BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

High Field Magnet R&D at BNL for Future High Energy Colliders

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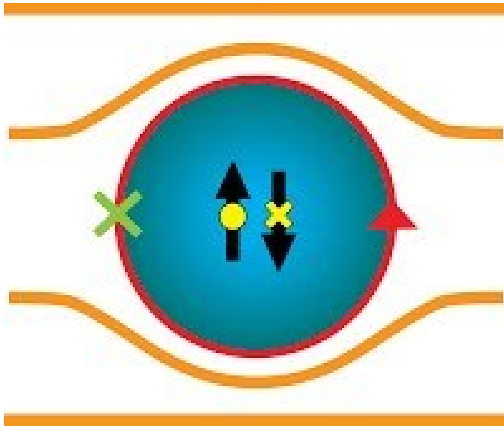
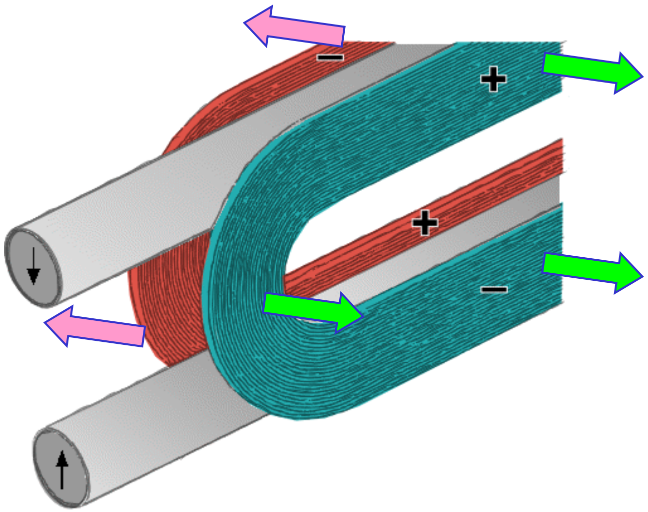
Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science



Main Features of the BNL High Field Magnet R&D Program

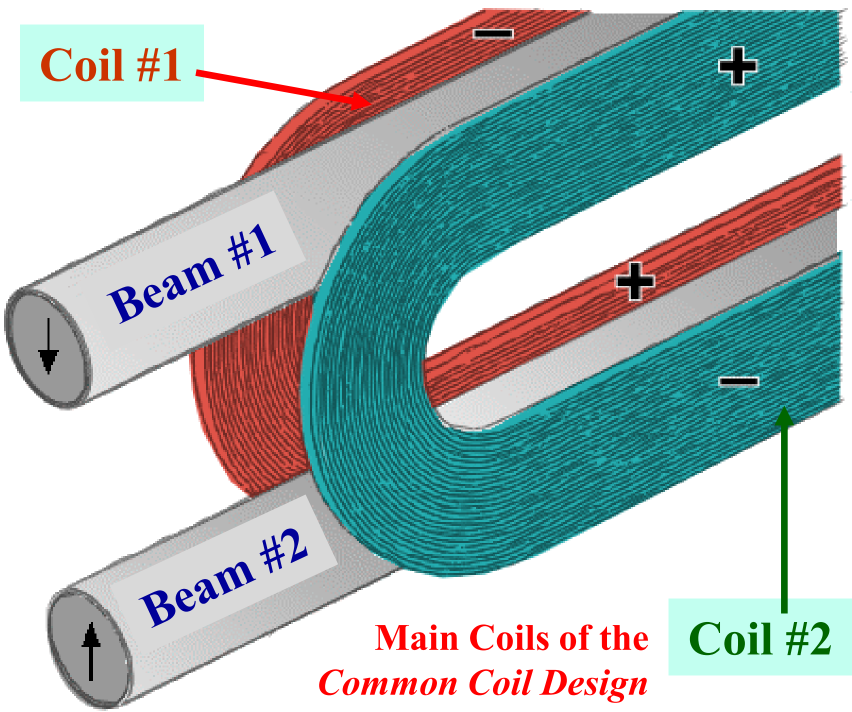
- Common Coil Design



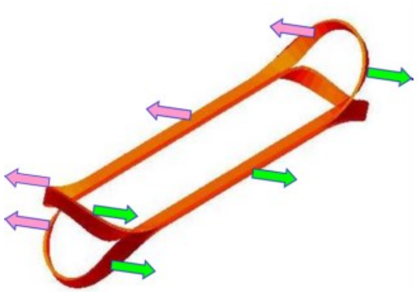
- Insert Coil Test Facility

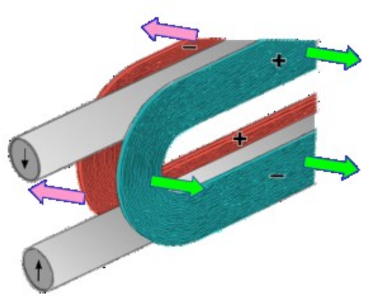
This presentation focuses on why and how?

Common Coil Design (Summary of Benefits)



Main Coils of the *Common Coil Design*





- **Simple 2-d coil geometry for colliders**
- **Fewer coils (about half) as the same coils are common between the two apertures (2-in-1 geometry for both iron and coils)**
- **Conductor friendly - large bend radii with simpler ends allowing many new options**
- **Block design with lower internal strain on the conductor under Lorentz forces**
- **Savings from less support structure**
- **Easier segmentation for hybrid designs (Nb_3Sn & NbTi and possible HTS?)**
- **Minimum requirements on big expensive tooling and labor**
- **Potential for producing lower cost, more reliable (less margin) high field magnets**
- **Efficient and rapid turn around magnet R&D due to simpler and modular design**

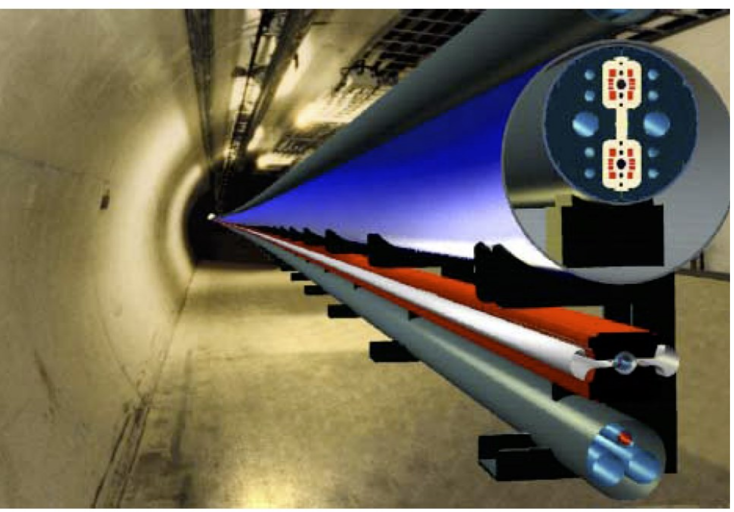
Brief History of Common Coil

Very Large Hadron Collider

SLAC-R-591
Fermilab-TM-2149
June 4, 2001

Design Study for a Staged Very Large Hadron Collider

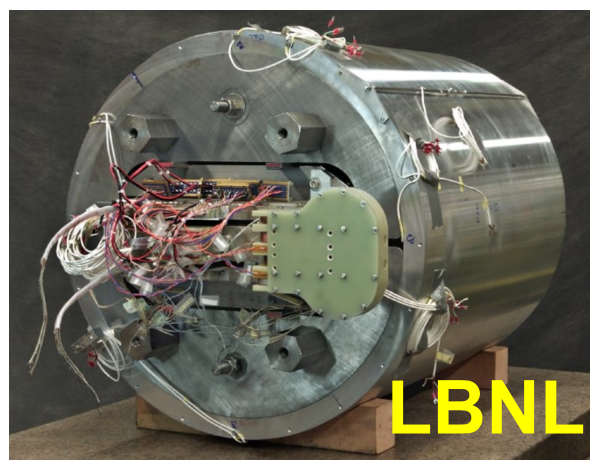
Report by the collaborators of
The VLHC Design Study Group:
Brookhaven National Laboratory
Fermi National Accelerator Laboratory
Laboratory of Nuclear Studies, Cornell University
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
Stanford University, Stanford, CA, 94309

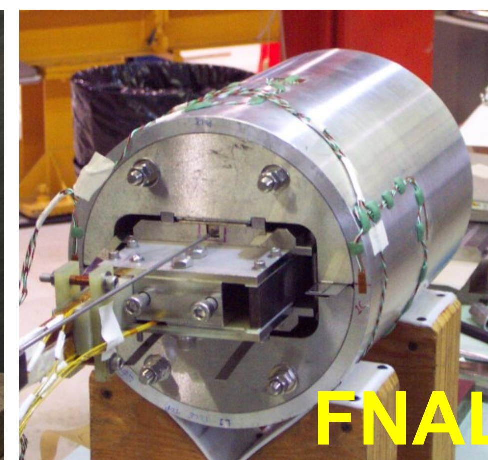


Work supported in part by the Department of Energy contract DE-AC03-76SF00515.

- R&D magnets built at LBL, BNL and FNAL
- Started the culture of fast turn-around R&D
- Base line design for VLHC; also for SppC

Work stopped after a few years for reasons other than the failure of the design





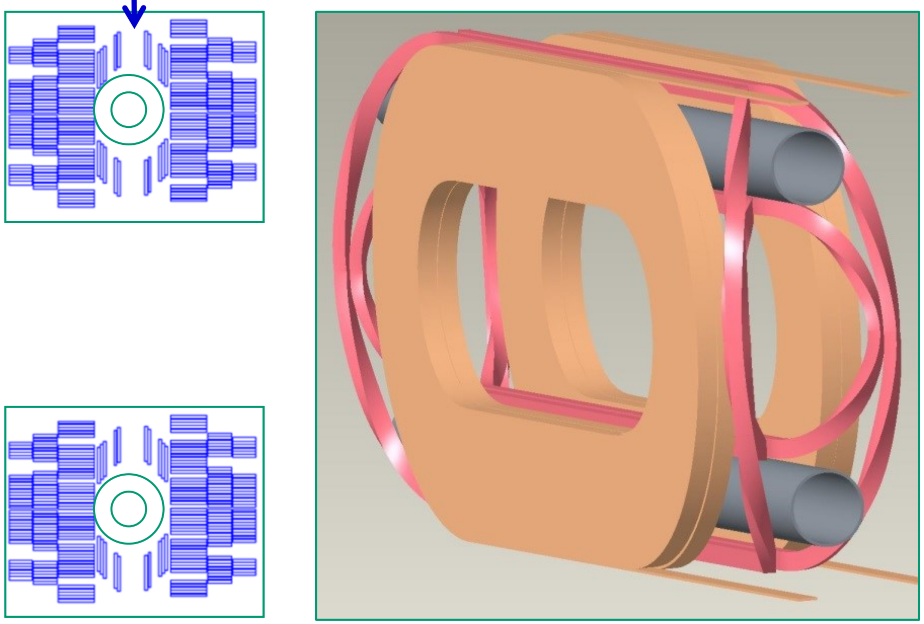
Remains to be Demonstrated Accelerator-type Field Quality

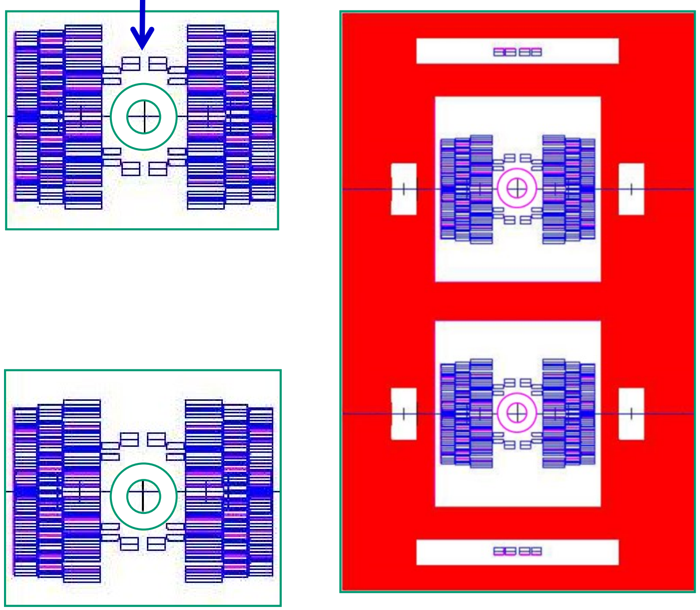
- Require "pole coils" which must clear the beam tubes in the ends

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

OR

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

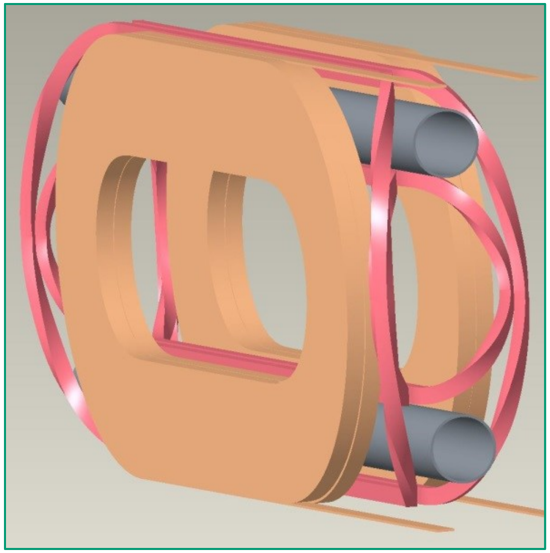


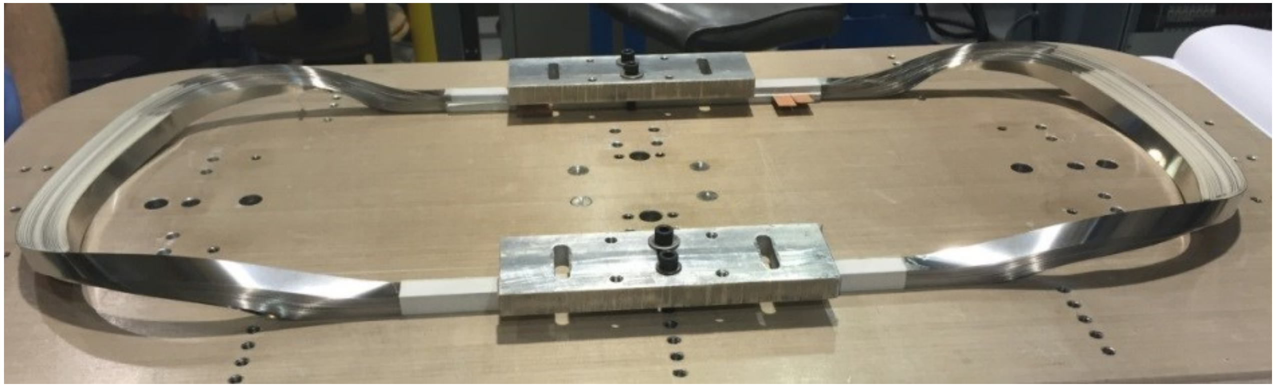


Good field quality have been shown in computer models but not yet demonstrated in a model magnet with added (minor) complication

Proposal with PBL to Demonstrate Nb_3Sn Proof-of-Principle Common Coil Dipole

- **Build Nb_3Sn pole coils and insert and test them inside the existing BNL Nb_3Sn common coil magnet with large open space**
- **Can be done within the budget of SBIR/STTR as the magnet doesn't have to dis-assembled**
- **These insert coils become an integral part of the magnet and run in series with other coils**

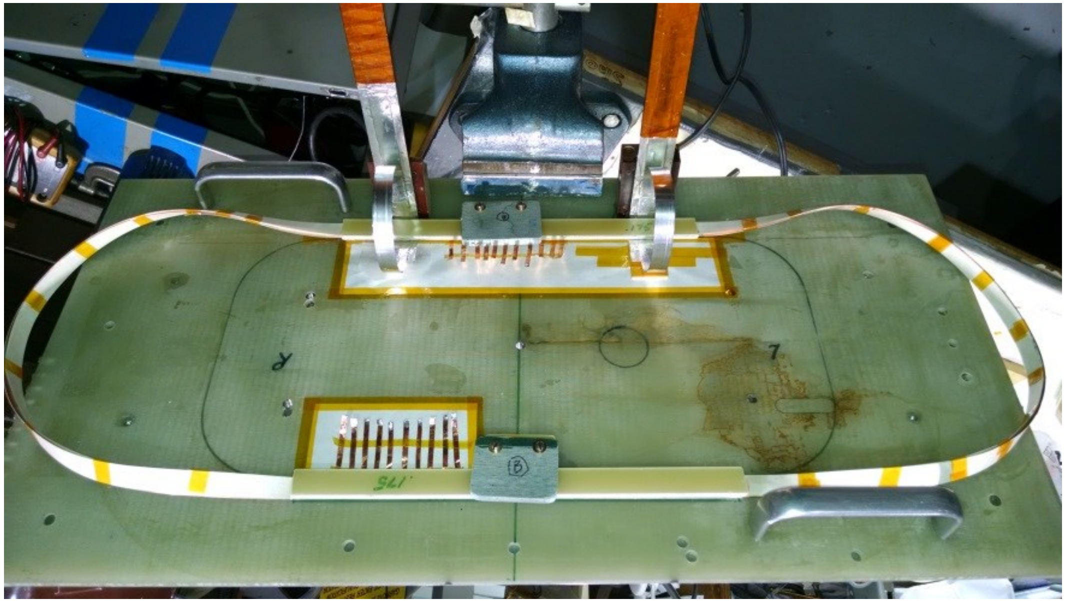




Made as a part of another PBL/BNL program

Plan to use 3-d printed parts to develop ends

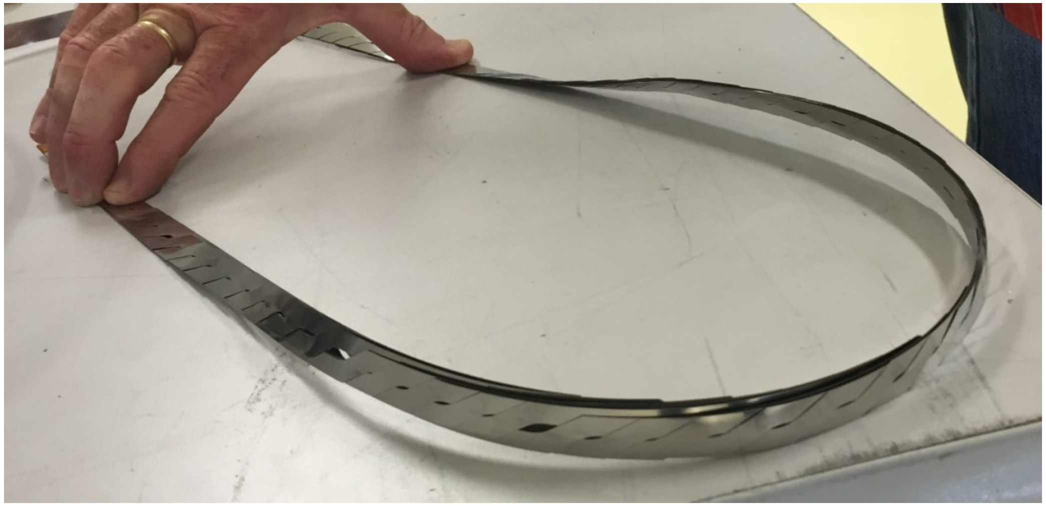
HTS Coil Winding



77 K Test (PBL/BNL STTR)

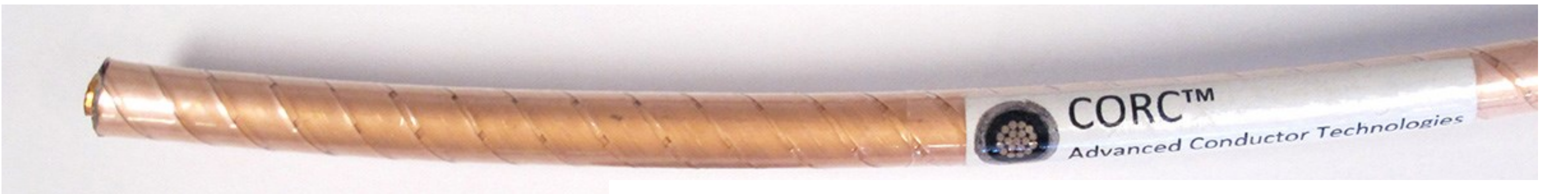
Over 350 A (No degradation)

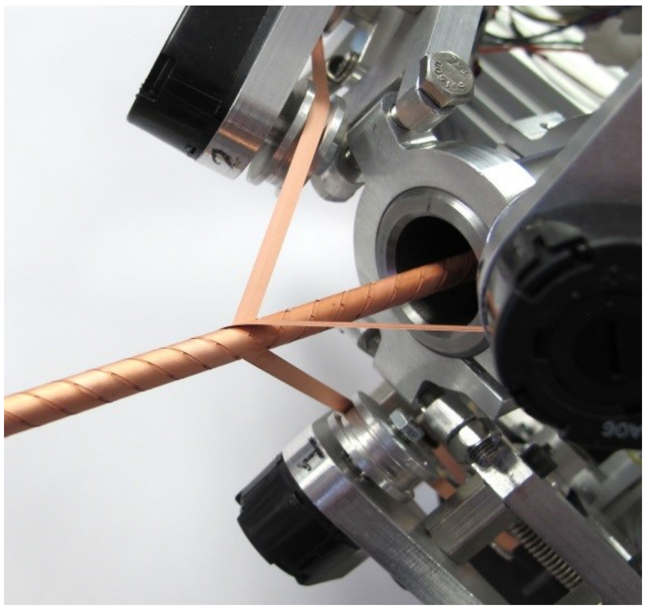
See test results of 2G coil in the poster tomorrow

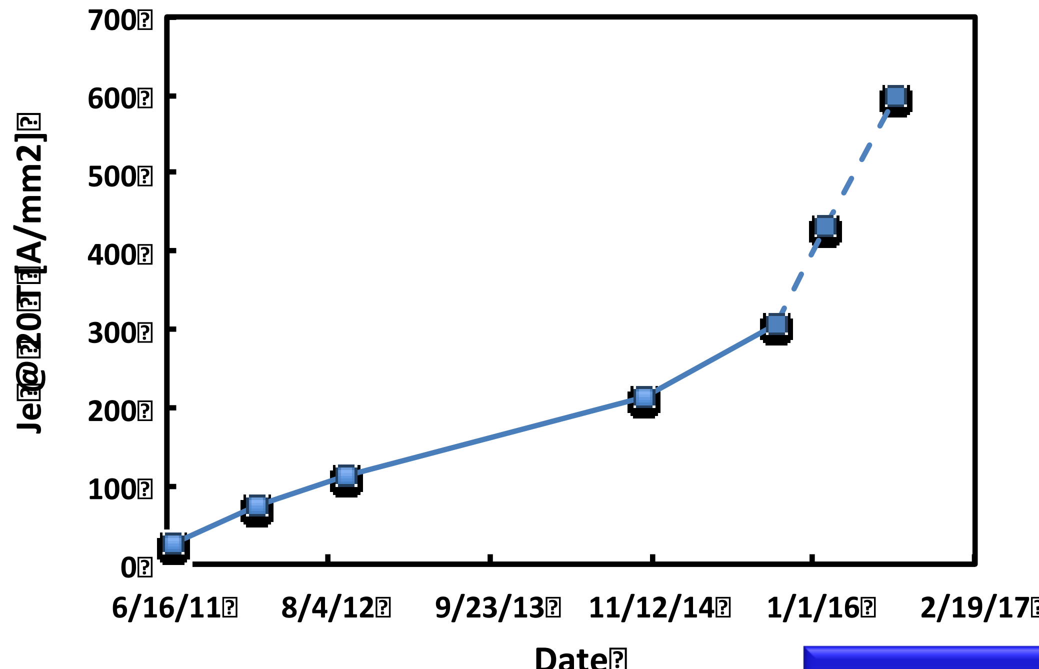


Also works for Roebel cable (large bend radii, bend in easy way, properly aligned)

Promising CORC® Cable
High Je, High Ic





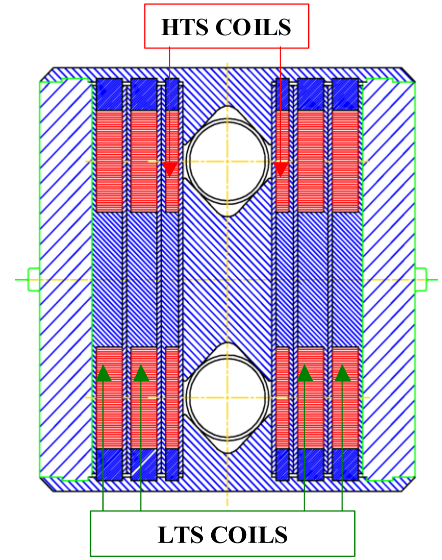


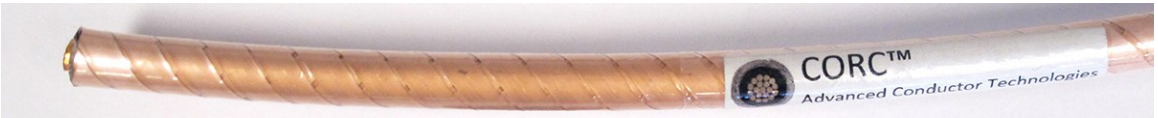
WOW!

- ➢ J_e of >600 A/mm^2 at 20 T for 10 kA cable next year?
- ➢ J_o of ~1000 A/mm^2 at 20 T for 20 kA cable in a few years?

High Current CORC® Cable in Accelerator Magnets

- High I_c, High J_e CORC® cable requires large bend radii - Common coil design allows that
- We propose HTS CORC® cable coil powered in series with LTS Rutherford cable coil
- Easier operation, easier protection – reasonable inductance (high current)
- Partially transposed CORC® cable also helps in reducing magnetization-induced field errors associated with the high strength ReBCO tape
- Proof-of-principle dipole with HTS insert running in series with Nb_3Sn BNL Common coil dipole within the budget of Phase II



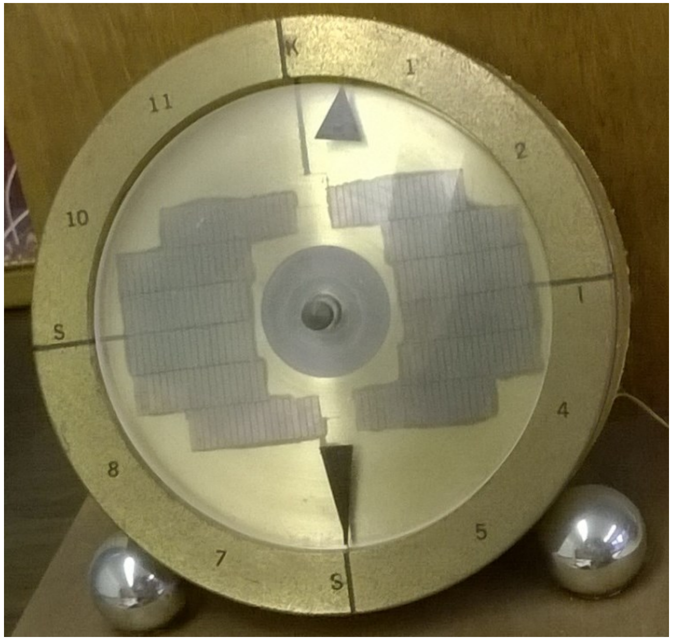


Single Aperture Block Coil

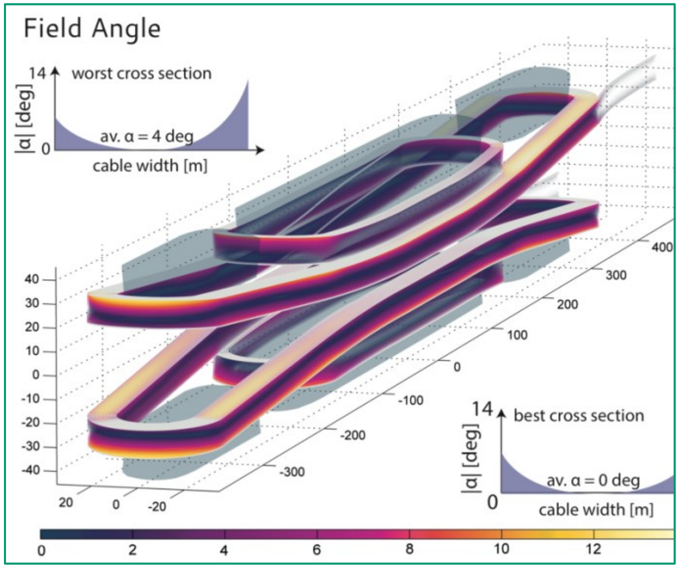
Phase I SBIR with e2P

Novel High Field Hybrid Dipole Magnet

Ends of Single Aperture Block Coil Design with Rutherford Cable



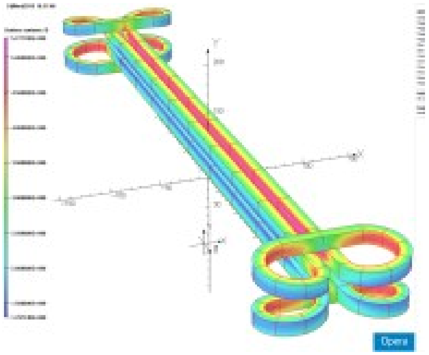
- **Cross-section is OK but the design gets complicated in the end region with bend of cable in hard direction – lifted ends to clear the tube, long length, reverse bend.**
- **The performance of such magnets often gets limited by the end region**



Freeway Overpass/UnderPass Ends

To understand it, imagine driving on high way

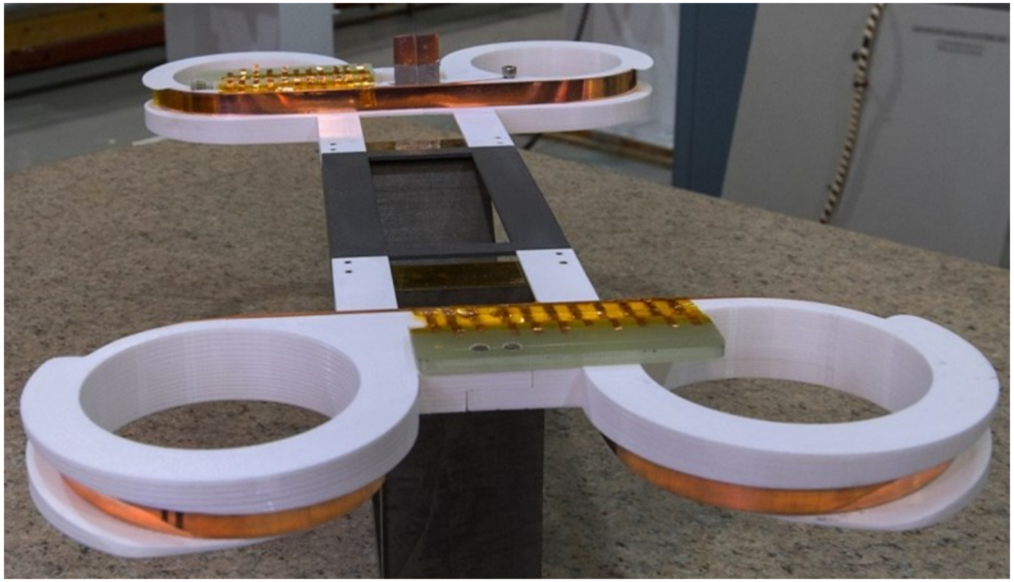
- **No hard-way bend**
- **No reverse bend**
- **Less strain – conductor friendly design**
- **Less axial space**

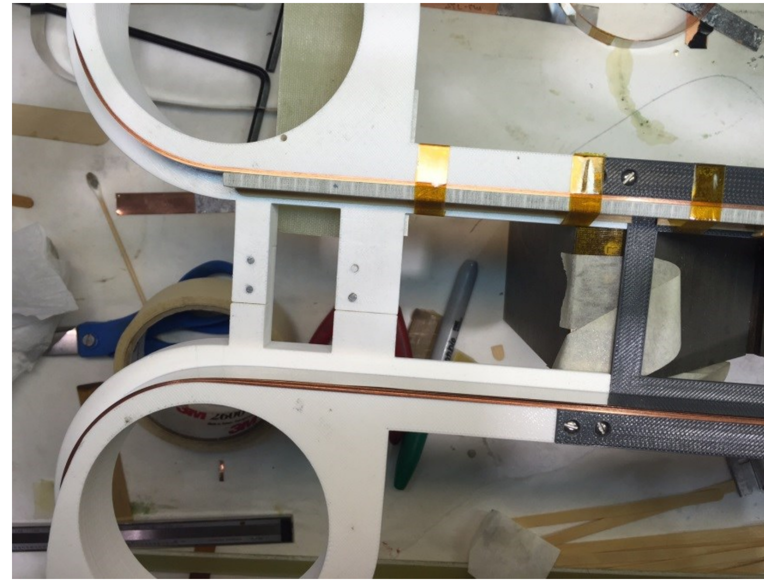


An Innovative design which could possibly bring a novel solution to an issue spanning over decades

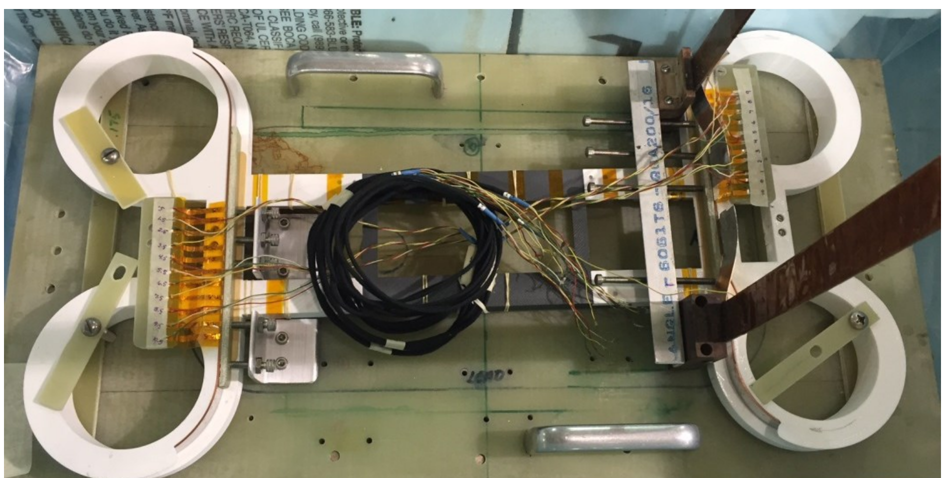
- **Thank you SBIR**

Actual Demonstrations in Phase I
(e2P poster for another coil)

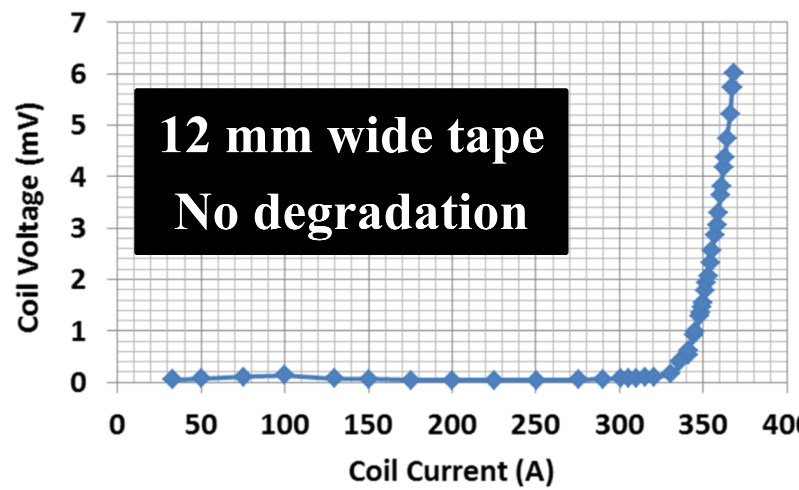




Courtesy 3d printer

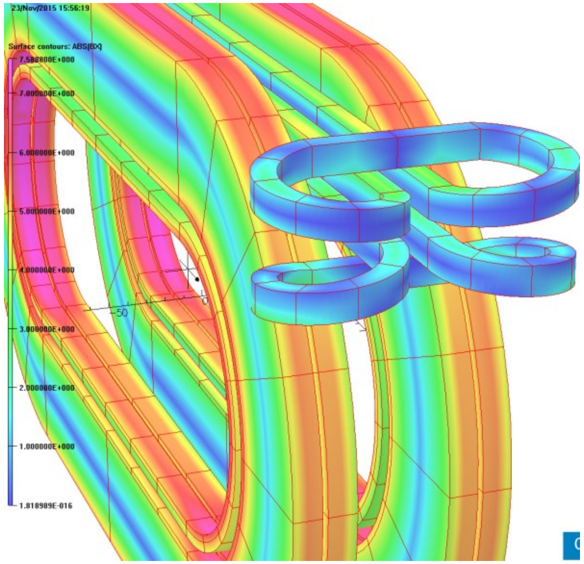


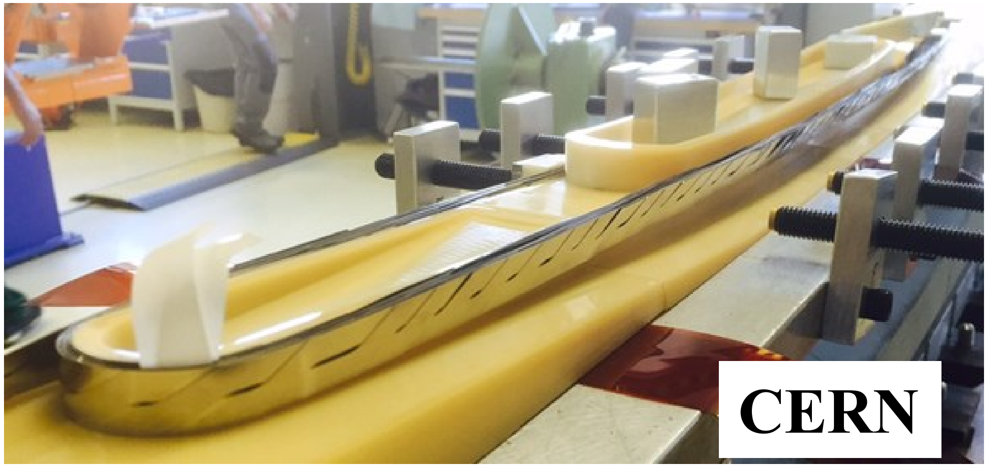
77 K Test Results



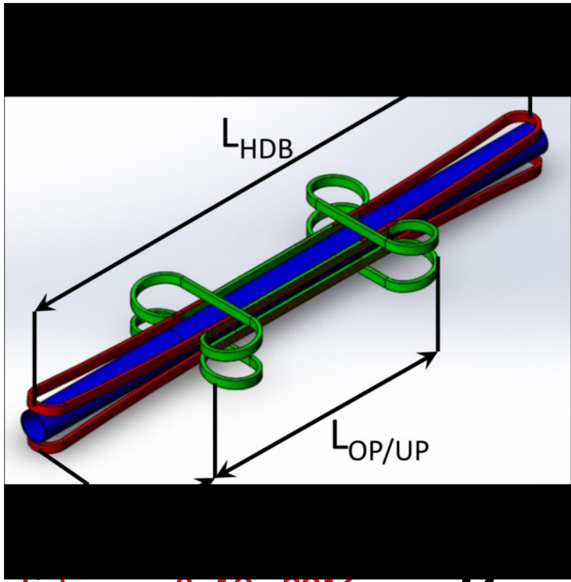
Future Possibilities

- A successful demonstration of this technology will open the door for many new possibilities
- In HEP high field magnets, it can be used for Roebel (CERN) with field in right direction
- It can also be used in Nb_3Sn magnets
- Phase II for more automated coil winding & insert high field coil testing inside BNL dipole





Please visit e2P/BNL Posters



SUMMARY

- Racetrack coil/common coil design for Nb_3Sn and HTS (particularly ReBCO) offer technically attractive options for future high field magnets.

- US should continue to maintain its leadership and remain in play with this option with small investment from whatever source(s) possible.

Extra Slides

HTS Coils Test Results

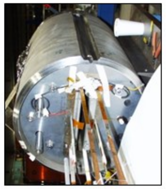
R. Gupta, M. Anerella, A. Ghosh, W. Sampson, J. Schmalzle & P. Wanderer, BNL; D. Larson, J. Kolonko, R. Scanlan, B. Weggel & E. Willen, PBL; C. Rey, e2P; S. Kahn, R. Johnson, Muons, Inc.; D. Doll, M. Rindfleisch & M. Tomsic, HyperTech; M. Sumpstion, OSU; and Y. Semertzidis, IBS

BNL Collaborators (mostly SBIR/STTR):

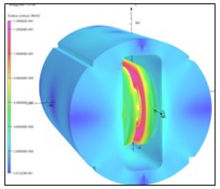
PBL; e2P; Muons, Inc.; HyperTech; IBS

POSTER TOMORROW

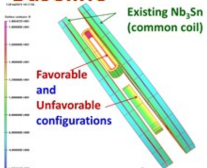
A Hybrid HTS/LTS Superconductor Design for High-Field Accelerator Magnets, PBL, DOE/HEP STTR Phase II

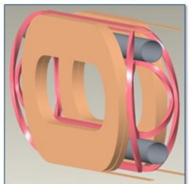


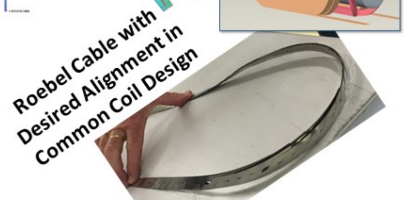
Baseline



Alternate



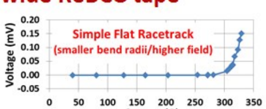


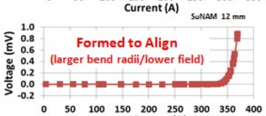


Baseline

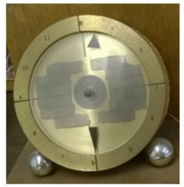
Alternate

77 K test to examine degradation, if any, with 12 mm wide ReBCO tape





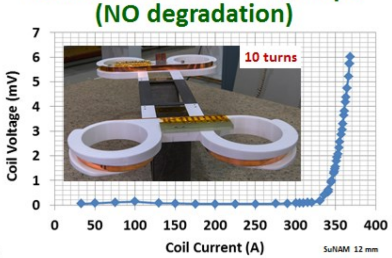
Novel High Field Hybrid Dipole Magnet, Energy-to-Power Solutions (e2P), DOE/HEP SBIR Phase I



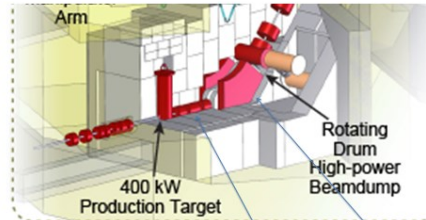
- Block designs with racetrack coils in the cross-section
- But ends of Rutherford cable magnet generally complicated
- Lifted ends, long length, reverse bend – generally limiting the performance

New Overpass/Underpass Design (Compact, NO hard-way lifting, NO reverse bend, low peak field

Test Results with ReBCO Tape (NO degradation)

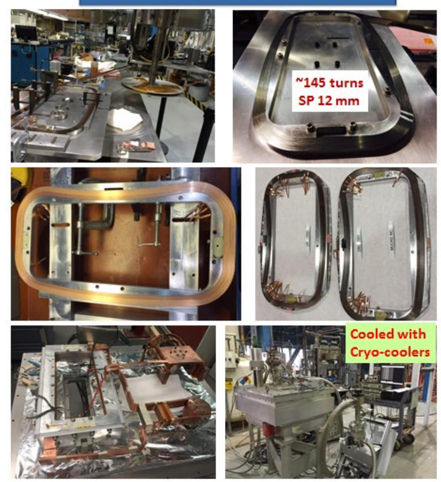


High Radiation Environment Nuclear Fragment Separator Magnet, Muons, Inc., DOE/NP STTR Phase II

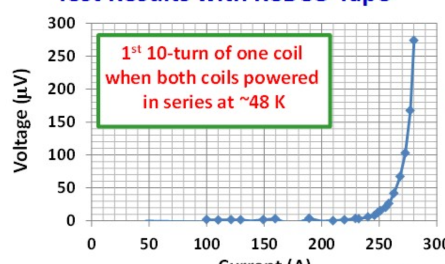


Radiation resistant Quads and dipole

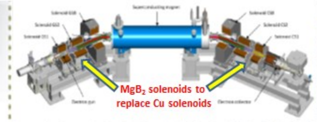
Dipole with Curved Coils

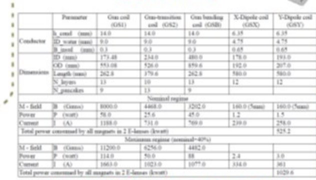


Test Results with ReBCO Tape

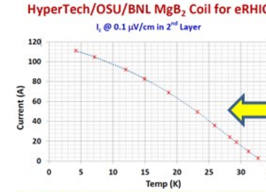


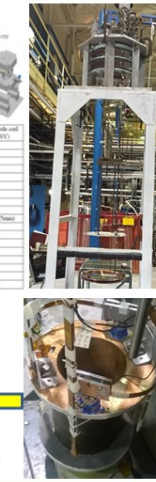
Development of MgB_2 Superconducting Coils for Nuclear Physics Applications, HyperTech, DOE/NP SBIR Phase II



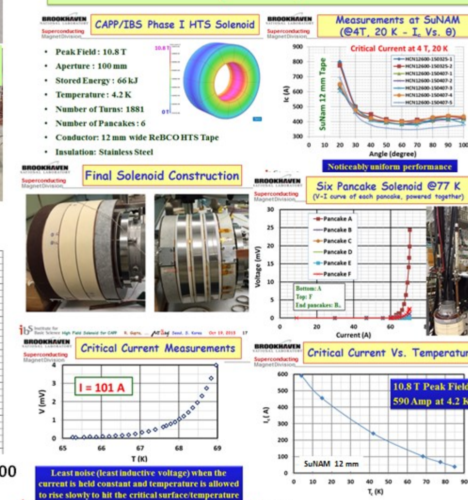


HyperTech/OSU/BNL MgB_2 Coil for eRHIC





High Field Solenoid Development for Axion Dark Matter Search at CAPP/IBS, KIST, Korea, WFO



BNL and the US Magnet Program

- BNL is the only national lab in US that has a significant size operating superconducting circular collider
- BNL is the most recent national laboratory in the US that has successfully built a significant quantities of superconducting magnets both with industry and in-house
  - These magnets have been cost-effective, reliable and have met or exceeded all requirements (magnetic, mechanical, cryogenic, electrical, etc.)
- BNL has also been taking bold steps in starting new R&D (HTS magnets, common coil design, etc.) - such steps often bring major changes in cost-performance matrix

BNL brings a unique insight and promise to the table for developing reliable and lower cost superconducting magnets. The collaboration and DOE should benefit from taking advantage of the asset it has.