

BNL's Magnet Program Vision for HEP Colliders

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a passion for discovery

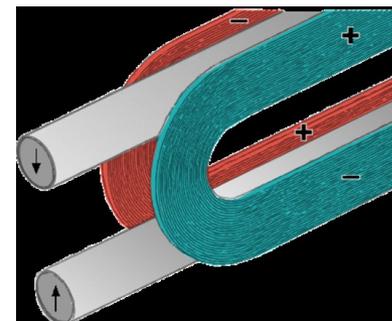


U.S. DEPARTMENT OF
ENERGY

Office of
Science

Overview of BNL Program Vision

- Develop a common coil design with the dual goal of improving performance and reducing cost
- Demonstrate 16 T Nb₃Sn accelerator quality dipole; build ReBCO HTS coils and integrate them with Nb₃Sn coils for ~20 T hybrid dipole
- Use a unique BNL magnet for testing coils at high fields – fast turn around, lower cost – ideal for advancing technology both for systematic optimization & for high risk, high reward R&D



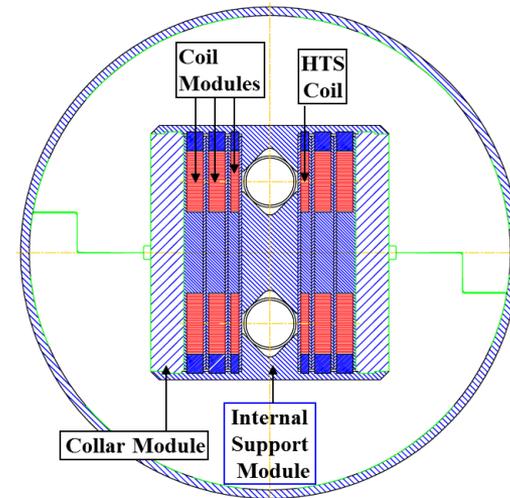
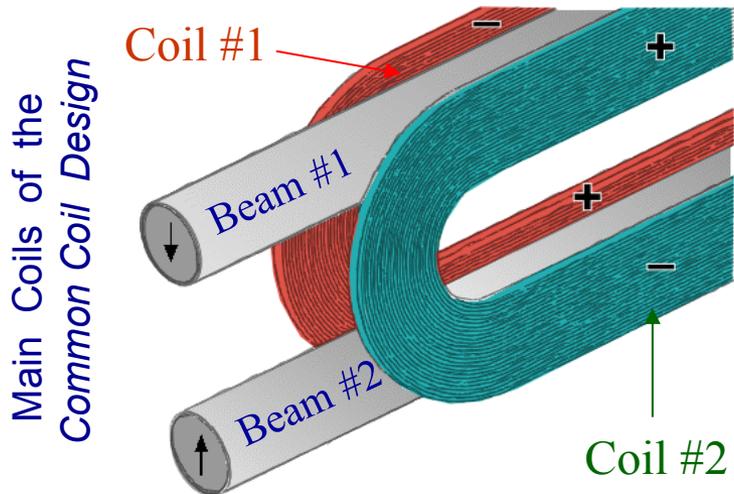
BNL's magnet program is naturally aligned with HEPAP Subpanel Recommendations

Relationship of BNL Magnet Program to other Magnet Programs

- BNL's high field magnet program is unique and is complementary to magnet programs in other U.S. labs (and around the world) with the common goal of developing lower cost, high field collider dipoles
- BNL's program is based on common coil design; Fermilab on cosine theta and LBL on Canted-Cosine-Theta (CCT)
- BNL's program is based on racetrack coils with large bend radii that allows both "React & Wind" and "Wind & React" Nb₃Sn technologies; Fermilab and LBL are based on "Wind & React"
- BNL's HTS program is based on ReBCO coils with a geometry that is very different from that being pursued by CERN and others
- RHIC experience in magnet production with industry is useful in taking designs from the drawing board to low cost manufacturing

Common Coil 2-in-1 Collider Dipole Design

(coils common to two apertures)

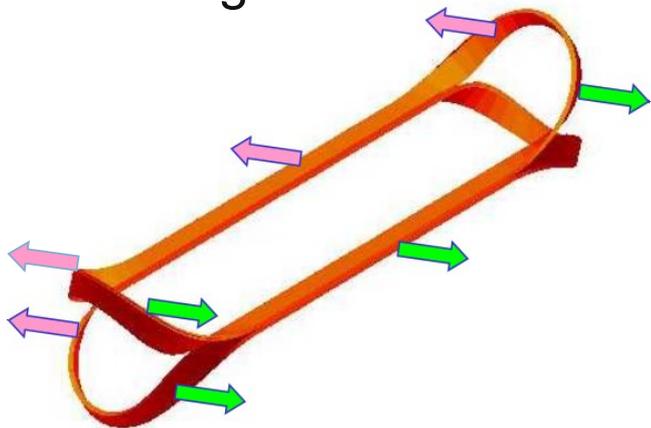


- Simple, large bend radii, conductor friendly design
 - General philosophy: work to the strength of conductor, allow various options
- Modular design: Good for mixing different conductors and for R&D magnets
- Same coils for two apertures : 2-in-1 design for both iron and coils
- Expected lower cost : Number of coils half, simpler geometry/ manufacturing, etc.

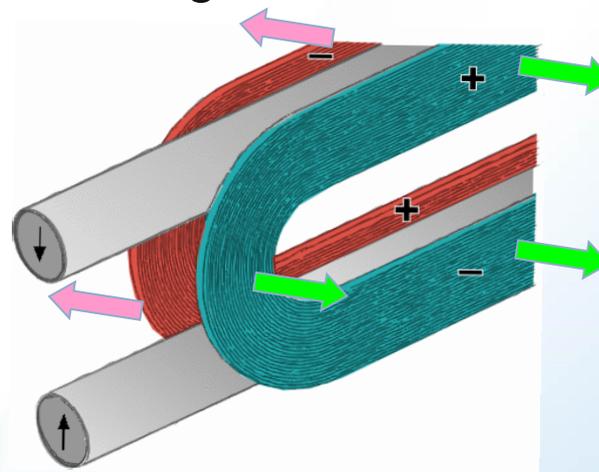
Advantage of Common Coil Design in High Field Magnet Structure

A key technical and cost issue in high field magnets is structure

In cosine theta and block designs, large forces put excessive stress/strain on the conductor in the end region



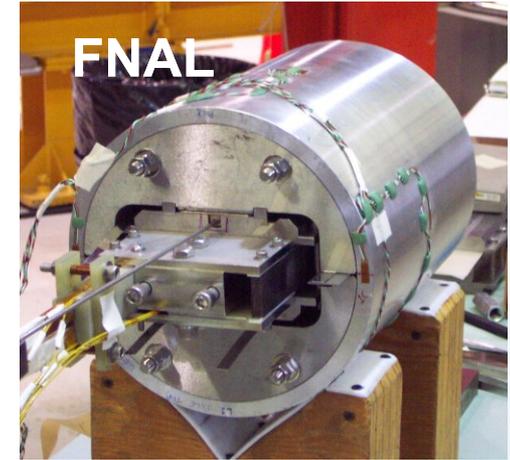
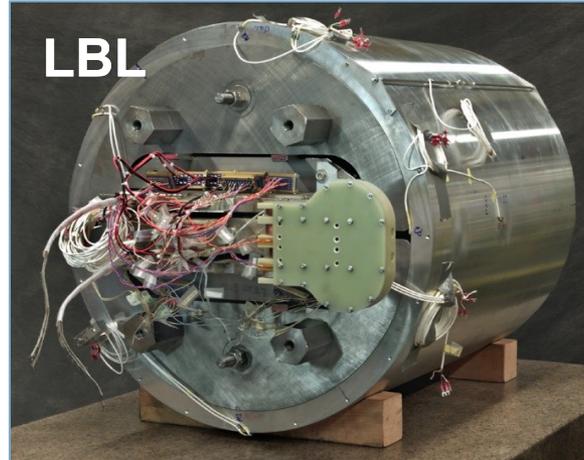
In a common coil design, coils move as a whole - much smaller stress/strain on the conductor in the end region



BNL common coil dipole tolerated ~200 microns motion (typical ~25-50 microns)

Expected lower cost due to less structure and better performance due to less strain

Common Coil 2-in-1 PoP Dipoles



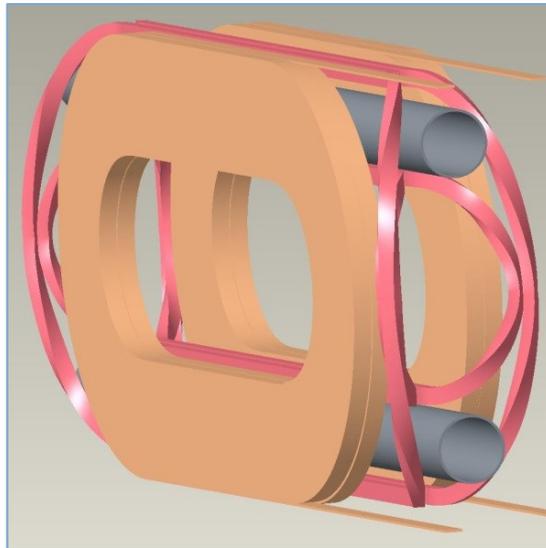
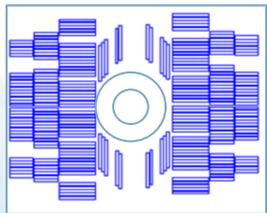
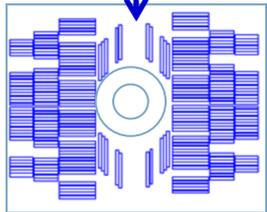
- R&D common coil Proof-of-Principle (PoP) dipoles built at BNL/LBL/FNAL
- LBL's first common coil dipole reached quench plateau right away and reduction in pre-stress (structure study) had no impact on performance
- BNL's ~30 mm aperture 10+ T (record for "React & Wind" technology) reached short sample (slightly exceeded)
- Despite a good start, the work didn't continue, partially because the design was specifically for a 2-in-1 dipole (required twice the conductor for a single R&D unit) and also LARP required single aperture quadrupole.

PoP to Accelerator Quality Dipoles

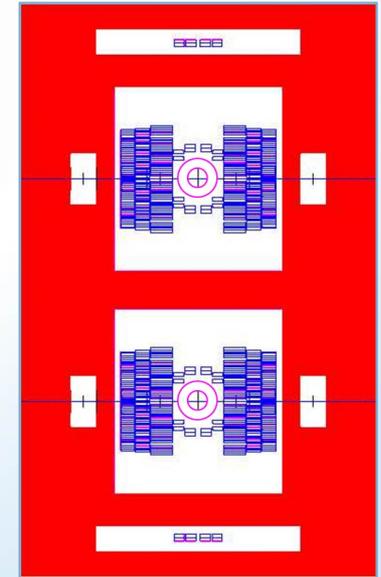
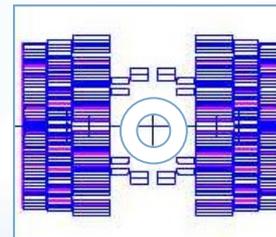
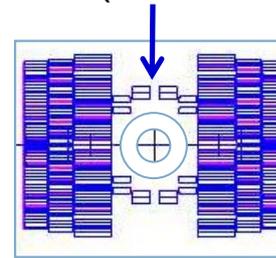
Next Step: Demonstrate field quality dipoles in model magnets

- Requires “pole coils” which were not in Proof-of-Principle dipoles
- Pole coil ends must clear beam tube; either (a) make it as in cosine theta dipoles or (b) keep it simple and waste some conductor

(a) Pole coils like midplane coils of cosine theta dipoles



(b) Simpler configuration of pole coils (waste some conductor)

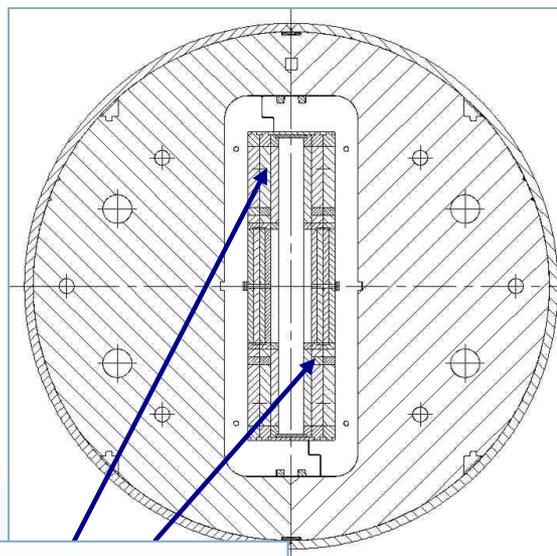


A New Way of Coil and Magnet R&D

Unique features of BNL's common coil dipole: large open space for inserting & testing "coils" without any disassembly (fast turn around, low cost)

- Build/Replace a coil, not the entire magnet for developing technology

Examples: (a) Pole coils for initial demo of accelerator type dipole
(b) New conductor, new insulation, variation in techniques
(c) HTS coil for high field HTS/LTS hybrid dipole

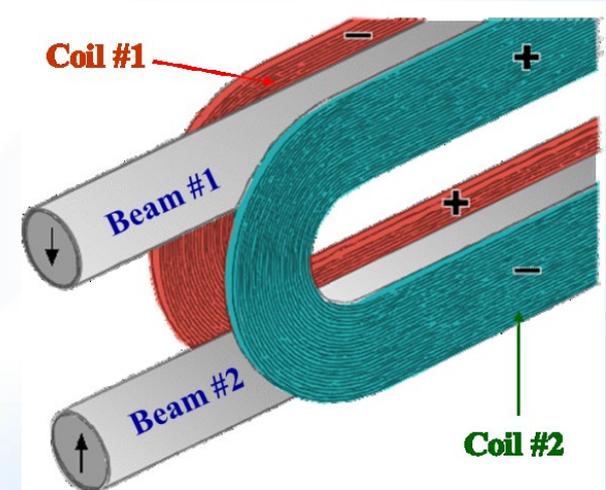


Insert Coils

Modular design allows coils of different width, etc.

Common Coil Design and React and Wind Technology

- Common coil design adds another option - “React & Wind” approach for Nb_3Sn and HTS coils - thanks to large bend radii
- Opens the door to another technology option for manufacturing
- It also allows several materials for insulation, conductor and other coil components as the coil doesn't have to go through the high temperature reaction cycle

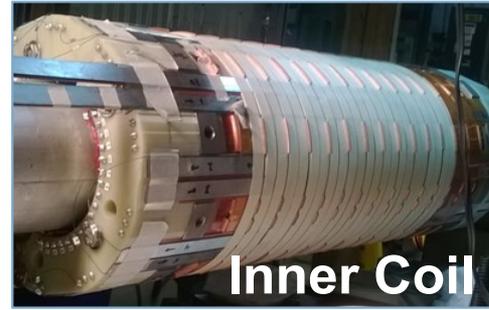


Previous Significant High Field ReBCO HTS Magnet R&D at BNL

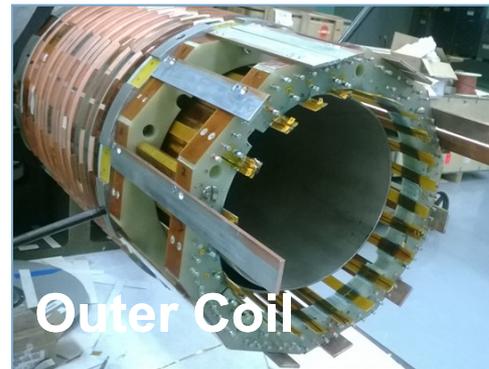
MAP High Field Solenoid

- Field on coil : 16 T
(original target of
PBL/BNL SBIR: 10-12 T)

- High risk, high reward R&D on HTS SMES
- Goal: 25 T @4 K in large aperture (100 mm)



Inner Coil



Outer Coil

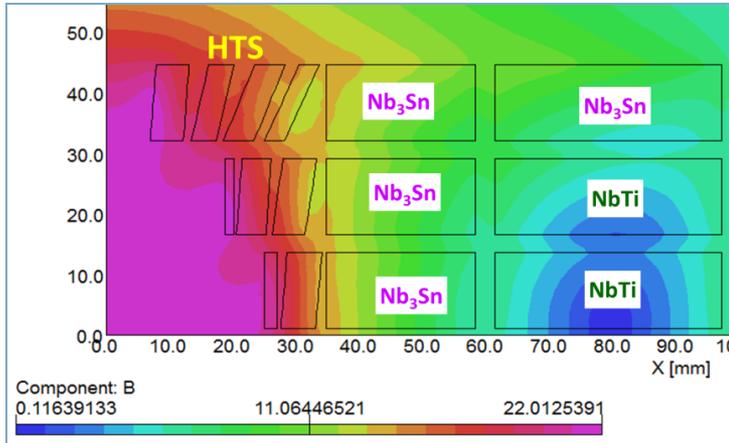


Overall J_o in coil:
>500 A/mm² @16 T

12.5 T @27 K (highest field ever at > 10 K)

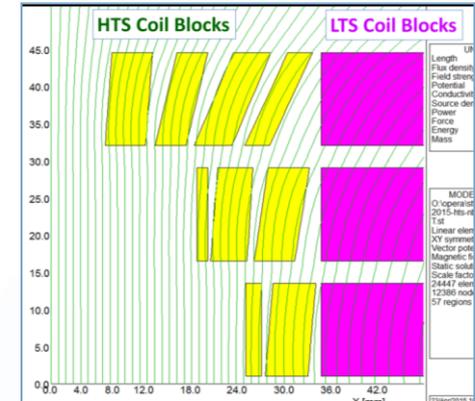
High Field (>20 T) HTS/LTS Hybrid Dipole

Hybrid Design to reduce cost



Aligning tape to field lines significantly reduces magnetization (DOE/HEP STTR); reduces conductor requirements (CERN)

Common coil for easy segmentation

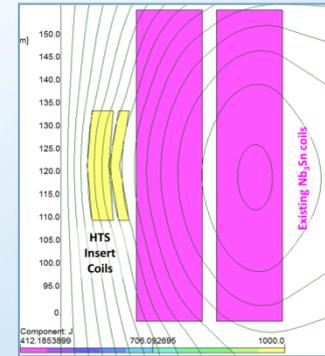


High current (>10 kA) new ReBCO cable options:

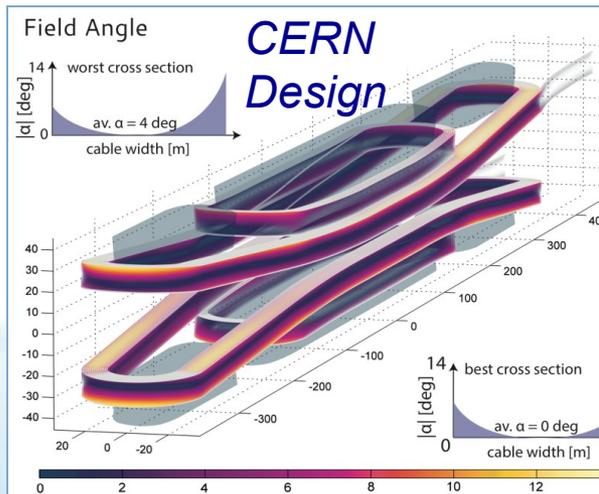
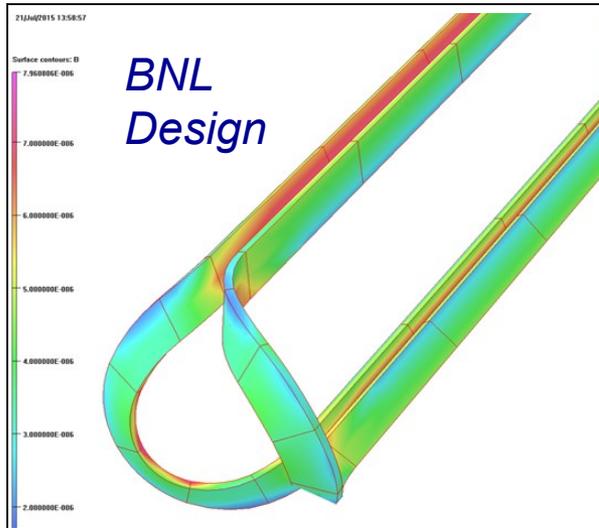
- a) Several tapes bonded together, parallel to field
- b) CORC cable (allowed by large radii in design)



PBL/BNL STTR



Complementary Nature of BNL and CERN ReBCO Programs



- BNL and CERN are both pursuing ReBCO technology but with very different designs
- BNL bends tape in easy direction in ends (allowed by common coil design); CERN bends in hard direction
- BNL is proposing simple multi-tape or CORC cable configuration (allowed by common coil); CERN is focusing on Roebel cable
- BNL also has a significant experience with HTS, particularly ReBCO magnet technology which the DOE could preserve and enhance
- HTS work at BNL in the past has been supported by several project/SBIR/STTR grants; GARD support will bring this R&D to a new level

Possible Time Line for High Field Magnet Development Program (subject to funding)

- Demonstrate basic design of common coil dipole by integrating pole Nb₃Sn coils (new) with main Nb₃Sn coil (existing) : 2 years
- Investigate techniques for taking advantage of simpler geometry of common coil dipole for cheaper manufacturing techniques: 1 year
- Develop engineering design of low cost 16 T Nb₃Sn dipole: 2 years
- Demonstrate 16 T, accelerator field quality common coil dipole with a couple of model magnets and series of Nb₃Sn coils: 5 years
- Develop and test ReBCO tape R&D coils (stand alone) that are suitable for accelerator dipoles and can be integrated with the above Nb₃Sn: 2 years
- Develop and test ReBCO cable coils: 5 years
- Demonstrate 20 T or more hybrid R&D common coil dipole: 7 years
- Demonstrate accelerator quality 20 T or more hybrid dipole: 10 years
- Testing of coils in the 10 T or more background field magnet to demonstrate new lower cost and high performance coil technology for high fields: ongoing

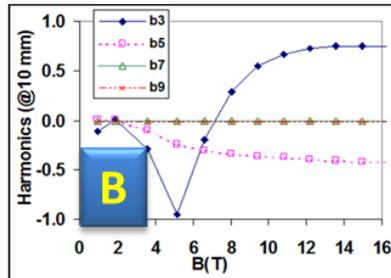
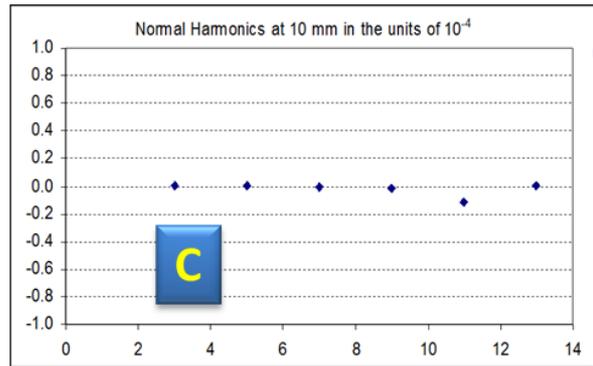
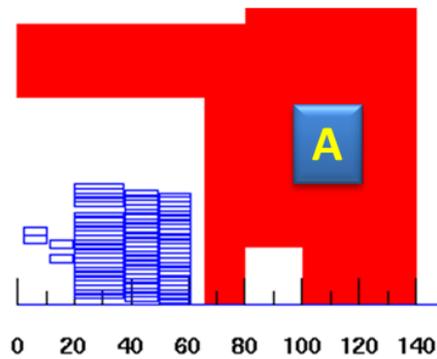
Work at BNL is cost-effective for OHEP due to the extensive infrastructure, test vehicles (magnet with gap), and funding from Nuclear Physics for facilities and staff

SUMMARY of BNL Vision and Possible Contributions to High Field Magnet Program

- Realize the advantages of common coil design: simpler conductor friendly geometry, less structure, attractive for high fields
- Demonstrate 16 T Nb₃Sn accelerator quality common coil dipole that can be built in industry at low cost
- Develop technology of very high field (20 T or more) hybrid common coil dipole with ReBCO and Nb₃Sn coils
- Commission a new type of high background field, low cost coil test facility to try out new magnet technologies with fast turn around

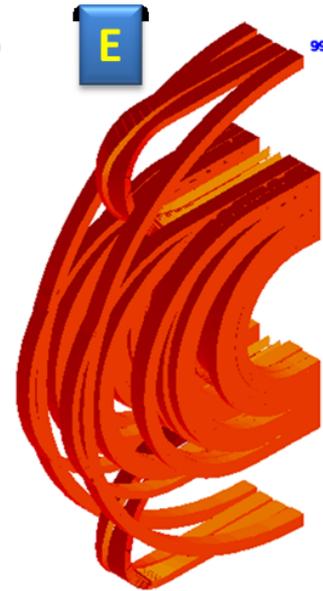
Extra Slides

Good Field Quality Common Coil Designs



MAIN FIELD: **-1.86463 (IRON AND AIR):**

b 1: 10000.000	b 2: 0.00000	b 3: 0.00308
b 4: 0.00000	b 5: 0.00075	b 6: 0.00000
b 7: -0.00099	b 8: 0.00000	b 9: -0.01684
b10: 0.00000	b11: -0.11428	b12: 0.00000
b13: 0.00932	b14: 0.00000	b15: 0.00000
b16: 0.00000	b17: -0.00049	b18: 0.00000



End harmonics in Unit-m

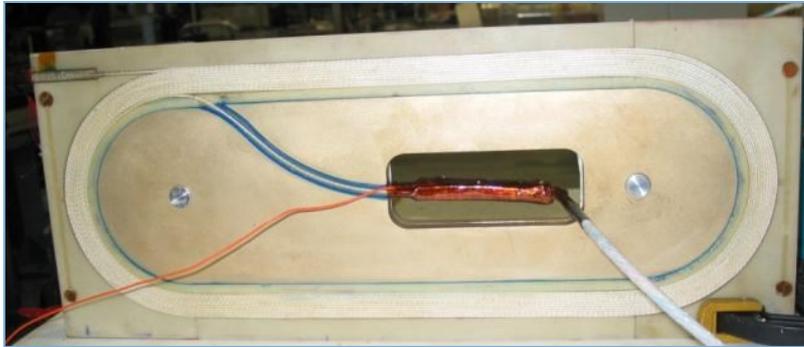
n	Bn	An
2	0.00	0.00
3	0.01	0.00
4	0.00	-0.03
5	0.13	0.00
6	0.00	-0.10
7	0.17	0.00
8	0.00	-0.05
9	0.00	0.00
10	0.00	-0.01
11	-0.01	0.00
12	0.00	0.00
13	0.00	0.00
14	0.00	0.00
15	0.00	0.00
16	0.00	0.00
17	0.00	0.00
18	0.00	0.00

Optimization for good field quality in a 15 T Nb_3Sn common coil design (coil aperture 40 mm, reference radius 10 mm).

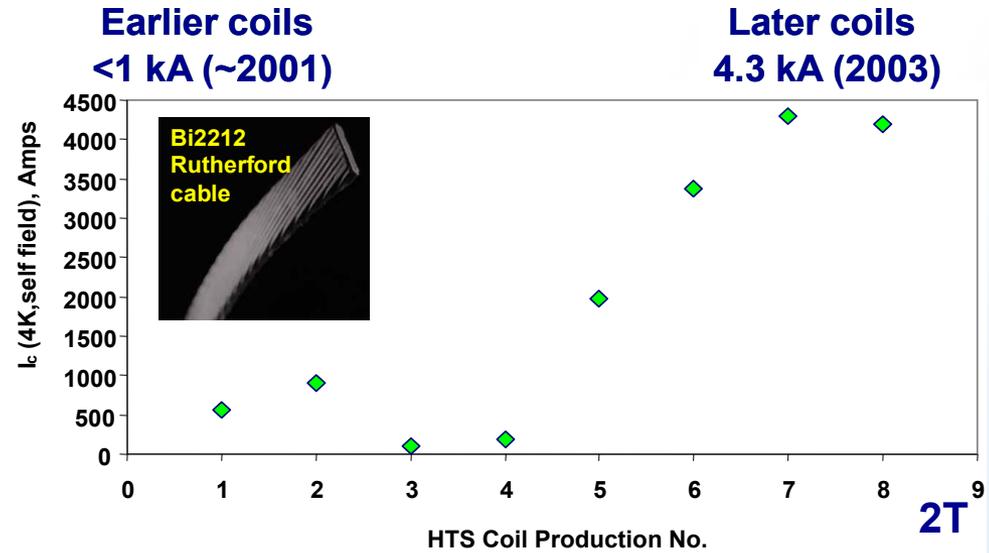
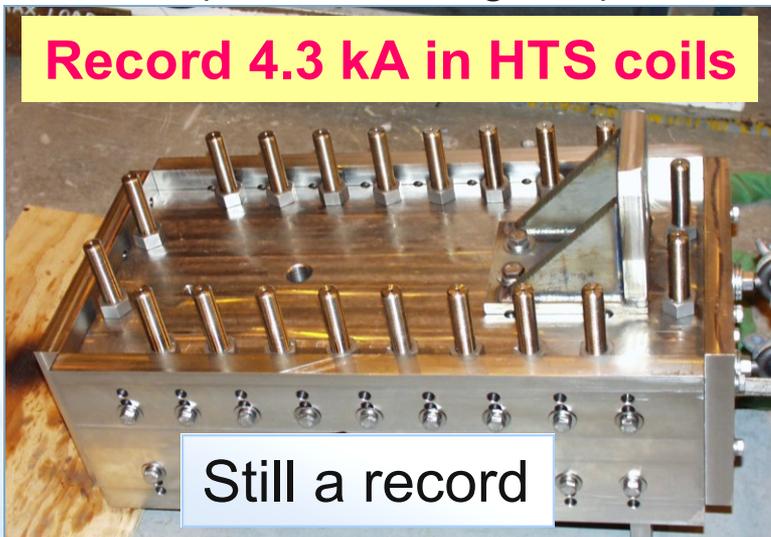
(a) 1/4 of magnet cross section in one aperture, (b) normal saturation induced-harmonics, (c) plot of geometric harmonics, (d) values of geometric harmonics, (e) optimized end geometry, and (f) end harmonics.

Prior HTS Magnet Work Under GARD

Common Coil Dipole with React & Wind Bi2212 Rutherford Cable



Bi2212 "React & Wind" coils
(8 coils, 5 magnets)



Initial goal was to insert these HTS coils in Nb₃Sn common coil dipole for a demo of hybrid high field dipole.

Funding & work stopped ~2005