Status and Development of a Nb_3Sn Canted-Cosine-Theta (CCT) Magnets

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Outline

- The CCT Technology
- Test results of 3 R&D dipoles (CCT1, CCT2 and CCT3)
- Prospects of a high field CCT dipole for the FCC

Future Magnet Technology

Seeking a fundamental shift in magnet technology

1) Technology that can reduce operating margin by half
   a) from 20% to 10%
2) Addresses issues related to training and brittle conductor
   a) stress
3) Reduces complexity beyond field quality
   a) tooling, assembly, pre-stress
4) An iterative R&D
   a) coil exchange
5) Compatibility between conductor and magnet design
   a) NbTi, Nb_3Sn and HTS

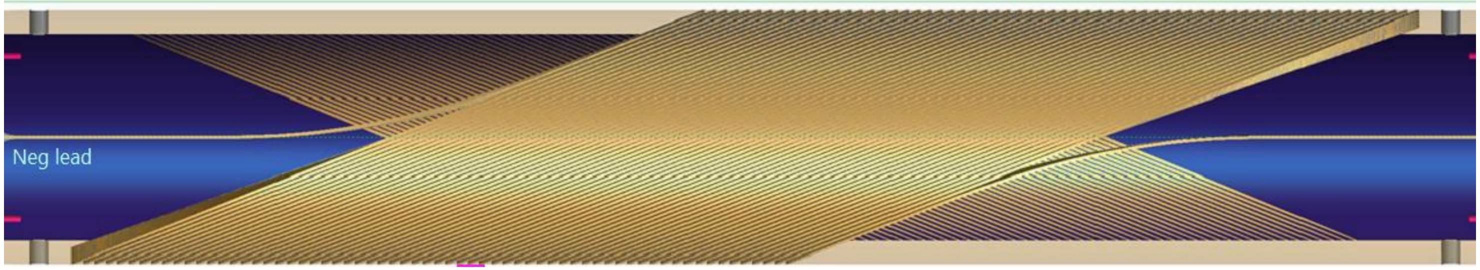
Magnet technology: a family of solutions

For the past 40 years LBNL has been focused on magnet R&D of accelerator magnets gaining experience in magnet such as

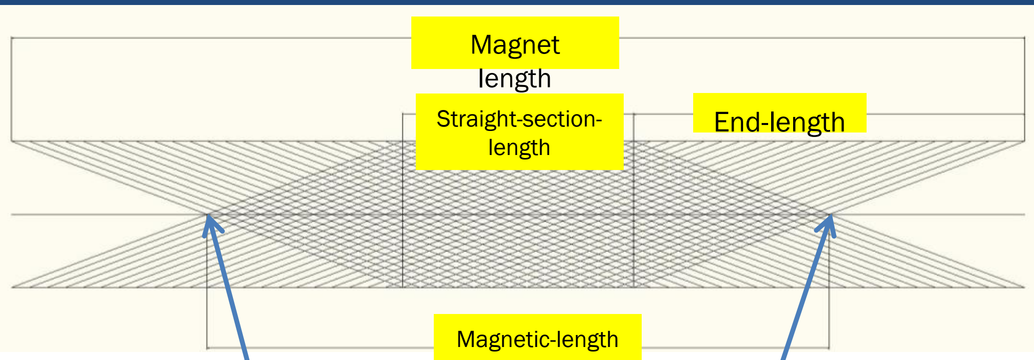
- Cosine-Theta (CT)
- Common-Coil (CC)
- Block (BK)

and is now exploring the Canted-Cosine-Theta (CCT)

The CCT is a paradigm shift with respect to all previous technologies and promises answers to issues facing present high field magnets

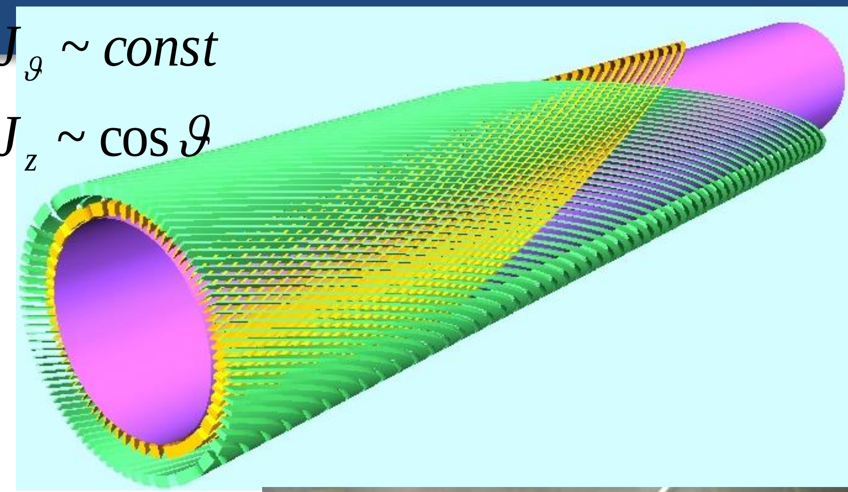


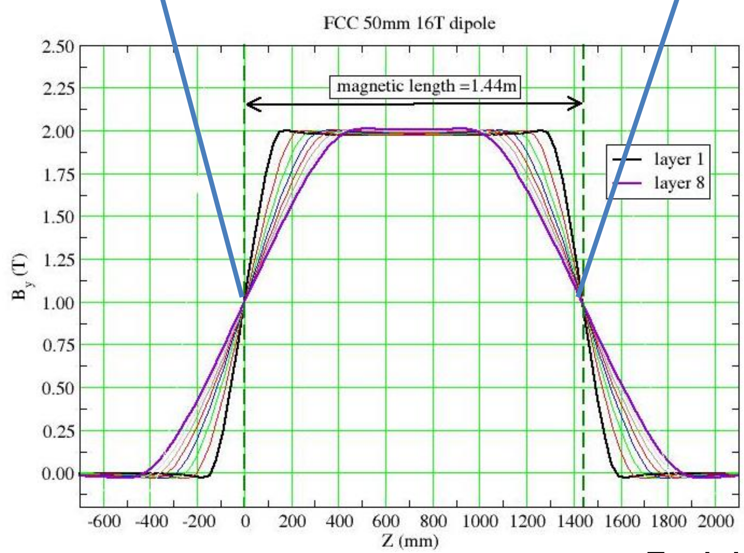
The CCT Technology



$J_\vartheta \sim const$

$J_z \sim \cos\vartheta$



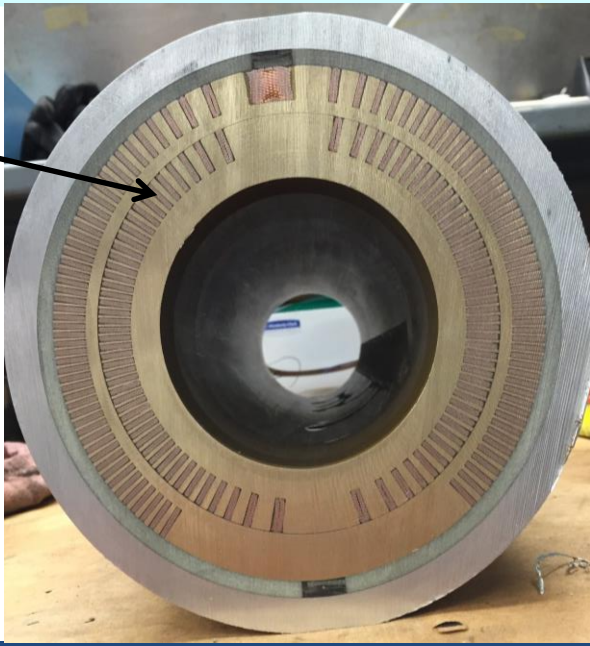


An 8 layers dipole 8*2T=16T

cable area varies

Jz=J0*cos(t)

Jz=(I/A(t))*cos(t)

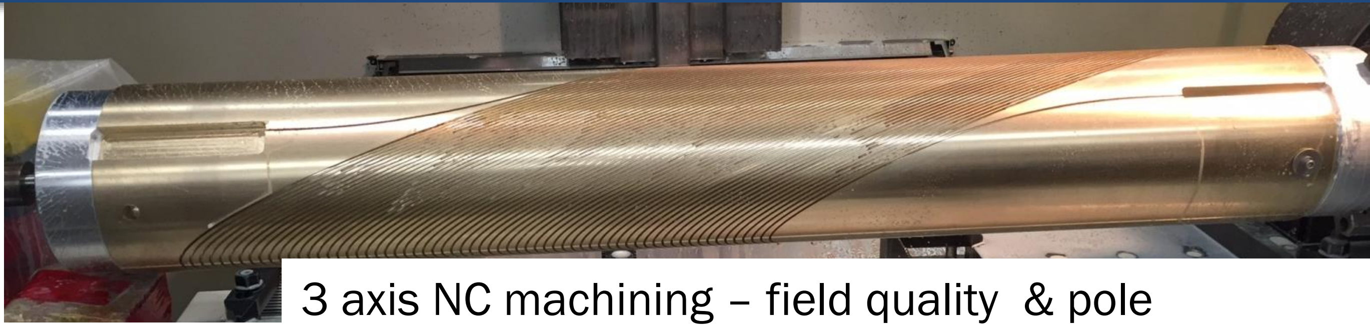


Each layer is a stand alone magnet:

1. same dipole field
2. Same magnetic length
3. Same field quality

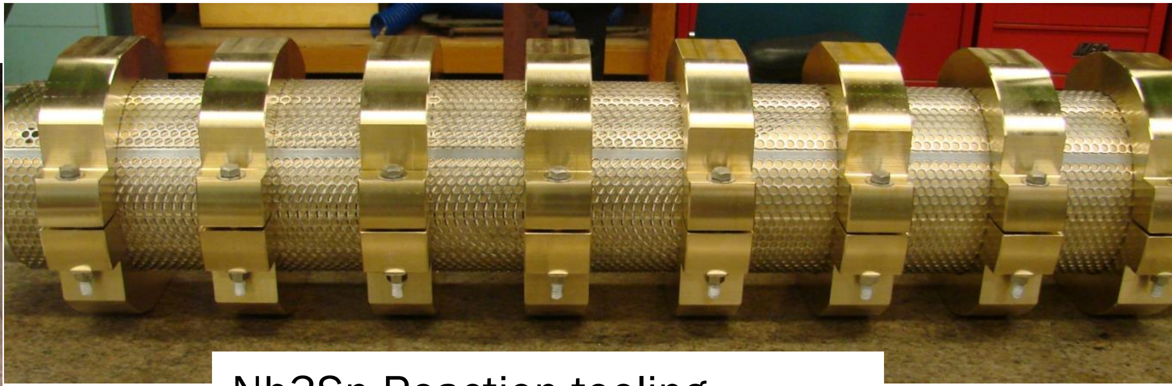
Coil Winding and Reaction using dramatically simpler tooling

Bronze tubing



3 axis NC machining – field quality & pole assembly

Winding – no tension



Nb3Sn Reaction tooling - clamps

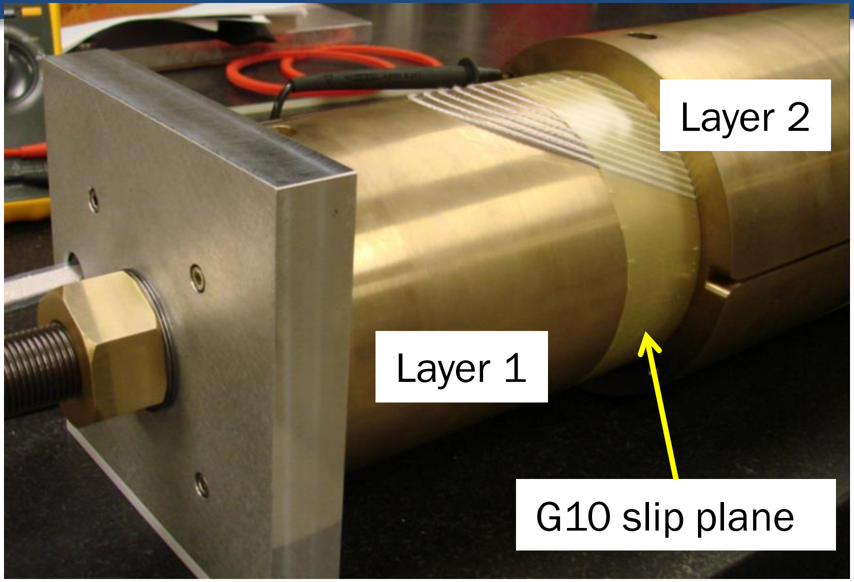
Machined channels provide conductor path

Conductor placed without tension

Mandrels are used for winding, reaction and impregnation

Assembly – Impregnation again minimizing tooling requirements

Layers are forced to slide over each other



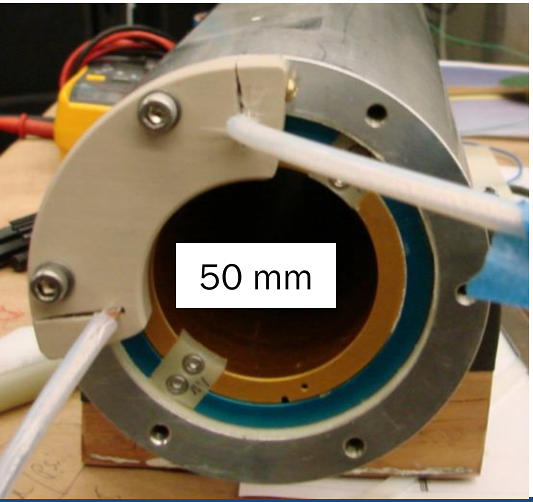
Two layers and outer Al shell impregnated together

Following the impregnation process the magnet is fully assembled

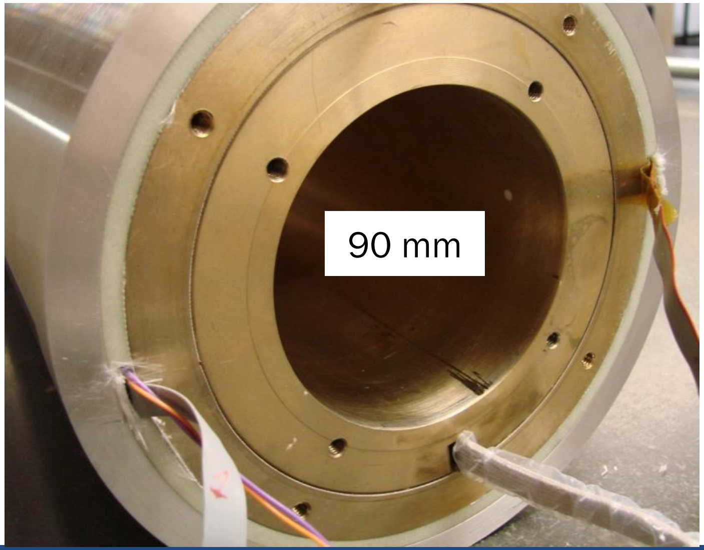
3 CCT Tests – 4.4K

Dipole	Cond.	material	Impreg.	Iron	Dia. (mm)	Field (T)	SS (%)	training
CCT1	**NbTi**	Al.	no	no	**50**	**2.4**	98	no
CCT2	**NbTi**	Bronze	yes	no	**90**	**4.6**	90	yes
CCT3	**Nb_3Sn**	Bronze	yes	yes	**90**	**7.4**	74	?/Conductor unstable; damage likely

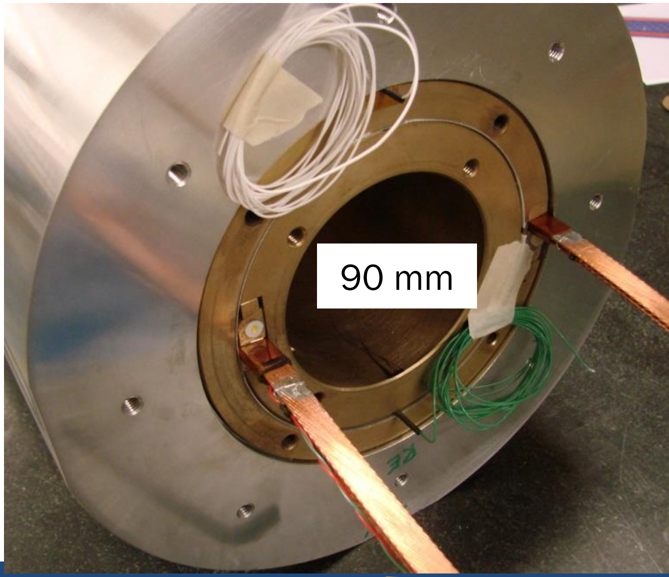
CCT1



CCT2



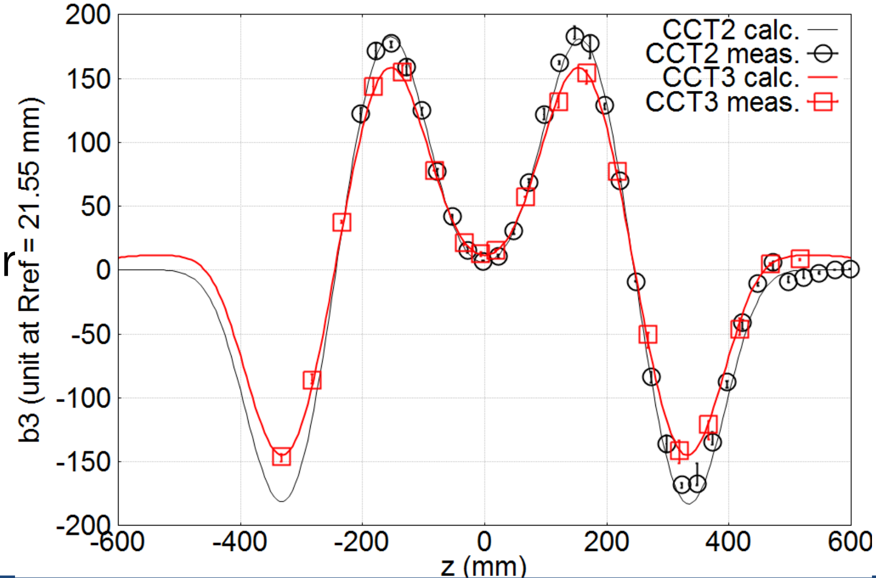
CCT3



CCT Tests

								Short-sample			
Name	test	layer s	Cond.	Bore (mm)	# strand	Yoke	Impreg.	I (kA)	B-bore (T)	B-cond (T)	B-bore Tested (T)
CCT1	4.4K	*2*	NbTi	50	8	no	no	4.0	2.5	3.1	2.4
CCT2	4.4K	*2*	NbTi	90	23	no	yes	10.3	5.1	5.77	4.6
CCT3	4.4K	2	Nb_3Sn	90	23	yes	yes	17.7	10.0	11.23	7.4

- CCT3 test not completed
- Conductor exhibits inverted ramp rate behaviour
- J_{cu} tested to 2500 A/mm^2

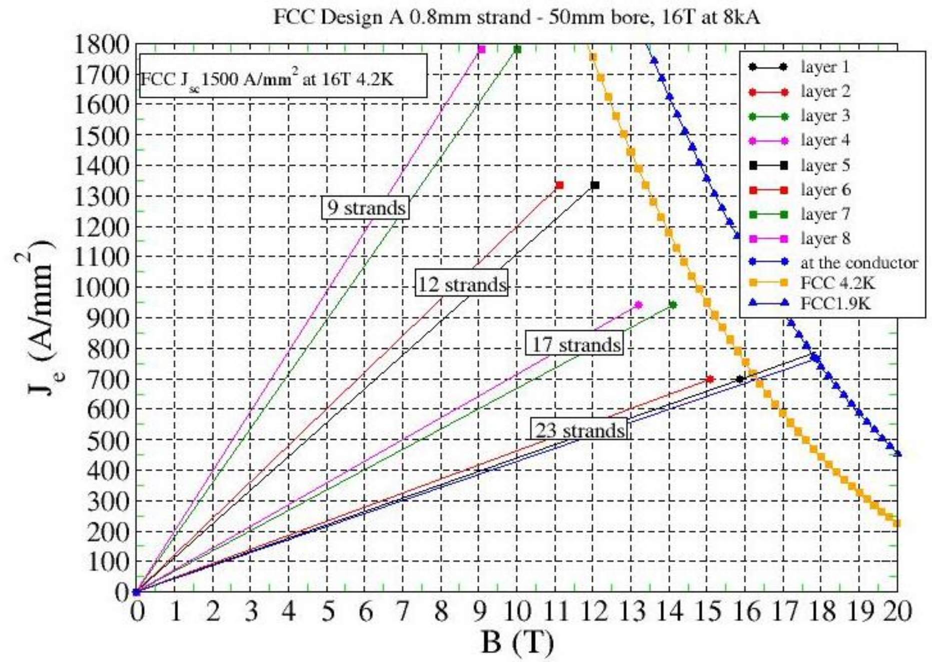


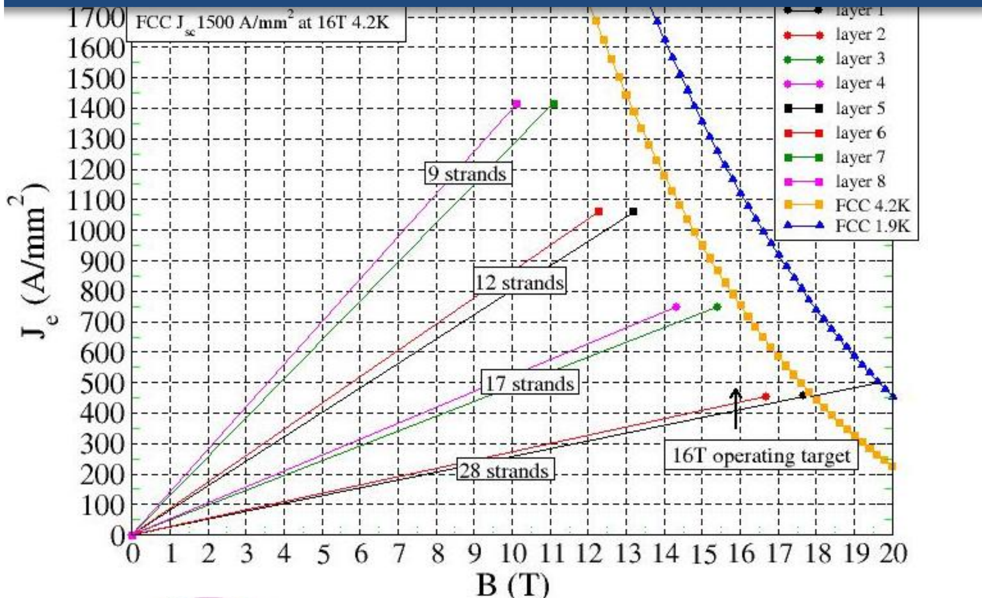
FCC – Dipole operating at 16 T

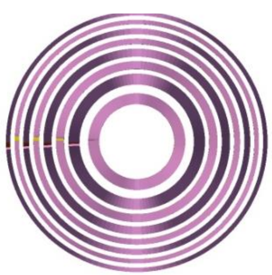
Prospects of a high field CCT dipole

Poster by Lucas Brouwer
“Multiphysics Modeling of Superconducting Canted-Cosine-Theta Dipoles”

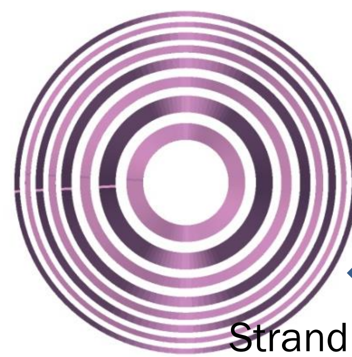
Two designs - 0.8mm and 1.0mm strand dia.







Clear bore ID=50mm,
Strand dia=0.8mm,
Coil OD=245mm



Clear bore ID=50mm,
Strand dia=1.0mm,
Coil OD=322mm

Larger strands and spars

Strand /magnetic length = 16.2(Km/m)
Weight/magnetic-length = 72.6(Kg/m)
Weight/magnet = 1.0(Ton/magnet)
Weight/beam = 4.7 (Kton/beam)

Strand /magnetic length = 19.8(Km/m)
Weight/magnetic-length = 138(Kg/m)
Weight/magnet = 2.0(Ton/magnet)
Weight/beam = 9.06 (Kton/beam)

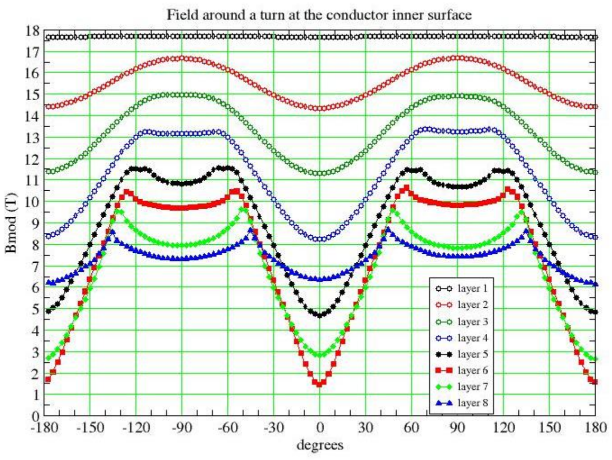
CCT for High Field – Design A and B

No - iron			At short-sample 4.2 K				At 16 T	
Name	Bore (mm)	Strand (mm)	I (kA)	B-bore (T)	B-cond (T)	Je (A/mm^2)	Margin (%)	Jcu (kA/mm^2) lay1/8
Design-A	50	0.8	8.07	15.9	16.3	701	0	1.4/3.6
Design-B	50	1.0	10.0	17.6	17.9	456	10	0.8/2.6

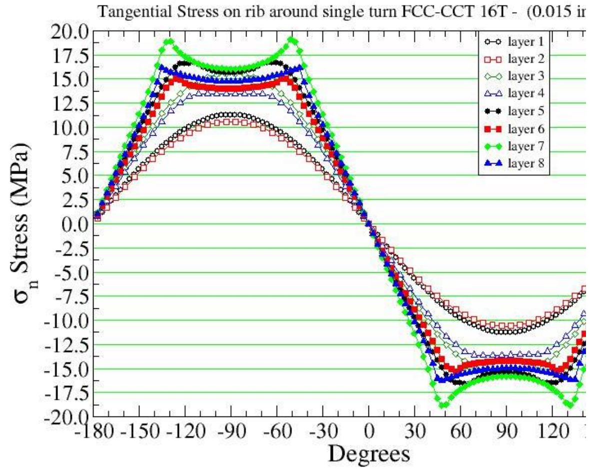
No - iron			At short-sample 1.9 K				
Name	Bore (mm)	Strand (mm)	I (kA)	B-bore (T)	B-cond (T)	Je (A/mm^2)	Margin at 16T (%)
Design-A	50	0.8	8.82	17.4	17.8	763	8
Design-B	50	1.0	11.0	19.3	19.7	500	18

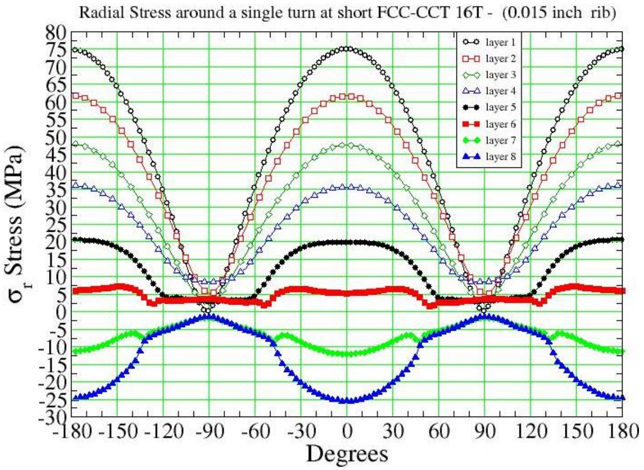
*adding iron will raise the field by ~0.5 T and reduce the current by ~10%

Lorentz coil stress (F/Area) at short sample 4.2 K



Design B





Name	MAX FIELD (T) LAYER 1/8	NORMAL STRESS (MPA) LAYER 1/7	RADIAL TRESS (MPA) LAYER 1/7
Design-A	16/8.5	12/18	63/-20
Design-B	17.6/8.5	12/20	75/-25

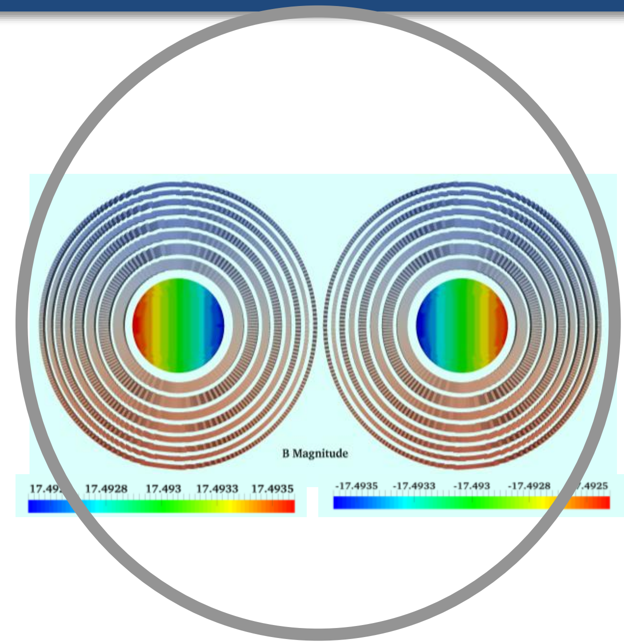
CCT for High Field – Design A and B

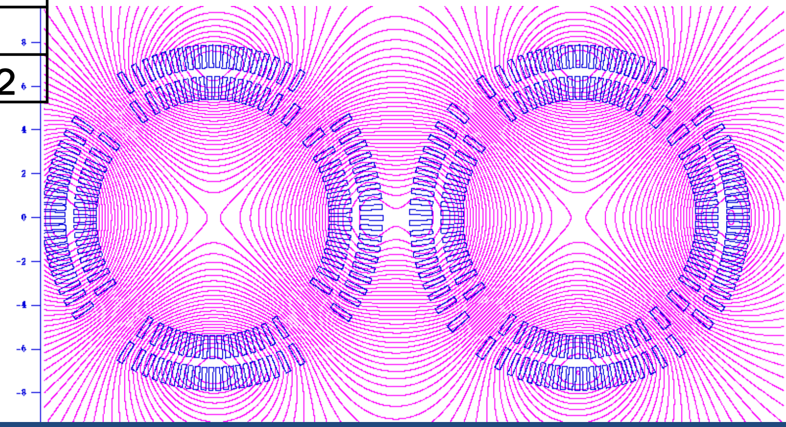
Name	Cond. Thick (mm)	Spar Thick (mm)	Coil OD (mm)	Conductor per bore (mm^2)	Strand per bore (km/m)	Cable per bore (km/m)
Design-A	55	42	245	8160	16.2	1.2
Design-B	75	61	322	15500	19.8	1.4

1. Mixing coil and structure requires more conductor
2. Overall magnet size
3. Doubling the margin from 10% to 20% will double the conductor volume
4. Placing the iron outside the cryostat should be considered

2-in-1 CCT Dipole with 50mm clear bore

Design		**A**	**B**
Number of apertures	(-)	2	2
Aperture (clear)	**(mm)**	**50**	**50**
Inter-aperture spacing	**(mm)**	**275**	**350**
Operating current	(KA)	8	9
Operating temperature	**(K)**	**1.9**	**1.9**
Operating field	**(T)**	**16**	**16**
Margin along the load line	**(%)**	**10**	**20**
Inductance (single bore)	(mH/m)	94	-
2-in-1- OD (no iron)	**(mm)**	**275x2**	**350x2**
Peak/mid-plane/pole stress	**(MPa)**	**<20/75**	**<20/75**
Short-Sample bore field	(T)	~17.4	~19.3
0.8mm/1.0 strand/1m-magnetic length	**(Km/m)**	**16x2**	**19x2**
Total amount of Nb3Sn /Rring	**(kton)**	**4.7x2**	**9x2**
Total amount of structural Bronze/Ring	**(Kton)**	**~17x2**	**~27x2**





Conceptual view of a 2-in-1 quadrupole.
Coil symmetry broken to reduce cross-talk harmonics

CCT - Summary

1. The CCT is a paradigm shift
2. Reduce the margin without compromising safety
3. Magnetic and structural elements brings simplicity
   a) Field quality
   b) No pre-stress (can be added, but would add complexity)
   c) Mechanically dominated by bronze structure
   d) Ease of grading
   e) Simplified tooling
   f) Iron not needed as a structural element, not part of the cold-mass