U.S. MAGNET DEVELOPMENT PROGRAM

US-MDP Nb_3Sn Cos-theta Magnets

FCC Week in Amsterdam,
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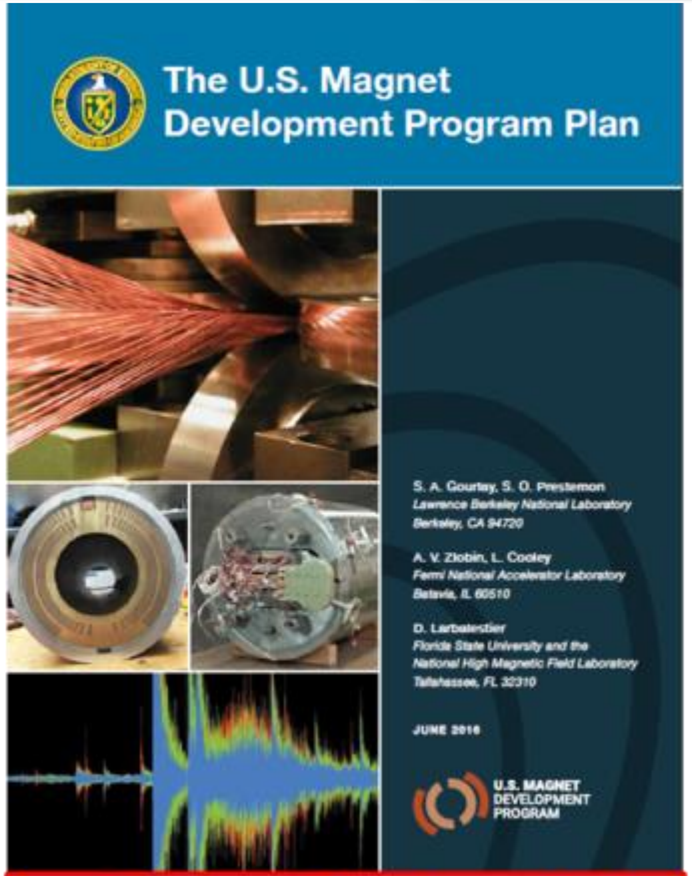
Outline



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Nb_3Sn Cos-theta dipole program plan and steps

- Step 1: 15 T dipole demonstrator
- Step 2: 15 T dipole demonstrator + utility structure
- Step 3: 16-17 T dipole with stress management
- Large-aperture Nb_3Sn dipoles: 120-mm aperture dipoles with stress management for HTS coil test
- Conclusions

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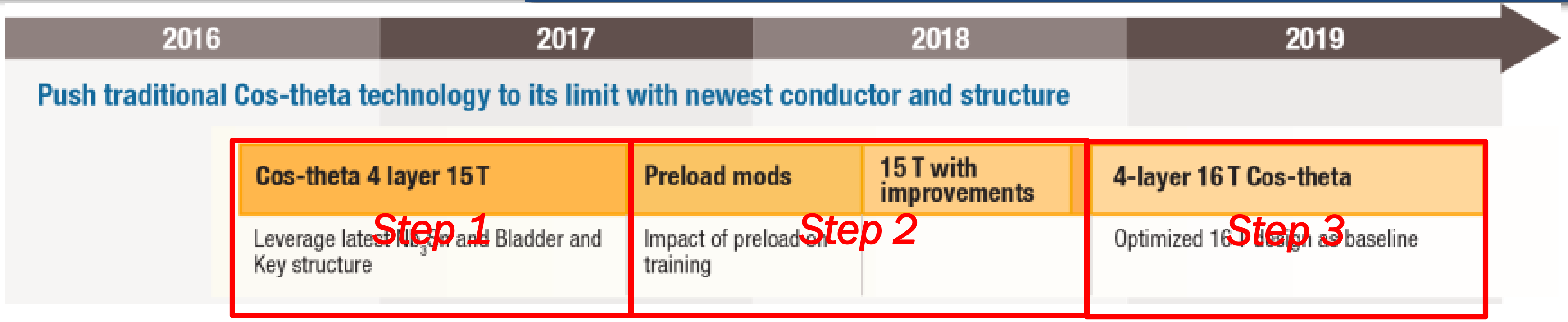
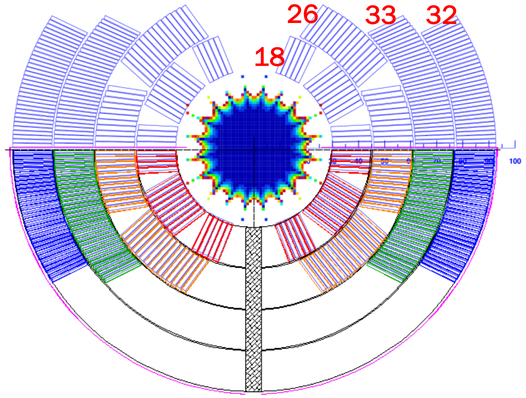
Nb_3Sn Cos-theta Magnet R&D Plan



- Step 1: 15 T dipole demonstrator design.
  - **Explore target field and force range.**
  - **Serve as technical and cost bases for comparison with new concepts.**
  - **Is an opportunity for program integration, particularly in the area of support structure design, and for exploration of different mechanical structures.**
  - **Most cost effective way to exceed the field obtained 20 years ago in the LBNL D20 dipole.**

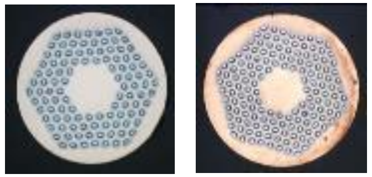
MDP 15 T Dipole Demonstrator Design

- **Coil:**
  - 60-mm aperture, 4-layer graded coil
  - W_{sc} = 68 kg/m/aperture

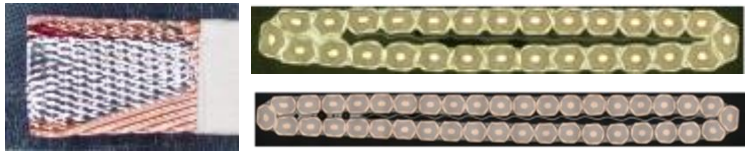


- **Cable:**
  - L1-L2: 28 strands, 1 mm RRP150/169
  - L3-L4: 40 strands, 0.7 mm RRP108/127
  - 0.025 mm x 11 mm SS core
  - Insulation: E-glass tape

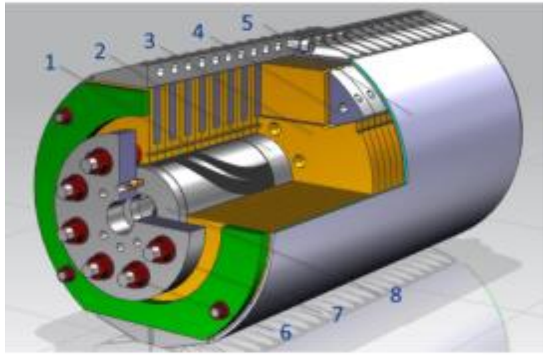
RRP-108/127
0.7 mm

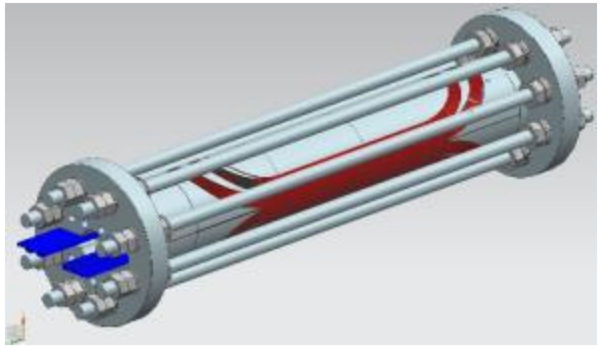


RRP-150/169
1 mm

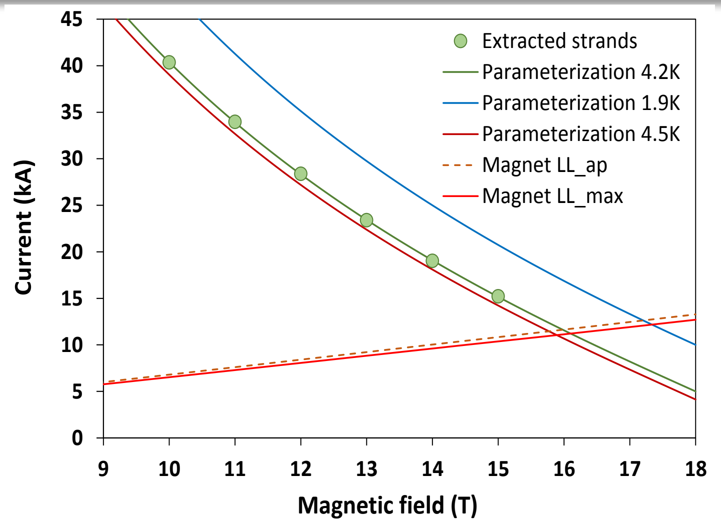


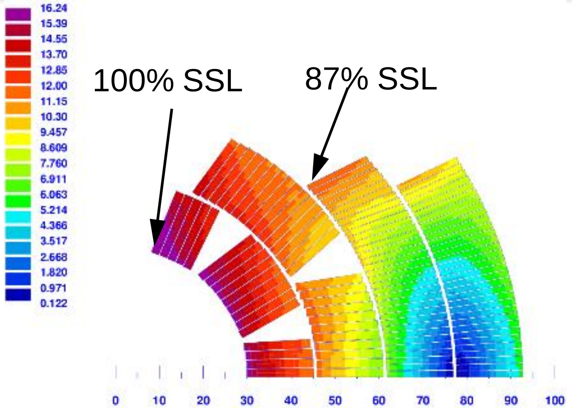
- **Mechanical structure:**
  - Thin StSt coil-yoke spacer
  - Vertically split iron laminations
  - Aluminum I-clamps
  - 12-mm thick StSt skin
  - Thick end plates and StSt rods
  - Cold mass OD<610 mm





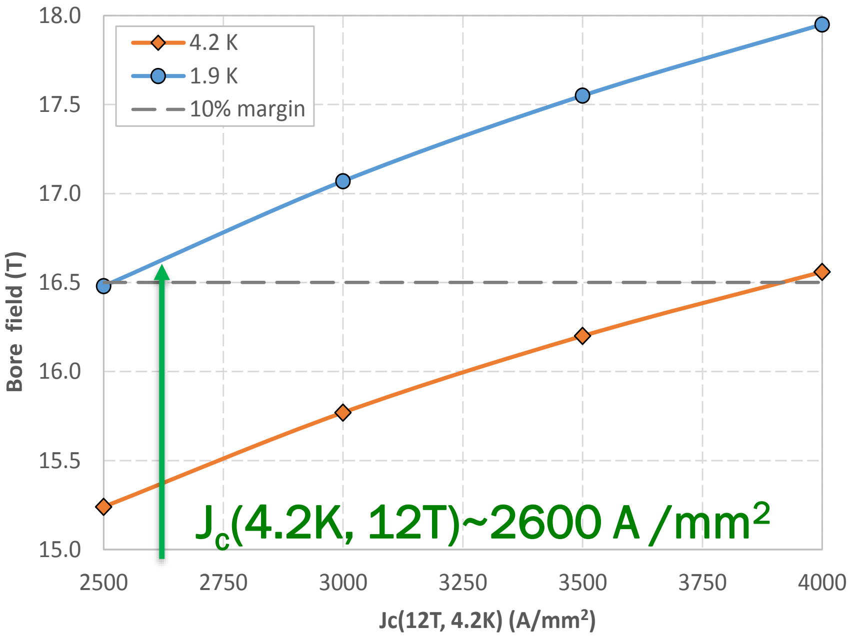
SSL and Design Field (or Magnet Design Limit)



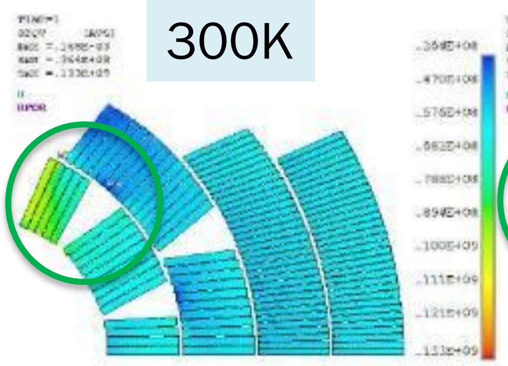


Magnet SSL:

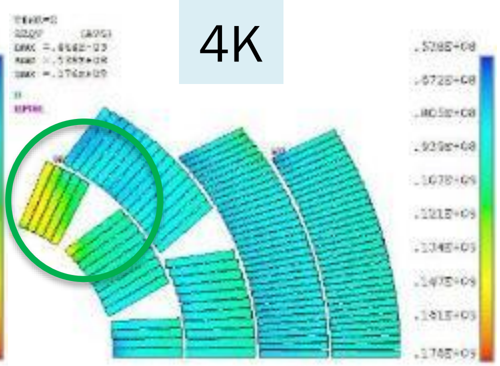
- B_{ap}=15.3T @4.5K
- B_{ap}=16.7T @1.9K



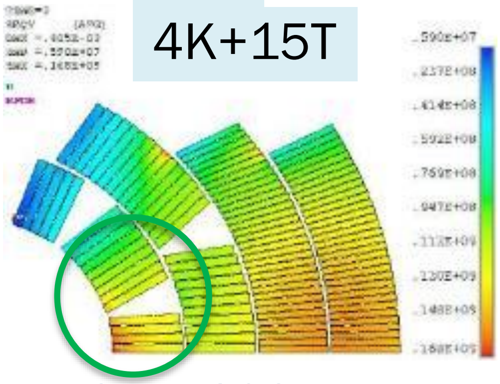
Magnet design limit is determined by the mechanical constraints and it is 15 T.



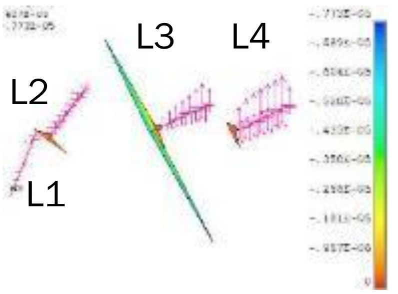
S_{eqv}=133 MPa



S_{eqv}=176 MPa

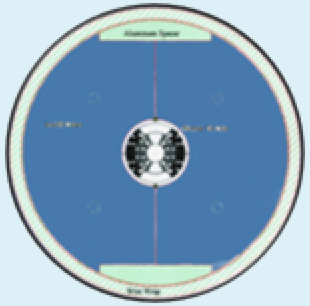
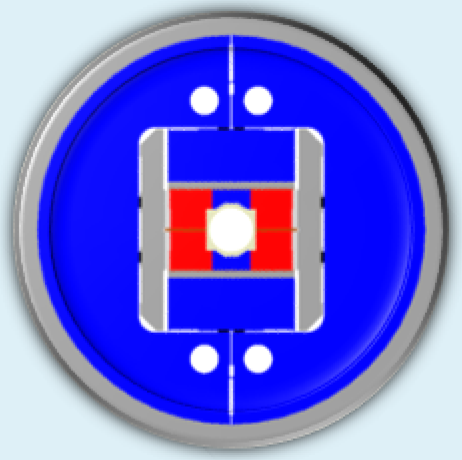
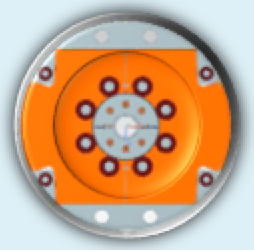


S_{eqv}=168 MPa

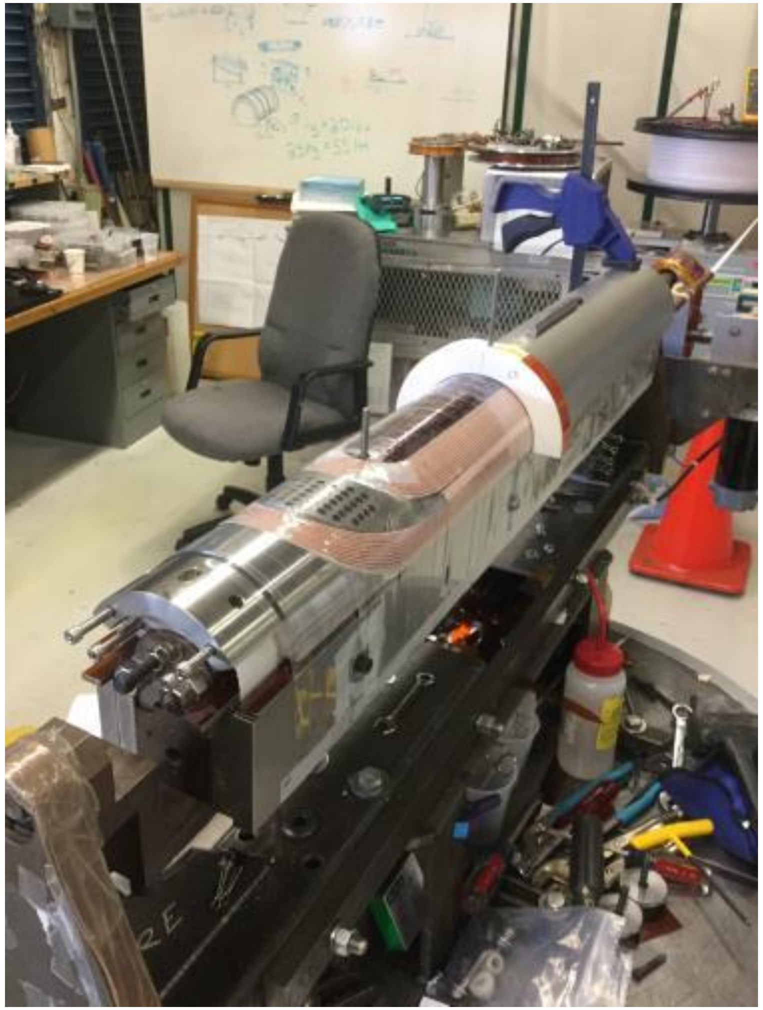


Gaps between poles and pole turns

Magnet Parameters at 4.5 (1.9*) K

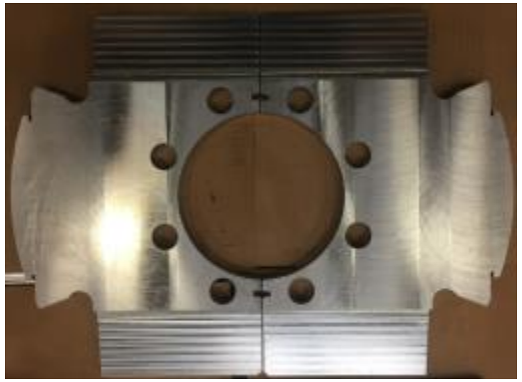
Parameter	D20 (LBNL)	HD2 (LBNL)	FRESCA2 (CERN)	HFDD (MDP)
				
Test year	1997	2008	2017	2018 (plan)
Max bore field [T]	13.35 (14.7*)	15.4	16.5 (18*)	15.2 (16.5*)
Design field B_{des} [T]	13.35	15.4	13	15
Design margin B_{des}/B_{max}	1.0 (0.9*)	1.0	0.8 (0.7*)	0.96 (0.89*)
Tested B_{max} [T]	12.8 (13.5*)	13.8	~13	TBD
St. energy at B_{des} [MJ/m]	0.82	0.84	4.6	1.7
F_x/quad at B_{des} [MN/m]	4.8	5.6	7.7	7.4
F_y/quad at B_{des} [MN/m]	-2.4	-2.6	-4.1	-4.5
Coil aperture [mm]	50	45	100	60
Magnet (iron) OD [mm]	812 (762)	705 (625)	1140 (1000)	612 (587)

Fabrication Status



- All coil parts and structural components are available.
- Coil and mechanical structure fabrication is in progress.

Mechanical Structure

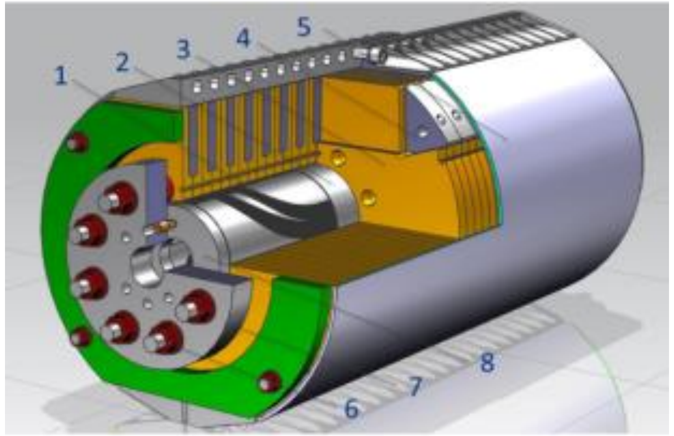


Iron Laminations

StSt Skin

AL I-Clamps

End Plates



Fillers

Axial Rods

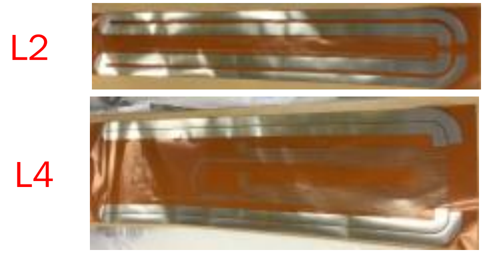
Coil Components

Cable (FNAL)

- 420 m of 28-strand cable (4UL)
- 350 m of 40-strand cable (3UL)

L3/4 parts (FNAL)

Traces (LBNL/FNAL)



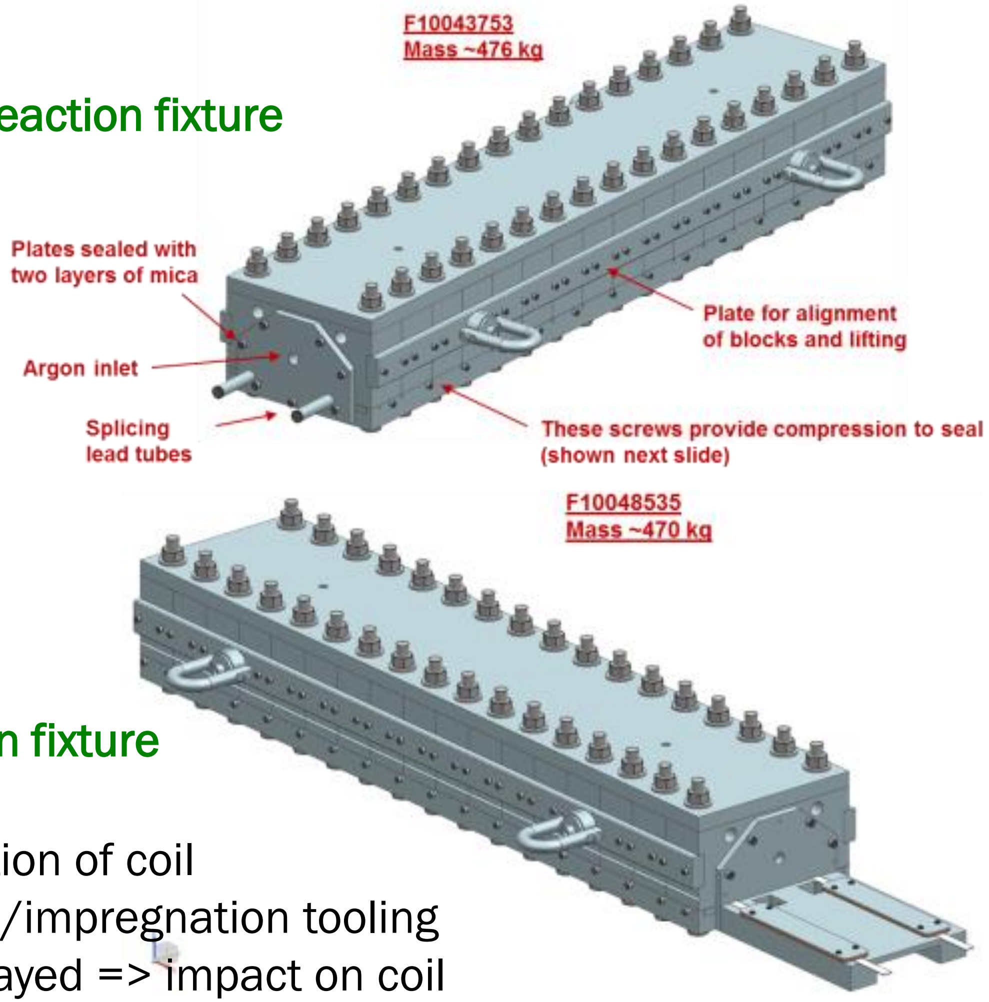
L1/2 parts (CERN)

Ti and Glidcop Wedges

Ti poles and spacers, SS saddles

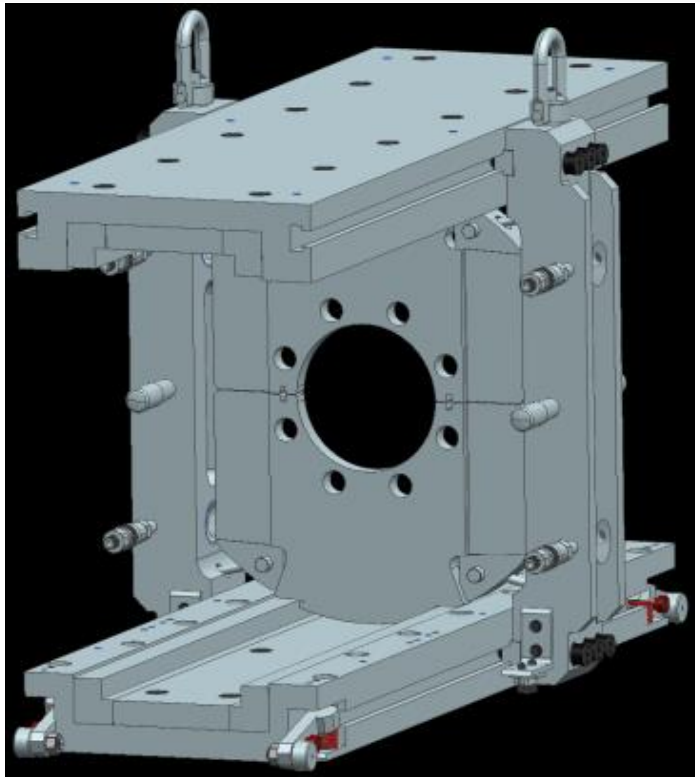
Tooling

Reaction fixture



Impregnation fixture

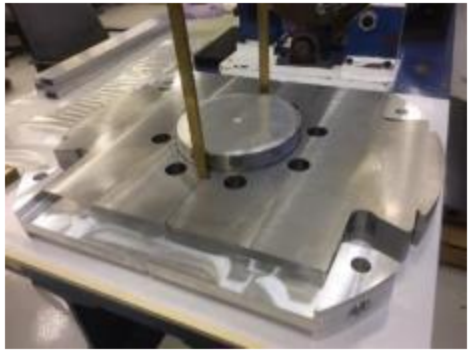
Fabrication of coil reaction/impregnation tooling was delayed => impact on coil fabrication schedule

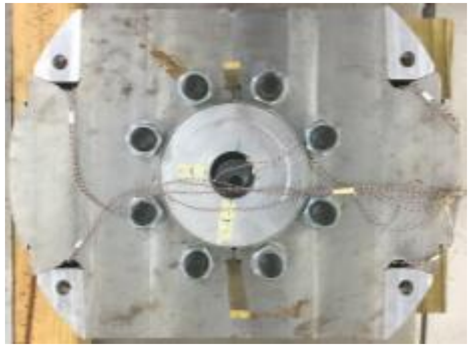


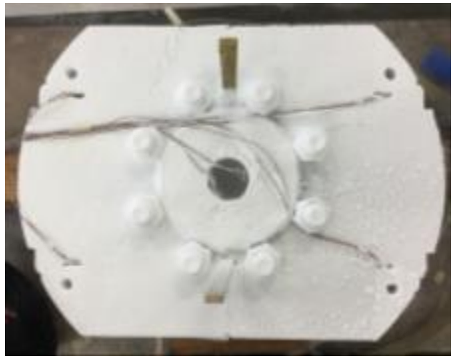
Yoking tooling

- Reaction/impregnation (2 sets)
  - L1-L2
  - L3-L4
- Yoking

Mechanical Models





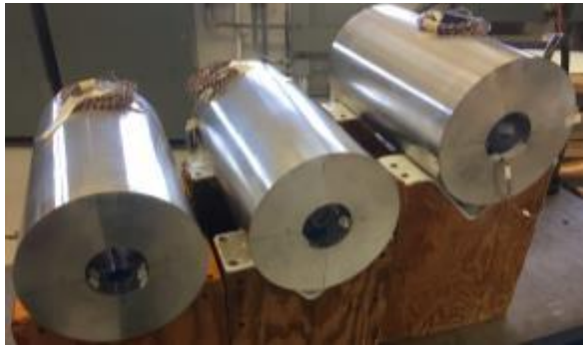


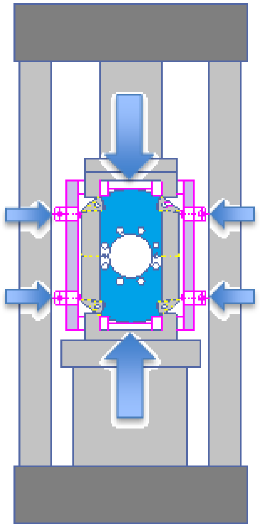
Models:

- 5 cm long
- 1 m long

MM components:

- Iron laminations
- Al I-clamps
- Coil-yoke shim
- Instrumented "dummy" Al coils (short and full-size)





Goals:

- **To test all main components of the mechanical structure and tooling.**
- **To develop a coil assembly plan and pre-stress targets.**
- **To check instrumentation.**
- **For FEA validation.**

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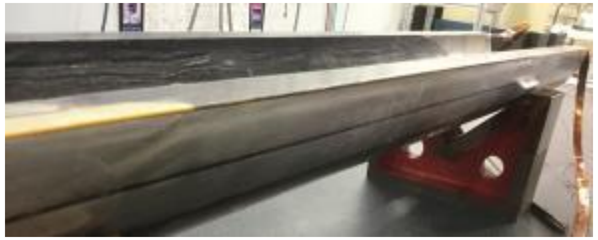
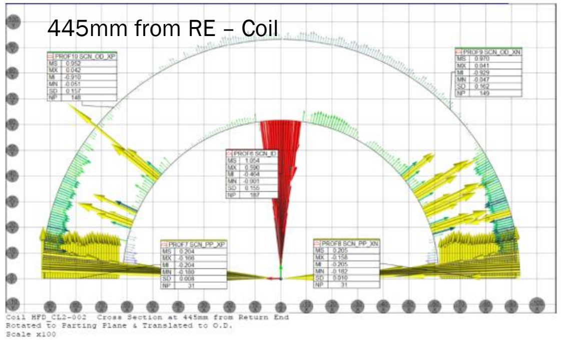
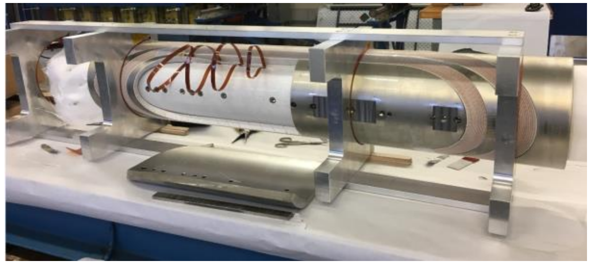
L3/L4 (Outer) Coil Fabrication

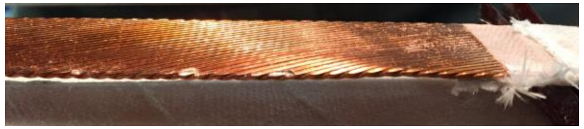
Coil #1
- Coil winding-curing-reaction-impregnation is complete
  - 8 witness samples tested
- Coil size was measured
- **Damaged due to shell buckling**

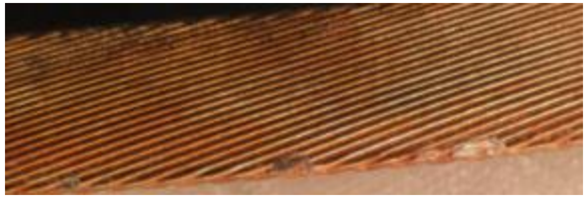




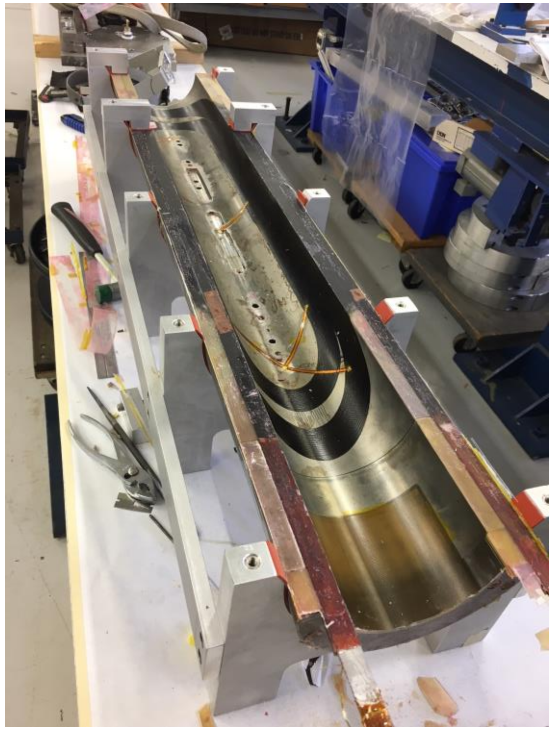
Coil #2
- Coil winding-curing is complete
- Short in the transition cable has been found and repaired
- **Strand damage was found in transition area**



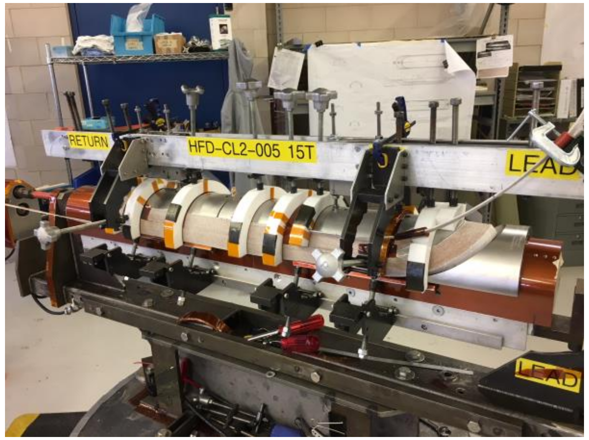




Coil #3
- Coil winding-curing-reaction-impregnation is complete
  - 7 witness samples tested
- Coil size measurements in progress



Coil #4 (to replace coil #1)
- Coil winding in progress
  - Coil parts from coil #2
  - Cable is available



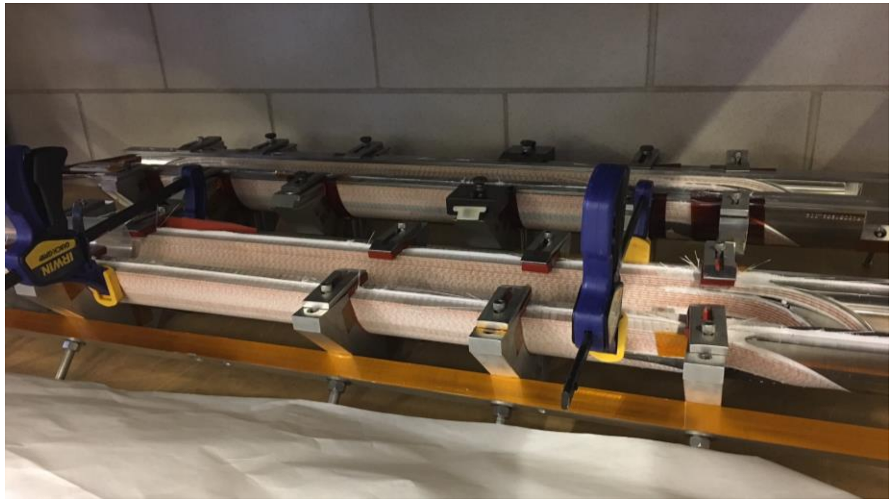
Coil #5 (spare coil)
- Need coil parts and cable

L1/L2 (Inner) Coil Fabrication

Coil #1
- Coil winding-curing-reaction is complete
- Preparation to impregnation in progress

Coil #2
- Coil winding-curing is complete
- Preparation to reaction in progress

Coil #3 (spare coil)
- Coil winding-curing is complete
- Coil stored in holding fixture



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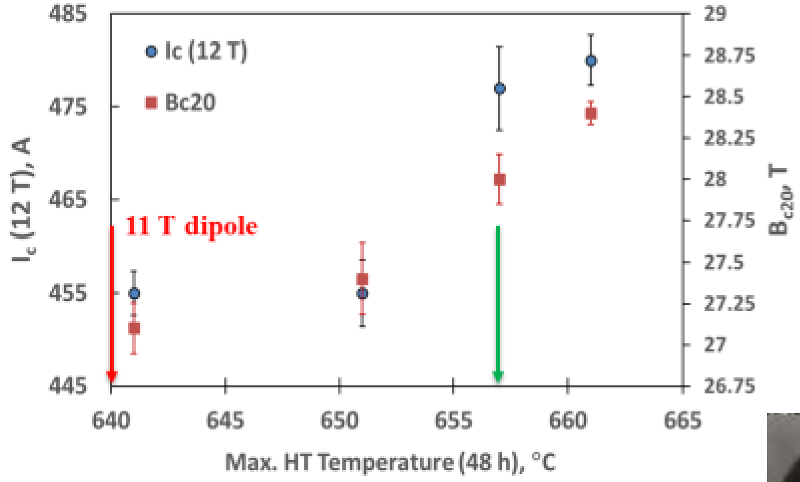
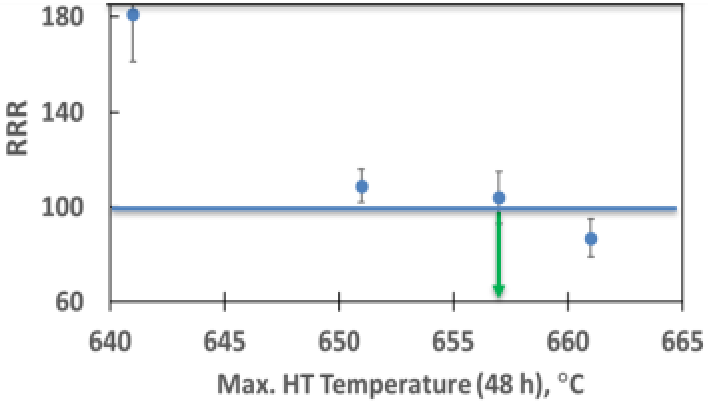
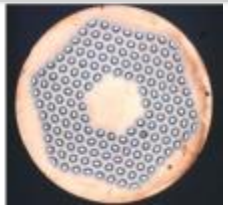
Coil Heat Treatment Optimization

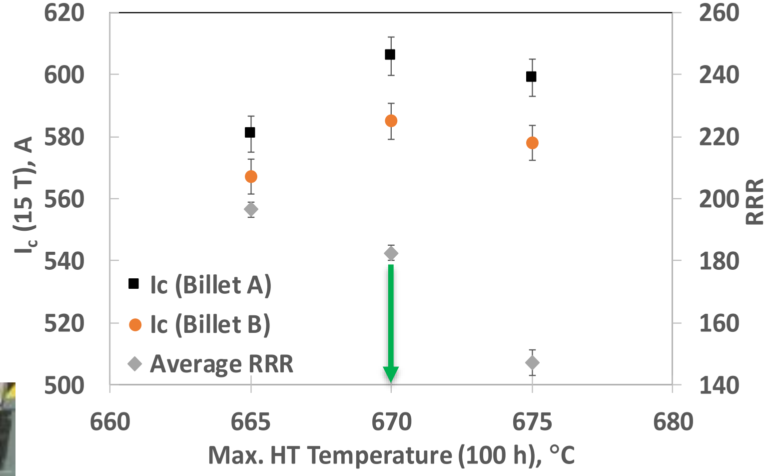
0.7 mm RRP108/127
40-strand cable with SS core





1 mm RRP150/169
28-strand cable with SS core





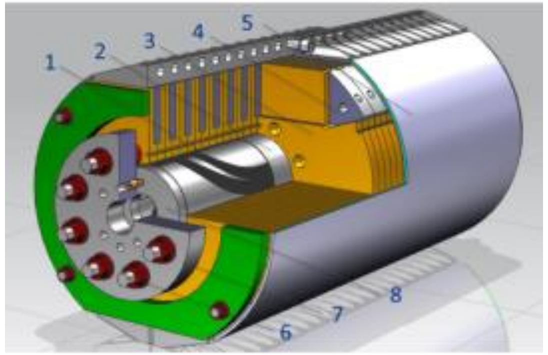
L3-L4 witness samples:

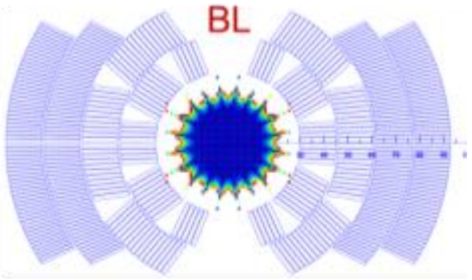
Location: tooling – 1 Rd+3 Ext, retort – 2 Rd+6 Ext

- Ic (12 T) = 504 A (tooling)
- Ic (12 T) = 498 ± 3 A (retort)
- RRR = 108 ± 22 (tooling)
- RRR = 74 ± 6 (retort)

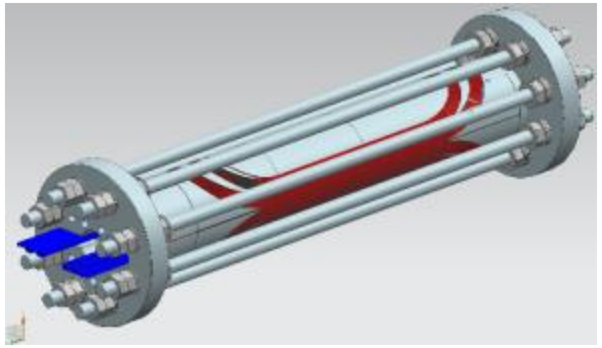
Step 2: Utility Structure with Key&Bladder Technology

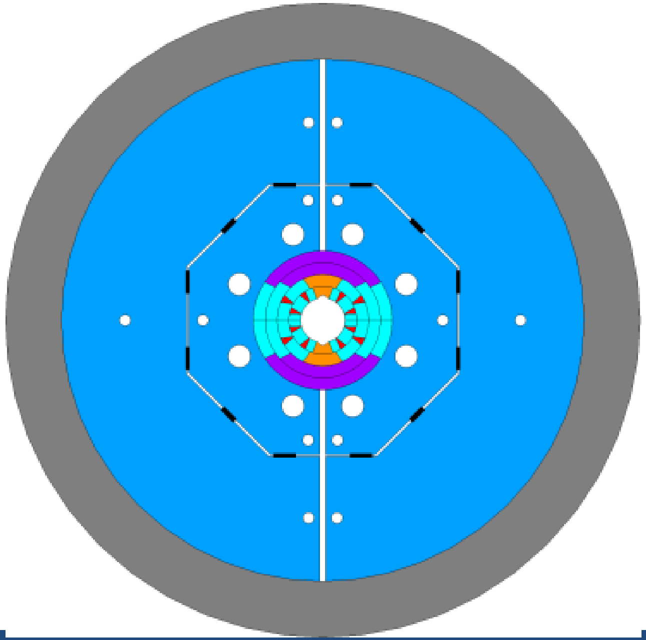
Step 2: A successful series of magnets will provide a platform for performance improvement.





60 mm aperture
B_{des}~15 T

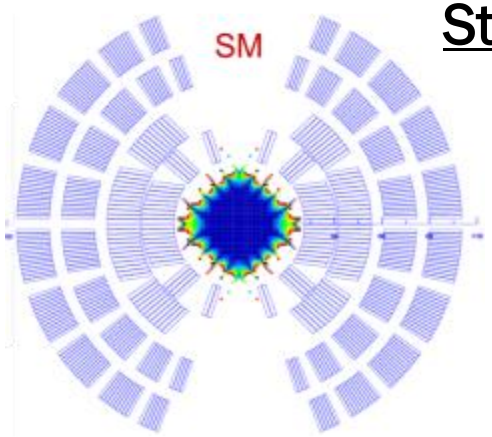




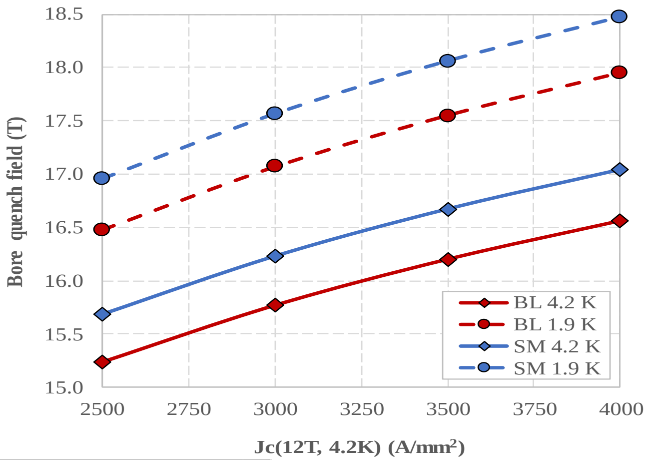
- Utility structure parameters:
  - Al shell OD: 750 mm
  - Al shell thickness: 75 mm
  - Coil-pack horizontal and vertical size: 320 mm
- Next steps:
  - Design studies are complete (M. Juchno)
  - Engineering design – FY2018
  - Fabrication – FY2019
- 15 T demonstrator assembly and test in FY2019

Step 3: 60-mm aperture 16 T Dipole

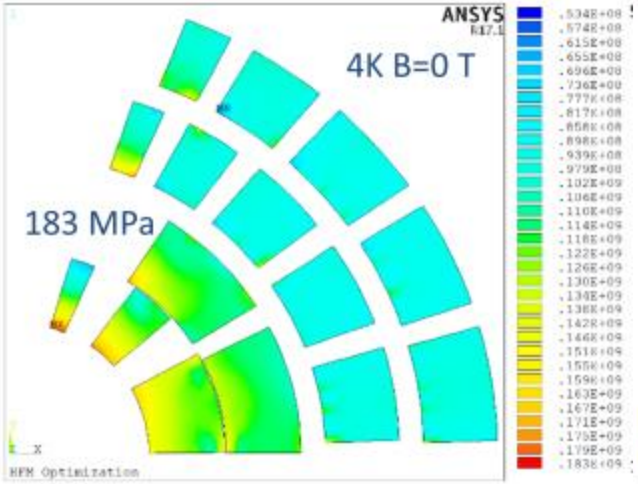
Step 3: 16 cos-theta design to explore the limit of Nb_3Sn in this geometry.

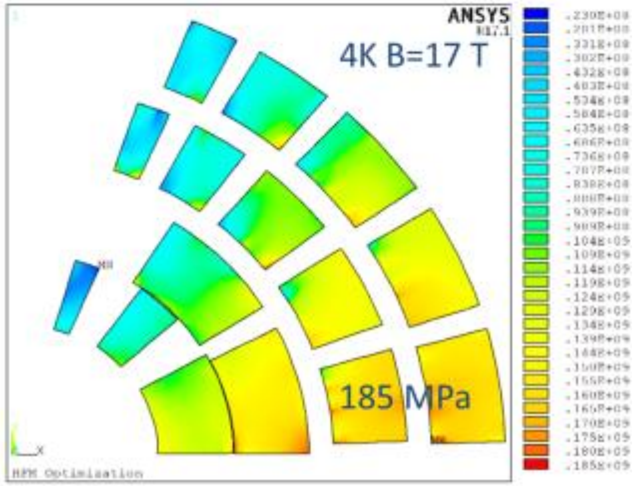


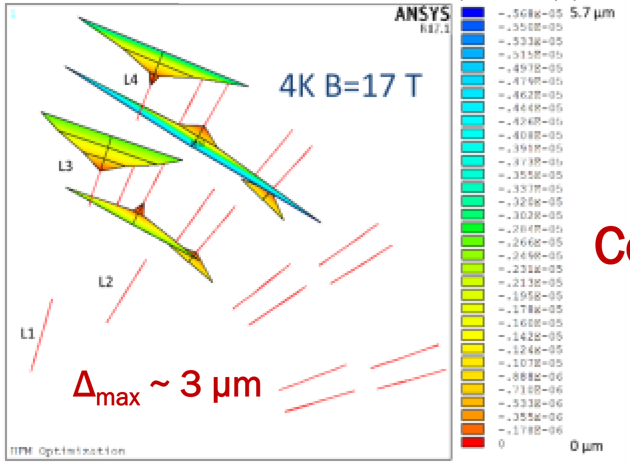
Parameter	BL		SM	
	IC	OC	IC	OC
Bore field, T	15.61		16.07	
Peak field, T	16.25		16.44	
Current, A	11.34		10.80	
Inductance, mH/m	25.61		35.42	
Stored energy, MJ/m	1.65		2.06	
F_x, MN/m/quadrant	5.8	1.6	4.8	4.7
F_y, MN/m/quadrant	-1.2	-3.3	-0.5	-3.6
Number of turns	44	65	38	102



Equivalent Stress

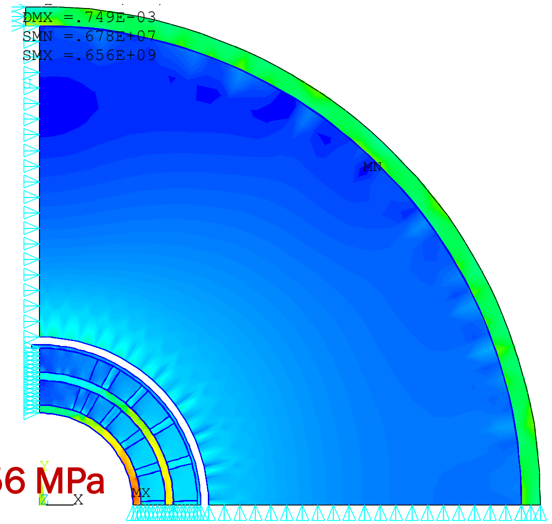




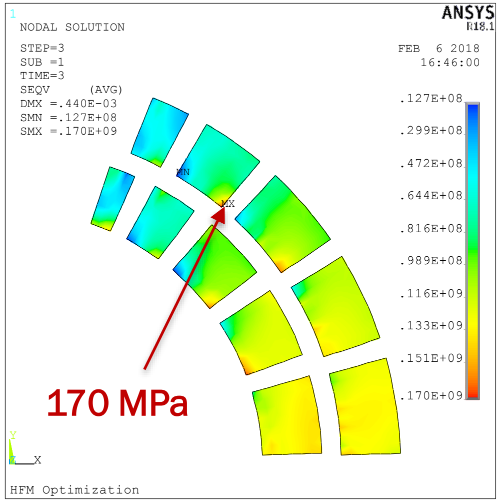


Coil-structure gaps

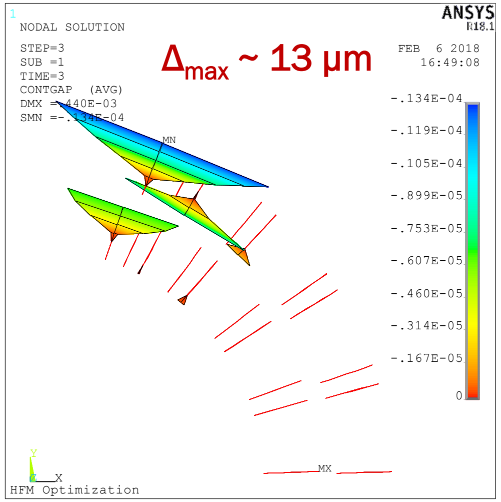
Next steps: 120 mm 2-layer and 4-layer dipoles



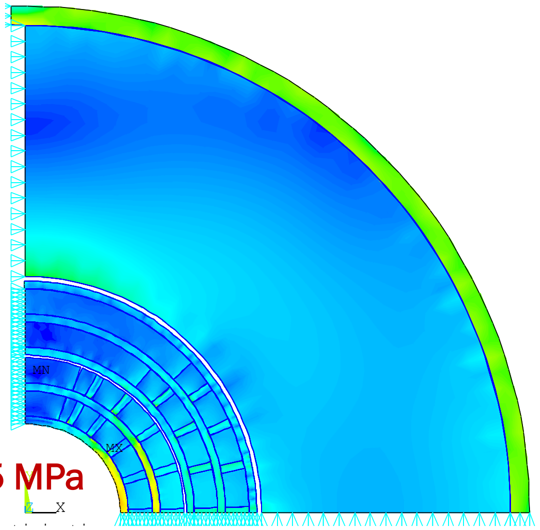
11 T
Structure: 556 MPa



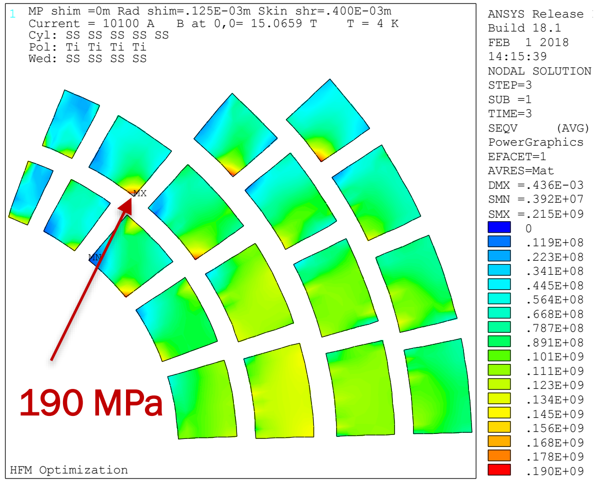
Equivalent Stress

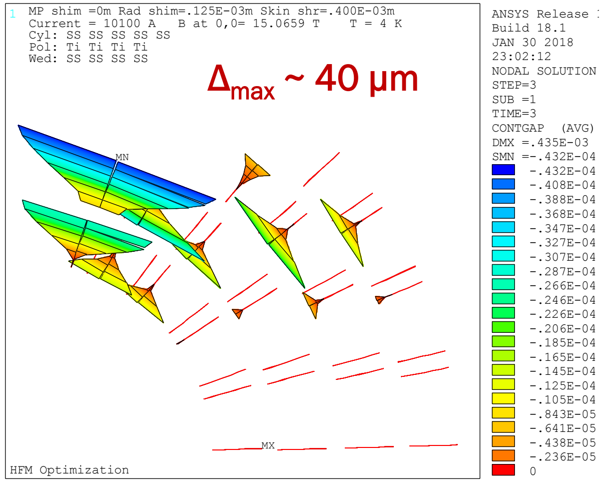


Coil-structure gaps



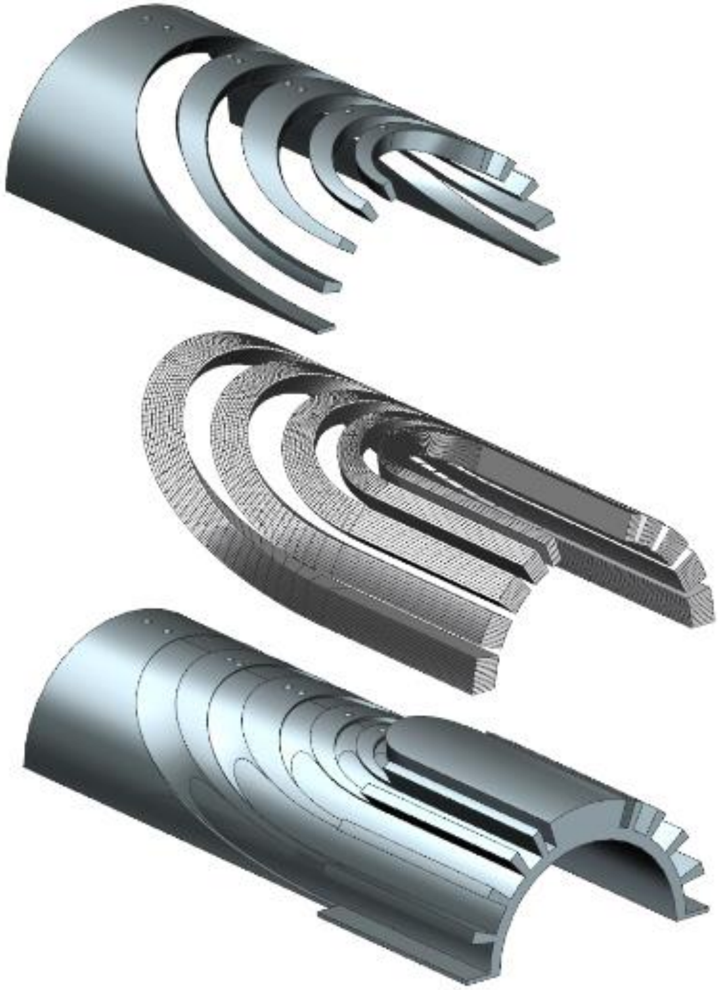
15 T
Structure: 575 MPa



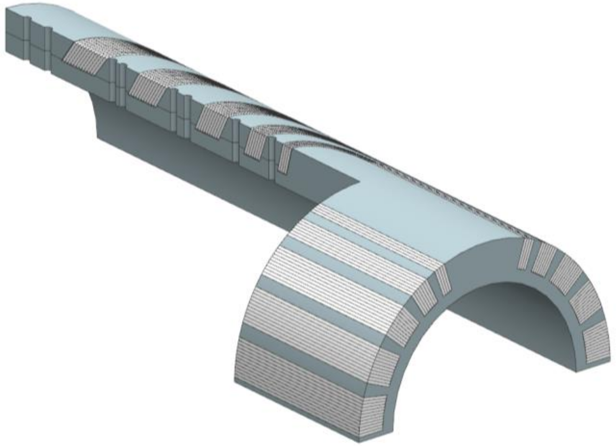


Coil Stress Management Technology

- Two possible end designs and technologies:
  - Design 1: winding with spacers;
  - Design 2: winding into slots.



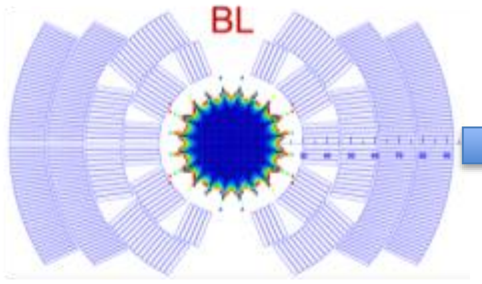
Design 1



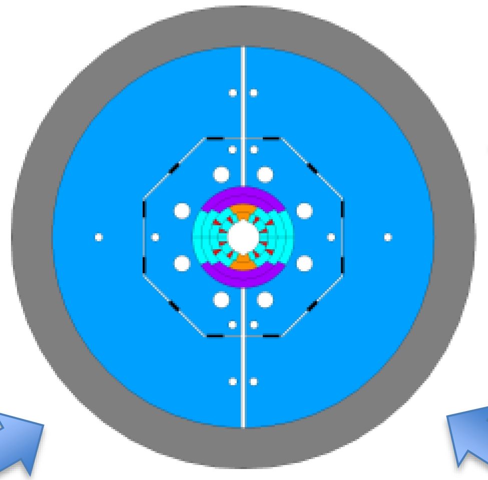
Design 2

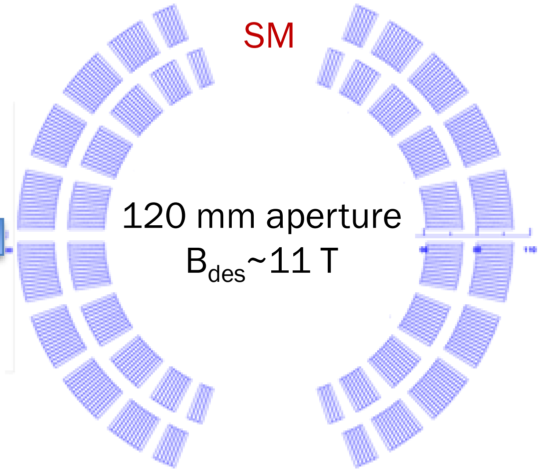
Cos-theta Dipole Test in Utility Structure

60 mm aperture
B_{des}~15 T

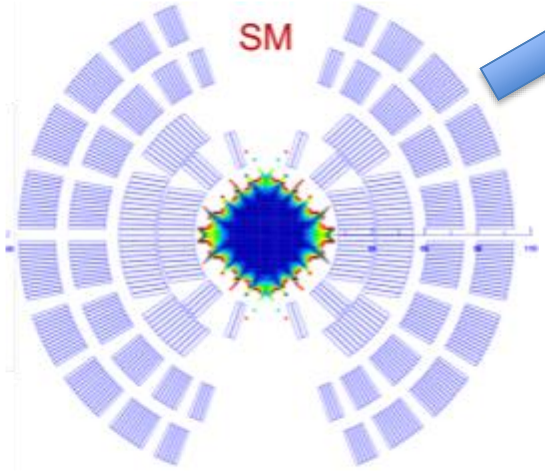


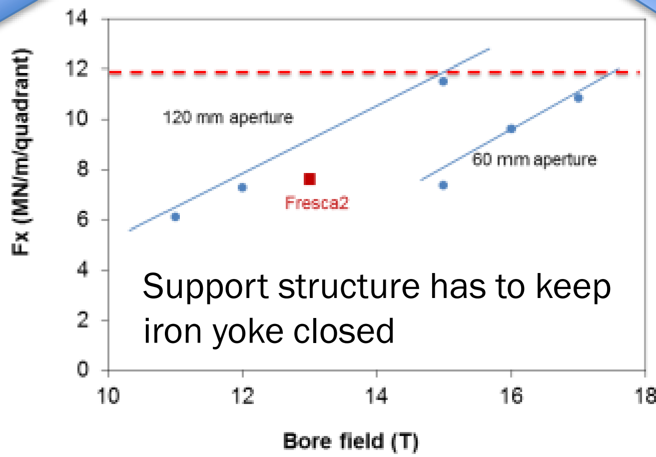
Utility structure

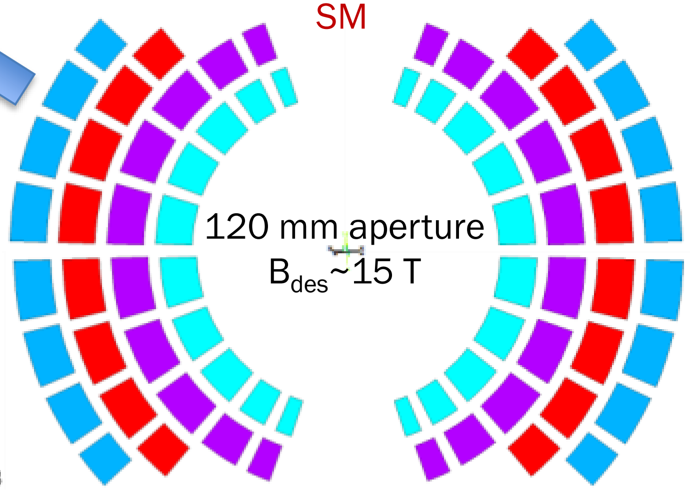




60 mm aperture
B_{des}~17 T







Conclusions

- Fabrication of 15 T dipole demonstrator is in progress:
  - Design and procurement are complete.
  - Coil fabrication is in progress.
  - Mechanical structure is being tested.
  - Magnet test is scheduled for September of FY18.
- Design study of 16 T dipole with small aperture is complete:
  - Ready to start SM coil technology development.
- Design studies of magnet Utility Structure are complete:
  - Engineering design is next.
- Design studies of large-aperture 15 T dipole continue.

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- LBNL: S. Caspi, M. Juchno, M. Martchevskii et al.
- CERN: D. Schoerling, D. Tommasini et al.
- FEAC/UPATRAS: C. Kokkinos et al.