U.S. MAGNET DEVELOPMENT PROGRAM

20 T HTS/LTS Hybrid Common Coil Design

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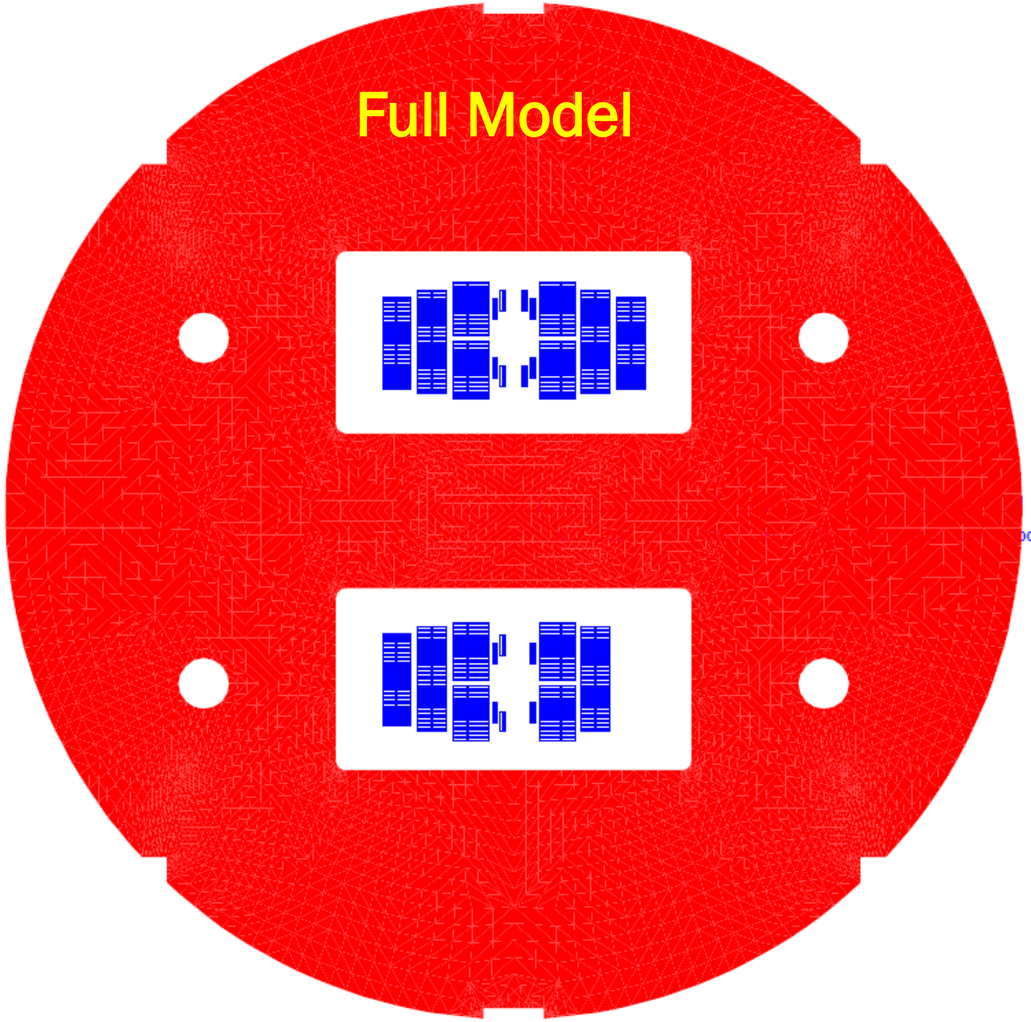
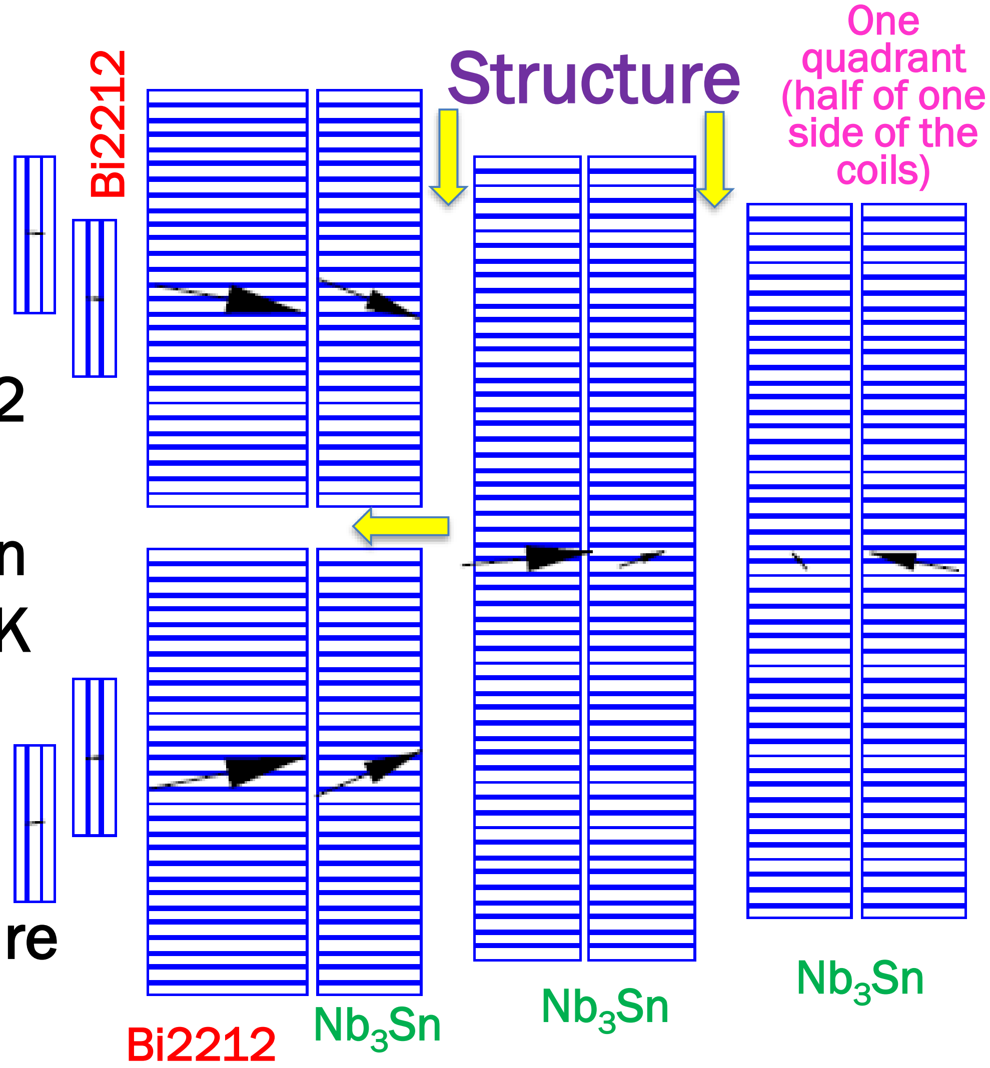
20 T HTS/LTS Hybrid Common Coil Design

- Hybrid designs for (a) Bi2212 and (b) CORC in series with Nb_3Sn
- Optimized for a good field quality
- 4.2K and 1.9 K design options
- HTS/LTS splice considerations
- Mechanical structure considerations
- Issues/benefits specific to common coil

50 mm, 20 T Bi2212/Nb_3Sn Common Coil



- 1 Layer of Bi2212 (+pole coils)
- 5 Layers of Nb_3Sn
- 20% margin at 4K
- 20 T @12.1 kA
- Space for structure (to be iterated)



Field Quality in 20 T Common Coil Bi2212/Nb_3Sn Hybrid Design

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REFERENCE RADIUS (mm) .............................         15.0000
X-POSITION OF THE HARMONIC COIL (mm) ...............         0.0000
Y-POSITION OF THE HARMONIC COIL (mm) ...............       169.0000
MEASUREMENT TYPE ....................... ALL FIELD CONTRIBUTIONS
ERROR OF HARMONIC ANALYSIS OF Br ...................    0.2696E-03
SUM (Br(p) - SUM (An cos(np) + Bn sin(np))

MAIN FIELD (T) ....................................      20.025677
```

All harmonics $<10^{-4}$ (normal and skew)

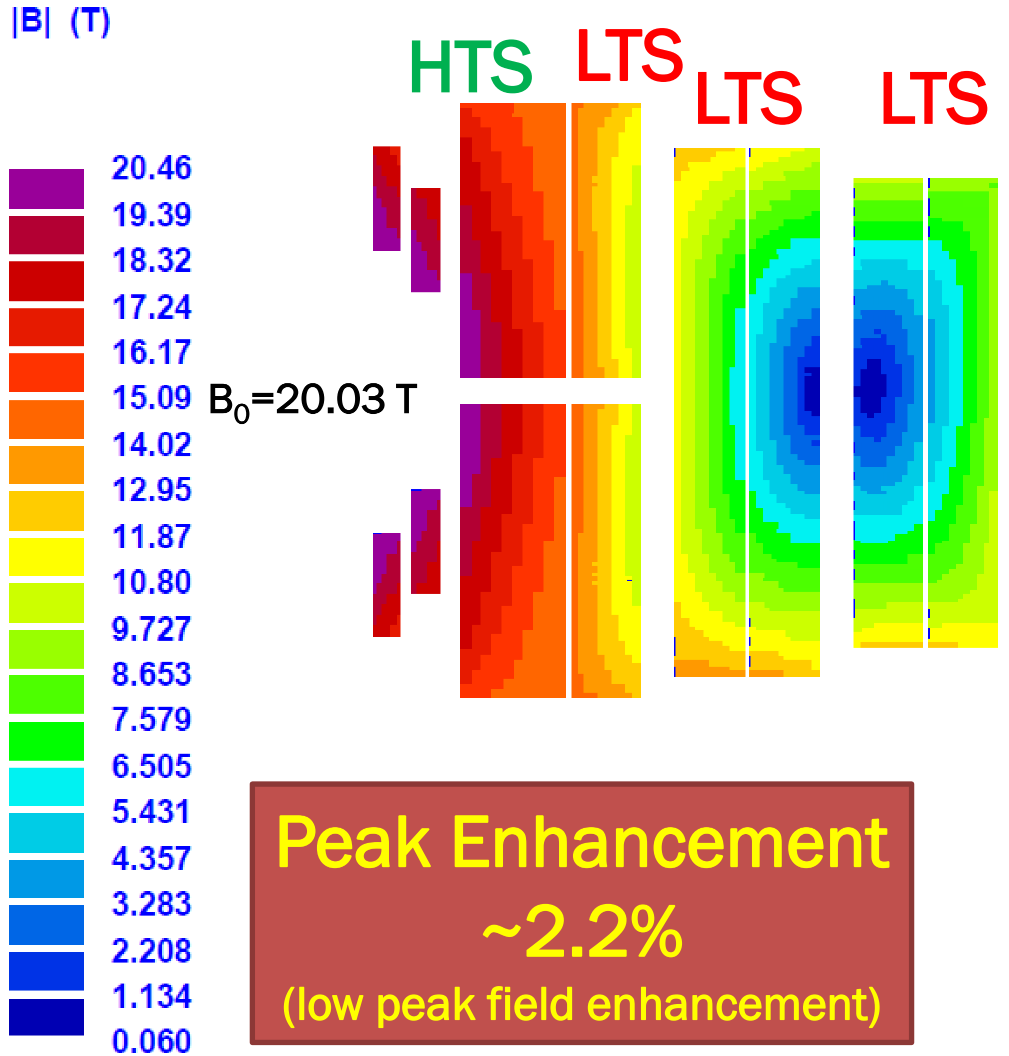
NORMAL RELATIVE MULTIPOLES (1.D-4):

b 1:	10000.00000	b 2:	0.00000	b 3:	0.00275
b 4:	0.00000	b 5:	0.00067	b 6:	-0.00000
b 7:	0.00388	b 8:	0.00000	b 9:	-0.78484
b10:	0.00000	b11:	-0.33370	b12:	-0.00000
b13:	-0.01708	b14:	0.00000	b15:	0.00605
b16:	0.00000	b17:	-0.00669	b18:	0.00000

SKEW RELATIVE MULTIPOLES (1.D-4):

a 1:	0.00000	a 2:	-0.00613	a 3:	-0.00000
a 4:	0.00048	a 5:	0.00000	a 6:	0.00101
a 7:	-0.00000	a 8:	0.28080	a 9:	0.00000
a10:	0.14694	a11:	0.00000	a12:	0.00855
a13:	0.00000	a14:	-0.00321	a15:	-0.00000
a16:	0.00545	a17:	-0.00000	a18:	0.00152

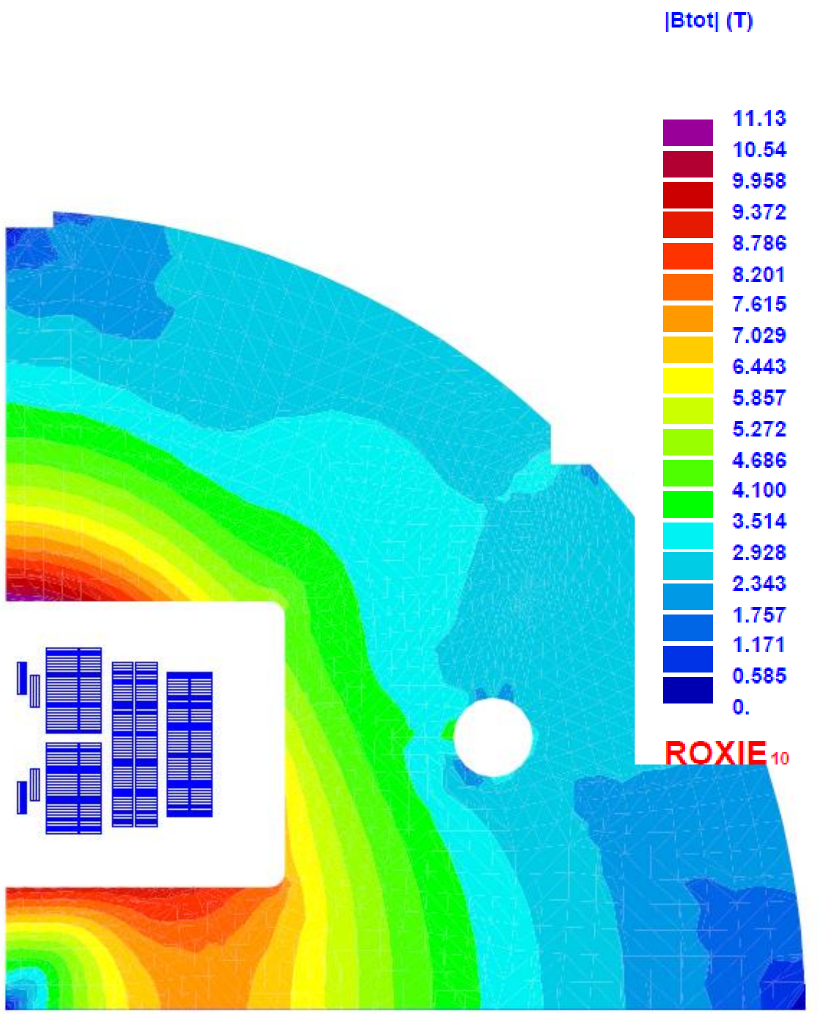
50 mm, 20 T Common Coil Bi2212/Nb_3Sn Hybrid Design



Peak Enhancement
~2.2%
(low peak field enhancement)

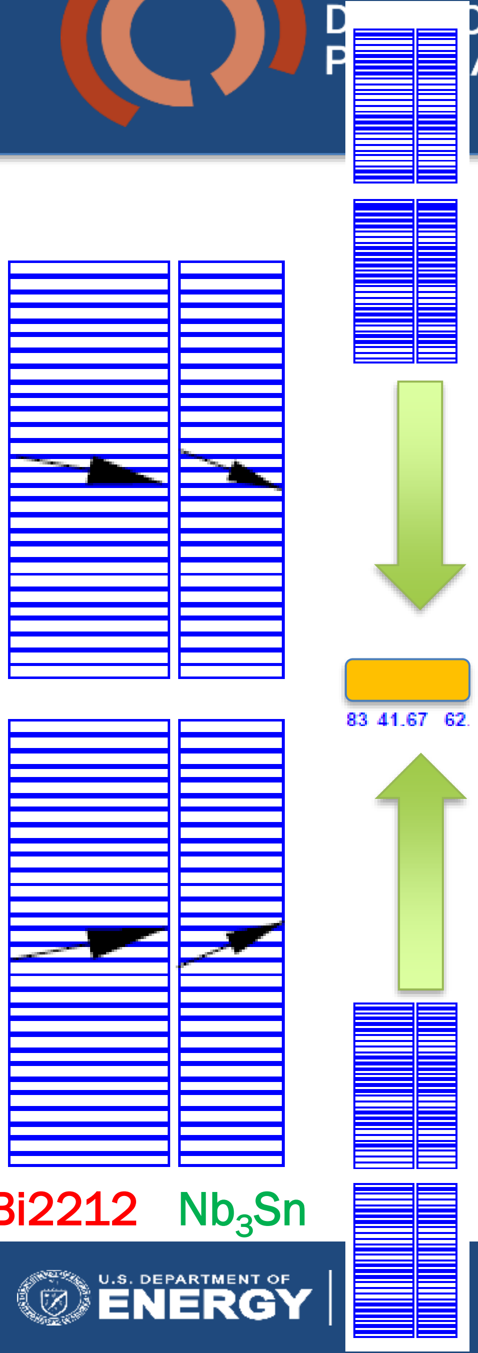
MDPCCCORC	Bi2212
Ins w	1.9
Ins h	20.3
Ins Area	38.570
Current	12100
Jo (A/mm^2)	313.72
Bpeak (T)	20.458

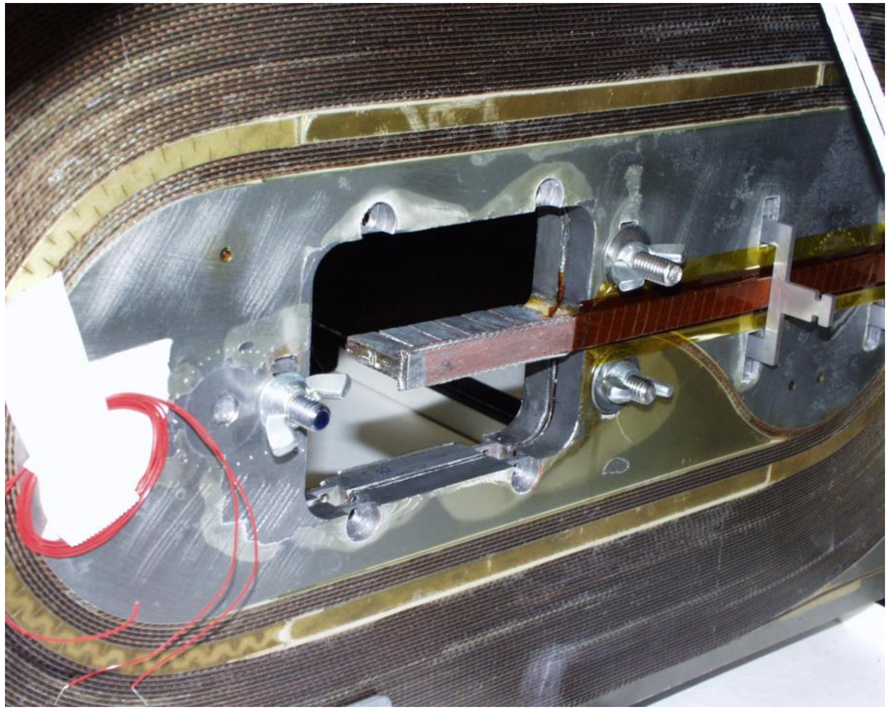
MDPH2	Nb_3Sn
Ins w	1.9
Ins h	13.6
Ins Area	25.840
Current	12100
Jo (A/mm^2)	468.27
Bpeak (T)	15.055



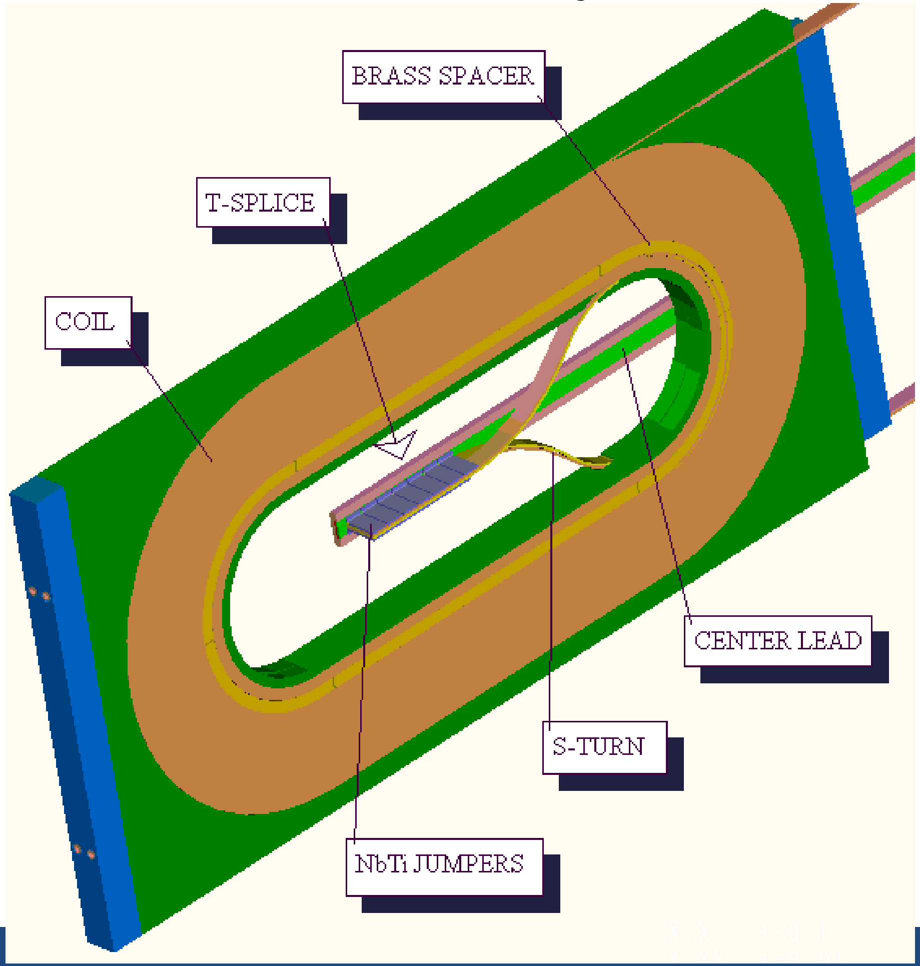
Splices in Common Coil Design (between two single layer coil)

In common coil design, splice (even between two types of coils), can be easily made in the middle of the coil where the field is very low





Perpendicular Nb-Ti splice in the low field region of BNL common coil dipole DCC017



Conductor Used

HTS (Bi2212)

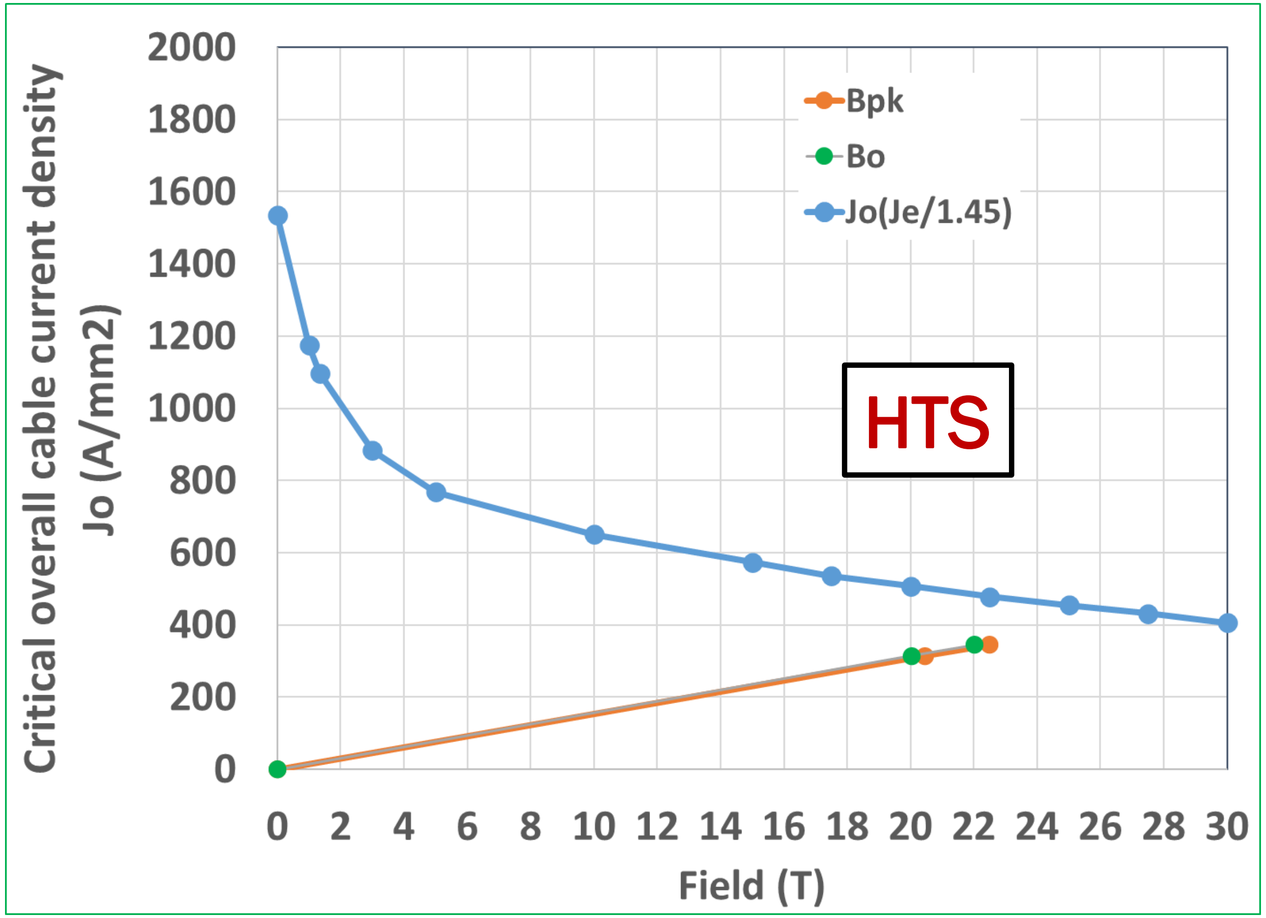
NUMBER OF BLOCK	1
NUMBER OF CONDUCTORS	3
POSITIONING ANGLE (DEG)	214.4000
INCLINATION ANGLE (DEG)	-90.0000
CURRENT IN EACH CONDUCTOR OF THE BLOCK (A)	-12100.0000
INNER RADIUS OF THE BLOCK (MM)......................	18.2000
CABLE HEIGHT (MM).(INSULATED)	20.3000
CABLE INNER WIDTH (MM).(INSULATED)	1.9000
CABLE OUTER WIDTH (MM).(INSULATED)	1.9000
CABLE HEIGHT (MM).(BARE)	20.0000
CABLE INNER WIDTH (MM).(BARE)	1.6000
CABLE OUTER WIDTH (MM).(BARE)	1.6000
RADIAL INSULATION THICKNESS (MM)....................	0.1500
AZIMUTHAL INSULATION THICKNESS (MM).................	0.1500
NUMBER OF STRANDS	50
DIAMETER OF STRANDS (MM)............................	0.8000
CU/SC RATIO	3.0000
RESIDUAL RESISTIVITY RATIO..........................	100.0000
TEMPERATURE AT WHICH JC AND DJC ARE GIVEN (K)	1.9000
LINEAR APPROXIMATION JC(20.0 T) (A/MM**2)...........	2944.000
LINEAR APPROXIMATION DJC/DB (A/MM**2 T).............	64.000
CABLING ANGLE (DEG)	1.373
NUMBER OF DISCRETISATION POINTS AZIMUTHAL	2
NUMBER OF DISCRETISATION POINTS RADIAL	10
CONDUCTOR NAME	MDPB2212

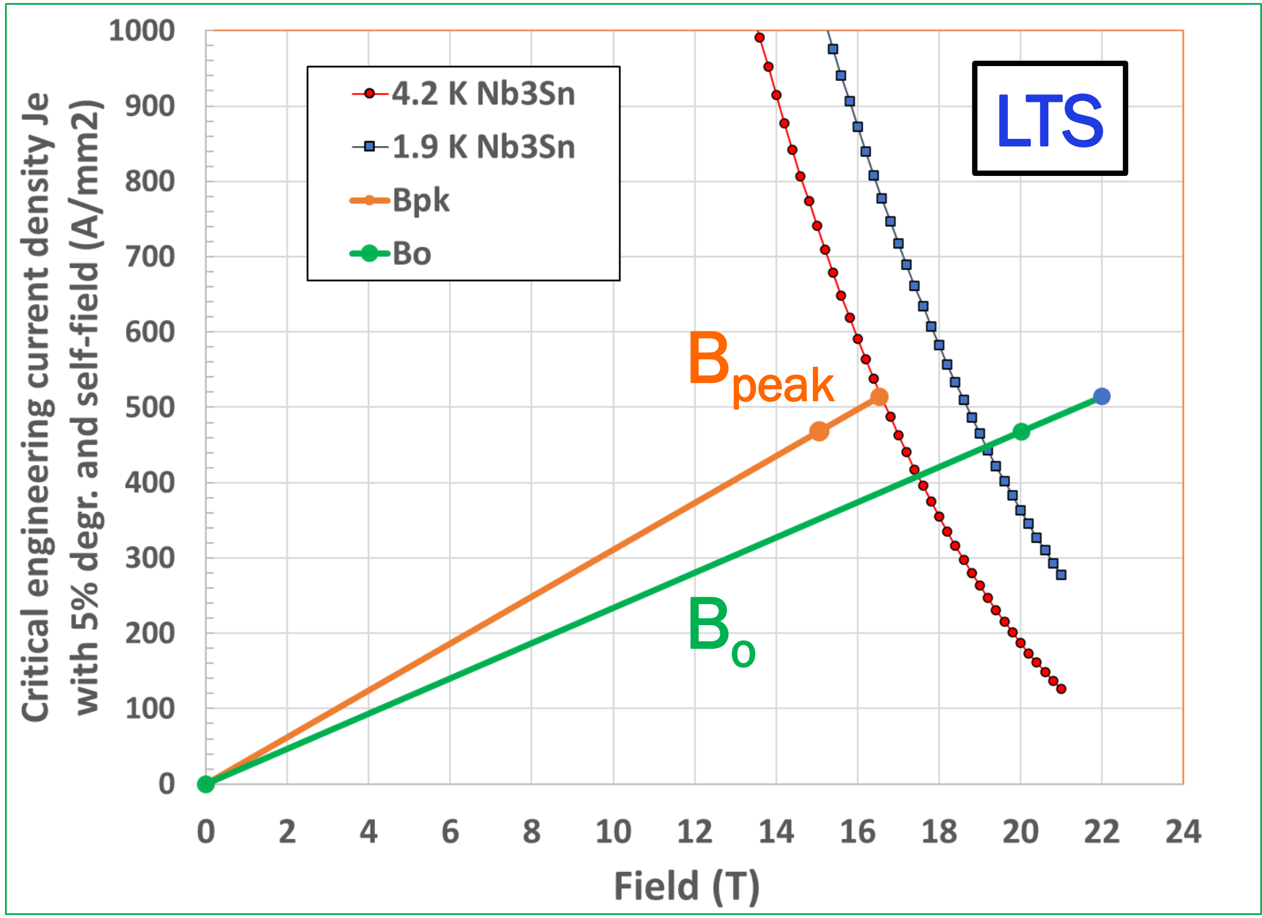
Nb_3Sn

NUMBER OF BLOCK	5
NUMBER OF CONDUCTORS	30
POSITIONING ANGLE (DEG)	110.0000
INCLINATION ANGLE (DEG)	0.0000
CURRENT IN EACH CONDUCTOR OF THE BLOCK (A)	-12100.0000
INNER RADIUS OF THE BLOCK (MM)......................	46.3000
CABLE HEIGHT (MM).(INSULATED)	13.6000
CABLE INNER WIDTH (MM).(INSULATED)	1.9000
CABLE OUTER WIDTH (MM).(INSULATED)	1.9000
CABLE HEIGHT (MM).(BARE)	13.3000
CABLE INNER WIDTH (MM).(BARE)	1.6000
CABLE OUTER WIDTH (MM).(BARE)	1.6000
RADIAL INSULATION THICKNESS (MM)....................	0.1500
AZIMUTHAL INSULATION THICKNESS (MM).................	0.1500
NUMBER OF STRANDS	37
DIAMETER OF STRANDS (MM)............................	0.8000
CU/SC RATIO	1.0000
RESIDUAL RESISTIVITY RATIO..........................	100.0000
TEMPERATURE AT WHICH JC AND DJC ARE GIVEN (K)	1.9000
LINEAR APPROXIMATION JC(16.0 T) (A/MM**2)...........	1928.000
LINEAR APPROXIMATION DJC/DB (A/MM**2 T).............	371.000
CABLING ANGLE (DEG)	1.439
NUMBER OF DISCRETISATION POINTS AZIMUTHAL	2
NUMBER OF DISCRETISATION POINTS RADIAL	10
CONDUCTOR NAME	MDPH2

Margins in 20 T Hybrid Common Coil Design @4K

- Enough (10%) margin at 4.2 K in Nb_3Sn as well





Lorentz Forces @20 T in Bi2212/Nb_3Sn Hybrid

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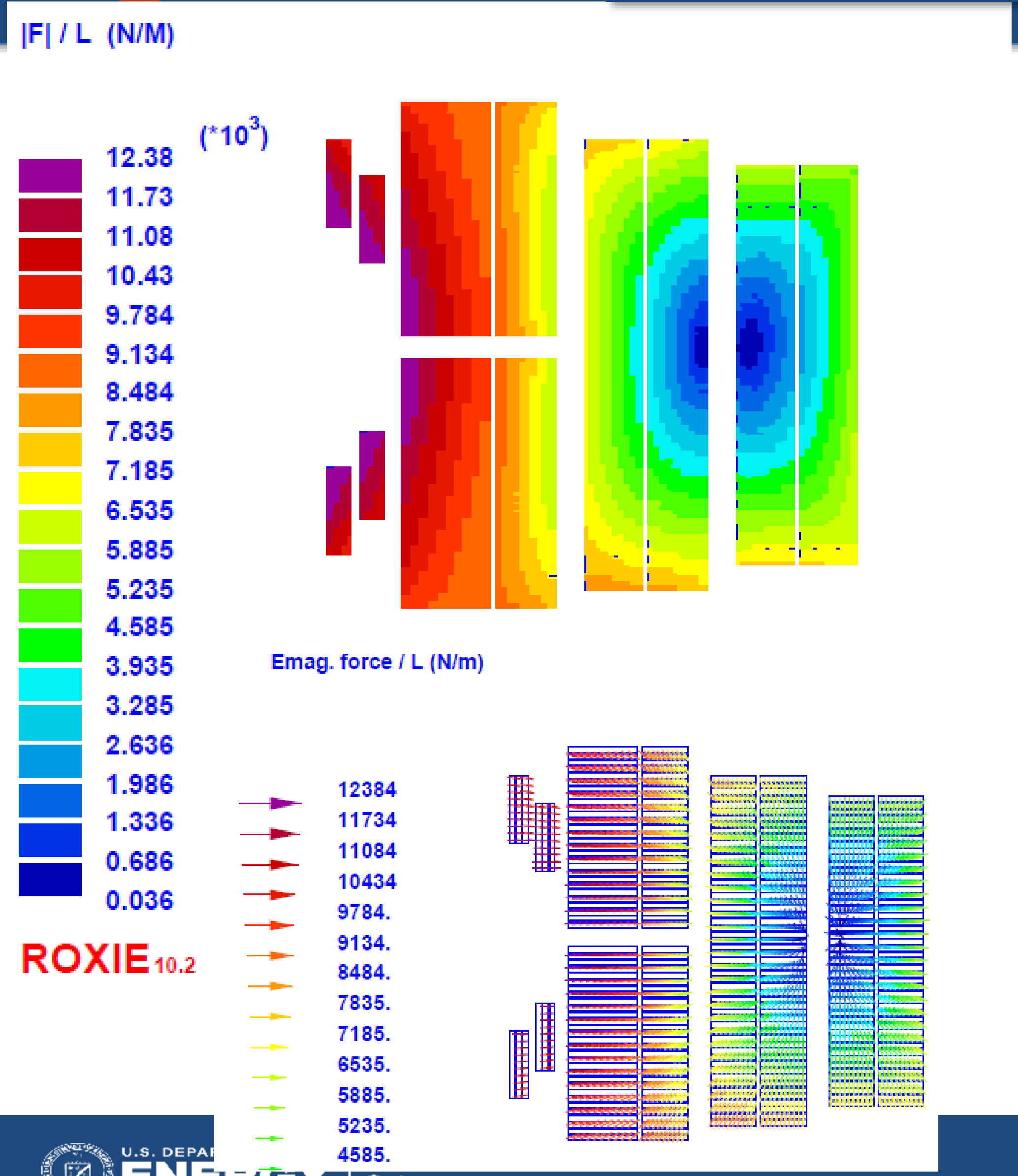
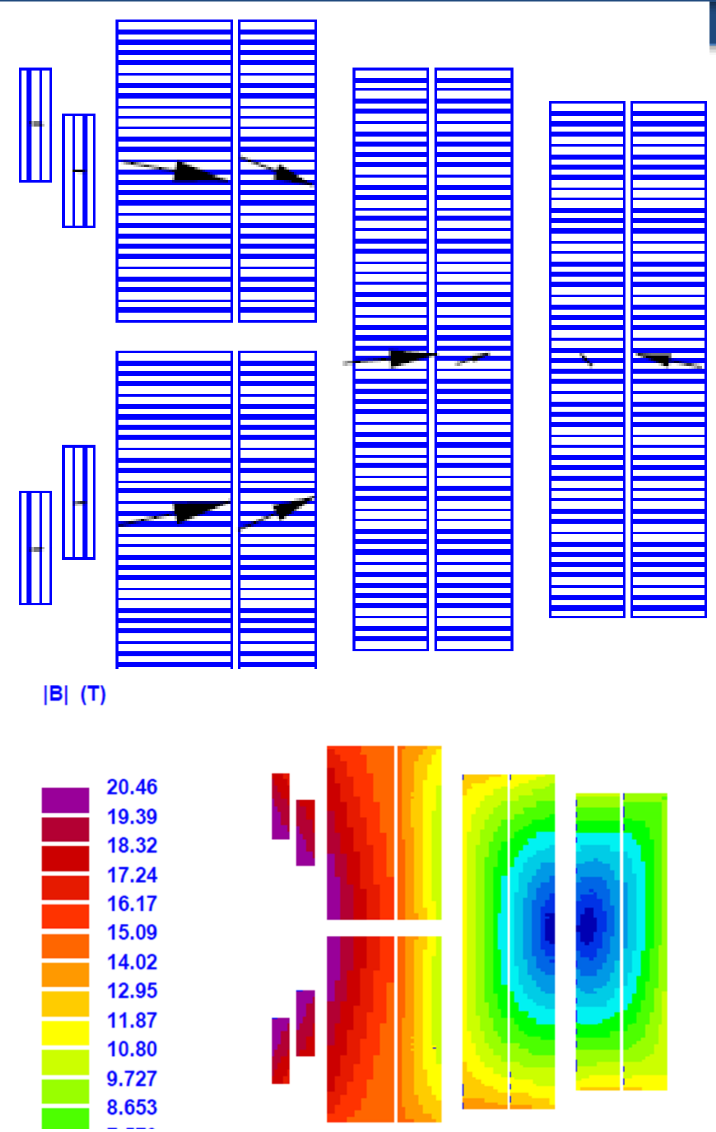
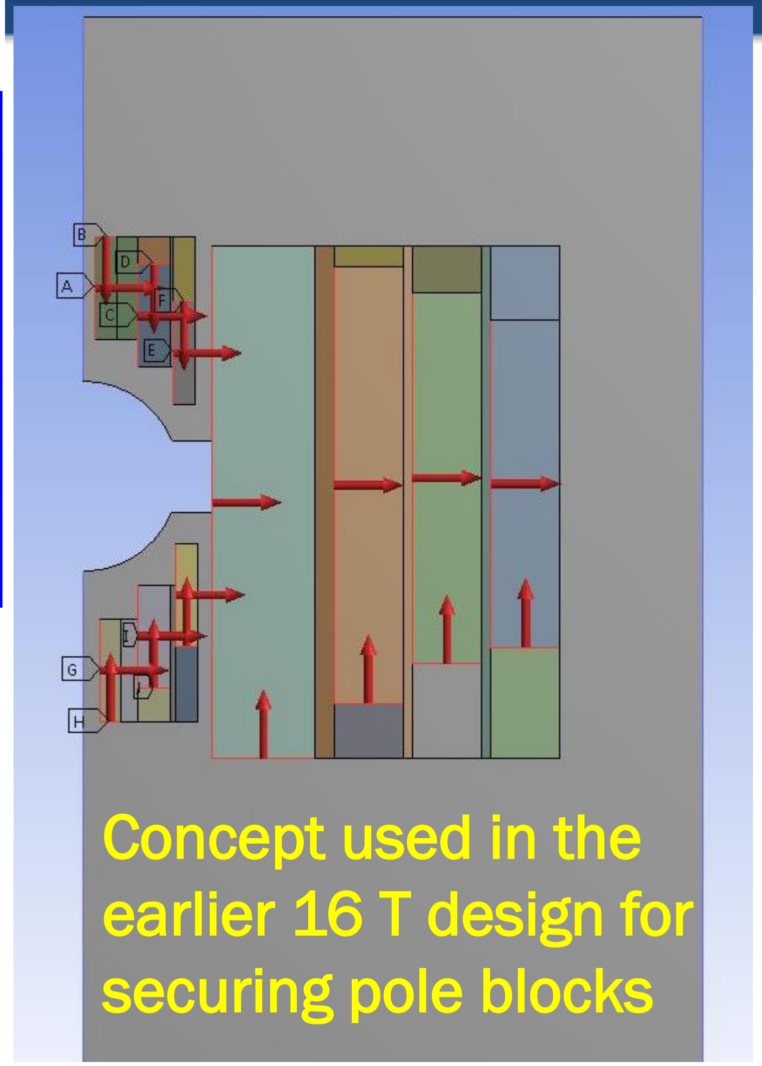






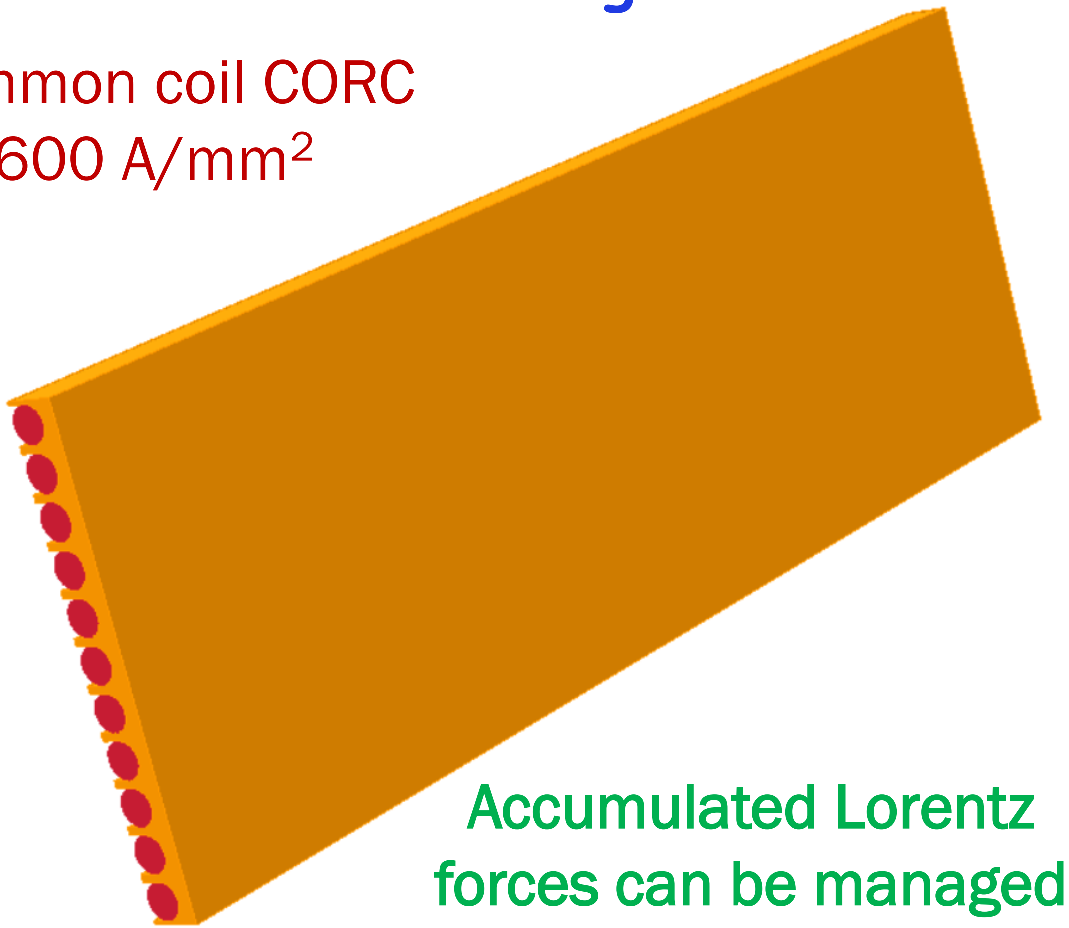
4.2 K and 1.9 K Hybrid Designs with CORC/Nb_3Sn (ReBCO Coils)

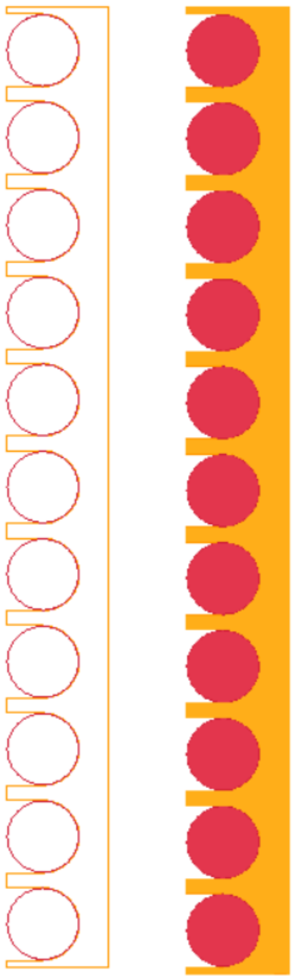
CORC in Common Coil

➢ **Common coil design allows higher Je CORC due to large bend radii**

❖ STTR with ACT anticipated a future common coil CORC with an engineering current density of 600 A/mm^2

- ❑ 800 A/mm^2 possible (STAR –Selva)
- ❑ Designs based on 600 A/mm^2 only





Overall Current density with structure:

- Area for 6 mm wire: pi*6*6/4 = 28.3 mm^2
- Area for 6.5mm X 8mm rectangle = 52 mm^2

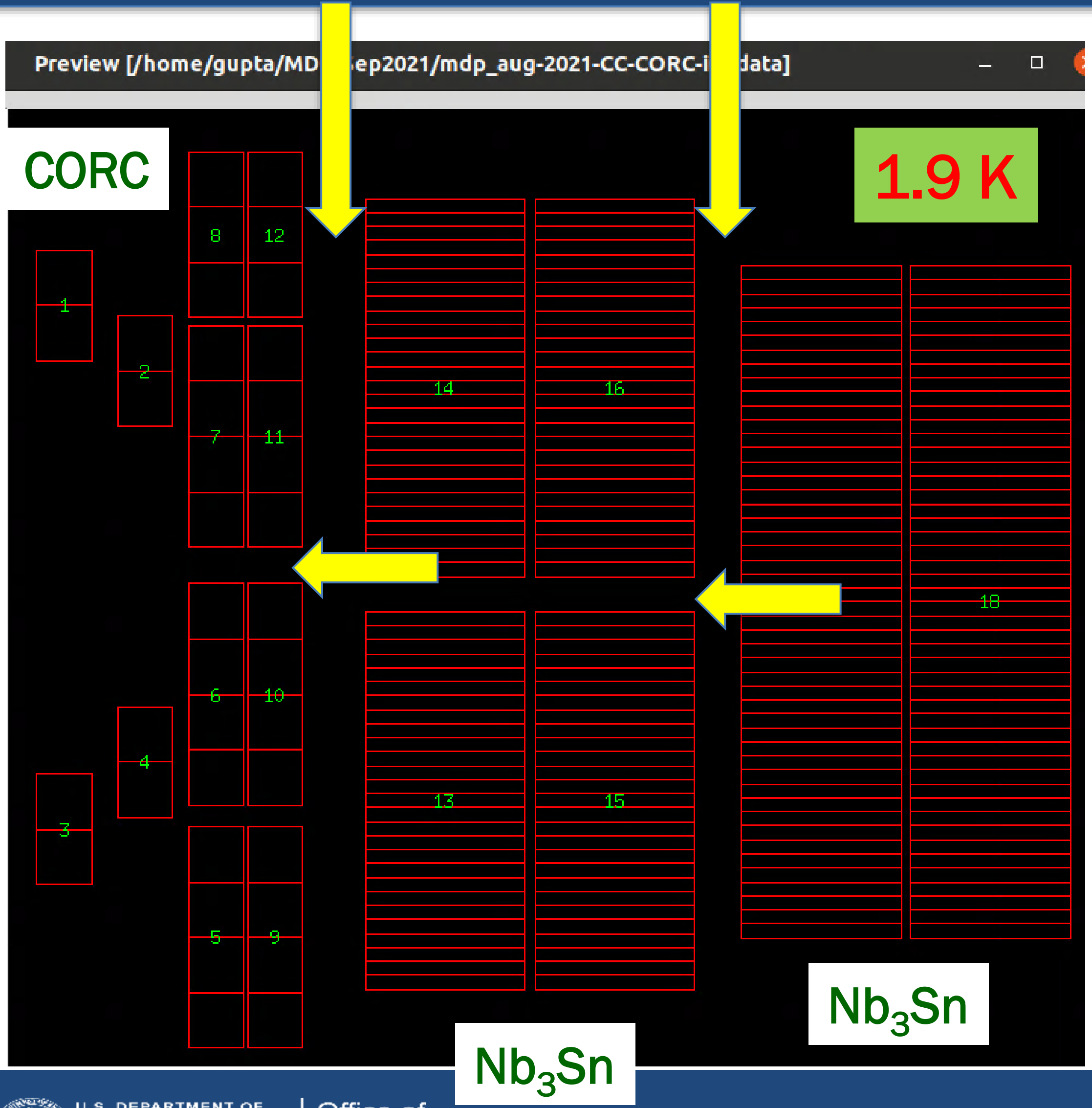
J_o for Je = 600 A/mm2:

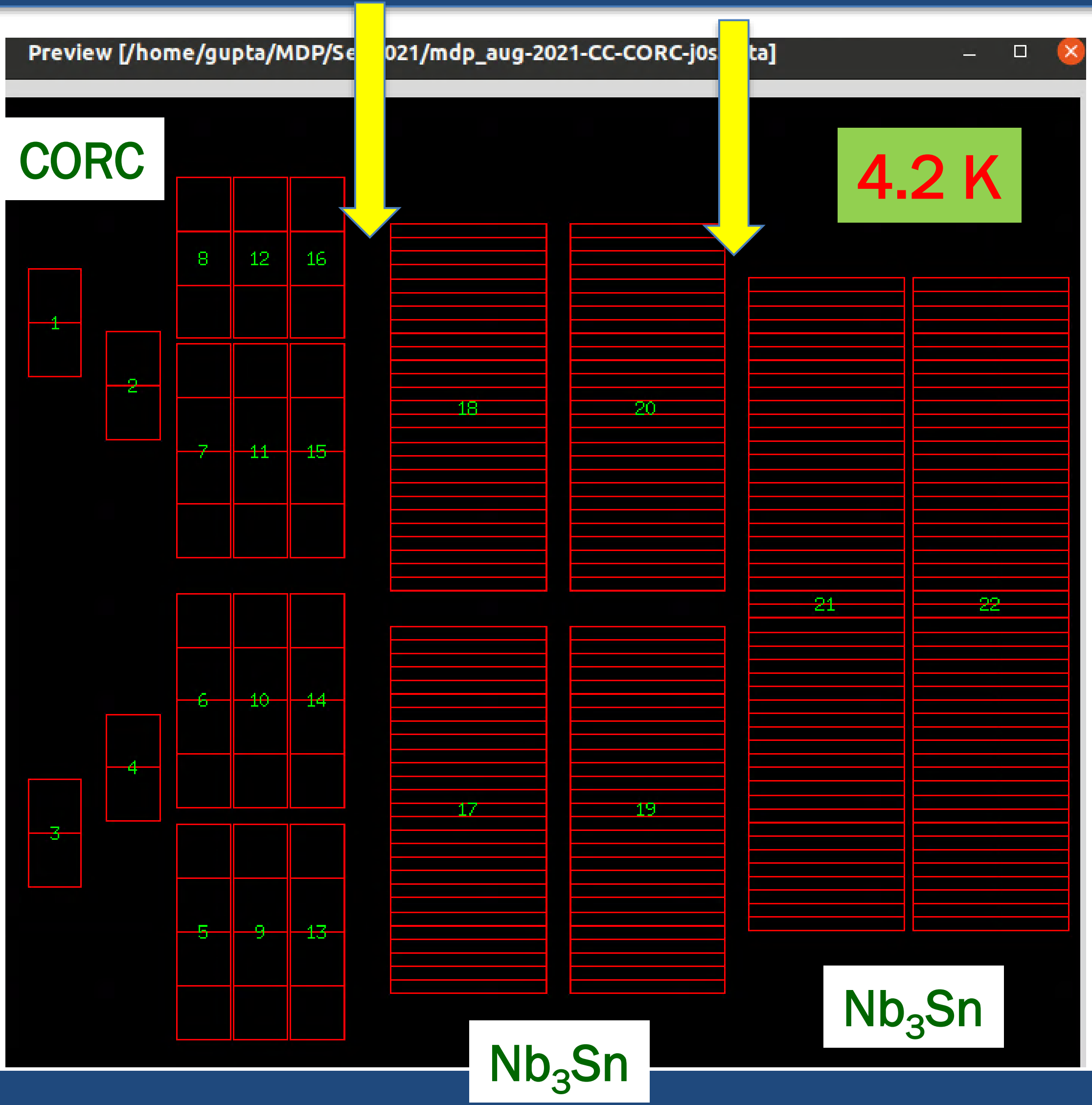
❑ J_o =600*28.3 /52 = 326 A/mm^2

➢ Similar to Bi2212; but with a structure

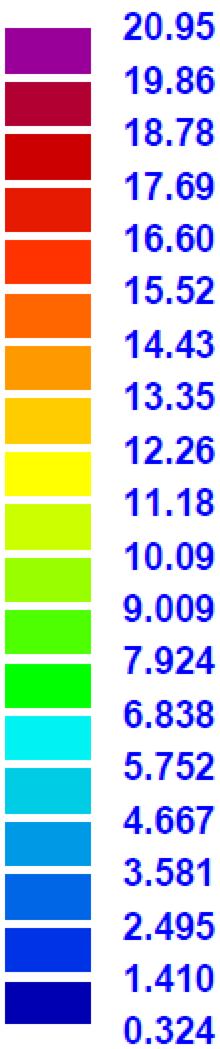
Accumulated Lorentz forces can be managed in a structure

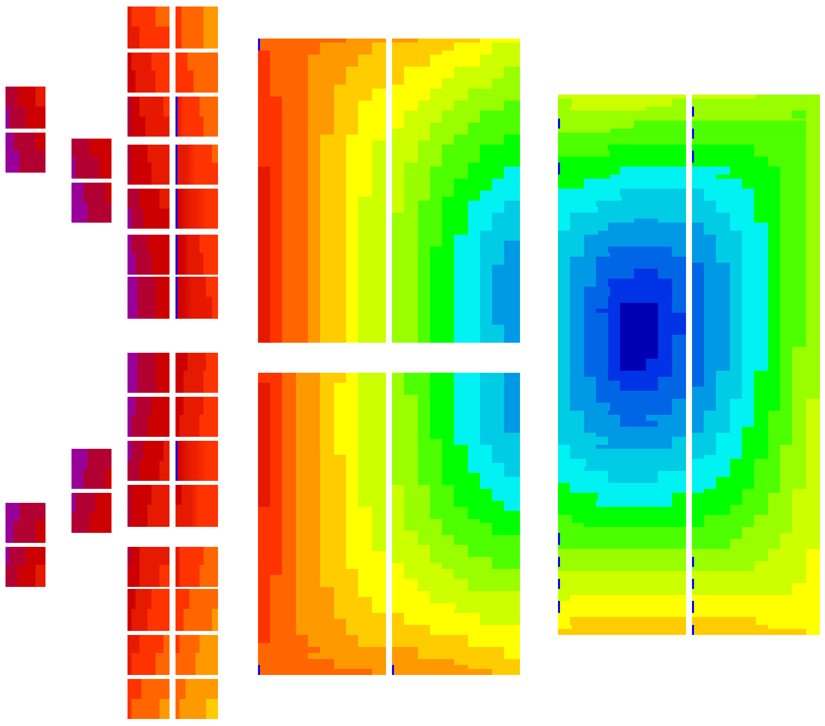
CORC 1.9 K (2 layers) and 4.2 K (3 layers) Designs (in series with Nb_3Sn; spaces for structure)



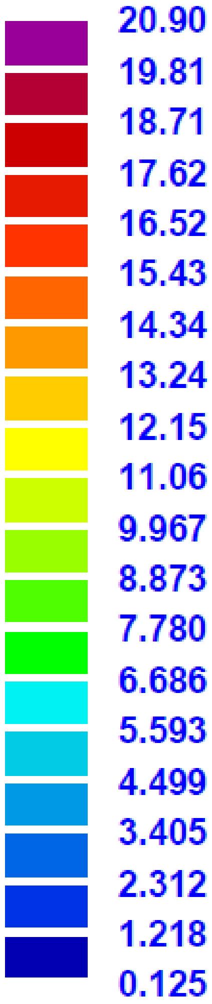


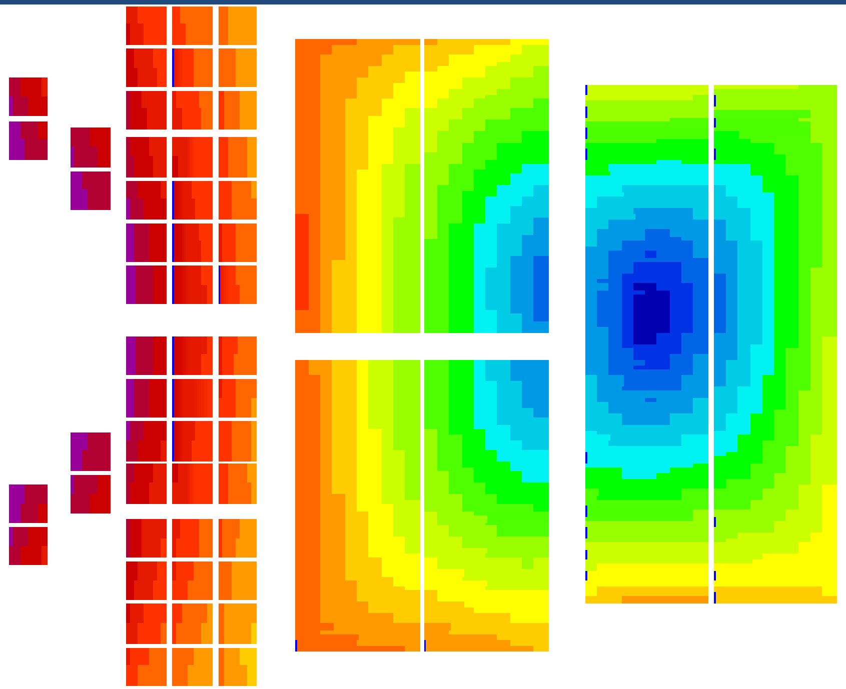
50 mm, 20 T Common Coil CORC/Nb_3Sn Hybrid Design





Field on the Conductor
2-layer CORC. 1.9 K Design
(10% Margin)





Field on the Conductor
3-layer CORC. 4.2 K Design
(10% Margin)

Designs limited by Nb_3Sn

Field Quality in 20 T Common Coil CORC/Nb_3Sn Hybrid Design

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2-layer ReBCO; 1.9 K

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HARMONIC ANALYSIS NUMBER ............................          1
MAIN HARMONIC .......................................          1
REFERENCE RADIUS (mm) ...............................    15.0000
X-POSITION OF THE HARMONIC COIL (mm) ...............      0.0000
Y-POSITION OF THE HARMONIC COIL (mm) ...............    169.0000
MEASUREMENT TYPE ........................ ALL FIELD CONTRIBUTIONS
ERROR OF HARMONIC ANALYSIS OF Br ...................  0.2671E-03
SUM (Br(p) - SUM (An cos(np) + Bn sin(np))

MAIN FIELD (T) ......................................  20.009287
MAGNET STRENGTH (T/(m^(n-1)) .......................     20.0093

NORMAL RELATIVE MULTIPOLES (1.D-4):
b 1:  10000.00000  b 2:     -0.00000  b 3:     -0.00157
b 4:     -0.00000  b 5:      0.00046  b 6:     -0.00000
b 7:     -0.01379  b 8:     -0.00000  b 9:     -0.22156
b10:      0.00000  b11:     -0.49290  b12:     -0.00000
b13:     -0.01713  b14:      0.00000  b15:      0.00929
b16:     -0.00000  b17:     -0.00697  b18:      0.00000
b19:     -0.00160  b20:      0.00000  b

SKEW RELATIVE MULTIPOLES (1.D-4):
a 1:     -0.00000  a 2:     -0.00529  a 3:     -0.00000
a 4:     -0.00138  a 5:      0.00000  a 6:     -0.00951
a 7:     -0.00000  a 8:      0.24968  a 9:     -0.00000
a10:      0.36533  a11:     -0.00000  a12:      0.02140
a13:     -0.00000  a14:     -0.00234  a15:     -0.00000
a16:      0.01042  a17:      0.00000  a18:      0.00292
a19:      0.00000  a20:      0.00042  a
```

All harmonics < 10^{-4}

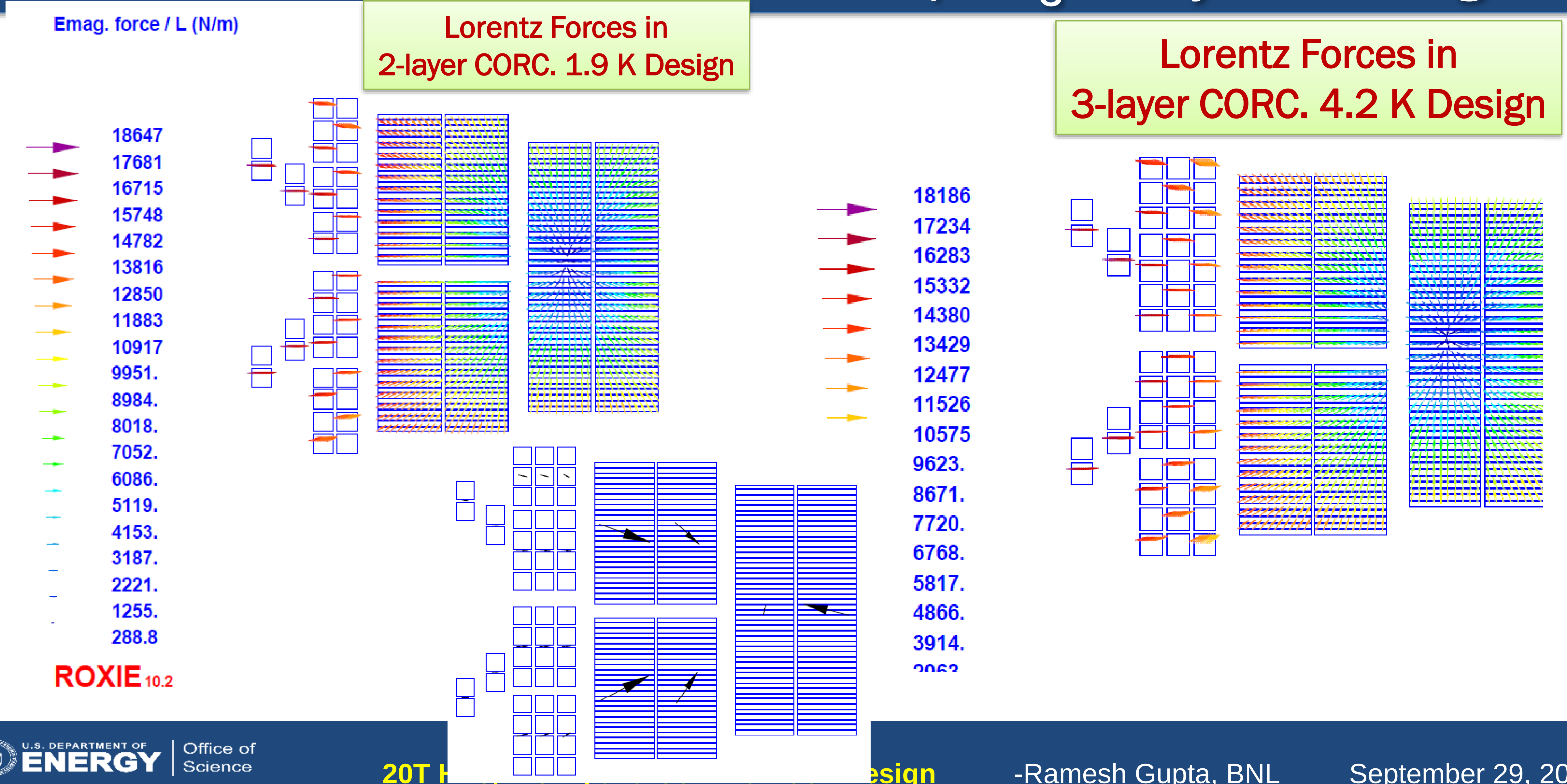
3-layer ReBCO; 4.2 K

```
HARMONIC ANALYSIS NUMBER ............................          1
MAIN HARMONIC .......................................          1
REFERENCE RADIUS (mm) ...............................    15.0000
X-POSITION OF THE HARMONIC COIL (mm) ...............      0.0000
Y-POSITION OF THE HARMONIC COIL (mm) ...............    169.0000
MEASUREMENT TYPE ........................ ALL FIELD CONTRIBUTIONS
ERROR OF HARMONIC ANALYSIS OF Br ...................  0.2730E-03
SUM (Br(p) - SUM (An cos(np) + Bn sin(np))

MAIN FIELD (T) ......................................  19.997422
MAGNET STRENGTH (T/(m^(n-1)) .......................     19.9974

NORMAL RELATIVE MULTIPOLES (1.D-4):
b 1:  10000.00000  b 2:      0.00000  b 3:      0.00080
b 4:     -0.00000  b 5:     -0.00477  b 6:      0.00000
b 7:     -0.01270  b 8:      0.00000  b 9:     -0.53135
b10:     -0.00000  b11:     -0.44273  b12:      0.00000
b13:     -0.00775  b14:     -0.00000  b15:     -0.00185
b16:     -0.00000  b17:     -0.00815  b18:      0.00000
b19:     -0.00109  b20:     -0.00000  b

SKEW RELATIVE MULTIPOLES (1.D-4):
a 1:     -0.00000  a 2:      0.00063  a 3:     -0.00000
a 4:      0.00190  a 5:      0.00000  a 6:      0.01017
a 7:      0.00000  a 8:      0.15699  a 9:     -0.00000
a10:      0.09500  a11:      0.00000  a12:      0.00766
a13:     -0.00000  a14:      0.00281  a15:     -0.00000
a16:      0.00343  a17:     -0.00000  a18:      0.00112
a19:     -0.00000  a20:      0.00059  a
```

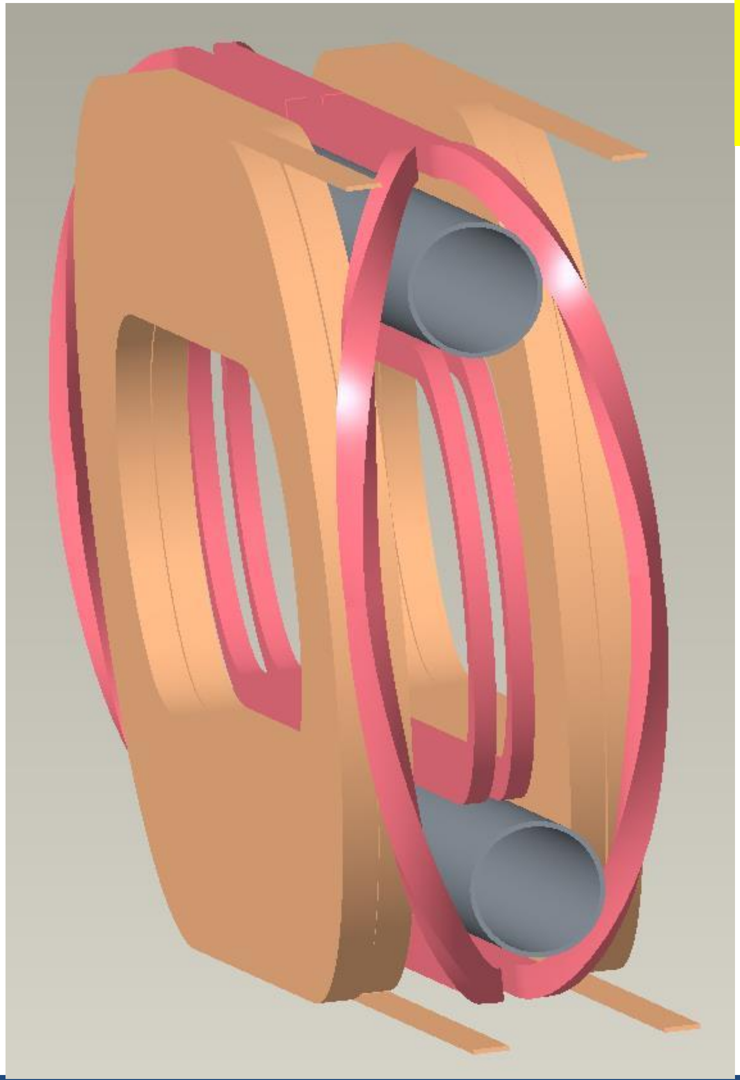
Lorentz Forces in 50 mm, 20 T Common Coil CORC/Nb_3Sn Hybrid Design

Lorentz Forces in 2-layer CORC. 1.9 K Design

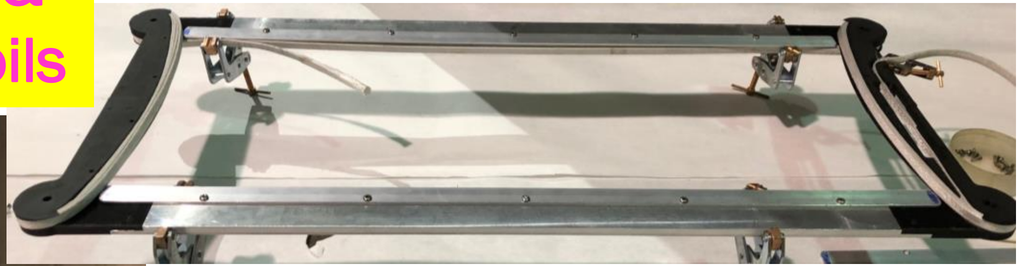
Lorentz Forces in 3-layer CORC. 4.2 K Design

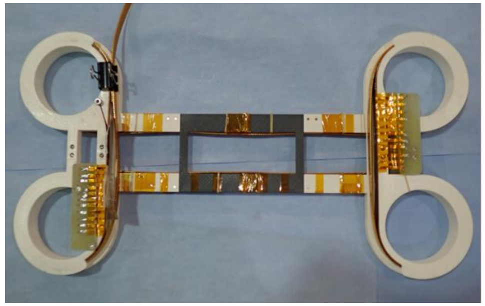


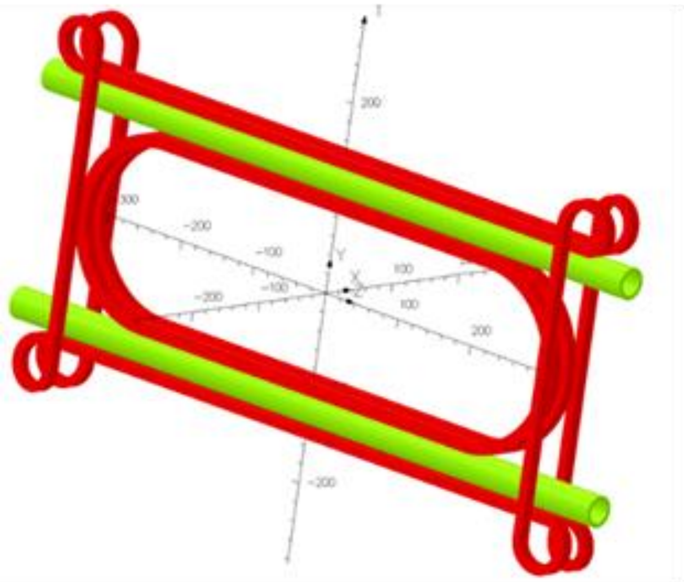
A Few Possible Layout of Away Pole Coils Clearing Bore (others shown elsewhere)

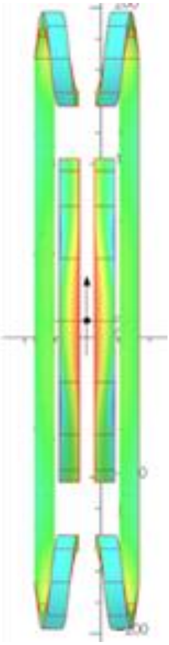


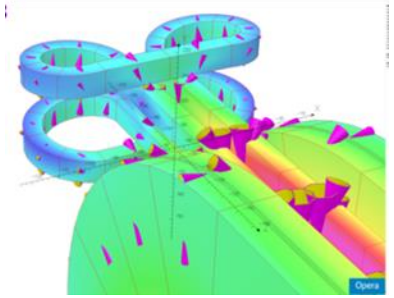
Practice & Tested Coils





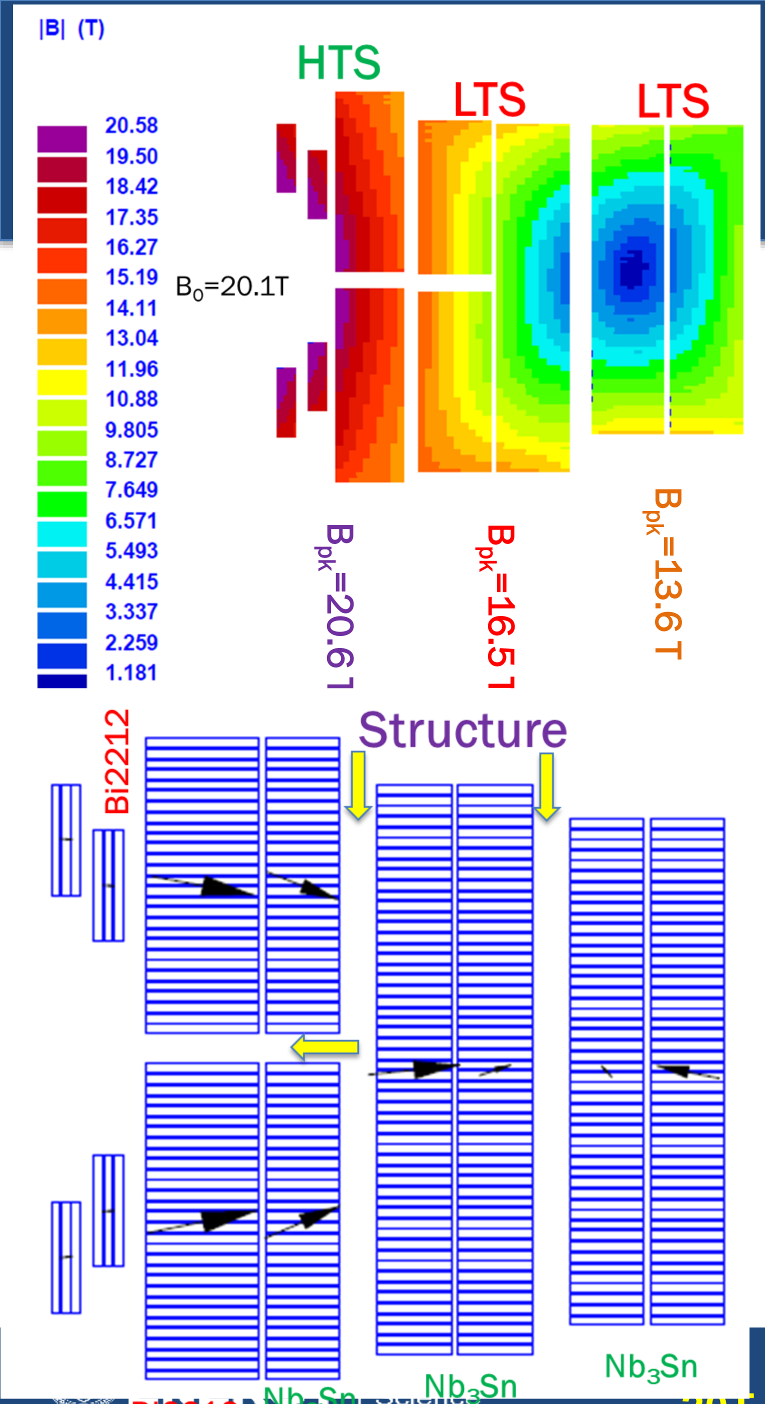


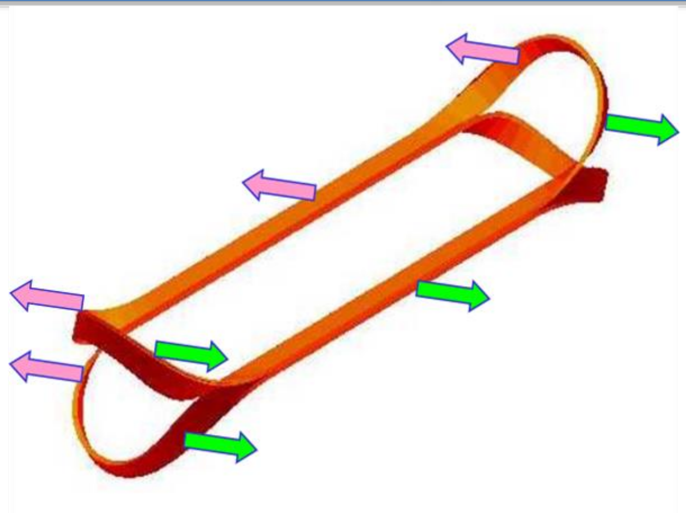


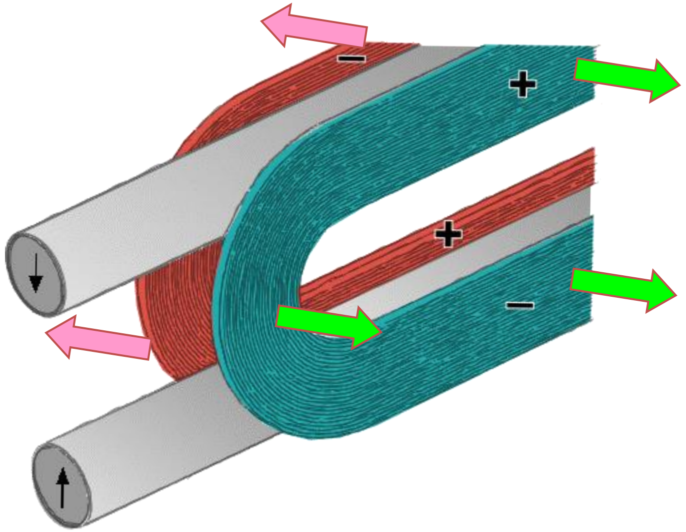


CORC coil can be bent first away and then up/down

Key Benefits of the Common Coil Design for HTS/LTS High Field Hybrid Dipoles







- ❑ Natural segmentation between HTS and LTS (and different cables)
- ❑ Easier tuning between HTS & LTS
- ❑ Coil layers move as a module without causing strain at ends (BNL common coil had 200 μm)
- ❑ Intermediate space for stress management structure. It can be easily adjusted, even at the late stage of the magnet construction