

PAUL SCHERRER INSTITUT



WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

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## Status of the CCT @ PSI

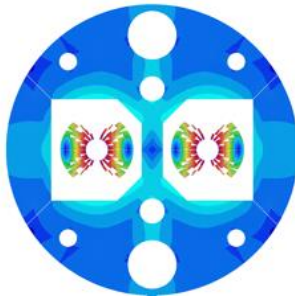
EuroCirCol/US-MDP Meeting, December 3rd, 2018.

Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI.

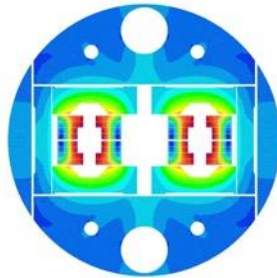
- CCT @ FCC
- SC Magnet Lab @ PSI
- CD1 Manufacturing and Trials

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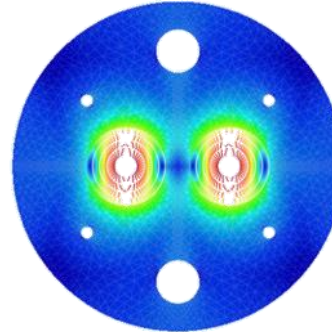
Cos-theta



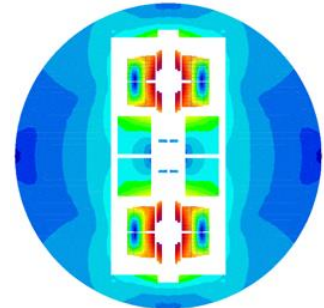
Block coil



Canted Cosine Theta

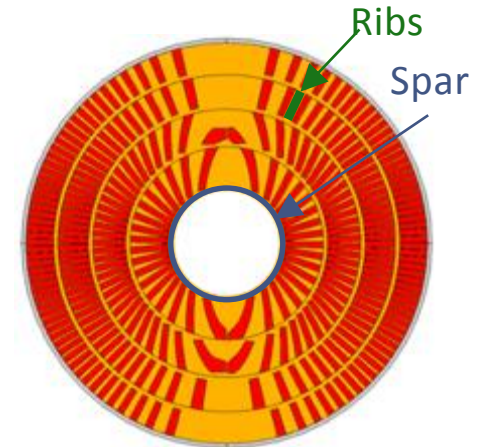


Common coils

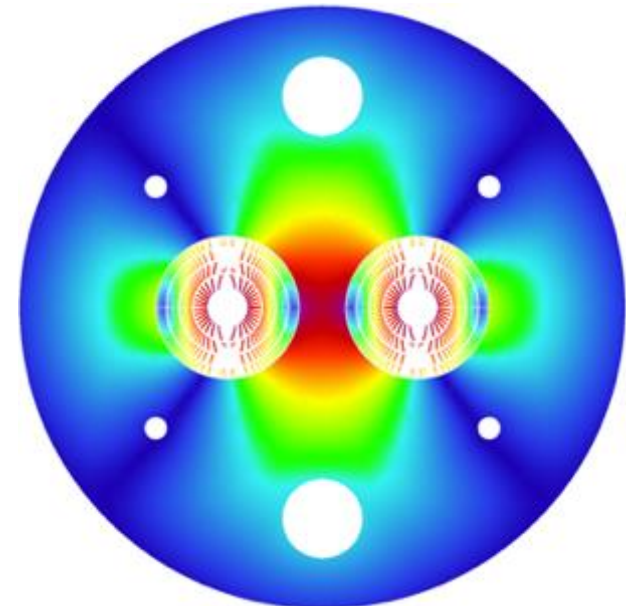


- Current: 18135 A

Layer #	$n_s$	diam [mm]	cuNc	loadline marg. [%]	current marg. [%]	$T_{peak}$ [K]	$V_{grnd}$ [V]	$J_{cu}$ [A/mm <sup>2</sup> ]
1	29	1.2	0.8	14.2	111	292	1133	1237
2	25	1.2	1.1	14.4	95	342	1264	1217
3	22	1.2	1.95	14.4	74	310	1156	1096
4	20	1.2	2.6	15.7	70	338	1144	1103



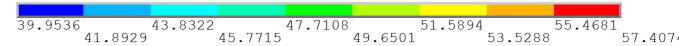
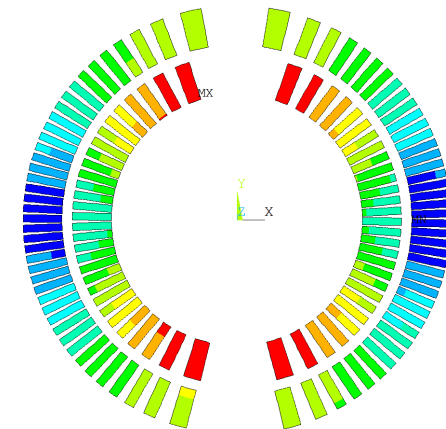
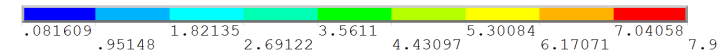
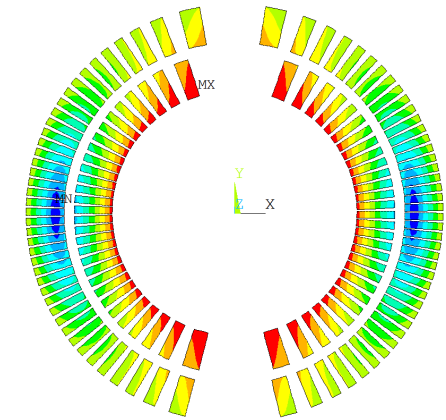
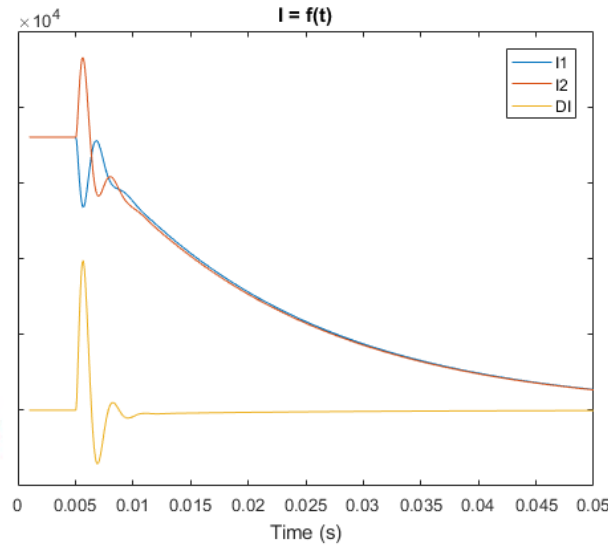
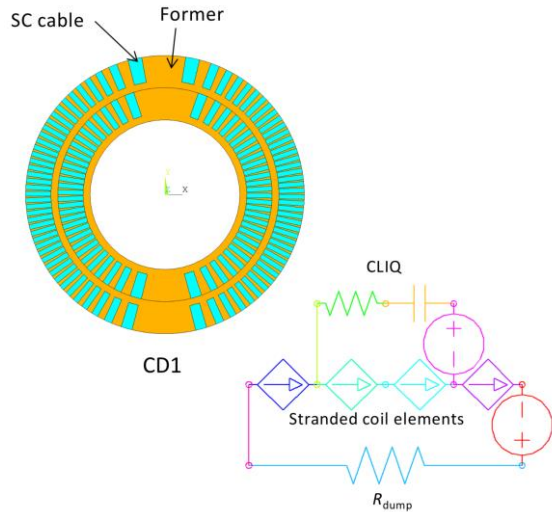
- Optimize  $J_e$  optimal winding angle, minimal spars, and ribs, wide cable.
- FCC-wide conductor use: **9.7 kt**  
Total inductance: 19.2 mH/m
  - Total energy: 3.2 MJ/m
- Opportunity to reduce unit length and peak voltage to ground via double-helix.



# Quench Simulation for CCT

081609  
.91045

- ANSYS user-defined elements by L. Brouwer (LBNL)
- CLIQ sim. on CD1 geometry in final debugging stage.
- 4-layer FCC CCT to follow.





# Overview

- CCT @ FCC
- SC Magnet Lab @ PSI
- CD1 Manufacturing and Trials

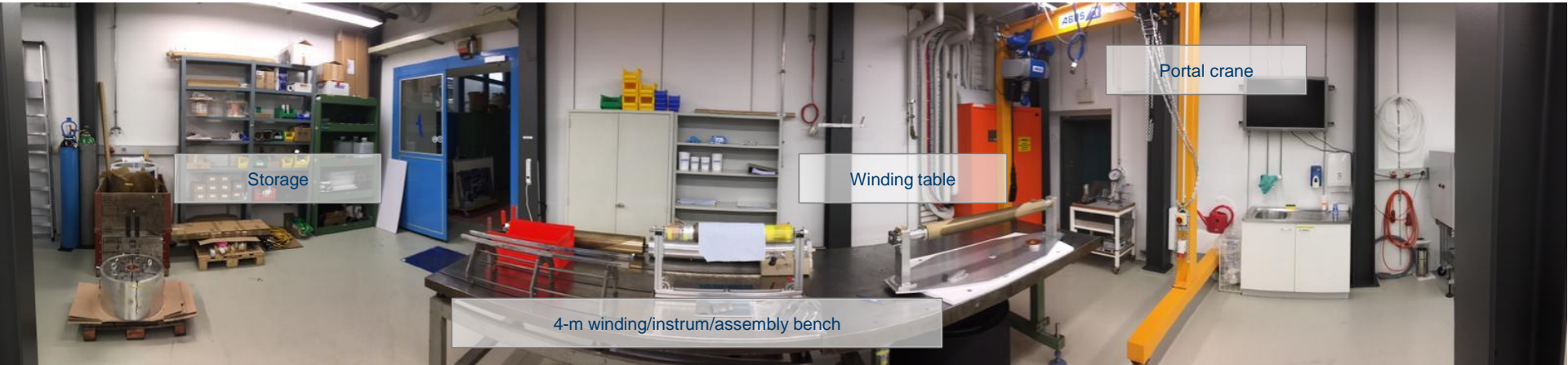


# CHART (Swiss Accelerator Research and Technology Center) – Magnet Activities



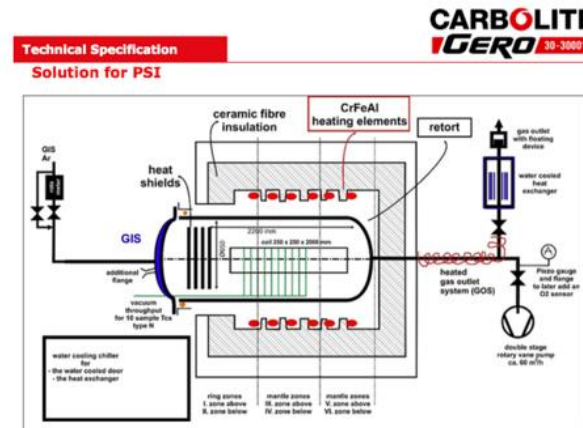
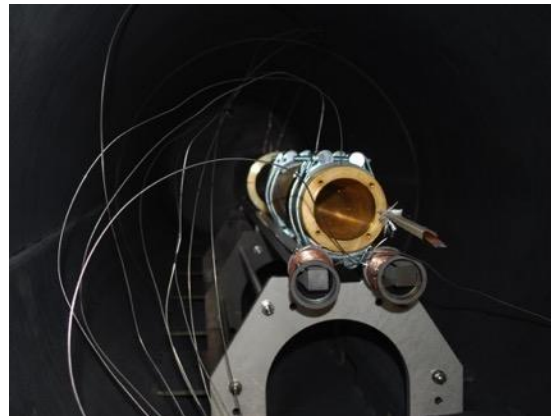






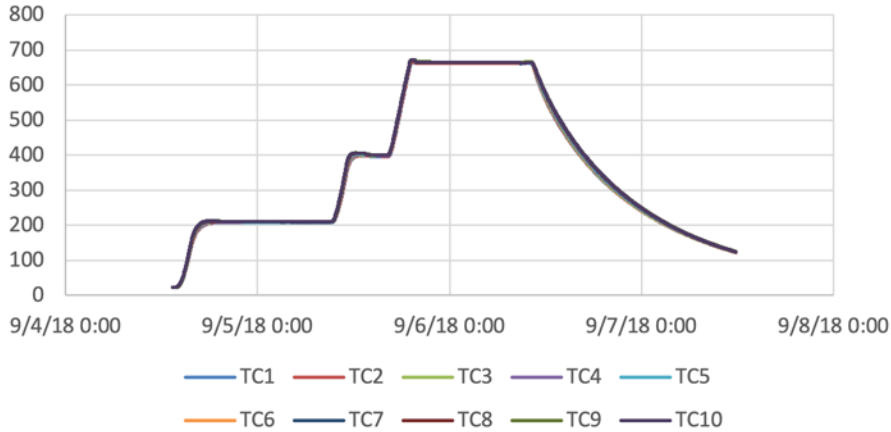
# Reaction Commissioning

- Furnace fully operational (Ar supply, water chiller, ventilation, electricity, DAQ).
- Loading tooling complete and tested.
- Reaction of 5-turn test former complete.
- Short-sample confirmation by UniGE not before ASC.
- First coil reaction expected for Week 44.

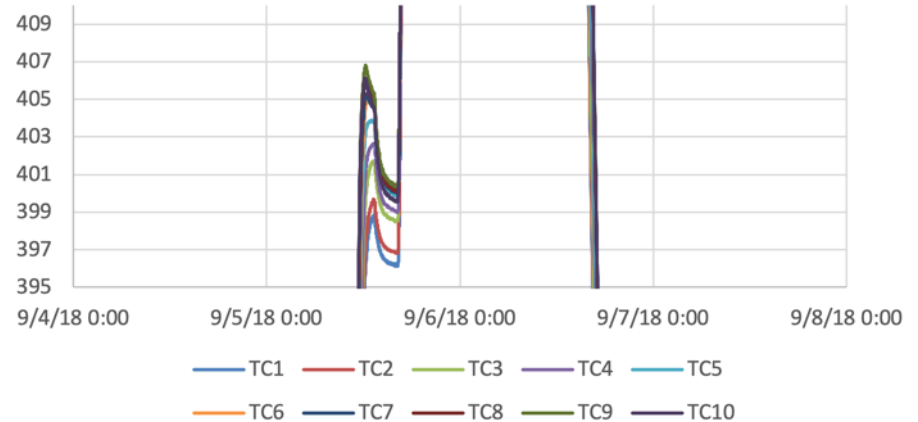


# Reaction Furnace Trimming

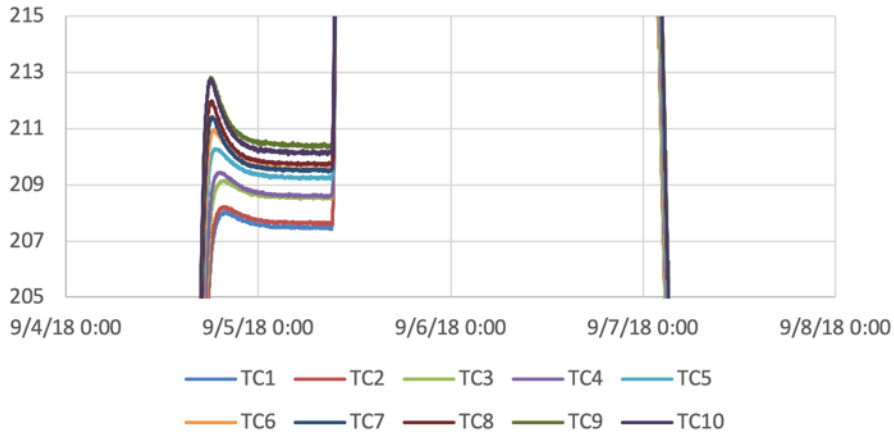
Trim Exercise



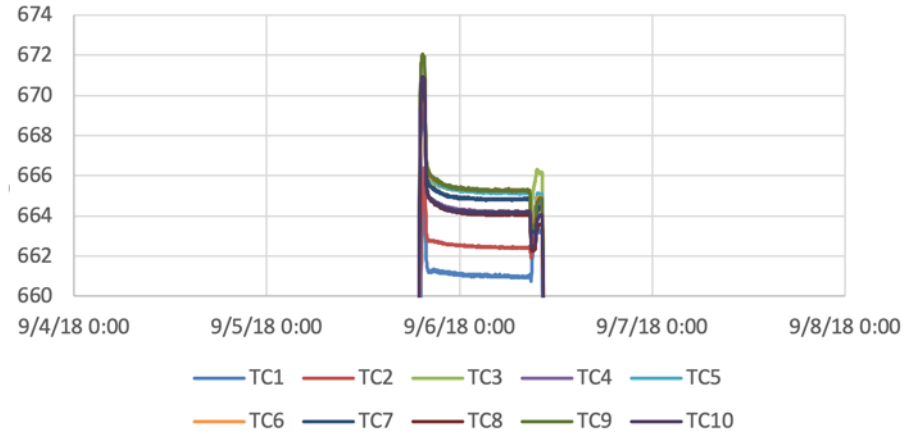
Trim Exercise



Trim Exercise



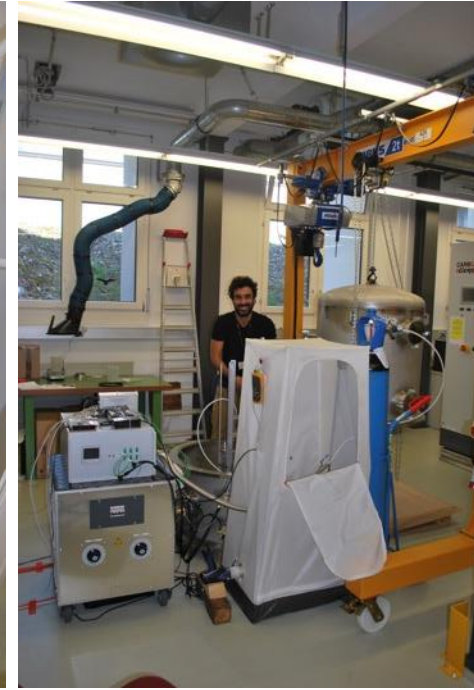
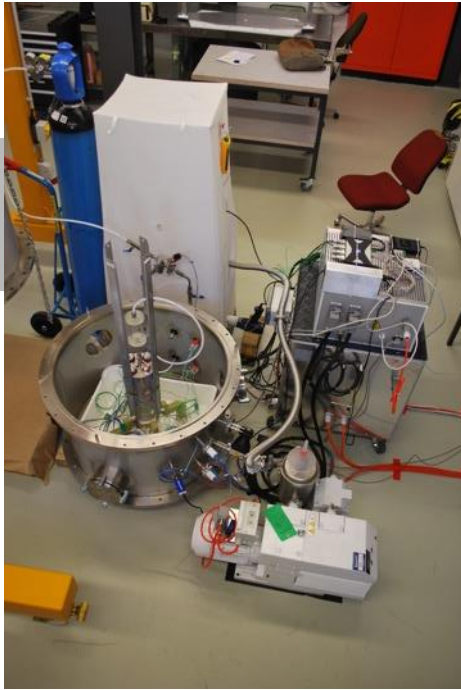
Trim Exercise



All plateau axial maps within +/- 3 K.



# Impregnation Infrastructure

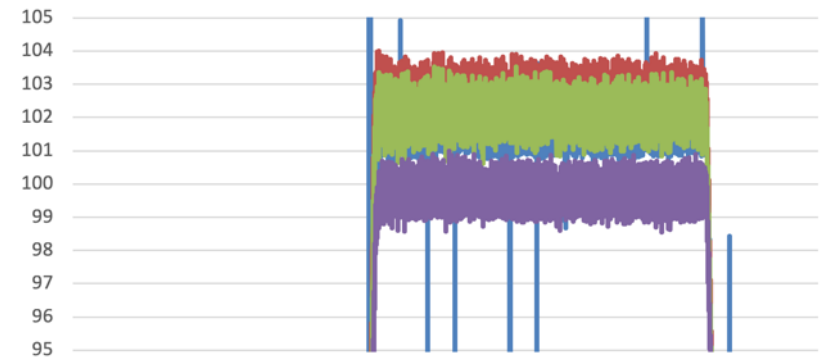
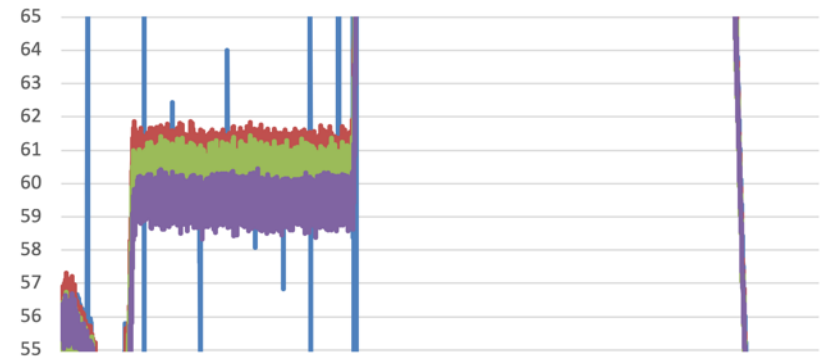
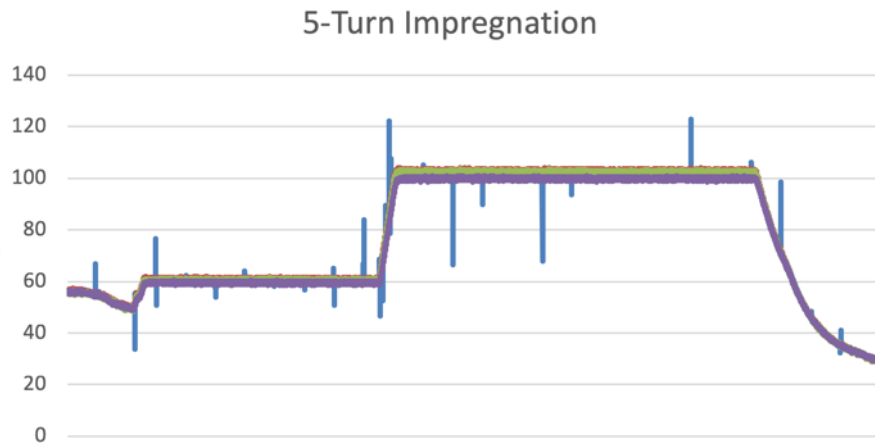


- Vacuum vessel with feed-throughs in bottom part.
- 50 m<sup>3</sup>/h vacuum pump with LN<sub>2</sub> trap
- N<sub>2</sub> bottle for over-pressure and purging.
- Control and powering units with voltage selection
- Heated “green-house”
- Heated feed-throughs into the vessel
- See-through mixing pot
- DAQ and alarm PCs
- Capacitive monitoring as level indicator
- Box oven for ingredient heating, sample and waste curing



# Impregnation Commissioning

- 5-turn coil impregnation.
- Coil temperatures (Top, Center, Down, Heater) within 3 K at curing plateaus.

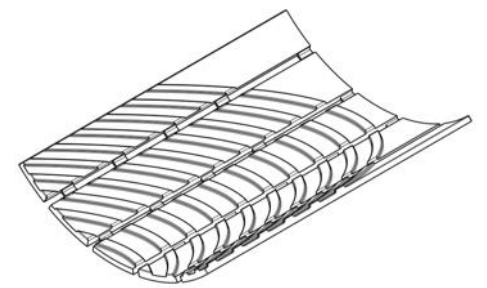




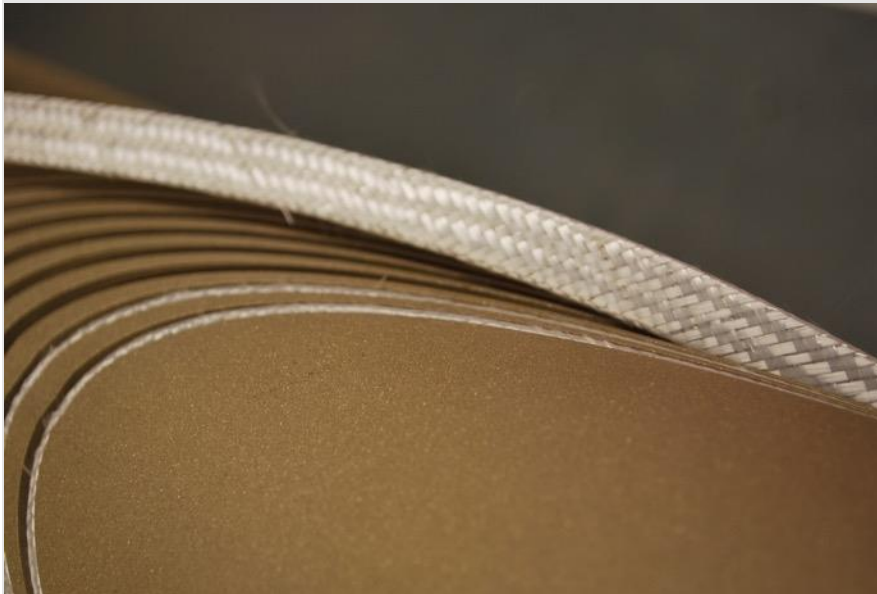


# Overview

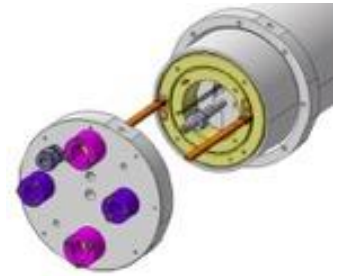
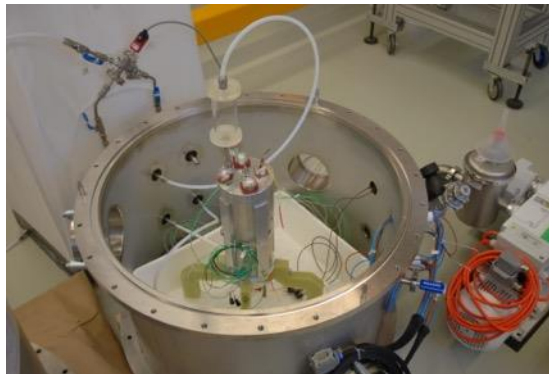
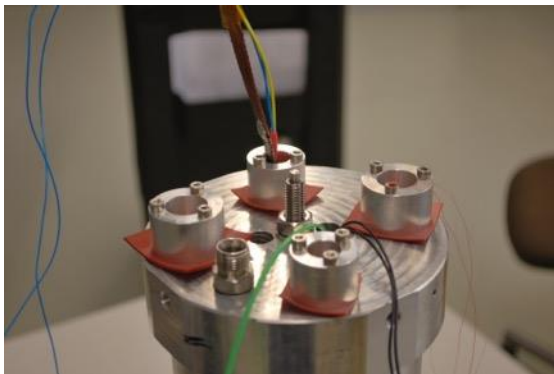
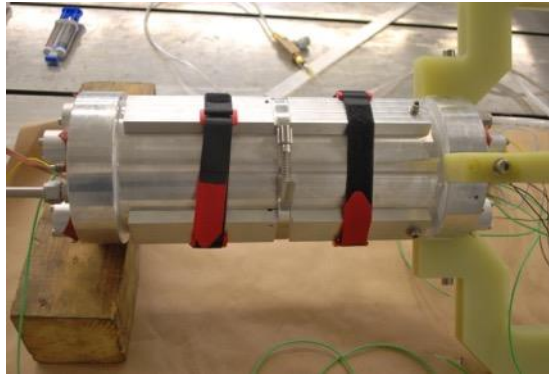
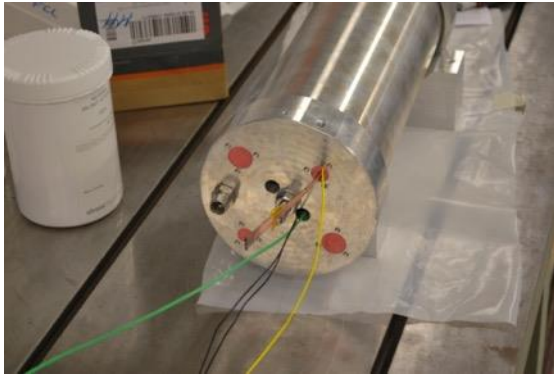
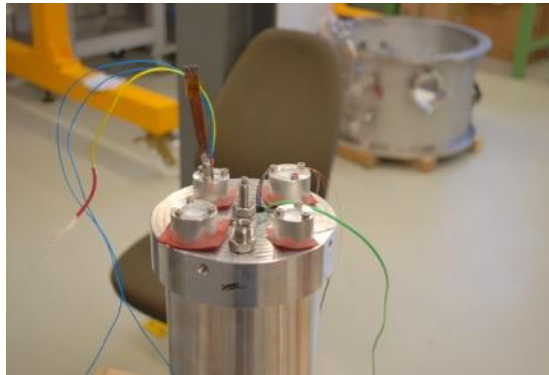
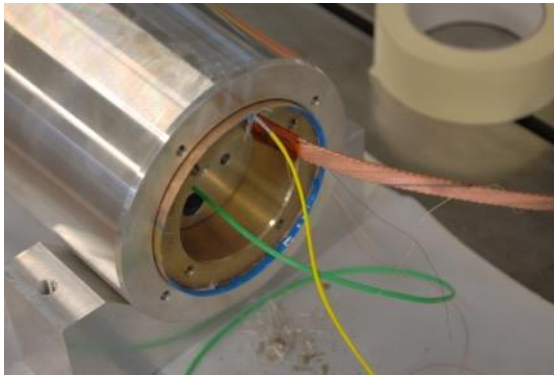
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- OL winds easily and without cable popping up (see below).
- IL has tendency to pop up from the channels.
- Cable keepers were designed, tested, and printed in steel for the CD1 IL.
- Insulation is an issue!

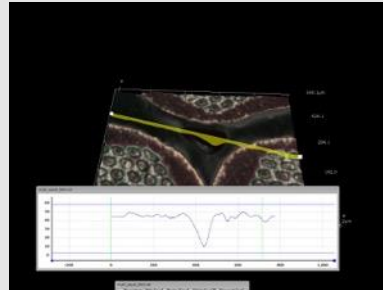
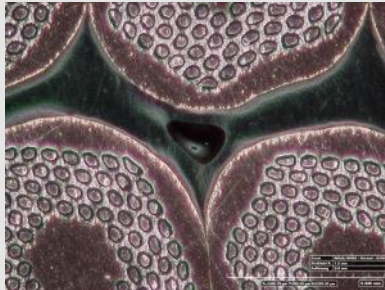
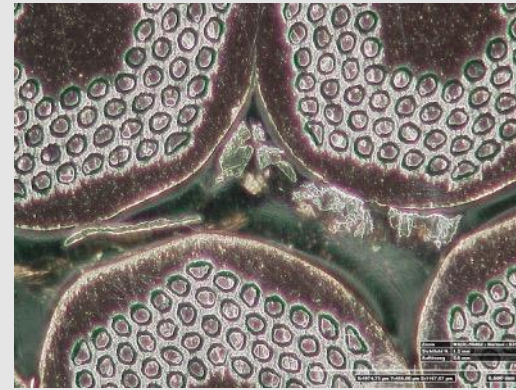
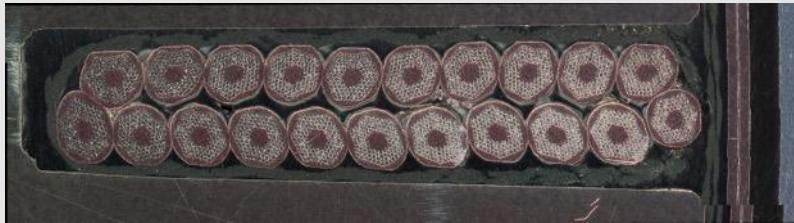


# 5-Turn Sample Preparation, CD1 Mold



# Impregnation Results

- Some potential bubbles visible.

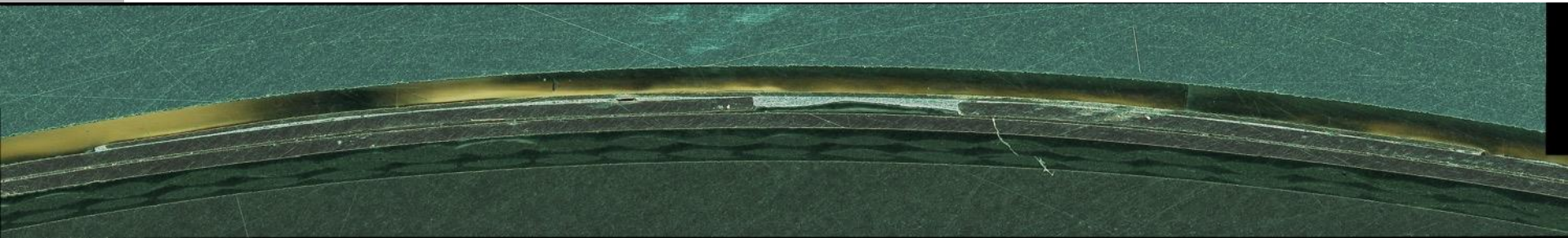


- Next step: improve control of injection flow rate via peristaltic pump.

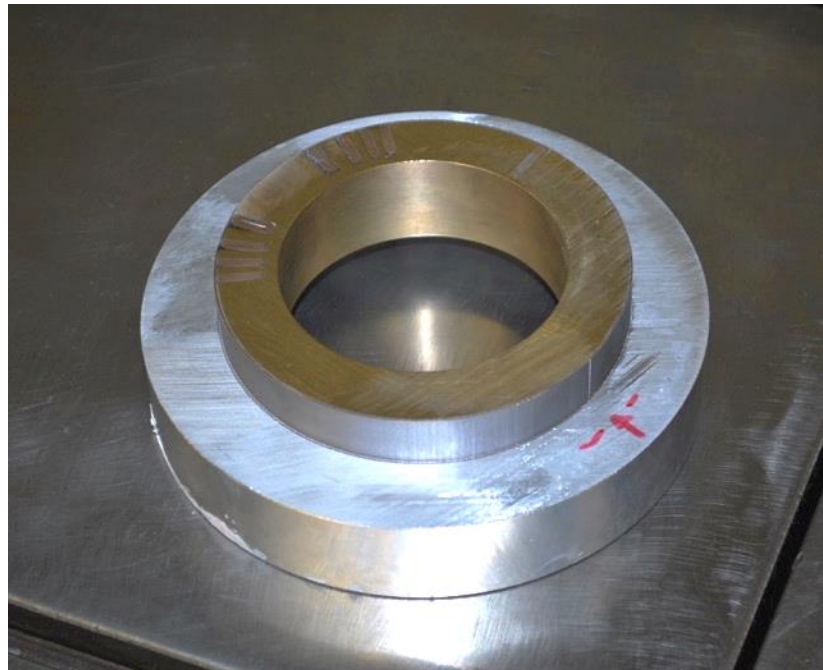


# Sliding Plane Tests

- Microscopic analysis – note glass wrap layers, inner and outer sliding planes, soldering, and filling of assembly gap with resin.



- Separation of layers post impregnation – sliding planes in action:

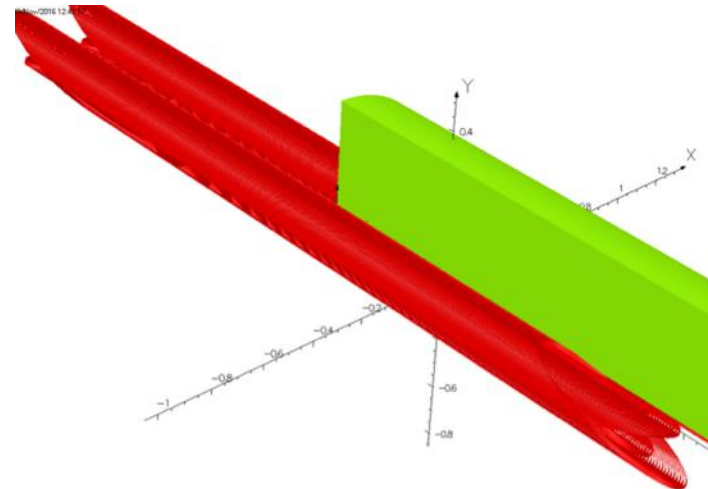
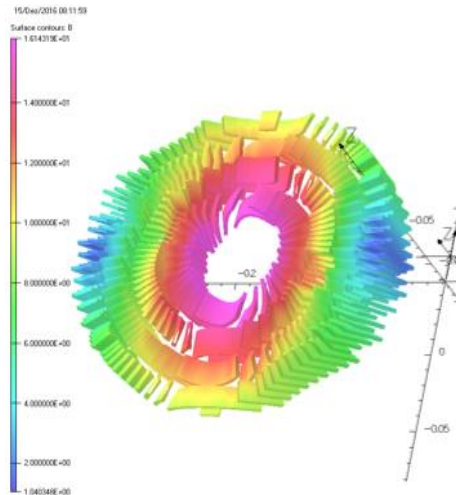


- FCC magnet design:
  - Compliant with FQ requirements.
  - Persistent-current simulations now available also for CCT.
  - Quench simulation (CLIQ with ANSYS) under preparation.
- Significant progress in infrastructure at PSI.:
  - Commissioning complete.
- Technology model magnet CD1:
  - Part design, procurement, QA complete.
  - Production-Readiness Review passed in August '18  
(<http://indico.psi.ch/event/cd1pr>)
  - Coil manufacturing started (and interrupted, restart imminent).
- Next steps:
  - High hopes that funding for coming 5 years of continued R&D is secured.
  - Main focus will be on CCTs for FCC.
  - First up: repeat CD1 to straighten out problems (or to show repeatability).
  - Only then we will step to a 4-layer design with wider cable.



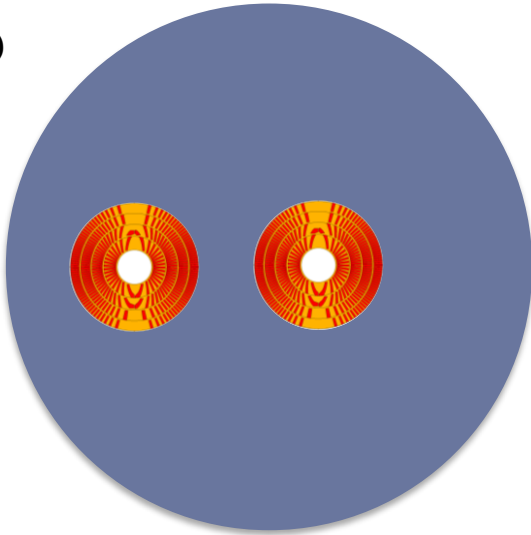
## 3-D modeling results:

- **Yoke cut-back** not needed (20 mT peak-field enhancement in ends).
- **Magnetic length** with yoke equal to that of bare coil.
- **Physical length** minus magn. length = 53 cm; equal to 11 T magnet.
- **Peak field** minus main field at 16-T bore field: 0.14 T excluding self field.
  - comparable or lower than cos-theta due to continuous current distribution.

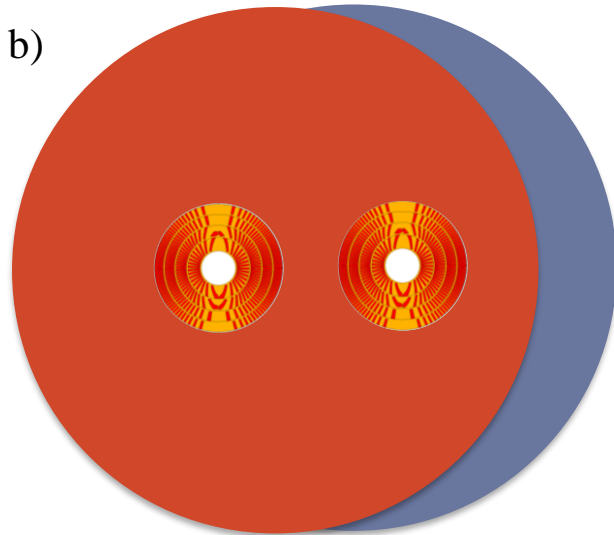


Courtesy M. Negrazus

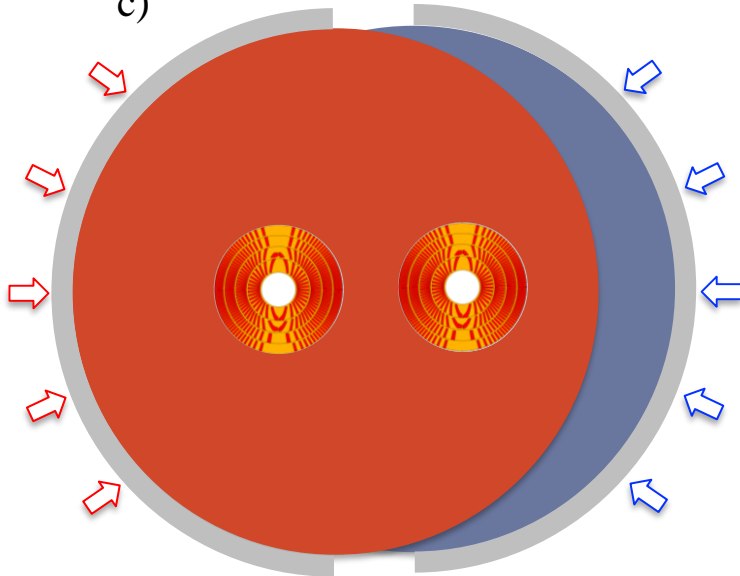
a)



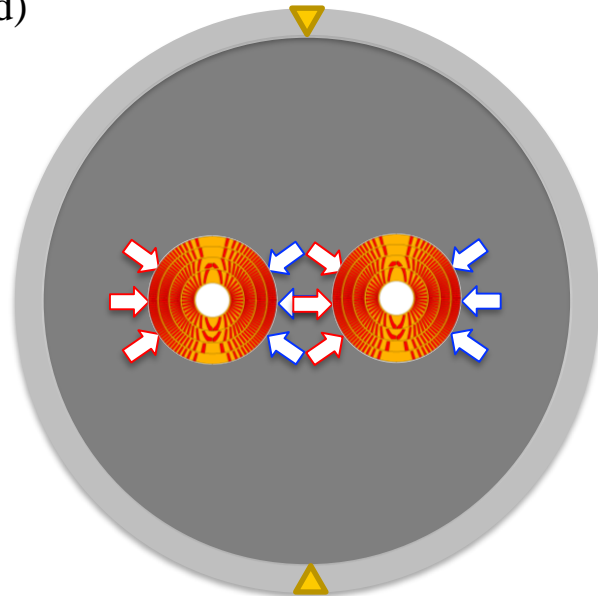
b)



c)

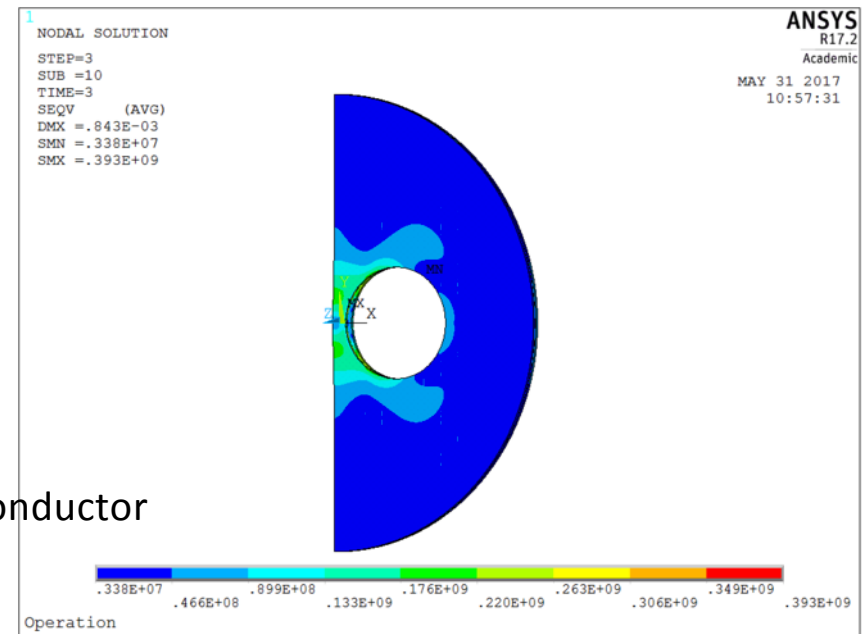
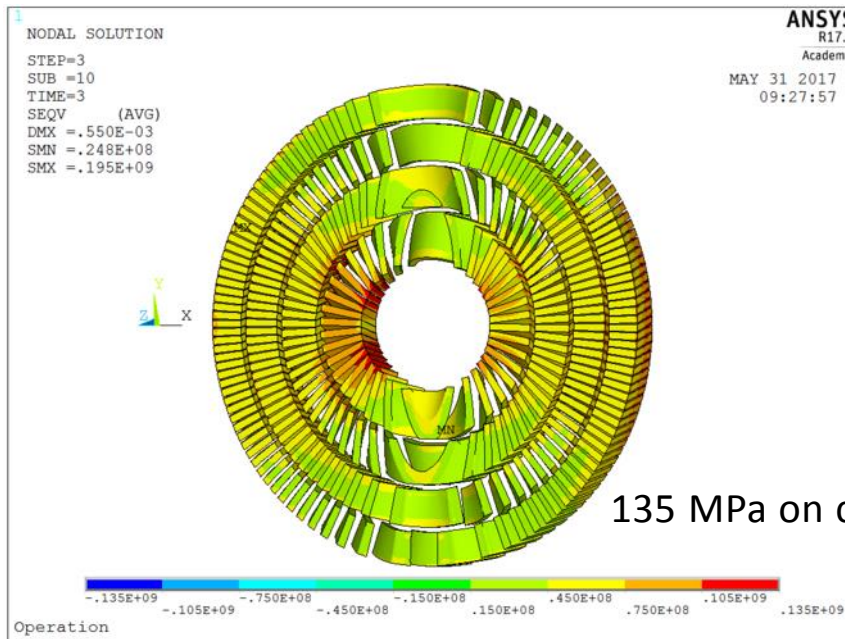


d)



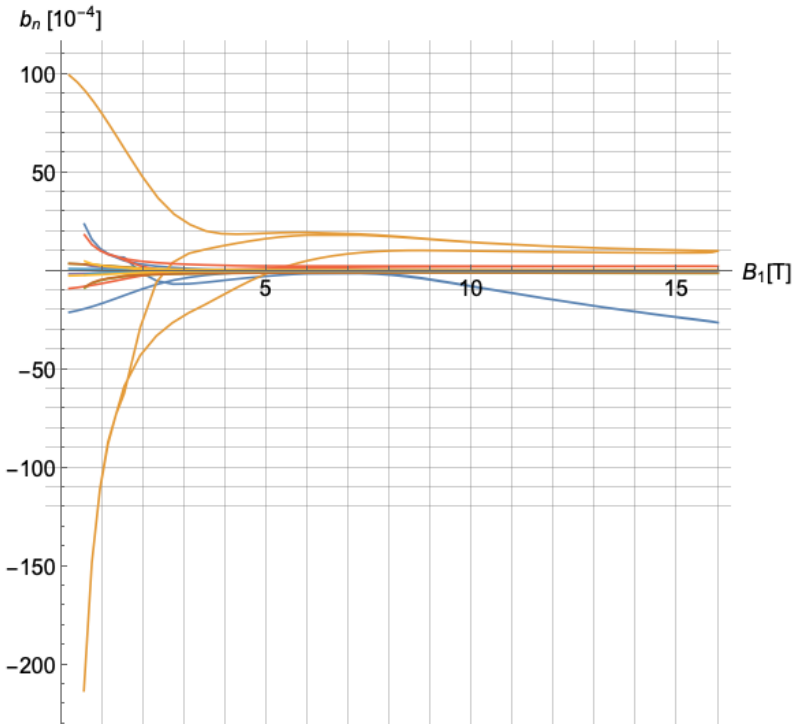
# 3-D Periodic Simulation

- Generalized plane stress condition applied (following D. Arbelaez, L. Brouwer, LBNL)
- Initial 3-D results confirm 2D, but show distinct imprint of scissors lams
  - increase protective shell thickness, change its material to iron
  - decrease lamination thickness.

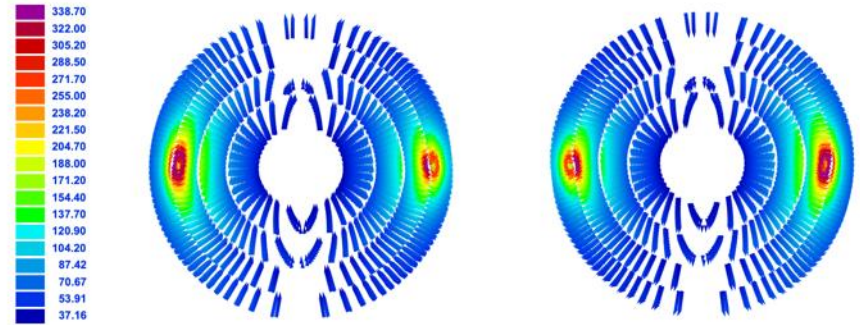


Courtesy G. Rolando

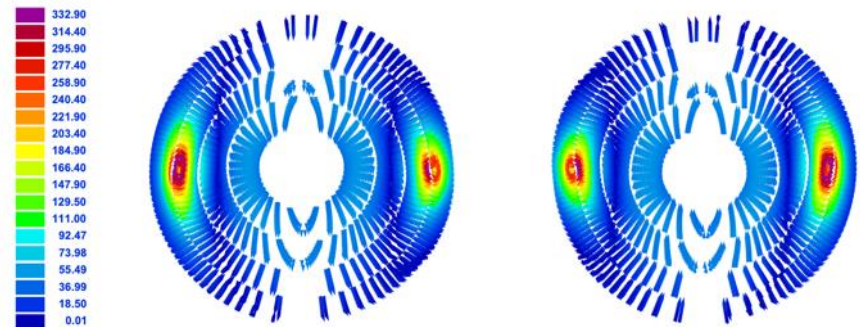
- First-of-a-kind CCT persistent-current simulation assuming axial current-flow like in any 2-D electromagnetic simulation.
- Similar order of magnitude as other designs.



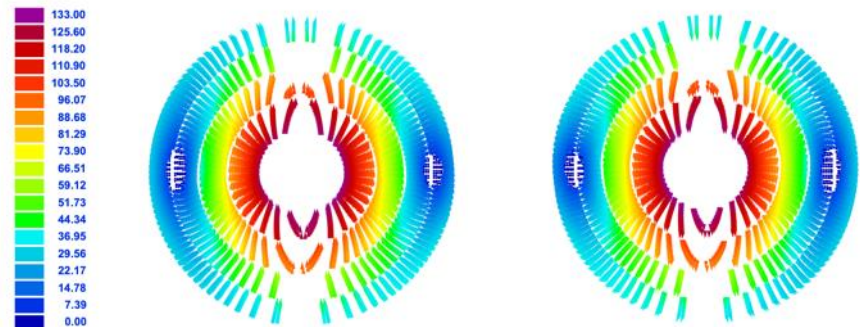
Magnetization [kA/m] @ 16. T



Magnetization [kA/m] @ 15.7 T



Magnetization [kA/m] @ 0.2 T



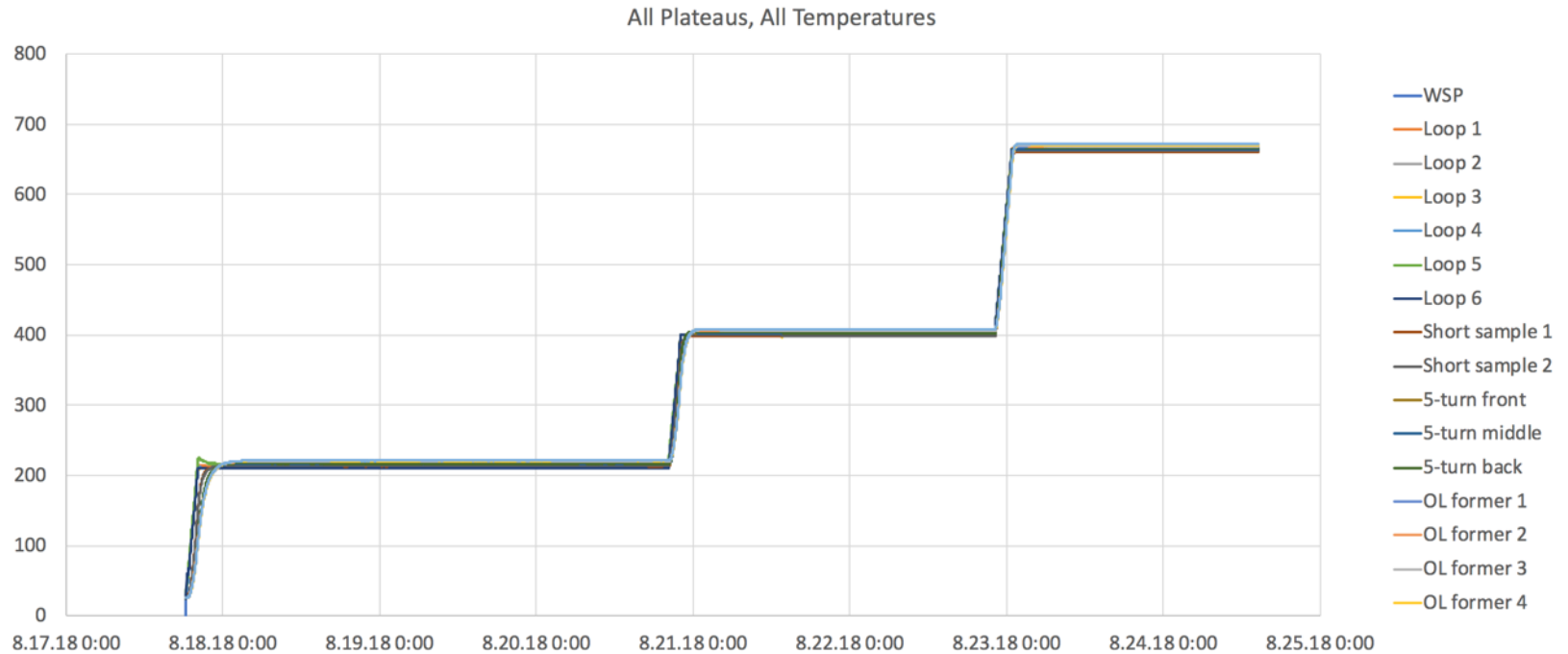
- $b_2$  correction (-26 to -16 units) by winding-path modification.
  - 25%-reduction in rib bottom thickness.
  - Chamfering/stepping of channel bottom may be required (could also be used to enhance efficiency).
  - Further FQ tuning is possible.

Main Field = 16.0015 T

	an	bn
1	-0.458577	10 000.
2	1.46377	-16.9835
3	0.197922	9.41813
4	-0.518893	0.113957
5	0.0145285	2.37396
6	0.675784	-0.202357
7	-0.0930704	-0.985619
8	-0.53873	0.0595043
9	0.0626084	0.295271
10	0.293446	-0.0128189



# 5-Turn Reaction



- Overshoots of loop temperatures diminish with temperature.
- Back-side probes arrive on
  - 210°C reached 6-7 hours after WSP out of 72 h on plateau.
  - 400°C reached 3 hours after WSP out of 48 h on plateau.
  - 665°C reached 50 min after WSP out of 50 h on plateau.



- Mechanical model test in Dec. 2017.

