U.S. MAGNET DEVELOPMENT PROGRAM

REBCO coils based on Twisted Stacked-Tape (TST) cable

A.V. Zlobin, Fermilab

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REBCO Round Table, Nov 2 – 3, 2023
Fermilab

U.S. DEPARTMENT OF ENERGY | Office of Science

TST cable allows small easy-bend radius and cable twist

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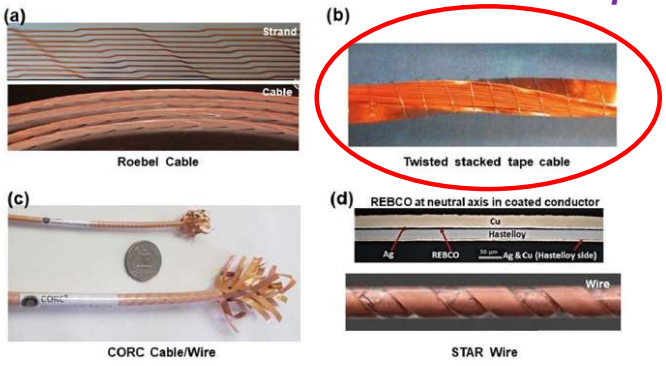
Topical Review

Development of RE-Ba-Cu-O superconductors in the U.S. for ultra-high field magnets

Mahesh Paidpilli and Venkat Selvamanickam*

Most efficient tape use

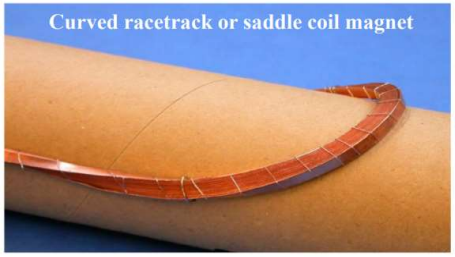


2014WAMHTS-1_REBCO Twisted Stacked-Tape Cable Takayasu

Stacked-Tape Twist-Winding (STTW) Method for 3D Magnets

New REBCO tape magnet winding concept

Stacked tape cable is twisted during winding



A U-turn portion of one turn coil demonstrating a curved saddle winding on a 50 mm diameter tube. The cable is composed of 50 YBCO tapes.

Applications
Small diameter magnet
3D HEP accelerator magnets, generator and motor magnets

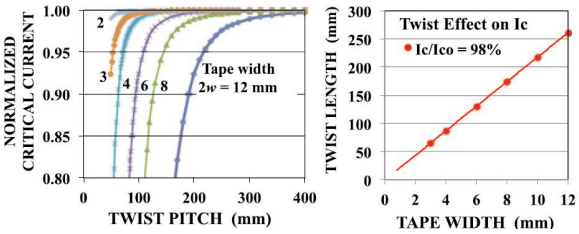
Issues:

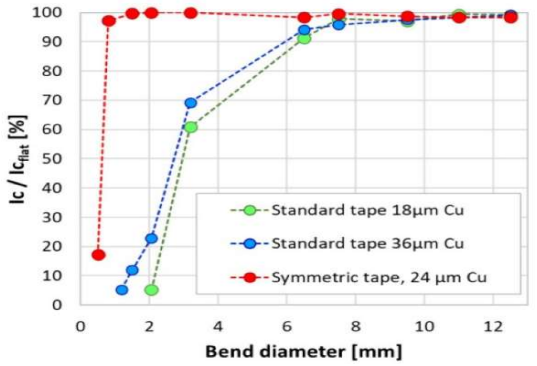
- ***tape relative axial shift during winding***
- ***twist pitch variation***

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 27, NO. 4, JUNE 2017 6000305

Electrical and Mechanical Characteristics of HTS Twisted Stacked-Tape Cable Conductor

Makoto Takayasu, Luisa Chiesa, Leslie Bromberg, and Joseph V. Minervini



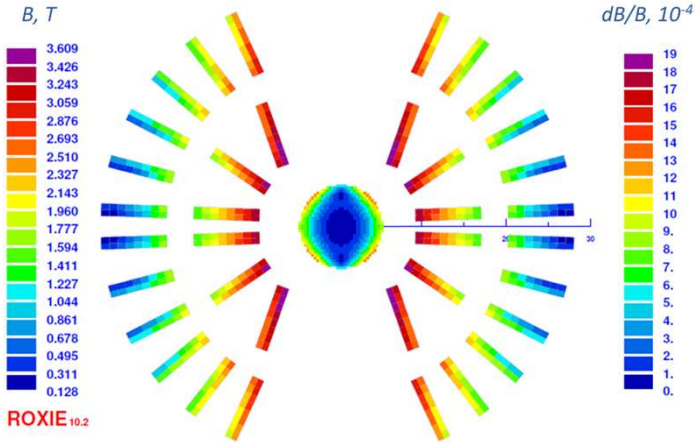


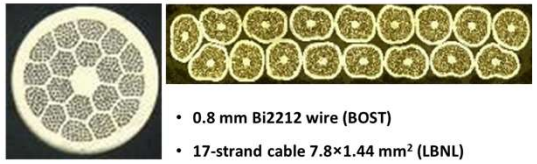
- ***Minimal bending D~8 mm***
- ***For 4 mm wide 0.1 mm thick tape minimal L_t~80 mm***

Bi2212 and REBCO SMCT small-aperture insert coils

Coil parameters.

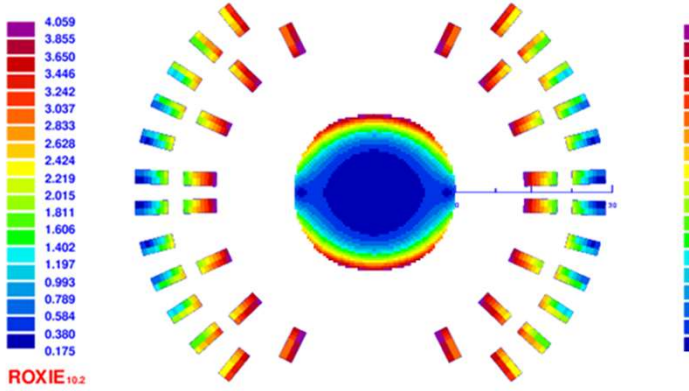
Parameter	Bi2212	REBCO
Number of layers	2	2
Number of turns	9 (3 IL+6 OL)	10 (4 IL+6 OL)
Coil ID-I/ID-O/OD, mm	9/20/59	19/25/59
Yoke R_{in}, mm	30	30
Yoke permeability	1000	1000
Coil B_{max}/I, T/kA	3.609/8	4.06/8
Coil B_o/I , T/kA	3.503/8	3.59/8
B_{max}/B_o	1.03	1.13
L. mH/m	0.200	0.345

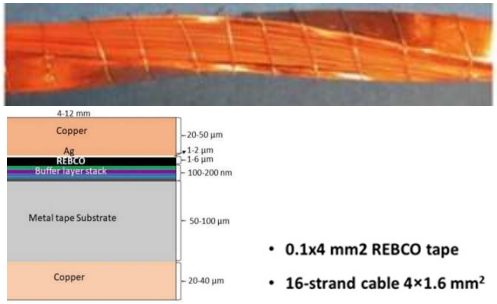




- 0.8 mm Bi2212 wire (BOST)
- 17-strand cable 7.8×1.44 mm² (LBNL)

Bi2212 round composite wire and Rutherford cable

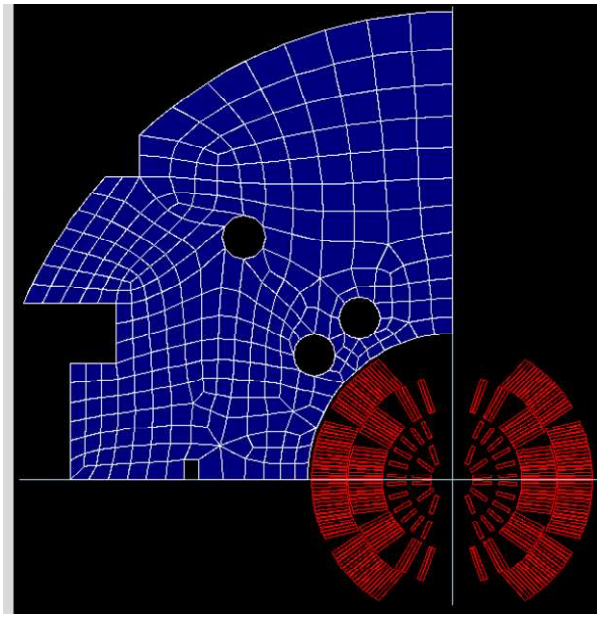


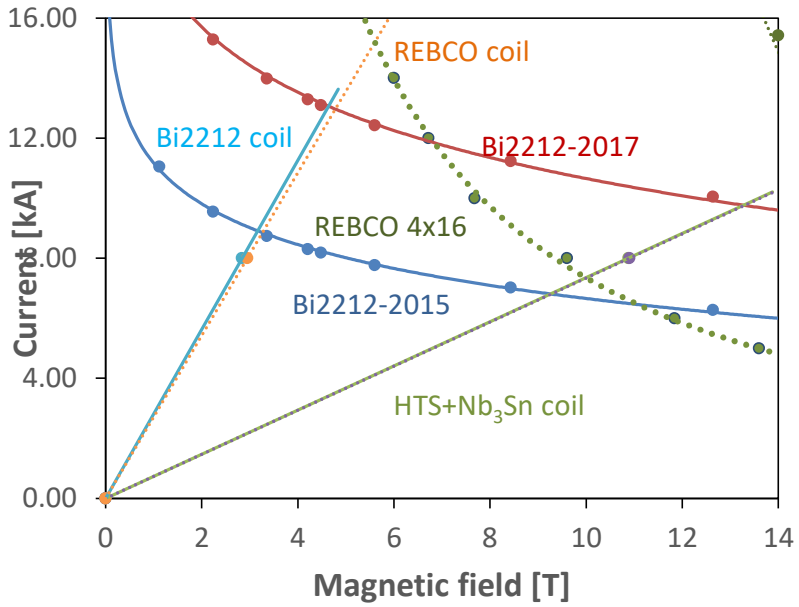


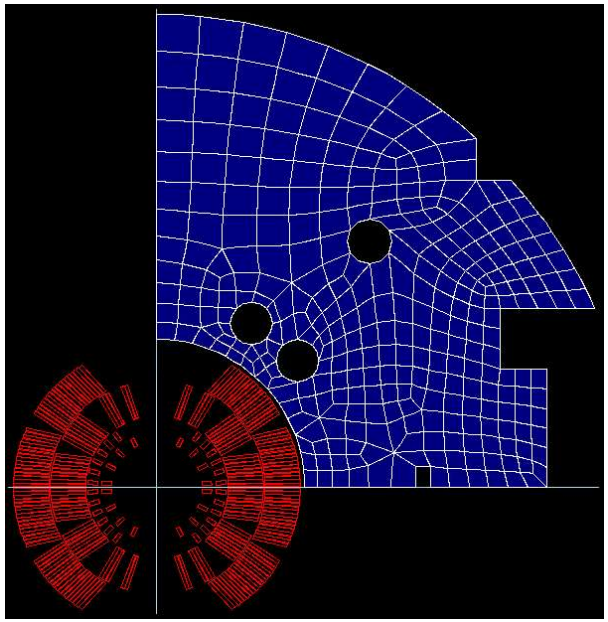
- 0.1x4 mm2 REBCO tape
- 16-strand cable 4×1.6 mm²

REBCO tape and twisted stacked-tape cable

Bi2212 and REBCO insert parameters



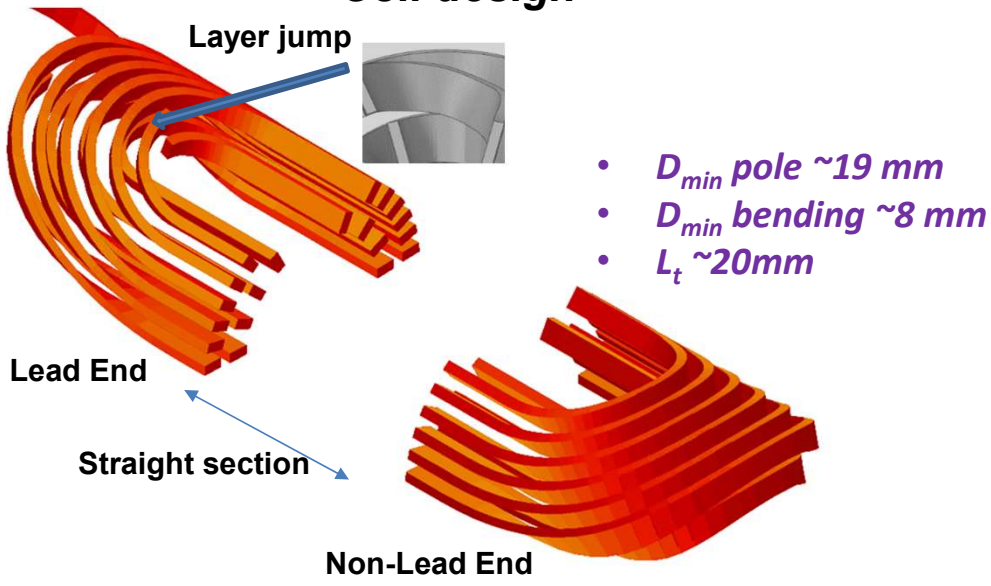




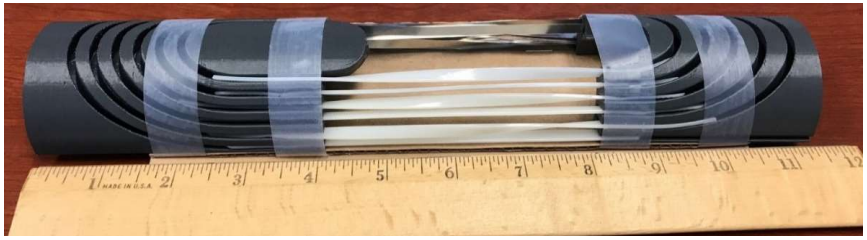
- The coils will be tested separately and as inserts into Nb_3Sn coils
- Load lines for Bi2212 and REBCO inserts (with 16-tape cable) are close
  - *good for direct technology and performance comparison*

REBCO coil design and TST cable twist during winding

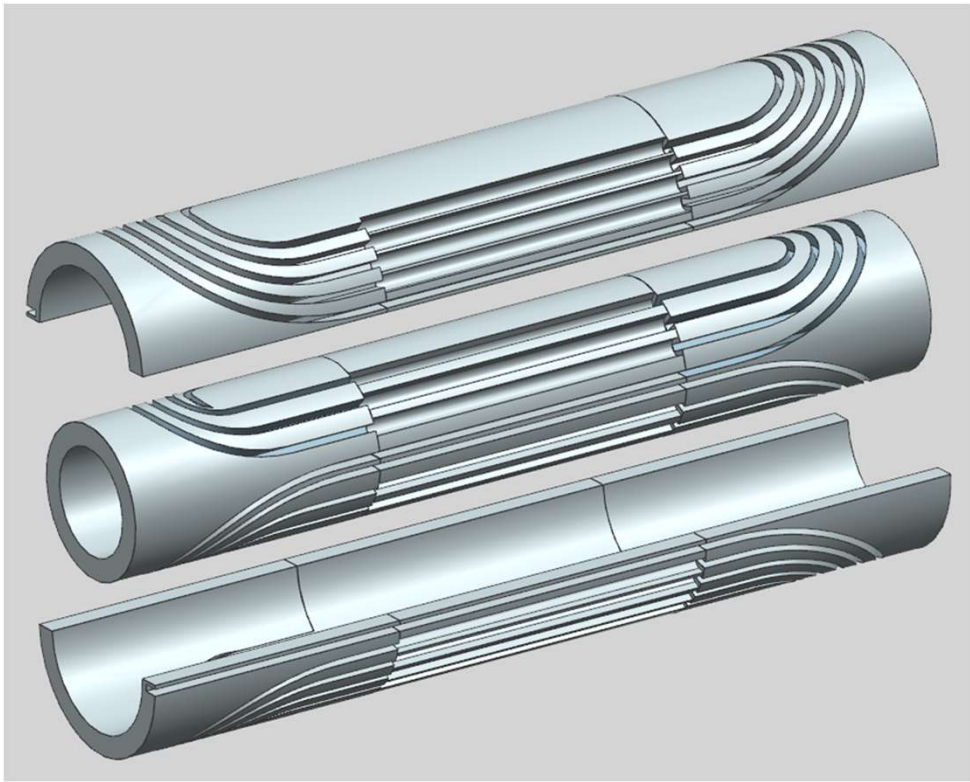
Coil design



- D_{min} pole ~19 mm
- D_{min} bending ~8 mm
- L_t ~20mm



Coil structure design



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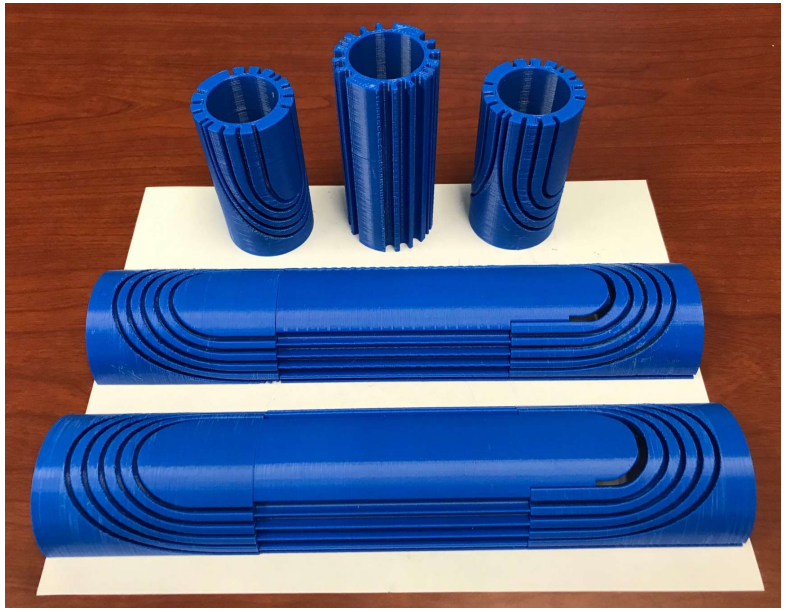
REBCO coil development plan and status



Spool	Tape length, m	Spool Ic, A	Cable length, m	Cable length, m	Coil length, m
			16 tapes	12 tapes	8 tapes
1	29	167	7.3	9.7	14.5
2	30	164	7.5	10.0	15.0
3	30	166	7.5	10.0	15.0
4	32	169	8.0	10.7	16.0

- 121 m (4 spools) of 4-mm wide 0.1 mm thick REBCO tape with test data have been provided by LBNL
- 480 m (4 spools) of 4 mm wide 0.1 mm thick SS-304 Annealed AMS-5513 tape

- Practice coil will use 16-tape stack cable made of 4 mm wide 0.1 mm thick SS tape
  - plastic parts and tape are available
- The REBCO coil will use 16-tape stack cable with 12 REBCO tapes and 2 SS tapes on each side
  - REBCO tape is available, preparing to procure coil parts from ULTEM

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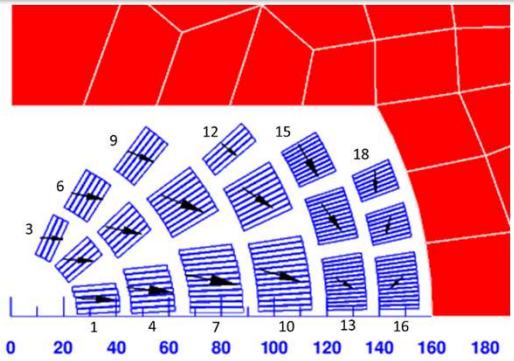
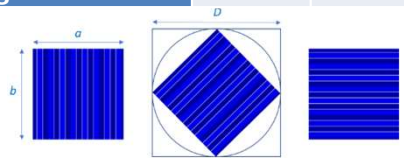
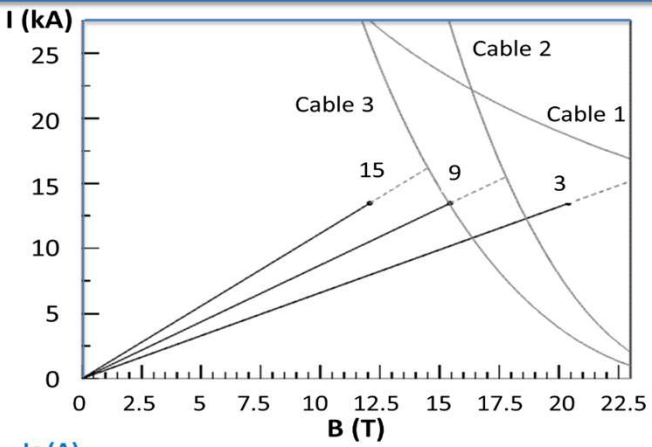
20 T small-aperture hybrid dipoles for HC with Bi2212 and REBCO coils

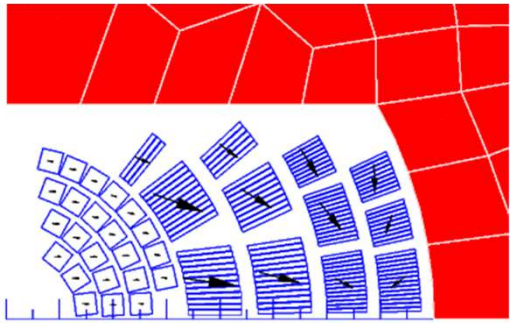


Presented at IPAC2023

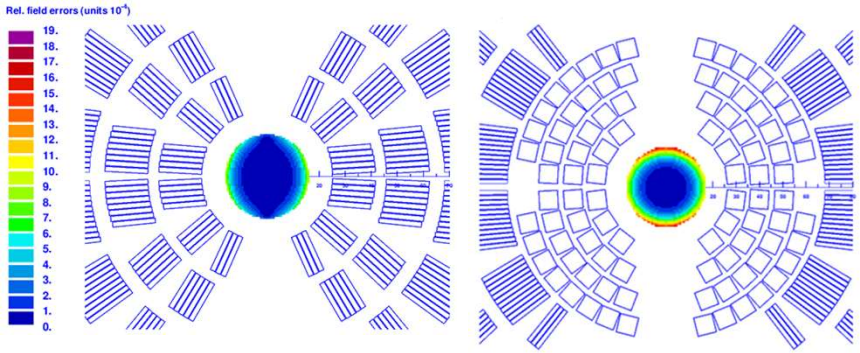
Parameter	REBCO	Bi2212	Nb_3Sn	Nb_3Sn
Strand size, mm	5×0.1	1.0	1.0	0.7
Number of strands	50	32	40	40
Cable width, mm	8	16.5	20.1	15.0
Cable small edge, mm	8	1.85	1.70	1.22
Cable large edge, mm	8	1.95	1.90	1.38
Cable packing factor	1.0	0.83	0.90	0.81

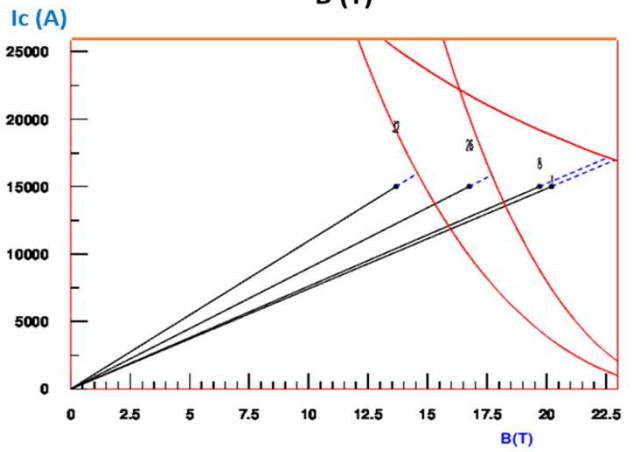






FERMILAB-TM-2807-TD
(in preparation)





- ***5 km of 5-mm wide REBCO tape/ meter length/aperture!***

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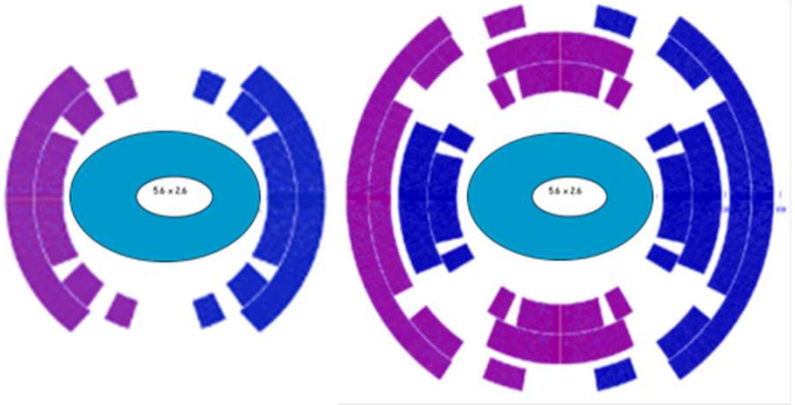
Large-aperture dipoles/quadrupoles for MC with REBCO coils based on TST cables – design approaches

Status

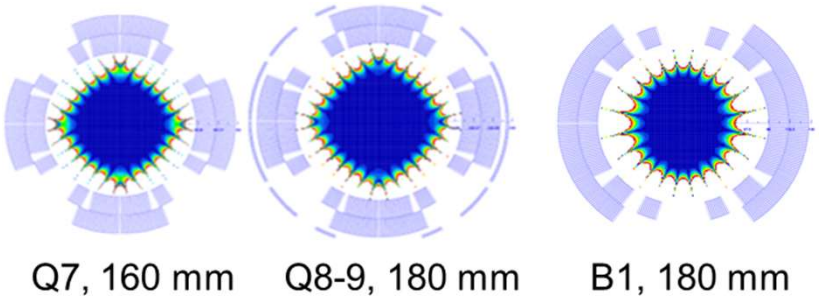
- Arc magnets
  - 150 mm aperture D and combined Q/D
  - B_{op}=10.4 T with ~30% margin at 4.5 K => *2-layer Nb_3Sn coils*
  - B_{op}~8-9 T and G_{op}~80 T/m with ~20% margin (B_{coil} ~18 T) at 4.5 K => *nested Q/D with 4-layer coils*
- IR magnets
  - B_{op}=8 T (D), B_{op}~11 T (Q)
  - Aperture 80-180 mm
  - B_{des}=14-15 T with 2-layer Nb_3Sn coils
  - 20-30% (Q) and 45% (D) operation margin

Next steps

- Magnet coils need to be updated to implement Stress Management elements – *critical for brittle superconductor!*
- REBCO use
  - hybrid design at 4.5 K with B_{max}~20 T + margin
  - HTS coil and operation temperature T~20 K



D, 150 mm Q/D, 150 mm



Q7, 160 mm Q8-9, 180 mm B1, 180 mm

Presented at IPAC2012

Summary

- **Recent studies show that TST cable can be used in shell-type high-field D and Q coils**
  - stack twist to be provided coil straight part during winding
- **2L design concepts of REBCO D insert coil with TST cable and SMCT coil support structure are being developed at Fermilab**
  - REBCO coil parameters with 16 tape cable are similar to Bi2212 coil parameters which allows direct technology and performance comparison
- **Practice D coil to optimize the cable insulation, coil design, SMCT structure and coil winding technology is in progress**
  - plastic coil parts have been printed
  - stainless steel tape of similar size has been procured
- **REBCO tape for the first insert coil is available**
  - material for the coil structure is being studied
  - coil structure procurement using ULTEM will start soon
- **Demonstration of this cost-effective approach will be done in FY24**
- **Possibilities of using this technology for small-aperture (~50 mm) 20 T hybrid dipole and large-aperture (~150 mm) 10-16 T D or Q/D are being studied**