OverPass/UnderPass (Clover-leaf) End Design for Block Coil Dipoles

MDP 20 T Design Study Meeting on June 30, 2020

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for PBL/BNL Collaboration

U.S. MAGNET DEVELOPMENT PROGRAM

Contents

Alternate End Design for Block Coil Dipoles

- Why
- What
- Progress and Plans
  - Proof-of-Principle test with dual goals
- Challenges

Introduction

- Block coil designs have many attractive features in the cross section due to their simplicity, easy to segment coils in hybrid dipoles and structure to manage the Lorentz forces in high field magnets
- The ends of certain coil blocks, however, don't remain simple (some had reverse bends as well). They also get longer. Moreover, the ends + transition regions have often limited the magnet performance

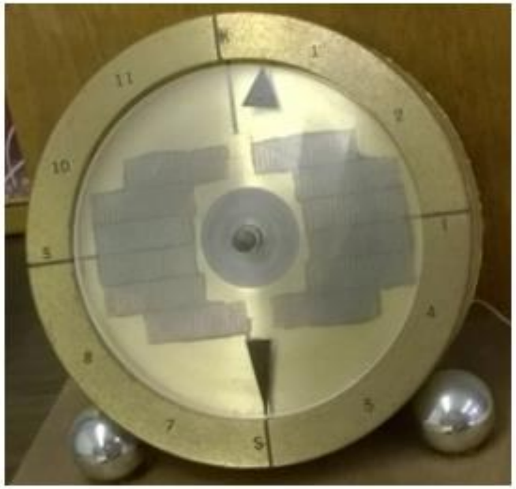


Figure 2: Nb_3Sn block coil dipole with cross-section (left) and lifted ends (right).

Single Aperture Dipoles (lifted ends to clear the beam tube)

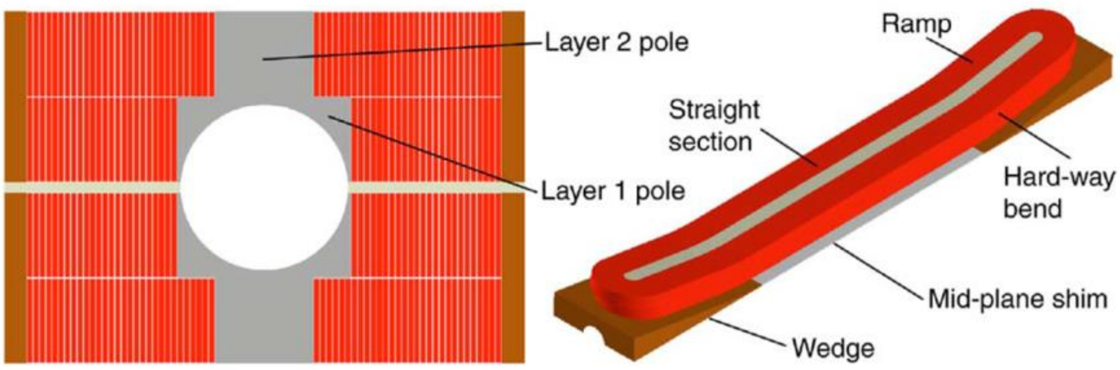
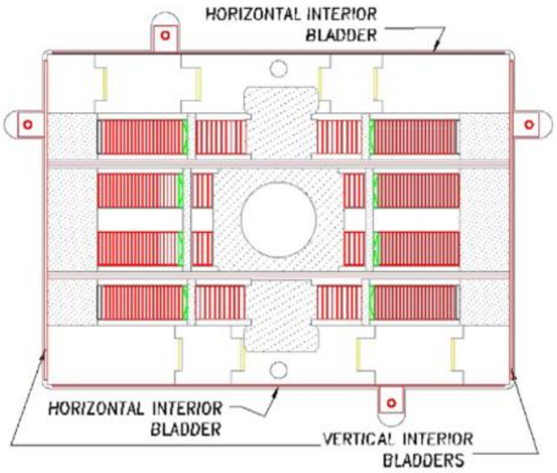


Figure 3: Block coil dipole HD2 designed, built and tested at LBNL.



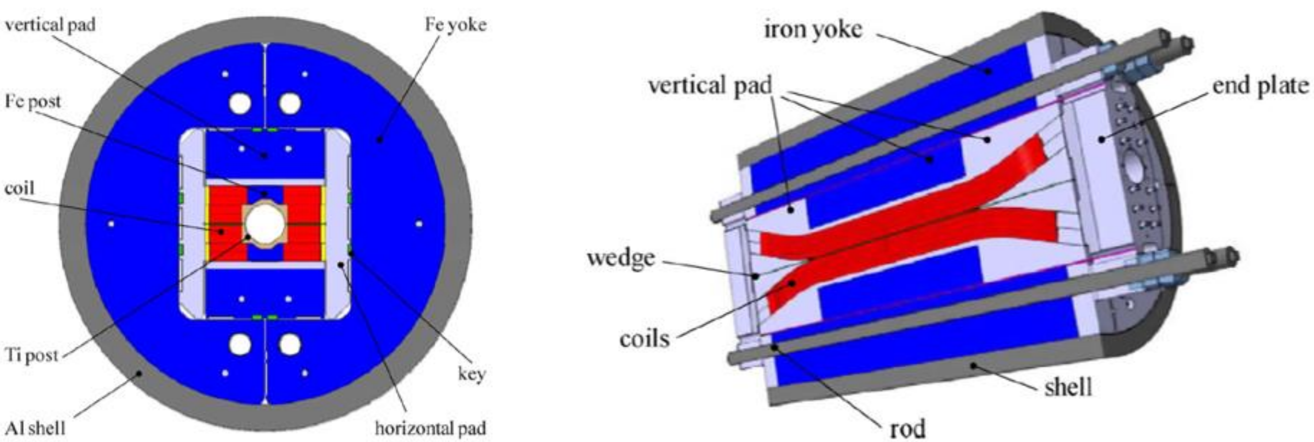
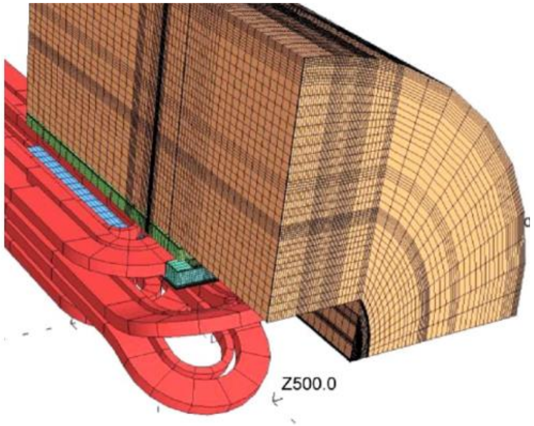


Figure 4: Block coil dipole FRESCA2 built at CERN.



Block coil dipole design at Texas A&M.

Dipoles for Colliders (some blocks must still be lifted in hard direction to clear the bore)

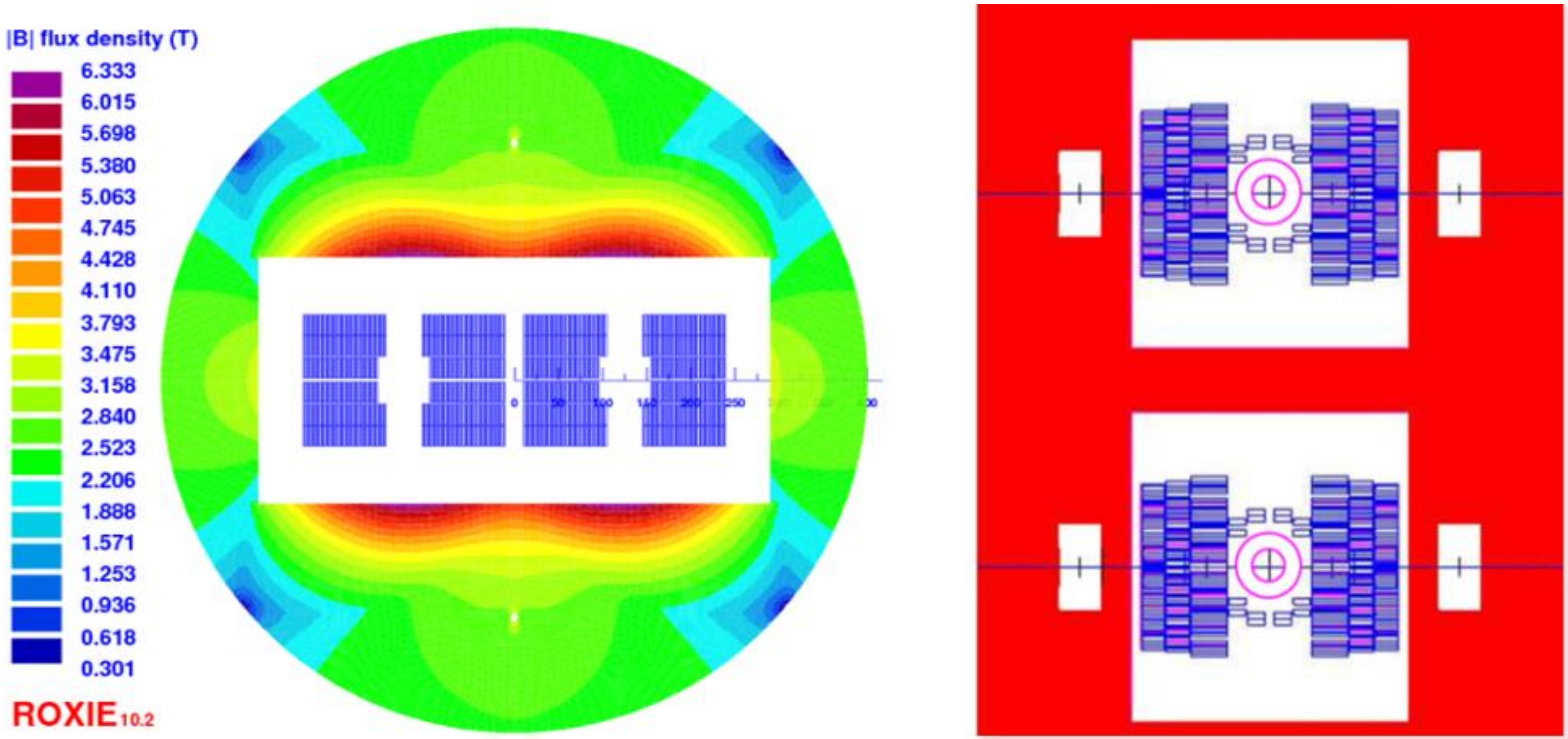


Figure 1: Cross-sections of European 2-in-1 block coil and U.S. 2-in-1 common coil designs.

Overpass/UnderPass End Design

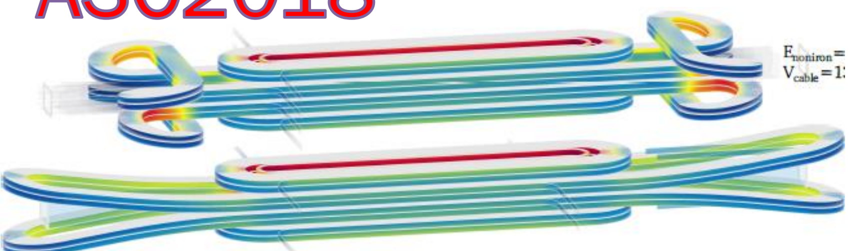
To visualize, imagine driving on a highway when you have to go back

- No reverse or hard way bend
- Conductor friendly design – less strain (primarily tilt)
- Less axial length of ends
- Useful for block coil designs

Rutherford Cable

Freeway Overpass/UnderPass (or clover-leaf) End Design

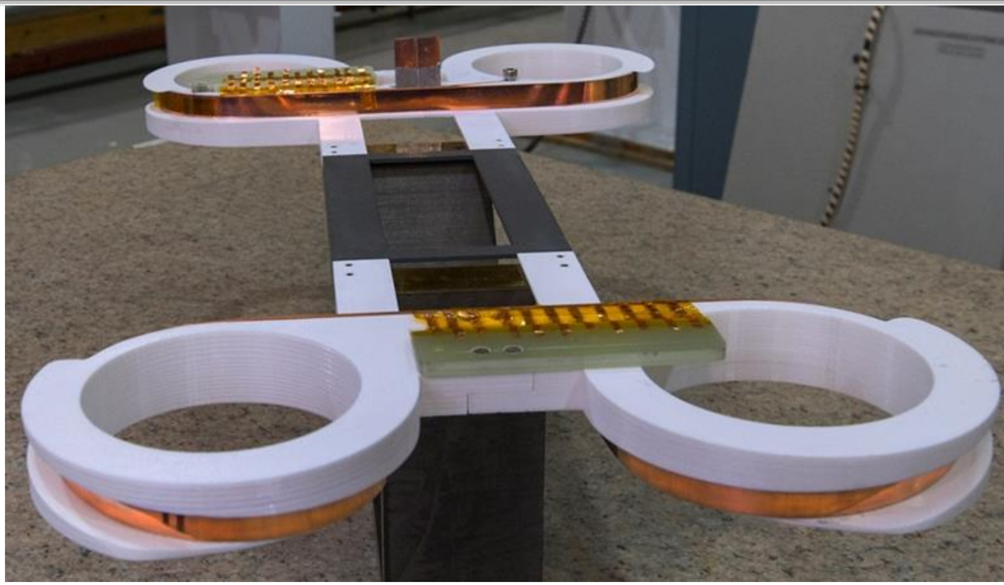
ASC2018

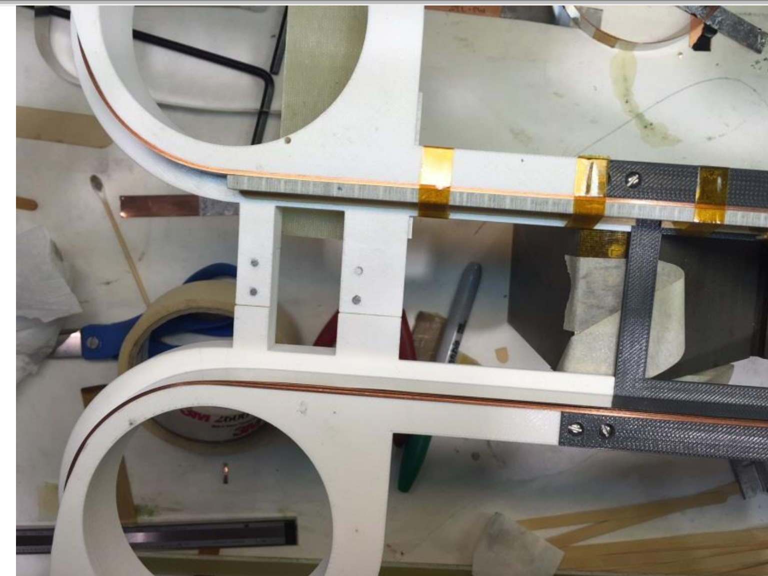


CERN

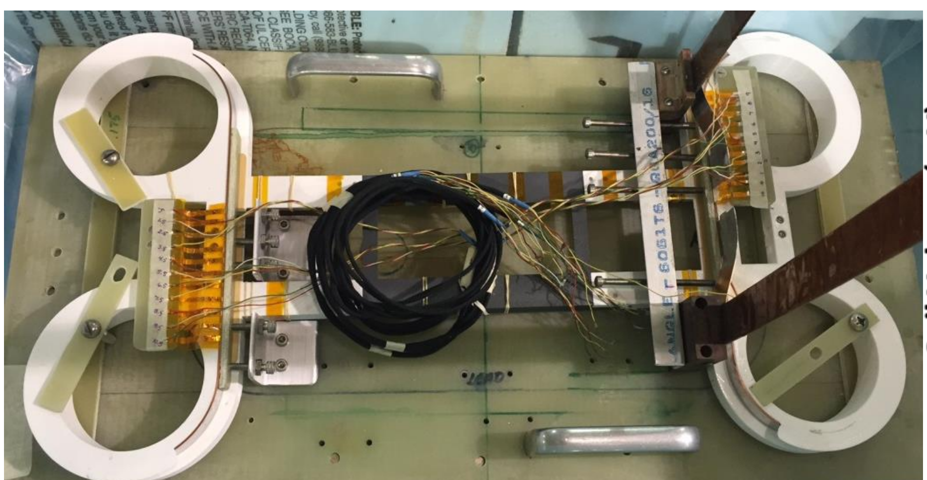
- Presented at ASC 2002
- Design attractive for the HTS and for the block coil dipoles
- SBIR Phase I with e2P in 2015
- *HTS* test coil wound in Phase I and produced good technical results
- CERN picked it up, made large invested and made significant progress - part of the 20 T design
- STTR Phase I with PBL in 2020
- Proof-of-principle *Nb_3Sn* demo in Phase II with common coil dipole

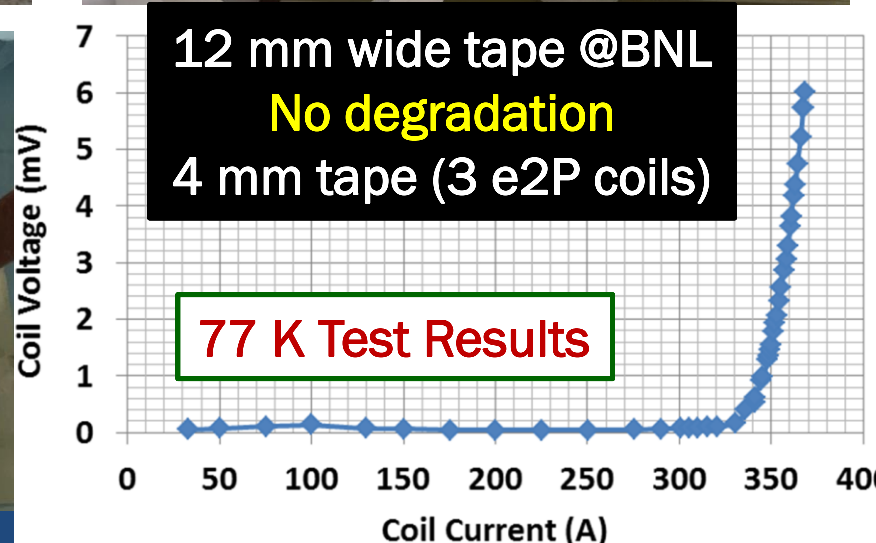
Demonstrations of the HTS Coils with Overpass/Underpass Design with SBIR





Courtesy 3d printer





Overpass/underpass clover-leaf design

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CERN

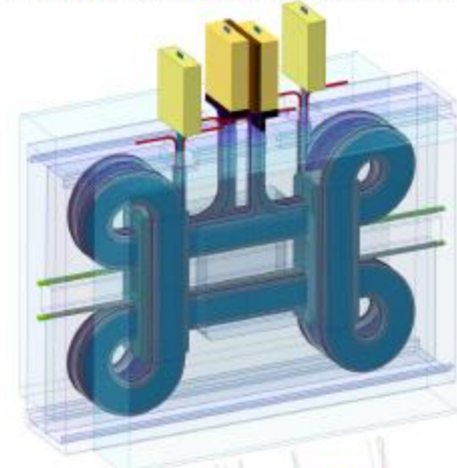
ASC SEATTLE 2018
SEATTLE, 2018 OCTOBER 28 - NOVEMBER 2

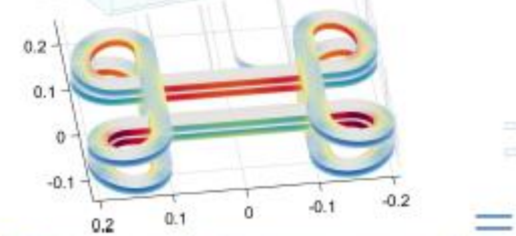
Design and Optimization of a Full HTS Accelerator Dipole for Achieving Magnetic Fields Beyond 20T

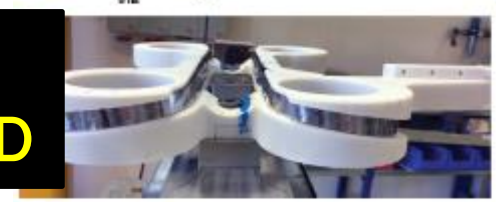
J. van Nugteren, J. Murtomäki, G. Kirby, T. Nes, G. de Rijk, L. Bottura, L. Rossi

9. Cloverleaf Prototype Magnet

Before constructing the large 20 T magnet it is planned to first construct a small coil containing most of the features of the larger magnet. This in order to attain experience with coil winding and impregnation of this relatively new geometry.







Another significant contribution of the US SBIR Program to the world wide high field magnet R&D

Similar design by wolf about a decade earlier – independent work

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Collaboration with CERN

G. Kirby
added an **update**

Jun 17

Collaboration with BNL

COVID19 has opened the door the closer collaborations with hts teams around the world.

The Cloverleaf original idea came from BNL.

2019-iwc-hts-gupta.pdf · 9.61 MB

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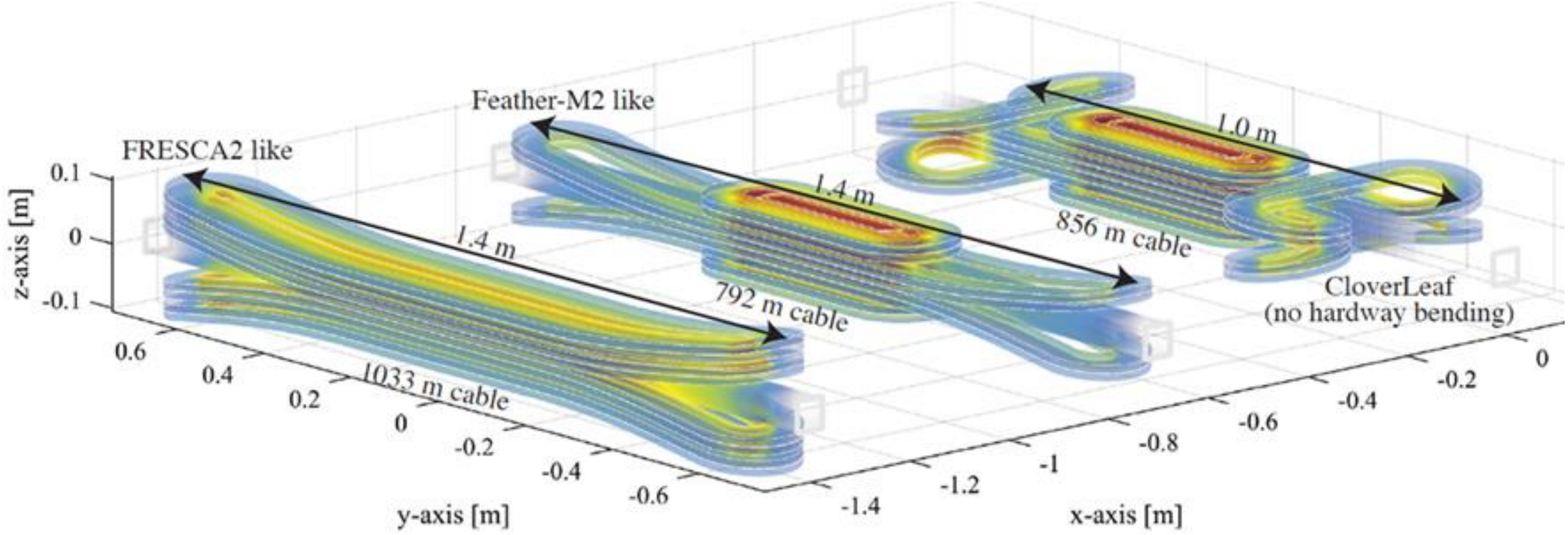
Work at CERN (1)

A comparison of the length of the ends in a coil with lifted ends (left) and a coil with overpass/underpass ends (right) to clear the bore tube



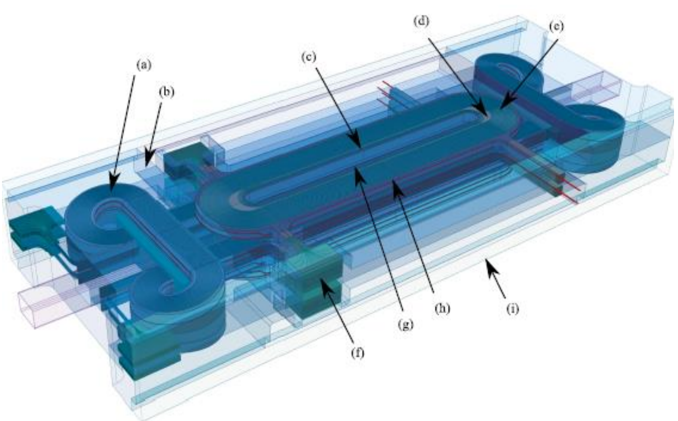
J. van Nugteren, G. Kirby, J. Murtomaki, G. de Rijk, L. Rossi and A. Stenvall, "Towards REBCO 20+ T Dipoles for Accelerators," presented at the European Conference on Applied Superconductivity (EUCAS 2017), September 2017

Work at CERN (2)

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 29, NO. 5, AUGUST 2019 4004608

3-D Mechanical Modeling of 20 T HTS Clover Leaf End Coils—Good Practices and Lessons Learned

Jaakko Samuel Murtomäki, Jeroen van Nugteren, Antti Stenvall, Glyn Kirby, and Lucio Rossi, *Fellow, IEEE*



l design of a 20 T magnet with a clover leaf end coil. (a) Clover leaf end coil (b) Top lid (c) Inner race-track coil (d) Spacer (e) Outer race ea (g) Inner cooling ring (h) External cooling ring (i) Side lid.

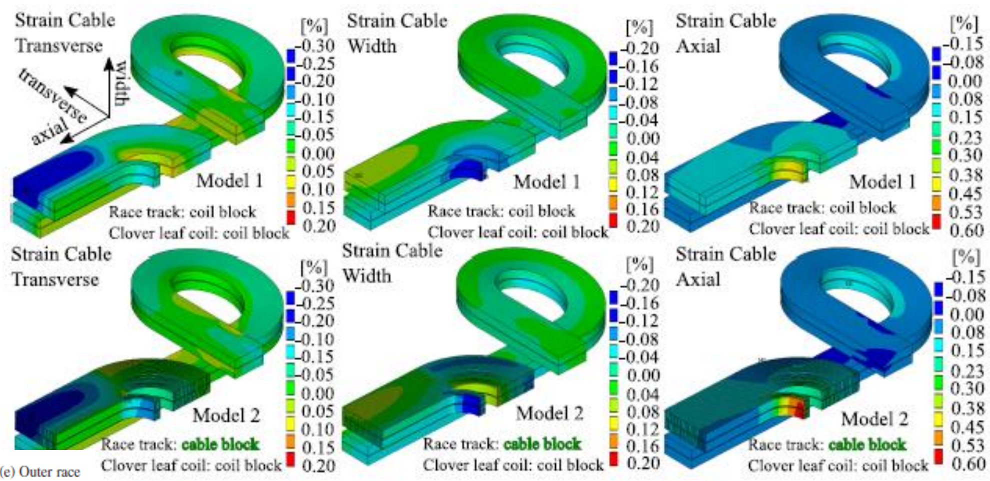
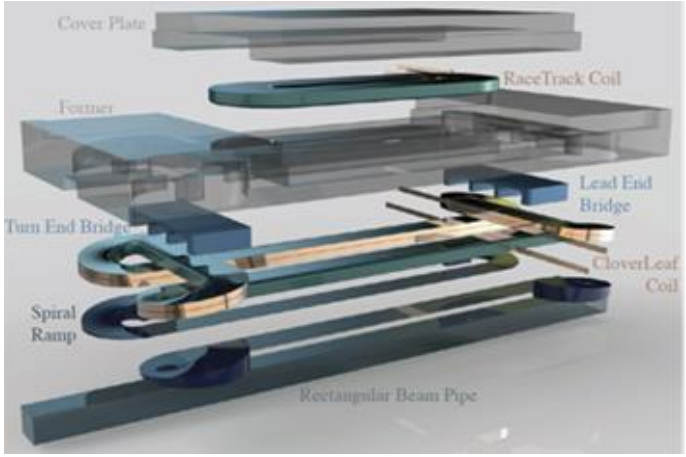
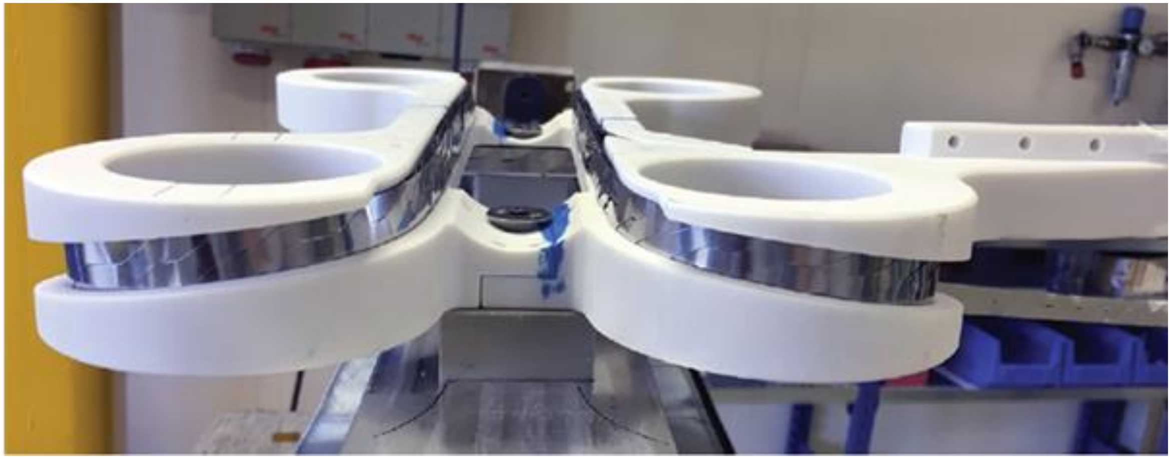


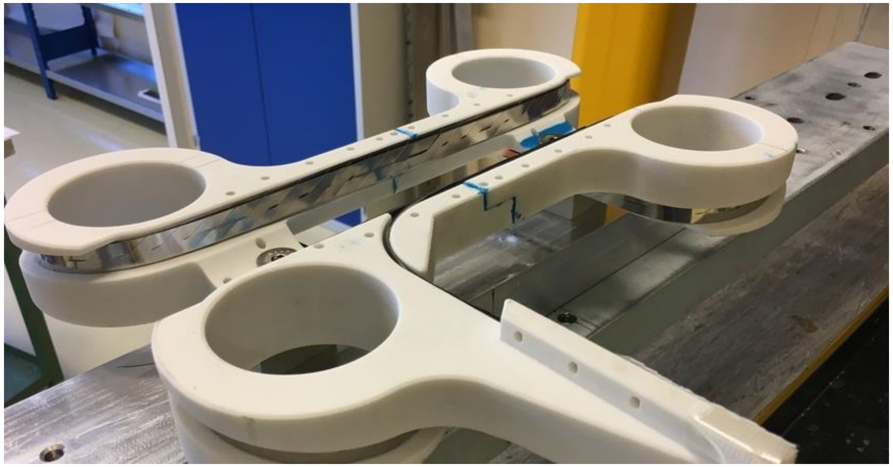
Fig. 6. Strain fields of the coils for the Model 1 and Model 2 at 20 T. The clover leaf end coil is modelled as a coil block in both the two Models, but race track is modelled as a coil block only in the Model 1. The strains are plotted in the inner surfaces of the turns for the cable block model. Coil block strains are plotted at the surface of the solid. The coil shape is plotted in undeformed state. The tapes of the race track coil in cable block model are modelled like in Case 2.

Test Coil Winding at CERN





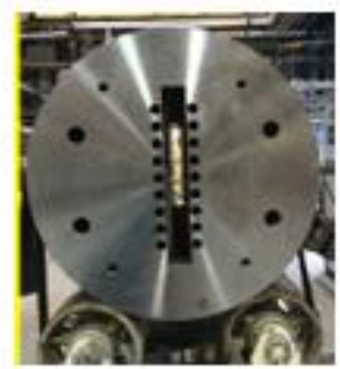
https://www.researchgate.net/project/Dipole-HTS-Magnets-at-CERN

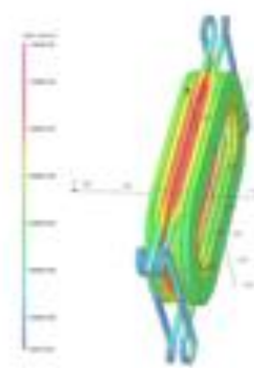


Recently Funded PBL/BNL STTR (work to start soon)

Cover Page

Company Name & Address:	Particle Beam Lasers, Inc. 8800 Melissa Court Waxahachie, TX 75167-7279
Principal Investigator:	Ramesh Gupta Brookhaven National Laboratory Upton, NY 11973
Project Title:	Overpass/Underpass coil design for high field dipoles
Topic No: 33	Superconductor Technologies for Particle Accelerators
Subtopic: (b)	Superconducting Magnet Technology





PBL Team

Current staff of Particle Beam Lasers, Inc. (PBL)

- James Kolonko (President)
- Delbert Larson (Vice President)
- Steve Kahn (Senior Engineer, BNL retiree)
- Ron Scanlan (Senior Scientist, LBNL retiree)
- Bob Weggel (Senior Engineer, MIT retiree)
- Erich Willen (Senior Scientist, BNL retiree)

Previous participants

- Bob Palmer (BNL)
- David Cline (UCLA)
- Harold Kirk (BNL)
- Al Garren (LBL)
- Shailendra Chouhan (FRIB)

PBL/BNL team has worked on several SBIRs/STTRs and has made important contributions in areas such as high field HTS solenoid, common coil dipole, hybrid dipole, open midplane dipole, etc.

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TASKLIST

- **Perform 2-d and 3-d magnetic design for the proof-of-principle Nb_3Sn dipole**
- **Perform 2-d and 3-d mechanical design for the proof-of-principle Nb_3Sn dipole**
- **Perform coil winding test**
- **Perform mockup assembly test**
- **Selection of conductor and cable for the proof-of-principle magnet**
- **Plan for proof-of-principle tests in Phase II**
- **Develop a conceptual design for the assembly and test of the overpass/underpass coils in the proof-of-principle dipole**
- **Develop a conceptual design of a 16 T, 50 mm aperture dipole for a future proton collider and a background field test facility magnet for HEP and FES**
- **Phase I Final Report and identify the key components for a Phase II proposal**

(PBL welcomes participation and collaboration with all USMDP partners)

Goal of Phase II, if funded (1)

Insert coil test in BNL DCC017 for a "Proof-of-Principle" demonstration of (a) overpass underpass end design (b) Field quality common coil design

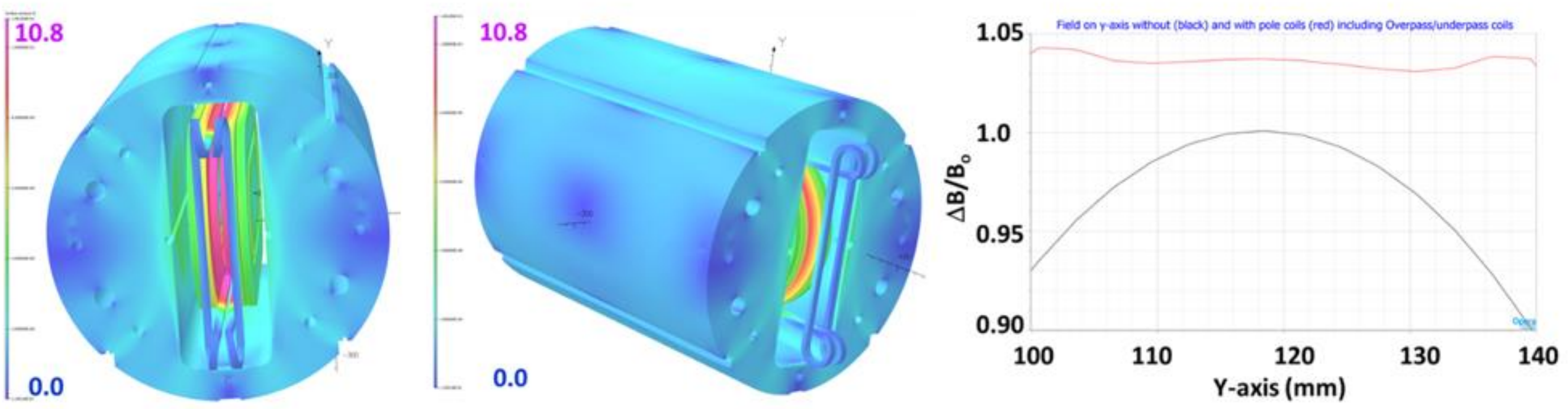


Figure 10: Initial magnetic model (left and middle) with magnetic field superimposed over the coils and the yoke of the BNL common coil dipole DCC017 with field shaping coil which include overpass/underpass coils (proposed to be built in Phase II). Improvement in field uniformity is clear from the picture on the right where the relative field uniformity is plotted with (above) and without field shaping coils.

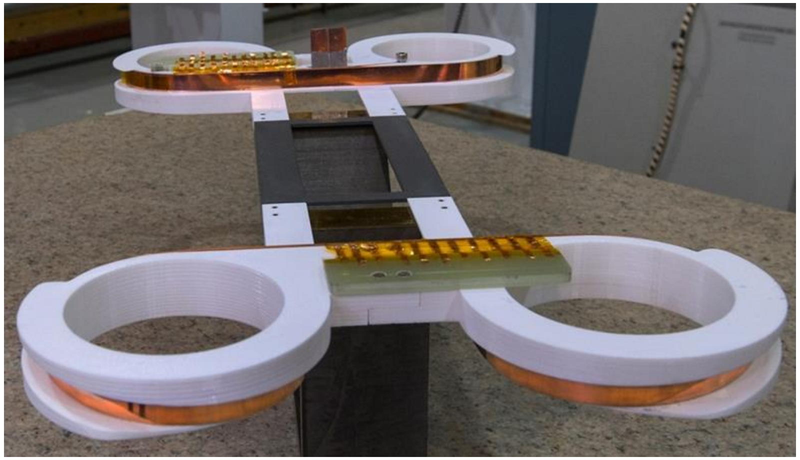
Goal of Phase II, if funded (2)

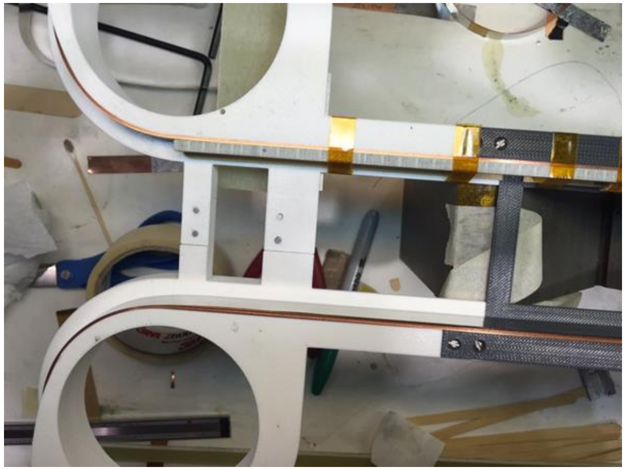
Insert coil test in BNL DCC017 for a "Proof-of-Principle" demonstration of (a) overpass underpass end design (b) Field quality common coil design

Figure 12: BNL common coil dipole with a large open space (left), with insert coil for another PBL/BNL STTR (middle), and the magnetic model of the proof-of-principle test (right). Similar to the design of the pole blocks of a high field common coil dipole, the overpass/underpass ends of the proof-of-principle design will be in a relatively lower field region, pointing to another advantage of the design.

Challenges (incomplete list)

- New Design – any new design, until demonstrated, has potential issues not fully appreciated initially
- Coil winding – coils are wound outside in, with no clear path, regular winding techniques don't work
- Mechanical design and analysis of the new end design





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Summary

- A new conductor friendly end design for block coils dipoles to reduce strain and length of the end region
- Relevant to Nb_3Sn and HTS and therefore relevant to high field 20 T design study
- Magnet ends and body to end transition region has often limited the performance of block coil dipoles. This new design has a potential of improving that performance.
- New designs typically comes with new challenges. All are invited to collaborate/participate in this PBL/BNL STTR.