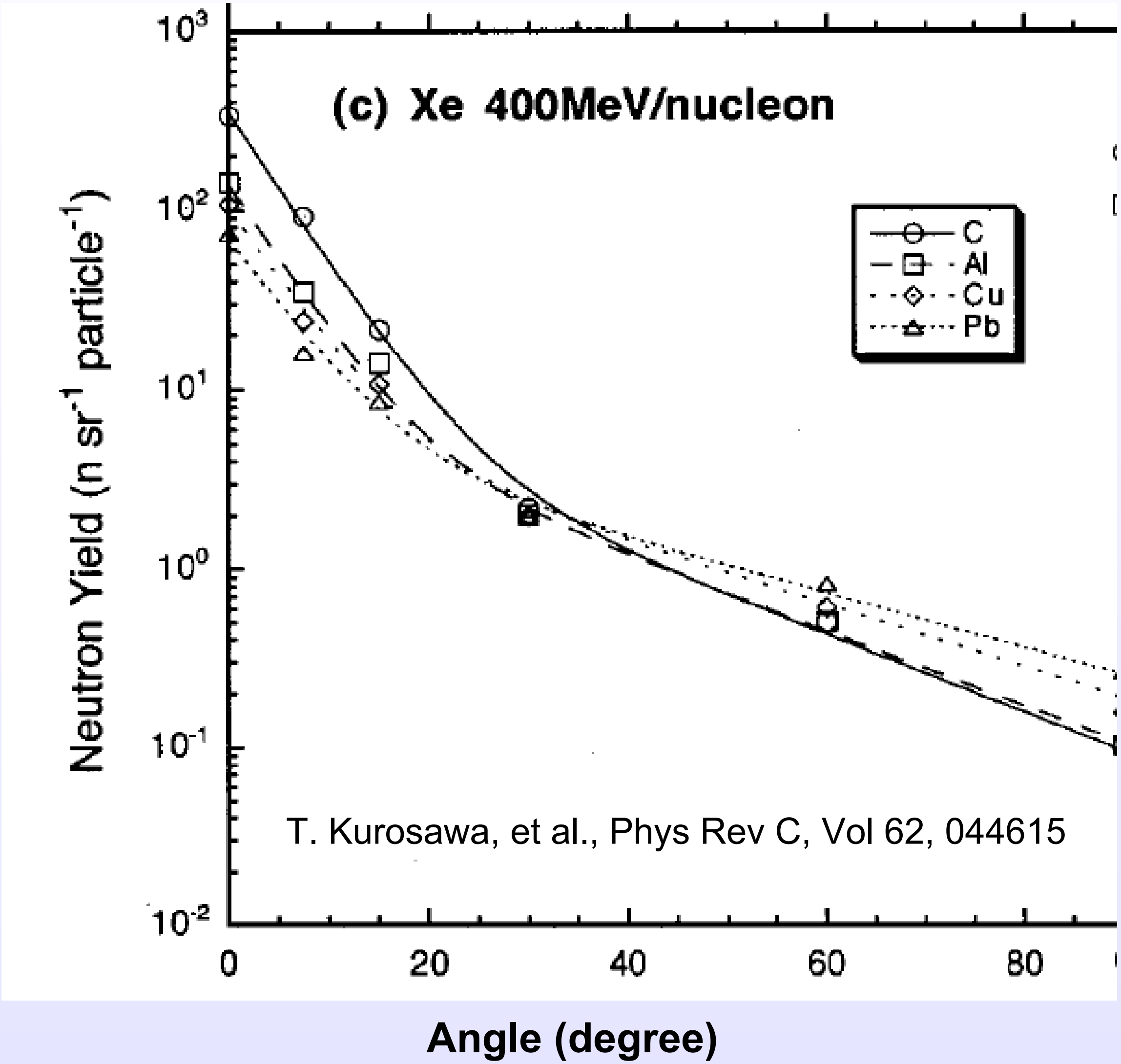
This temperature dependent I_c characteristic is very relevant to RIA Application.



Mixed strand cable
(2 BSCCO 2212, 16 Ag)

4 coil halves
(2 each of two coils)

Significant Reduction in Neutron Fluence at Larger Angles



The plot on the left shows a typical neutron dose as a function of angle, away from the target.

One must look at the impact on the material properties of such a high radiation dose over the magnet life time.

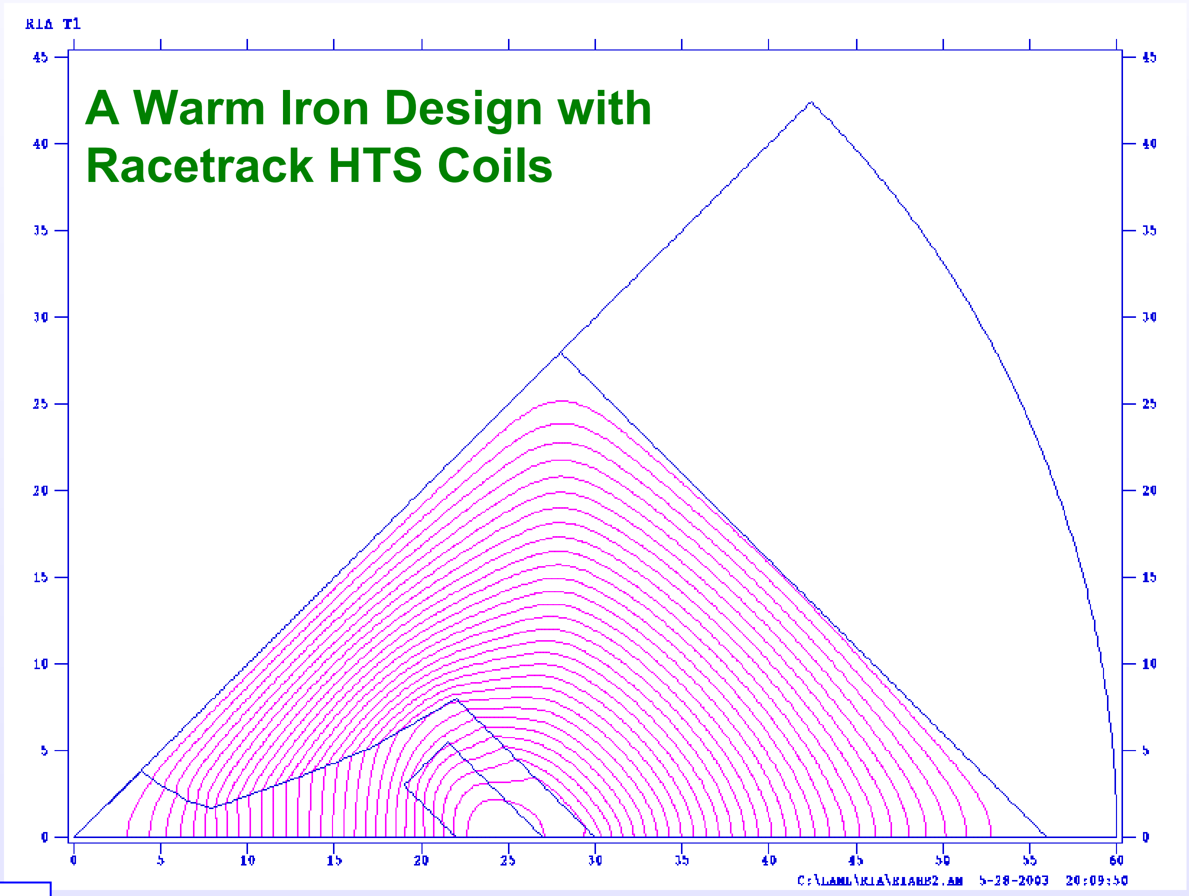
Estimated value in ~12 year period:

10^{19} neutrons/cm^2 in 0^o to 30^o region.

An Earlier Design (10 cm) for the 1st RIA Quad in the Triplet of Fragment Separator

A Super-ferric design with yoke making significant contribution to field. Simple racetrack coils, yoke starts at R_{yoke} = 5.5 cm. Gradient = 32 T/m.

- Coils are moved further out to reduce radiation dose.
- The magnet is designed with warm iron and a compact cryostat to reduce the amount of coldmass on which the heat and radiation are deposited. This design reduces the heat load on the system by a large amount.
- Field lines are funneled to the pole to create a larger pole tip field, and gradient.

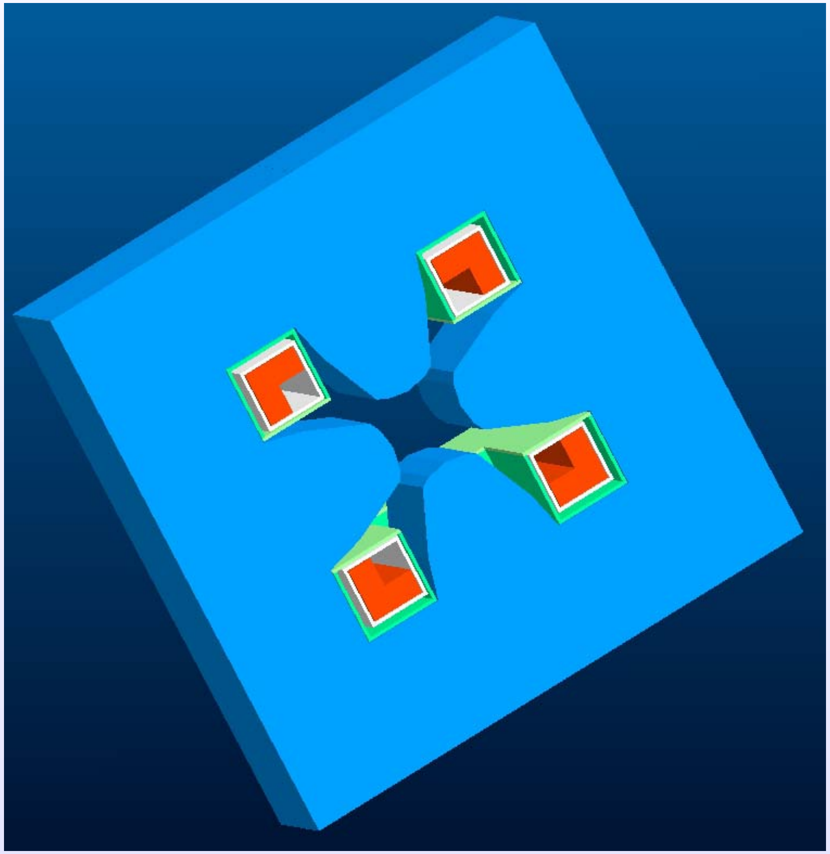


BNL/NSCL Collaboration

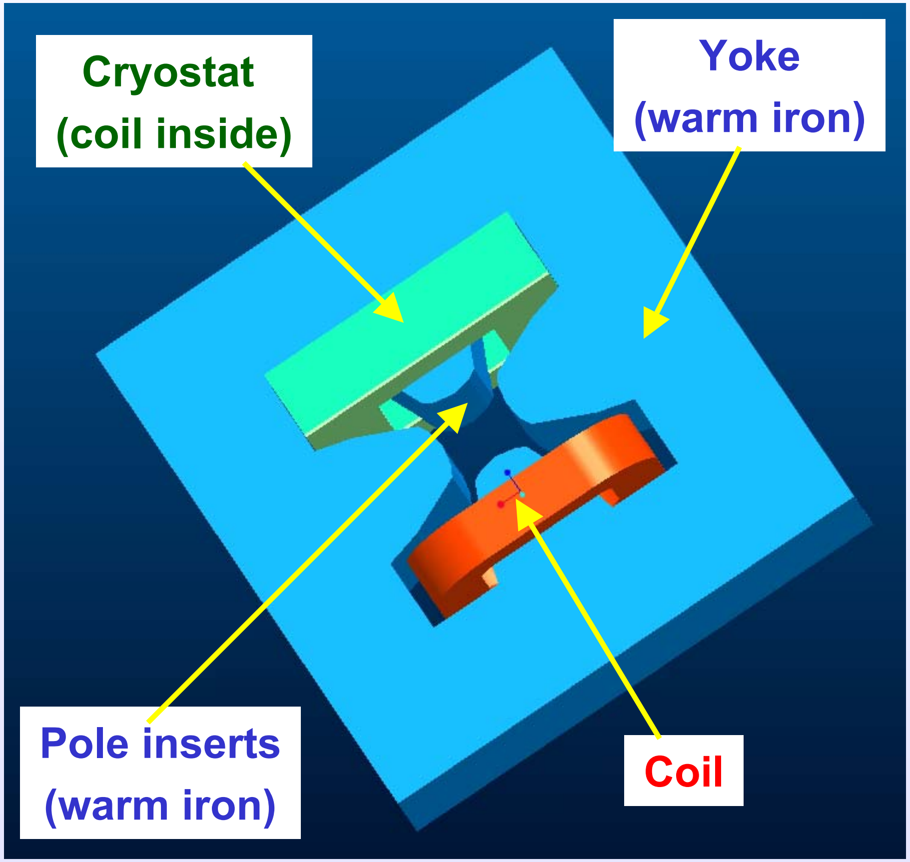
Preliminary Mechanical Concept of the Proposed Quad for RIA

A simple warm iron super-ferric quad design with two racetrack HTS coils

Note that only a small fraction of mass is cold (see green portion), and also that it is at a large solid angle from the target



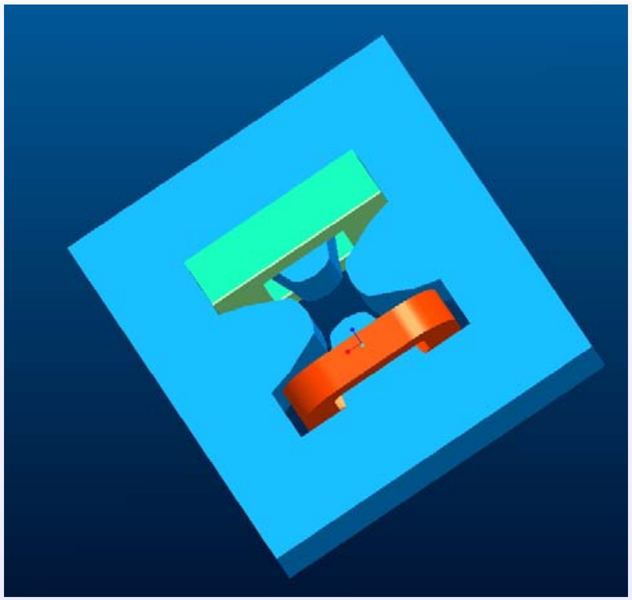
Cutout at the middle of the magnet

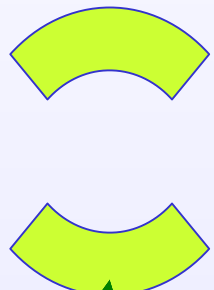


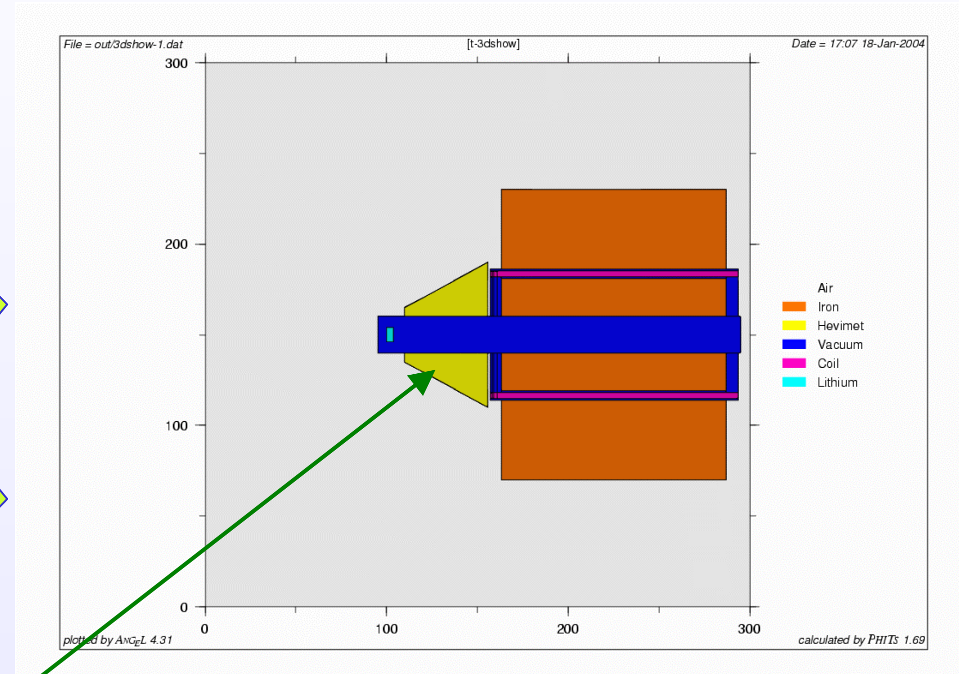
Coils inside the cryostat at the end of the magnet

Heat Load and Shielding

BNL/NSCL Collaboration







Heat Load on Tungsten ~3.3 kW

Note: The volume (and hence cost) of Tungsten shield can be significantly reduced because coil ends do not cover the entire annulus.

Iron heat load = 9 kW ☆

Coil heat load = 130 W ☆

Coil dose rate (assumed to be silver) = 1 MGy/year

(organic materials would be a factor of 200 times more)

Influence of Radiation Damage on HTS

Most of the literature surveyed mentions enhancement in J_c from radiation, especially at 77 K. But that is from a relatively small and controlled dose. With the amount of dose relevant to this application, J_c should go down; don't know how much - need to determine that experimentally.

S. Tönies et al. / Physica C 341–348 (2000) 1427–1430 1429

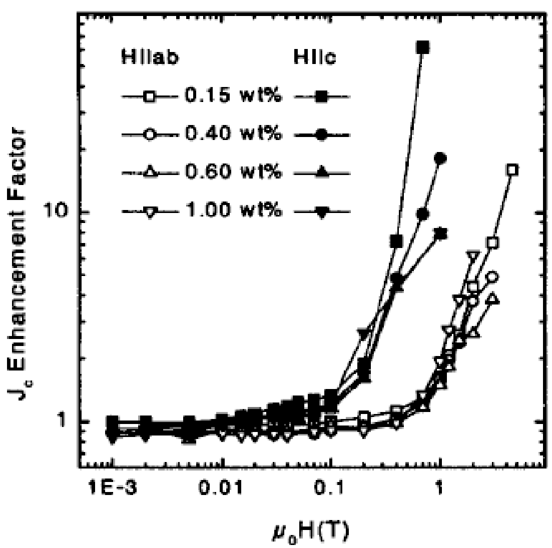


Figure 2. Enhancement of the critical current densities for samples with different amounts of uranium at 77 K, but at fixed track density.

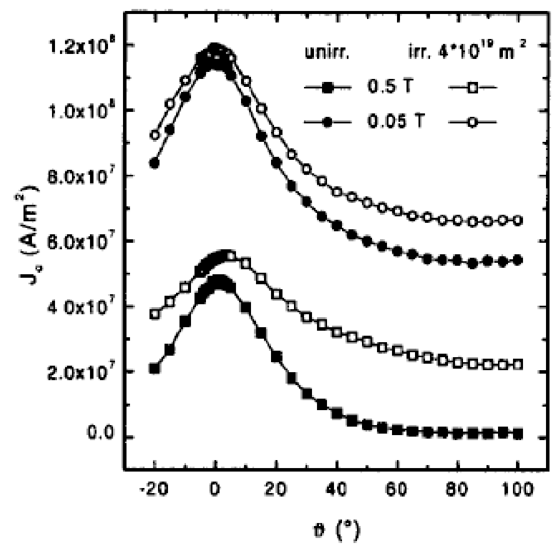


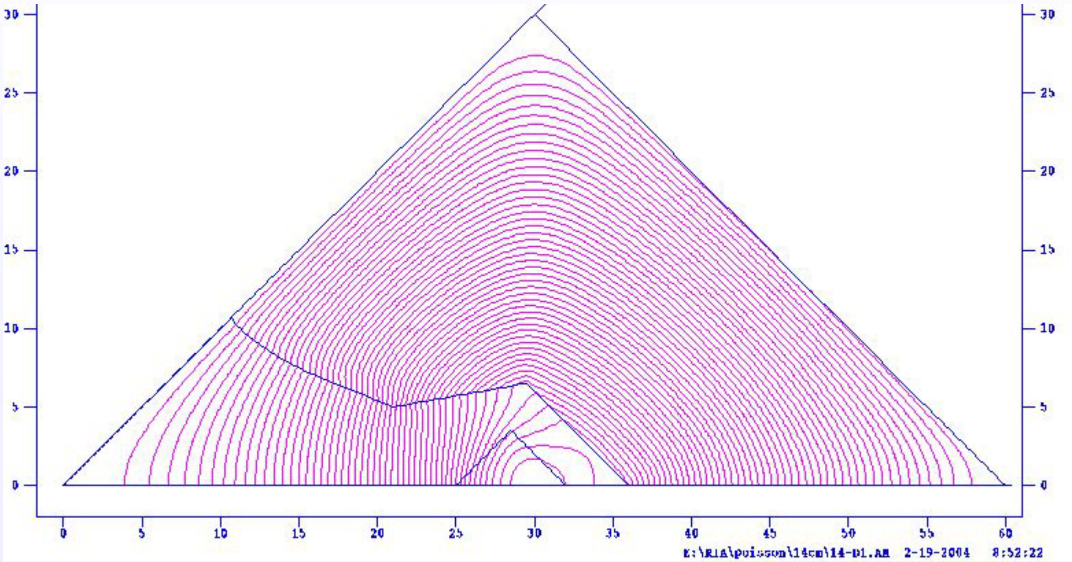
Figure 3. Anisotropy of J_c before and after irradiation to $4*10^{19}$ m^{-2} at 77 K and 0.5 T.

NSCL/BNL collaboration will plan experiments and do studies to determine the choice of magnet materials and the radiation load the chosen materials can tolerate.

BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Preliminary Design of 30 cm Aperture (15 cm radius) HTS Quadrupole magnet



Present HTS cost : $200/kA/m

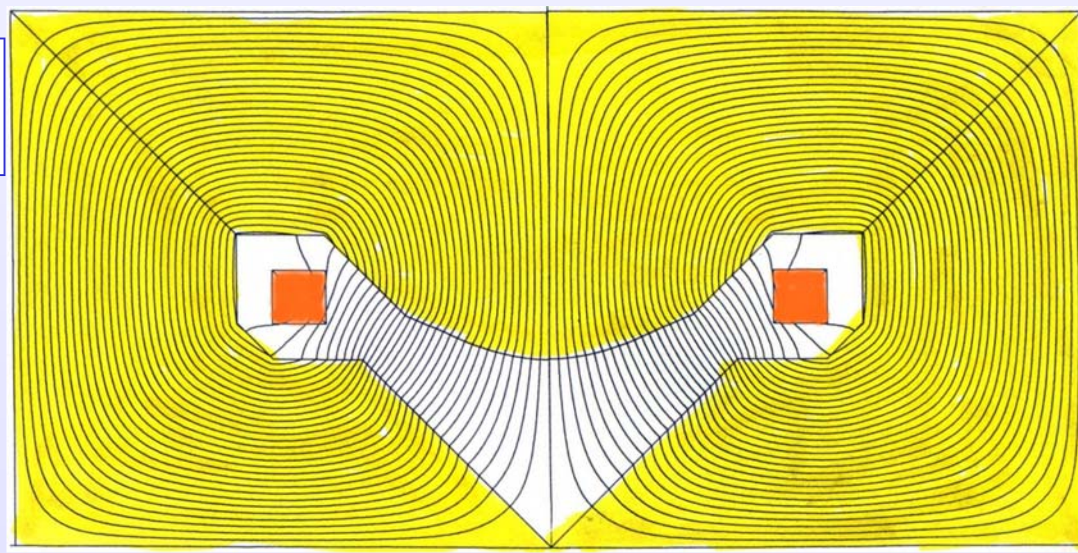
Total HTS cost in magnet: ~$400K

According to American Superconductor corporation, the cost is expected to go down by a factor of 3-4 in 3-4 year because of new larger facility.

Remember, the key goal is to reduce operating cost.

Operating Temperature ~30 K;
Coil current density ~100 A/mm^2

BNL Plans to demonstrates the basic HTS technology this calendar year by building and testing a magnetic mirror configuration of the design.



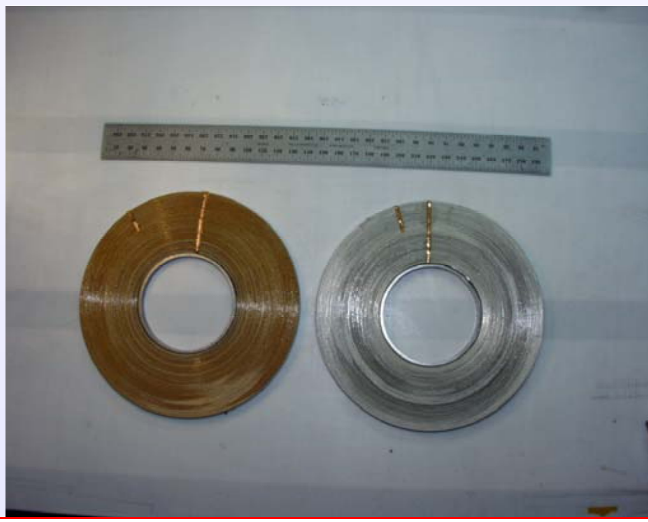
BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Insulation in HTS Coils Built at BNL

Insulation is another major concern in radiation resistant magnets.

We have built HTS coils with <u>stainless steel tape as the insulation material between turns</u>. Being metal, stainless steel is highly radiation resistant.



Two double pancake NMR coils, one with kapton insulation and the other with stainless steel.

S.S. insulation works well with superconductors

HTS Test Coil for an Accelerator Magnet

Dialogue with Accelerator Physicists (1)

- A good interaction between magnet scientists/engineers and accelerator physicists is essential to develop an overall system design that minimizes cost and maximizes performance.
- Cost to benefit ratio between magnet performance and optical solution
    - This is an important exercise that usually requires a lot of interaction and some iterations in beam line optics and magnet designs
    - At this stage, don't be afraid to ask for field (or any other performance parameter), if it helps.
- We can look for alternate designs and let you know what is involved.
- Feel free to discuss general issues, etc. any time, however, please be selective in a number of special request of detailed designs.
- Minimize the variety of magnets as the design and R&D cost (plus time) on each type of magnet may be significant.
- Need a baseline working solution soon. We need NOT fix it, but need one soon.

BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Dialogue with Accelerator Physicists (2)

new optics as of 3/5/04								
number	Length (m)	req pole tip rad(cm)	B at re pole (T)	G (T/m)	actual rad	B at actual	L/R	actual length
2	1	15	1.5	10.00	15.5	1.55	6.45	0.92
2	1.5	20	1.49	7.45	20.5	1.53	7.32	1.37
2	1	20	1.46	7.30	25.5	1.86	3.92	0.86
2	1.25	25	1.48	5.92	30	1.78	4.17	1.09
2	1.25	25	1.44	5.76	30	1.73	4.17	1.09
2	0.75	25	1.03	4.12	30	1.24	2.50	0.57
2	0.75	25	1.03	4.12	30	1.24	2.50	0.57
2	1.25	25	1.44	5.76	30	1.73	4.17	1.09
2	1.25	25	1.48	5.92	30	1.78	4.17	1.09
2	1.2	25	1.43	5.72	30	1.72	4.00	1.04
2	1.5	25	1.59	6.36	30	1.91	5.00	1.35
2	1	25	1.1	4.40	30	1.32	3.33	0.82

new optics as of 3/5/04								
number	Length (m)	req pole tip rad(cm)	B at re pole (T)	G (T/m)	actual rad	B at actual	L/R	actual length
1	1	15	1.20	8.00	18	1.44	5.56	0.91
1	1.2	22	1.41	6.41	25	1.60	4.80	1.08
1	1	25	0.99	3.97	30	1.19	3.33	0.82
1	1	30	0.80	2.65	33	0.88	3.03	0.80
1	1	30	0.44	1.45	33	0.48	3.03	0.80
1	1	35	0.51	1.45	38	0.55	2.63	0.77
1	1	35	0.51	1.45	38	0.55	2.63	0.77
1	1	35	0.44	1.24	38	0.47	2.63	0.77
1	1	35	0.80	2.27	38	0.86	2.63	0.77
1	1	25	0.99	3.97	30	1.19	3.33	0.82
1	1.2	22	1.41	6.41	25	1.60	4.80	1.08
1	1	15	1.20	8.00	18	1.44	5.56	0.91
1	1	25	0.99	3.97	30	1.19	3.33	0.82
1	1.2	22	1.41	6.41	25	1.60	4.80	1.08
1	1	15	1.20	8.00	18	1.44	5.56	0.91
1	1	15	1.20	8.00	18	1.44	5.56	0.91
1	1.2	22	1.33	6.05	25	1.51	4.80	1.08
1	1	25	0.74	2.97	30	0.89	3.33	0.82
1	1	30	1.24	4.13	33	1.36	3.03	0.80
1	1.5	30	1.69	5.63	33	1.86	4.55	1.33
1	1	35	1.42	4.06	38	1.54	2.63	0.77
1	1	35	1.42	4.06	38	1.54	2.63	0.77
1	1.5	35	1.69	4.83	38	1.83	3.95	1.29
1	1	35	1.24	3.54	38	1.35	2.63	0.77
1	1	25	0.74	2.97	30	0.89	3.33	0.82
1	1.2	22	1.33	6.05	25	1.51	4.80	1.08
1	1	15	1.20	8.00	18	1.44	5.56	0.91
1	1	25	0.74	2.97	30	0.89	3.33	0.82
1	1.2	22	1.33	6.05	25	1.51	4.80	1.08
1	1	15	1.20	8.00	18	1.44	5.56	0.91
1	1	25	0.74	2.97	30	0.89	3.33	0.82
1	1.2	22	1.33	6.05	25	1.51	4.80	1.08
1	1	15	1.20	8.00	18	1.44	5.56	0.91

Reduce the magnet types

- More magnet types cost significantly more money!!!
- Can optics accommodate with 3 types of quads; e.g., with magnet radius being16 cm, 25 cm and 35 cm? (adjust length to get required integral gradient)?

Is this really the optimum solution for the key magnets?

- How much do you gain by some more gradient?
- If you tell us, we can focus on those in key magnets.
- Alternatively, we could try (in the range indicated) and let you know how much pain it is to get more and then you can take advantage of that in your optics.
- Similarly, let us know where it is not so critical, so that we can see if there are some opportunity to make those magnets simpler/cheaper.

SUMMARY

- Presented a brief idea of what we can offer.
- Would like to understand the requirements of RIA magnets.
- Looking forward to participating in this project and looking forward to an interactive way to contribute the best we can to optimize the cost and performance.