The Swiss Contribution – First CCT Design Considerations

EuroCirCol WP5-CM 16

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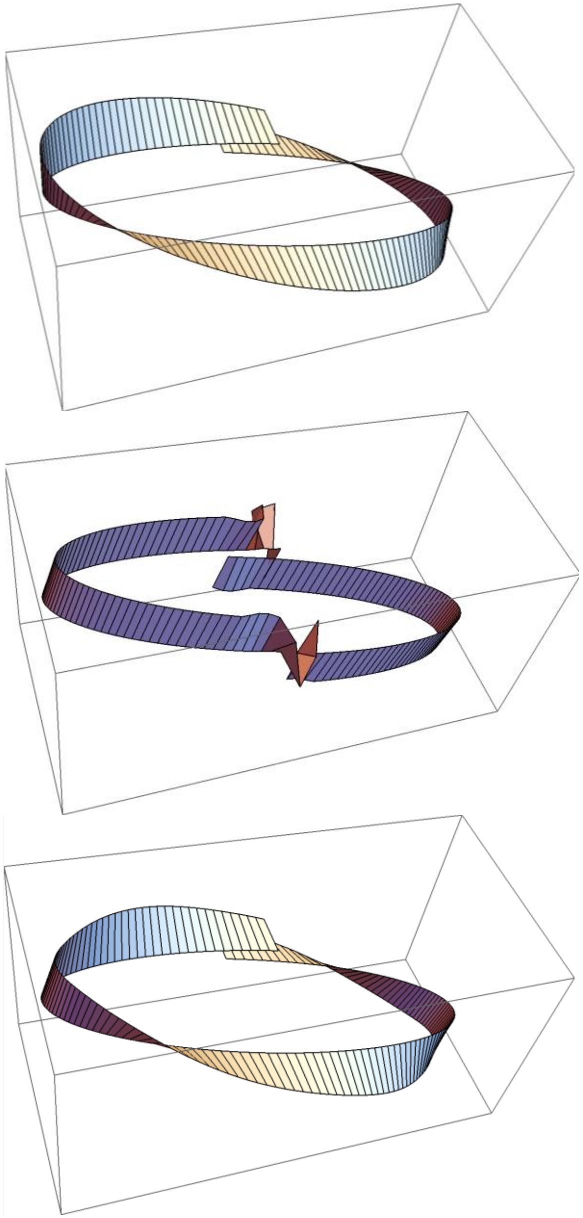
and LBNL: L. Brouwer, S. Caspi

Towards a EuroCirCol Design

1. Prove that a large Rutherford cable can be wound CCT-style around a 50-mm aperture.
2. Provide design following strictly EuroCirCol criteria.

Windability

- The ideal CCT magnet places the cable radially on the mandrel.
- This approach induces moderate hardway bend on the midplane, and strong hardway bend (bending rad. ~ mandrel rad.) on the pole.
- A tilted-racetrack-shaped solution exists that has zero hardway bend (and a discontinuity on the midplane).
- Assumption: We can use an interpolation between the radial solution (around the midplane) and the tilted solution on the pole to improve windability.



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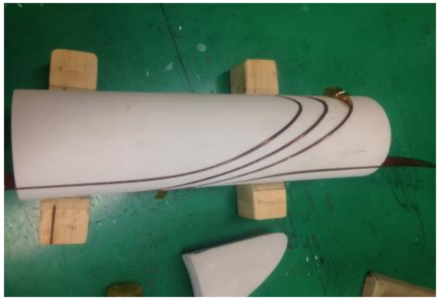
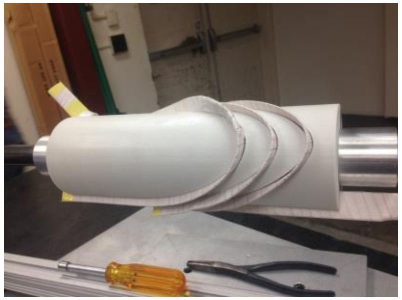
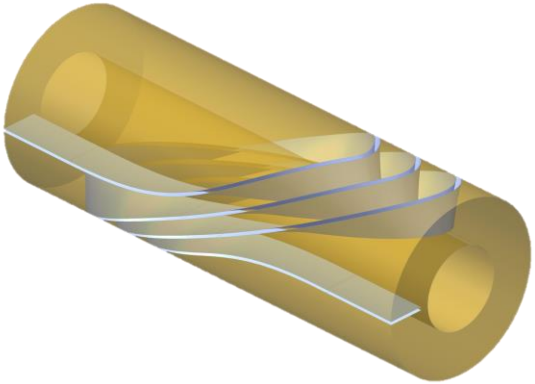
Winding Test 1-3

- ***Conclusion: A very wide cable like the LD1 cable (1.38 mm x 22 mm) can be wound into a 56-mm ID channel (50-mm mandrel clear bore).***

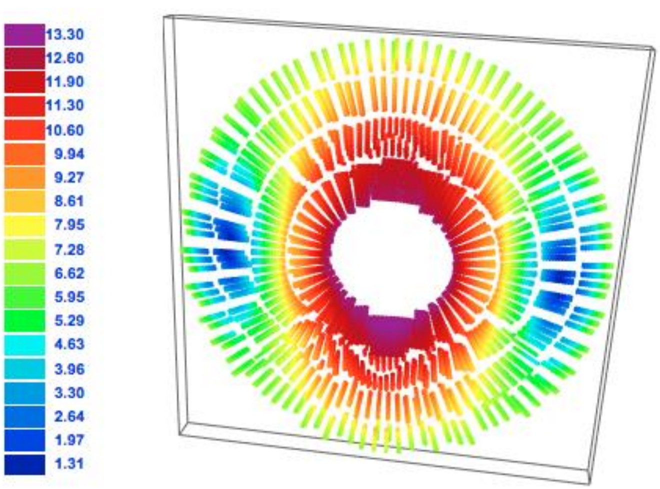


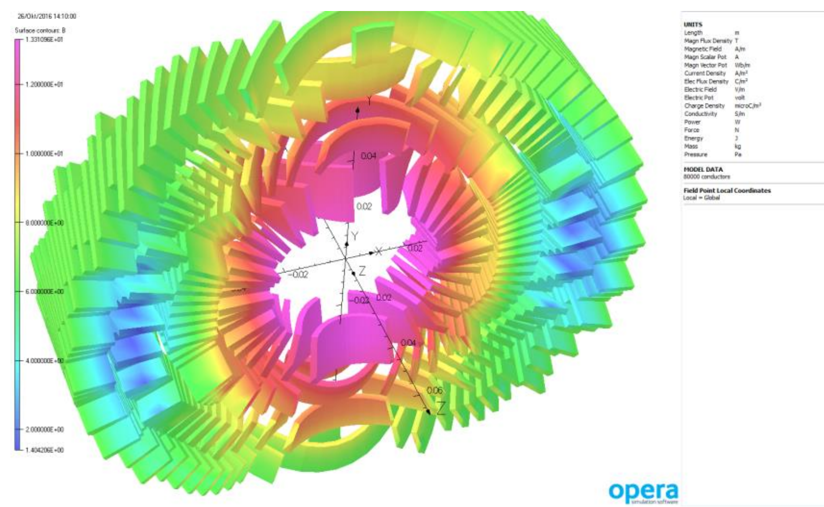




V2 vs. V1

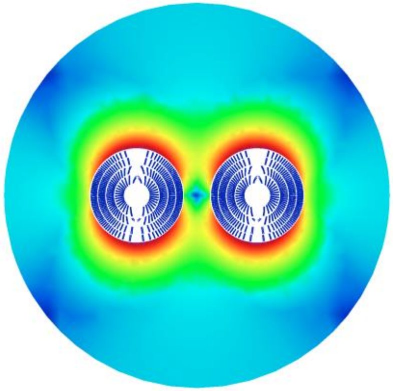
- Correction of the J_c degradation (V1 Jc was 3% too low; thanks to D. Schörling for helping to debug).
- Current margins reduced from 100% to 70% in the outer layers to match cosine-theta design.
- Ongoing work and caveats:
  - Multipole variation without further optimization is 20 units b_2, 13 units b_3.
  - 3-D peak field calculation under way, may lead to increase in B_{peak}.
  - Minimum rib thickness to be confirmed by production tests.
  - Computation of physical length vs. magnetic length under way.





Here: coil peak fields without iron.

Results v2



- Coil data
  - Current: 18010 A

Layer #	n_S	cuNc	"n_{Turn}"	loadline marg.	current marg.	T_{peak} [K]	V_{grnd} [V]	J_{cu} [A/mm^2]
1	28	0.85	17.5	14.2	104	290	930	1237
2	24	1.2	31.5	14.6	93	343	1028	1216
3	22	1.85	43.5	15.5	83	303	933	1115
4	20	2.75	54.5	16.1	71	325	931	1086

- Conductor use
  - Total: 9.49 kt
  - NonCu: 3.56 kt
  - Cu: 5.93 kt

4578 magnets
8700 kg/m^3
1294 turns for 14.3 m magnetic length

- Total inductance: 17.1 mH/m, Total energy: 3.1 MJ/m

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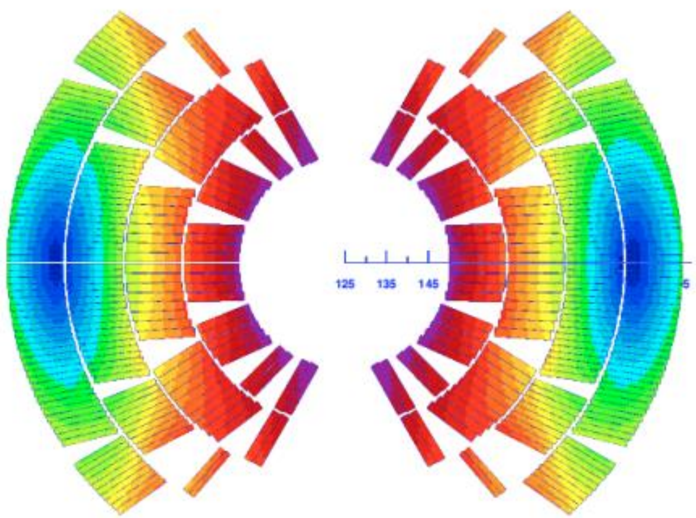
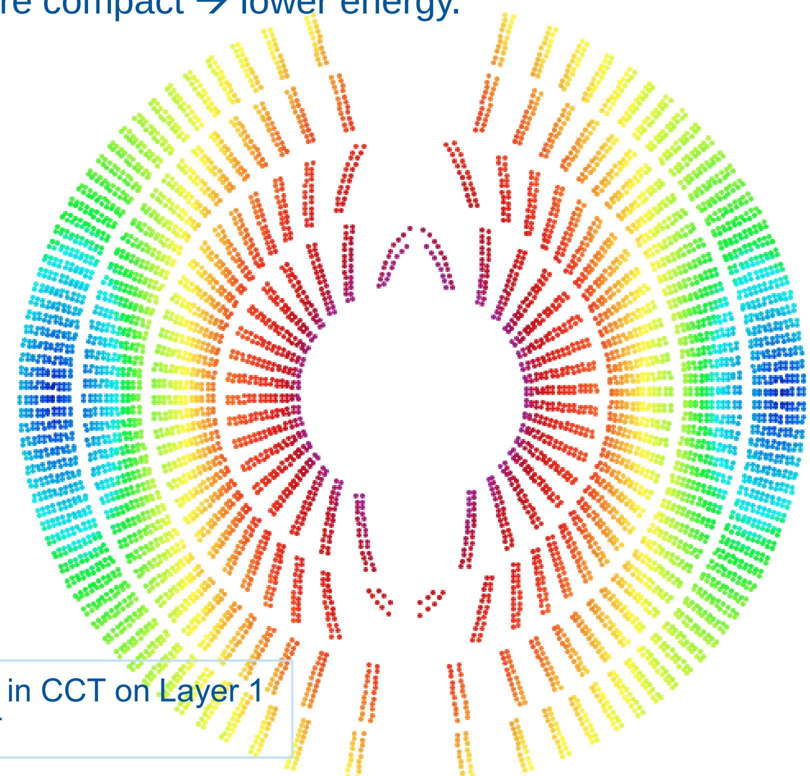
Comparison with Cosine Theta

- Cos-theta can pack more x-section “turns” on the innermost layer.
- CCT has to use higher currents to achieve similar ampere-turns.
- CCT outer-layer conductor length grows with radial position.
- CCT tilted-helix winding increases SC use by ~10%.
- CCT has larger stored energy → needs more copper.
  - Note the field pattern. CT field lines more compact → lower energy.
  - Roughly same peak fields.





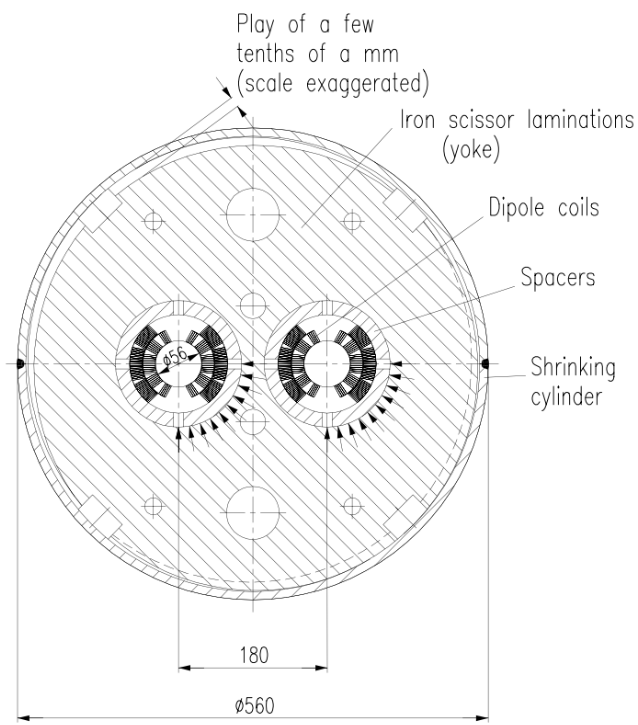
26 turns in cos-theta vs. 17 “turns” in CCT on Layer 1
11 kA in cos-theta vs 18 kA in CCT

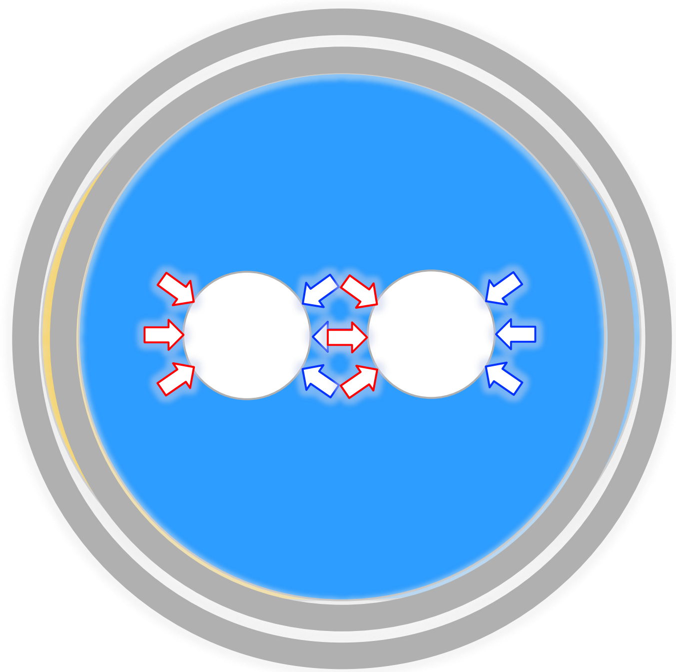
Mechanical Model 2D

- CCT does not require azimuthal prestress.
- Radial prestress on the midplane provided by “scissor” laminations.

SUPERCONDUCTING COIL COMPRESSION BY SCISSOR LAMINATIONS

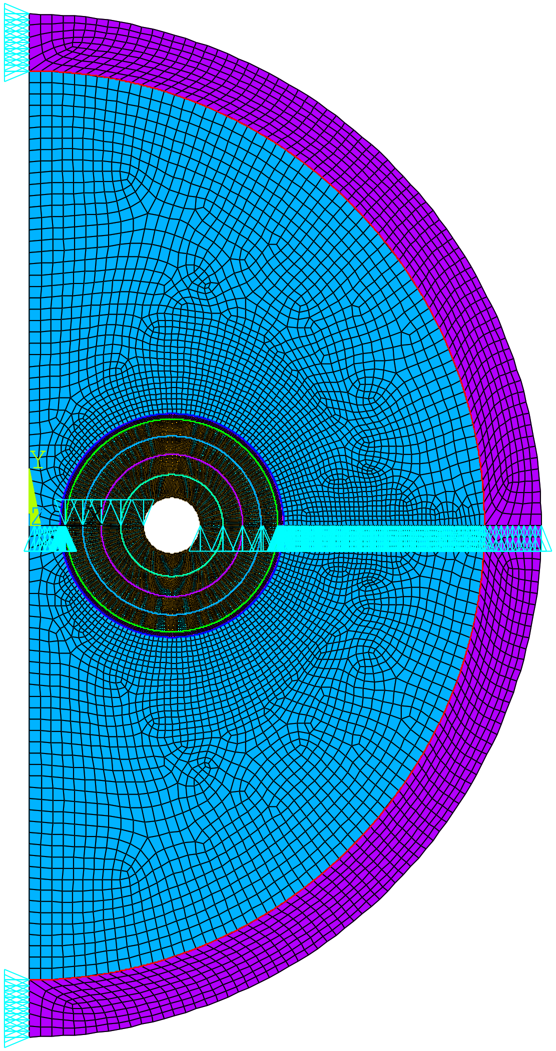
Albert Ijspeert, Jukka Salminen, CERN, Geneva, Switzerland





V2 Mechanical Model 2D

- Update wrt. V1:
  - Al shrink cylinder instead of SS shell.
  - Optimization of loading.
  - Updated E-moduli.
- Next steps:
  - Finish 3-D periodic model with load transfer from Opera 3D.
  - Optimize external structure.



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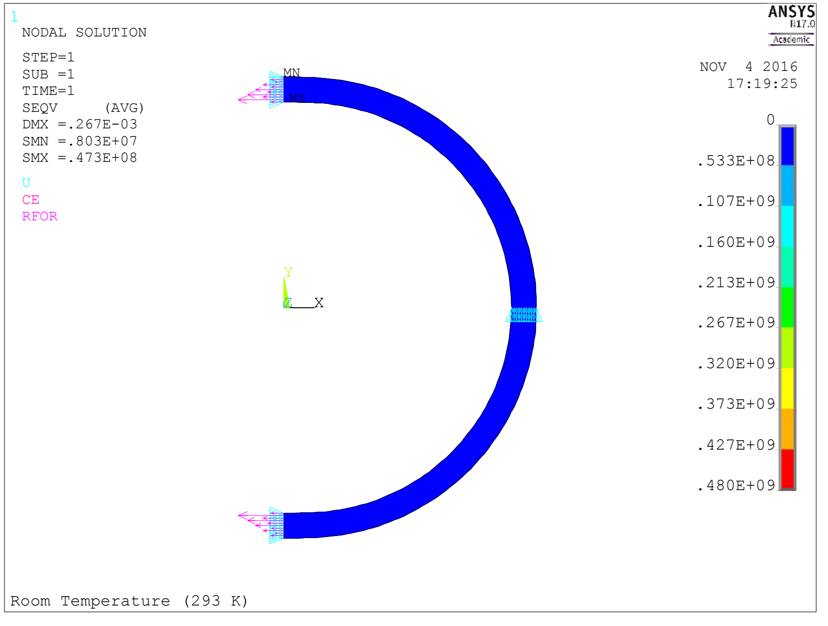
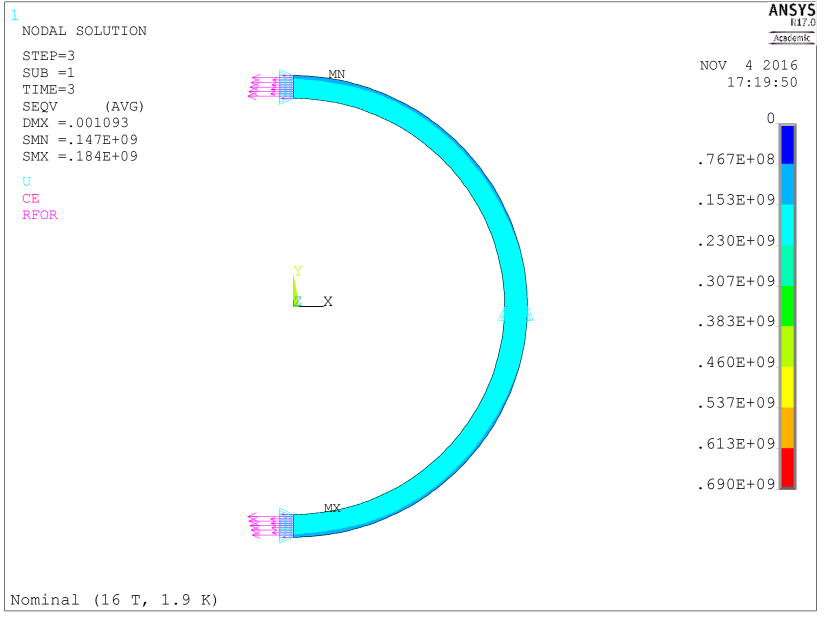
Mechanical Results

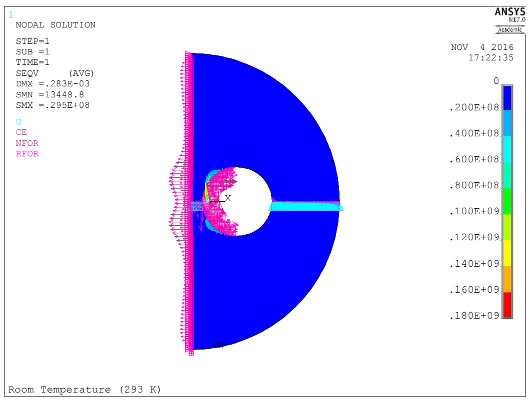
- Shell: 5-cm-thick torus to provide enough stiffness pushing on the off-center laminations.

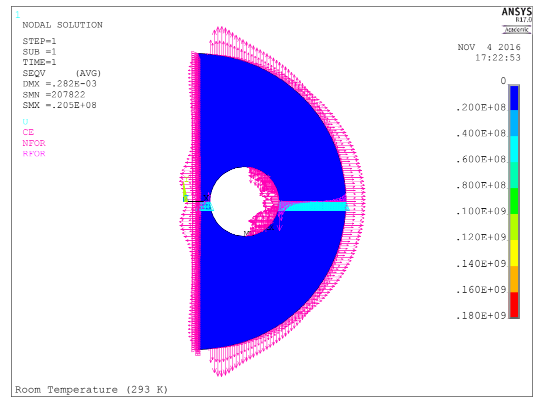


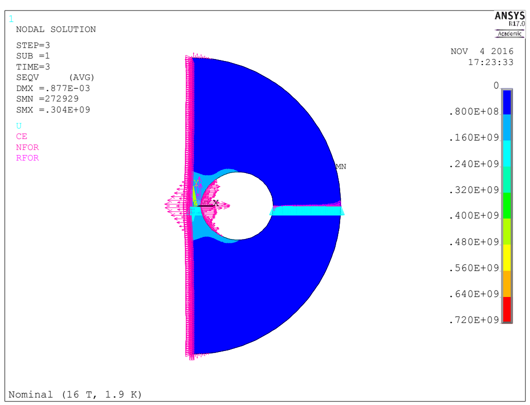


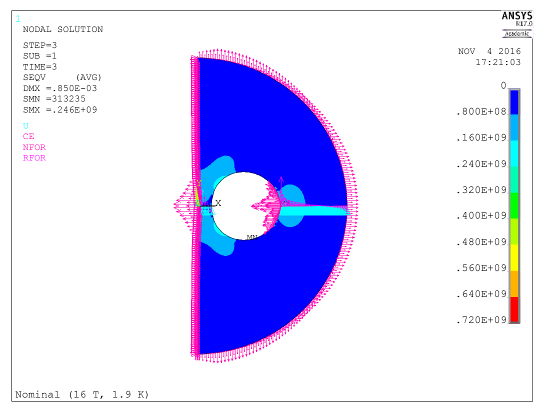
Mechanical Results

- Future work: more sophisticated shape on ID can potentially minimize stress peak on midplane.









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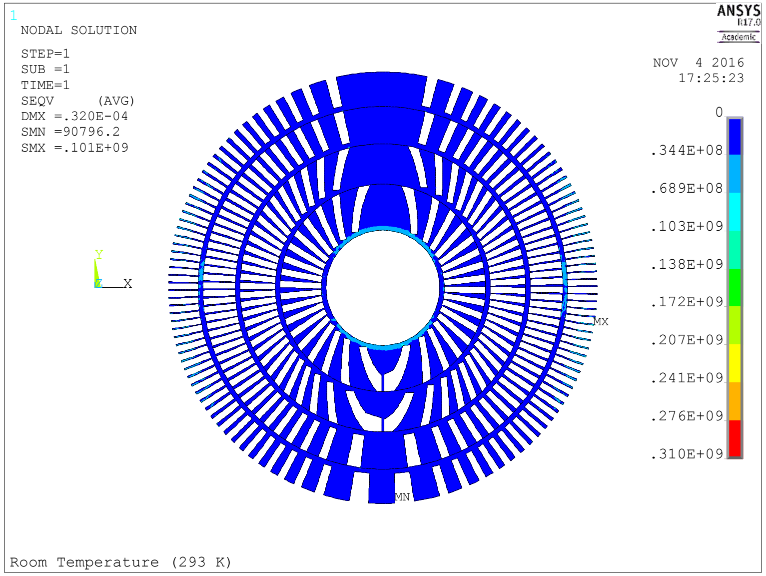
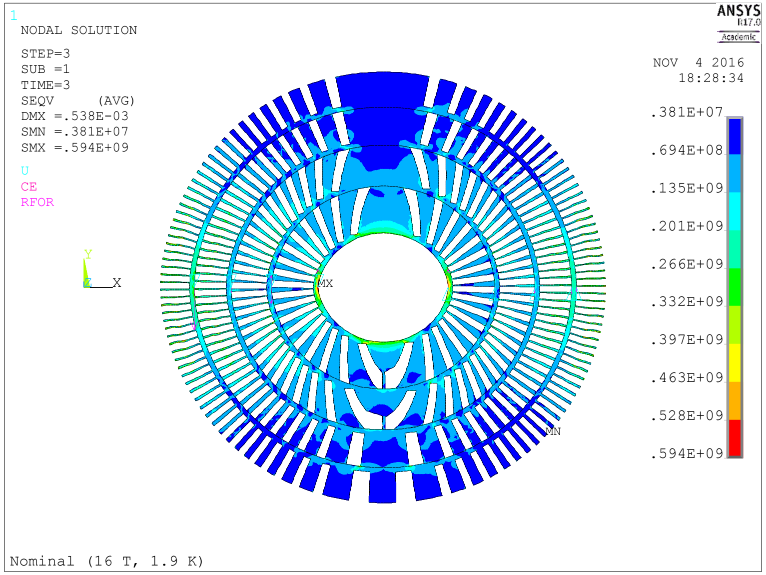
Mechanical Results

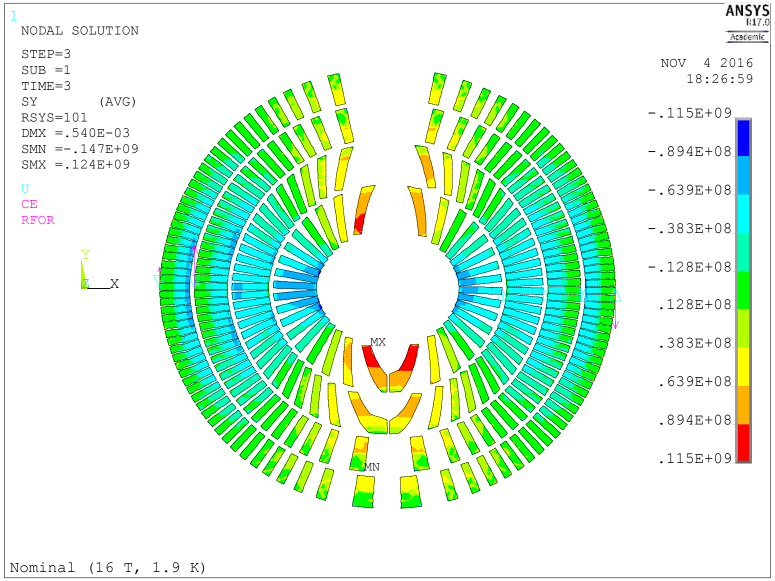
- Former:
  - Stress limit of Al-Bronze at cryogenic temperature not known. Room-temperature limit 250-310 MPa.
  - Steel structure to be studied.

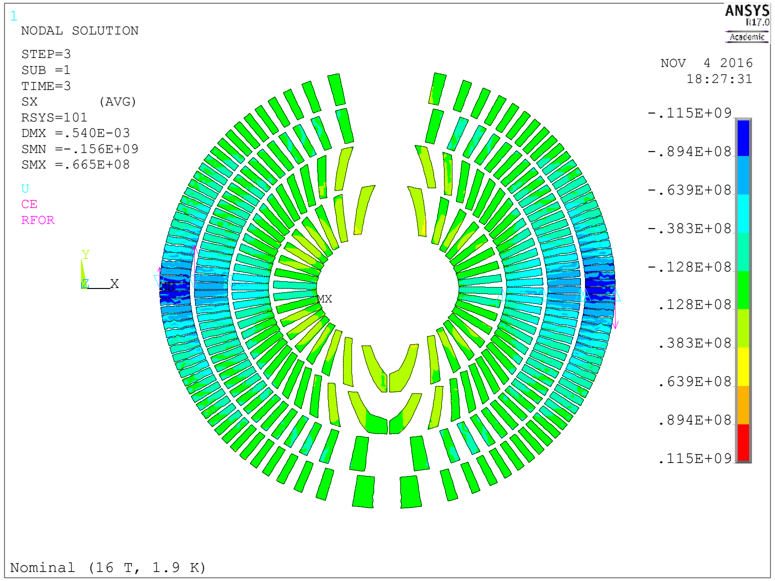




Mechanical Results

- Conductor:
  - Very low stresses at room-temperature thanks to Al shell.
  - 115 MPa coil stress at 16 T. To be confirmed and investigated in 3D model!





A PSI-built Technology Model

- CCT HFM technology is still young – much needs to be tried out.
- CCT is a small-lab friendly technology.
- LBNL strongly support our endeavor with weekly counsel, exchange between labs, and, if required, use of facility.
- Some ingredients of a PSI 2-layer high-field CCT magnet:
  - wide aspect-ratio cable.
  - if possible, inclined winding on small diameter.
  - thin spar (inner tube) and external mechanical structure.
  - study of alternative protection strategies.
- Important upcoming decisions: Nb-Ti or Nb_3Sn and coil ID.
  - Nb-Ti: No reaction, simpler insulation, harder winding, risk of worse performance of potted magnet (lower enthalpy margin).
  - Nb_3Sn: Closer to FCC goals (strain sensitivity), LBNL experience and support, relatively simple reaction, larger risk of conductor damage, 10-T is a much larger step into the unknown.

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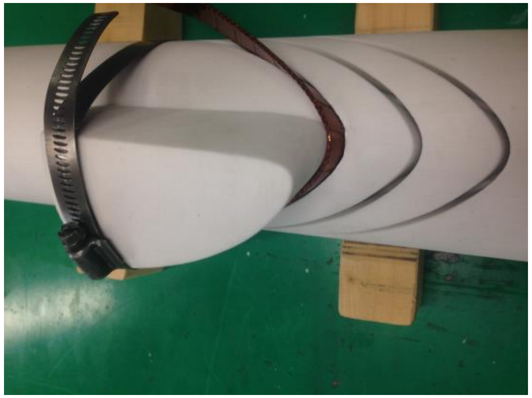
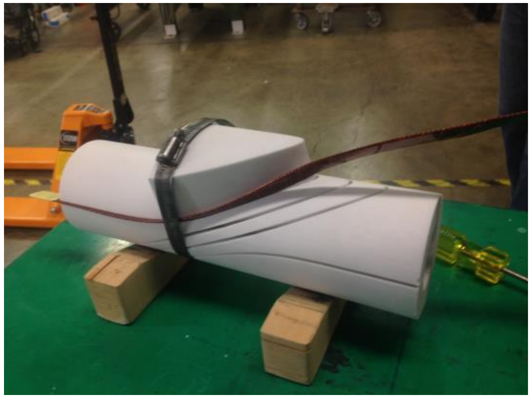
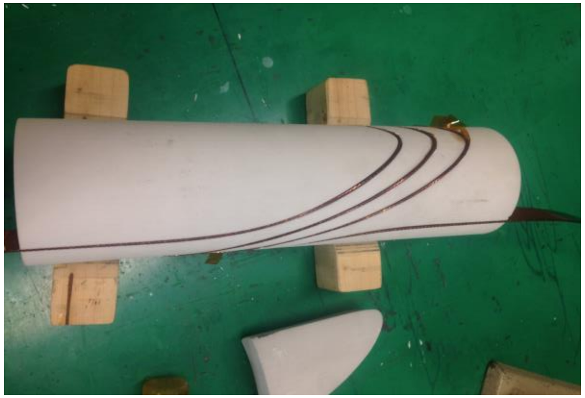
Nb-Ti Winding Test @ LBNL

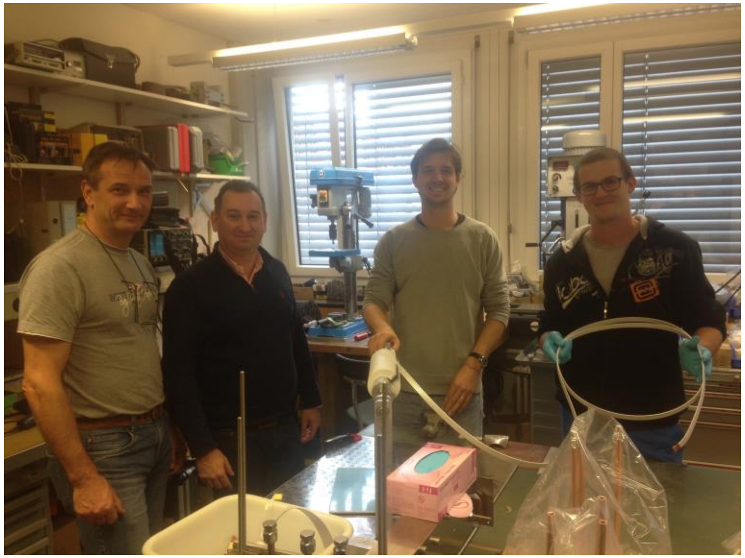
- Preliminary conclusion: much harder to deform plastically than Nb_3Sn.
  - Cable provided by CERN.
  - “The hog wire”.

- To be repeated next week at PSI with appropriate winding table.

First PSI Winding Test

- With support from LBNL and CERN:



- 11-T cable (provided by CERN) on 56-mm ID.
- Confirmed LBNL winding tests. Inclined channels make a magnet with 11-T cable appear a realistic option.

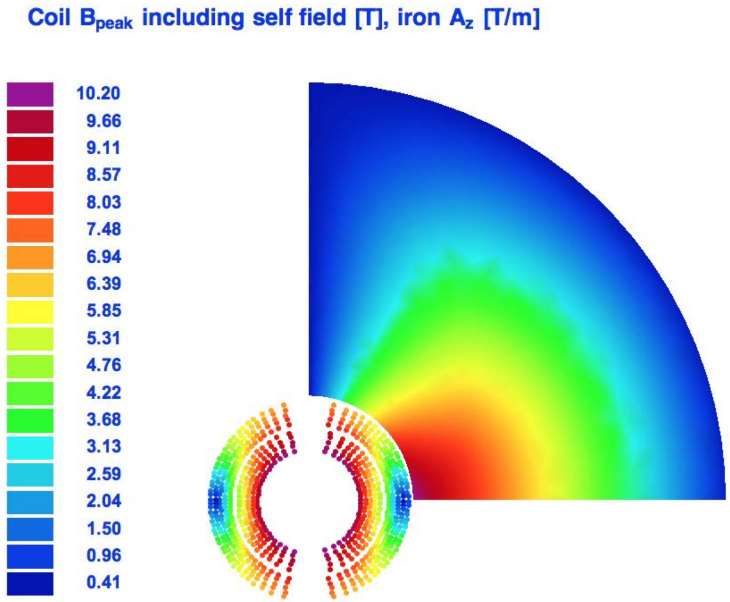
Summary

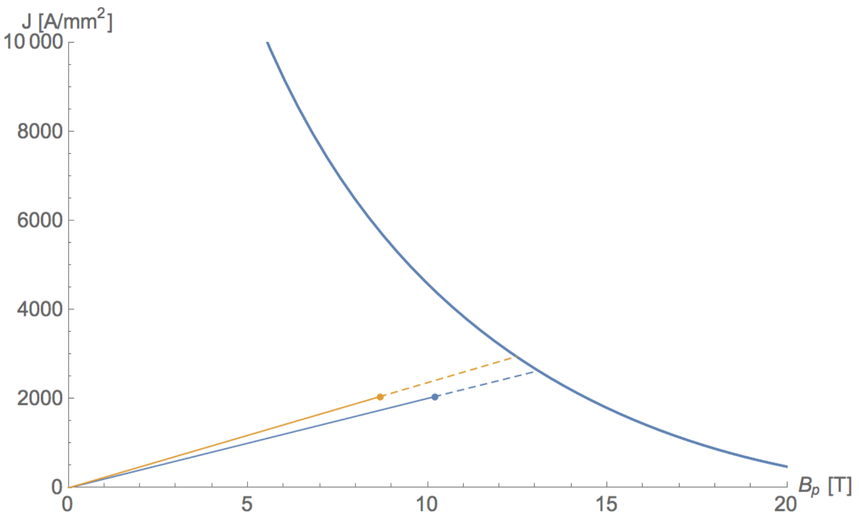
- Improvement in efficiency with respect to V1.
- Still 25% more SC than cosine theta.
- Steady progress on 3D magnetic and mechanical modeling.
  - L. Brouwer from LBNL at PSI for coming 2 weeks.
  - Work on 3D quench modeling is starting as well.
- Should PSI provide input to the cost model?
- Focus shifting to manufacturing issues for PSI technology model.
- A PostDoc and a PhD will start on December 1st.
- Highly motivated team at PSI with LBNL support as well as CERN guidance and support.

THE END

A 10-T CCT with 11-T Cable?

- 10 T@15 kA with 22% loadline margin, 115% current margin.
- 100 m unit length (40 IL, 60 OL)
- 20 ms protection budget (or EE with 25 ms delay).





	B_{peak}	Loadline	Temperature	Current
Layer 1	10.2 T	22.0404%	5.20042 K	115.874%
Layer 2	8.67524 T	30.4575%	6.58488 K	180.66%