B. Auchmann CERN/PSI, R. Felder PSI, J. Gao PSI, G. Montenero PSI,
S. Sanfilippo PSI, S. Sidorov PSI, L. Brouwer LBNL, S. Caspi LBNL

Status of the CCT @ PSI

SPS Annual Meeting, 29.8.2018
Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI.

Overview

- CCT @ FCC
- SC Magnet Lab @ PSI
- CD1 Manufacturing trials

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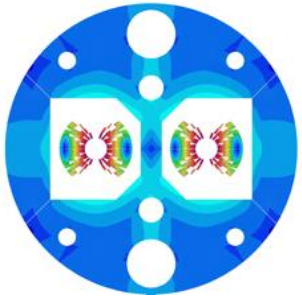
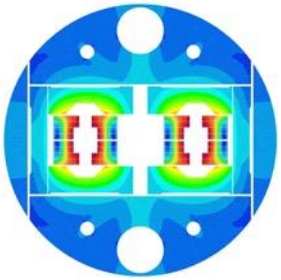
EuroCirCol Designs

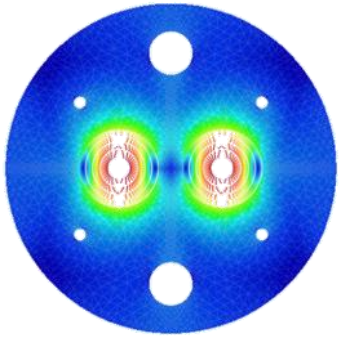
Cos-theta



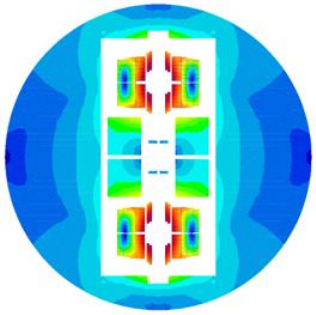
Block coil



Canted Cosine Theta



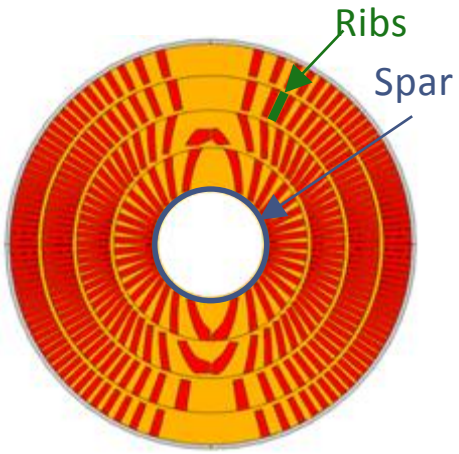
Common coils



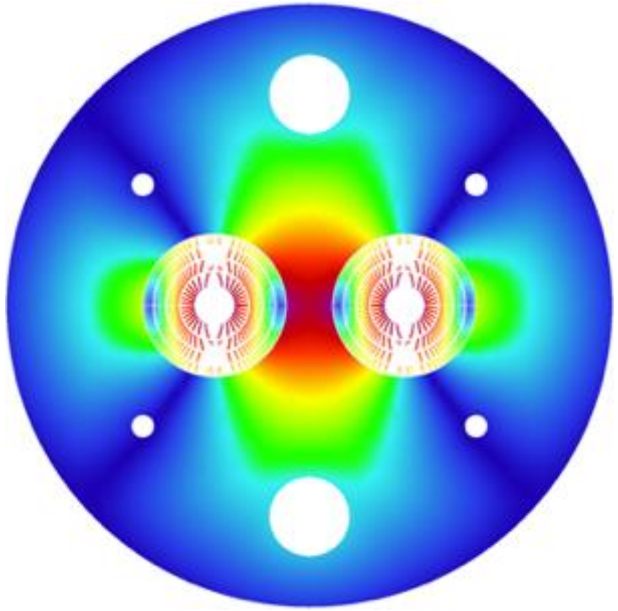
PSI's CCT Design for FCC

- Current: 18135 A

Layer #	n_s	diam [mm]	cuNc	loadline marg. [%]	current marg. [%]	T_{peak} [K]	V_{grnd} [V]	J_{cu} [A/mm^2]
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



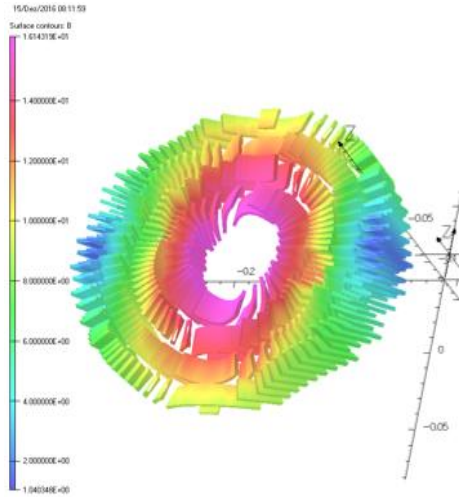
- Optimize J_e optimal winding angle, minimal spars, and ribs, wide cable.
- FCC-wide conductor use: **9.7 kt**
  Total inductance: 19.2 mH/m
  - Total energy: 3.2 MJ/m
- Opportunity to reduce unit length and peak voltage to ground via double-helix.

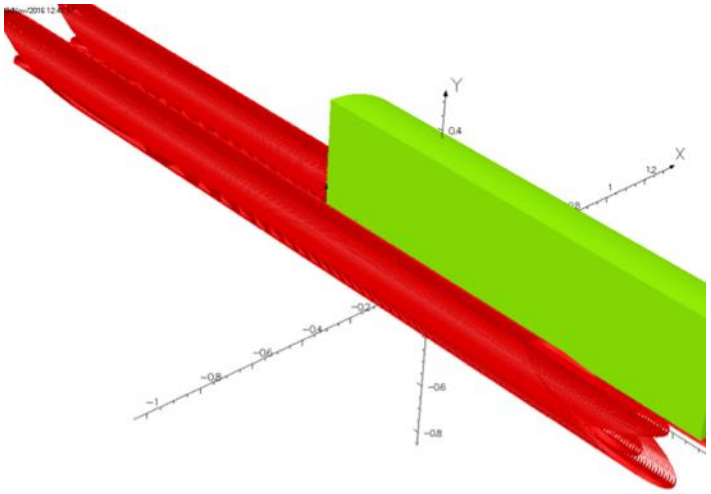


3-D Magnetic Design

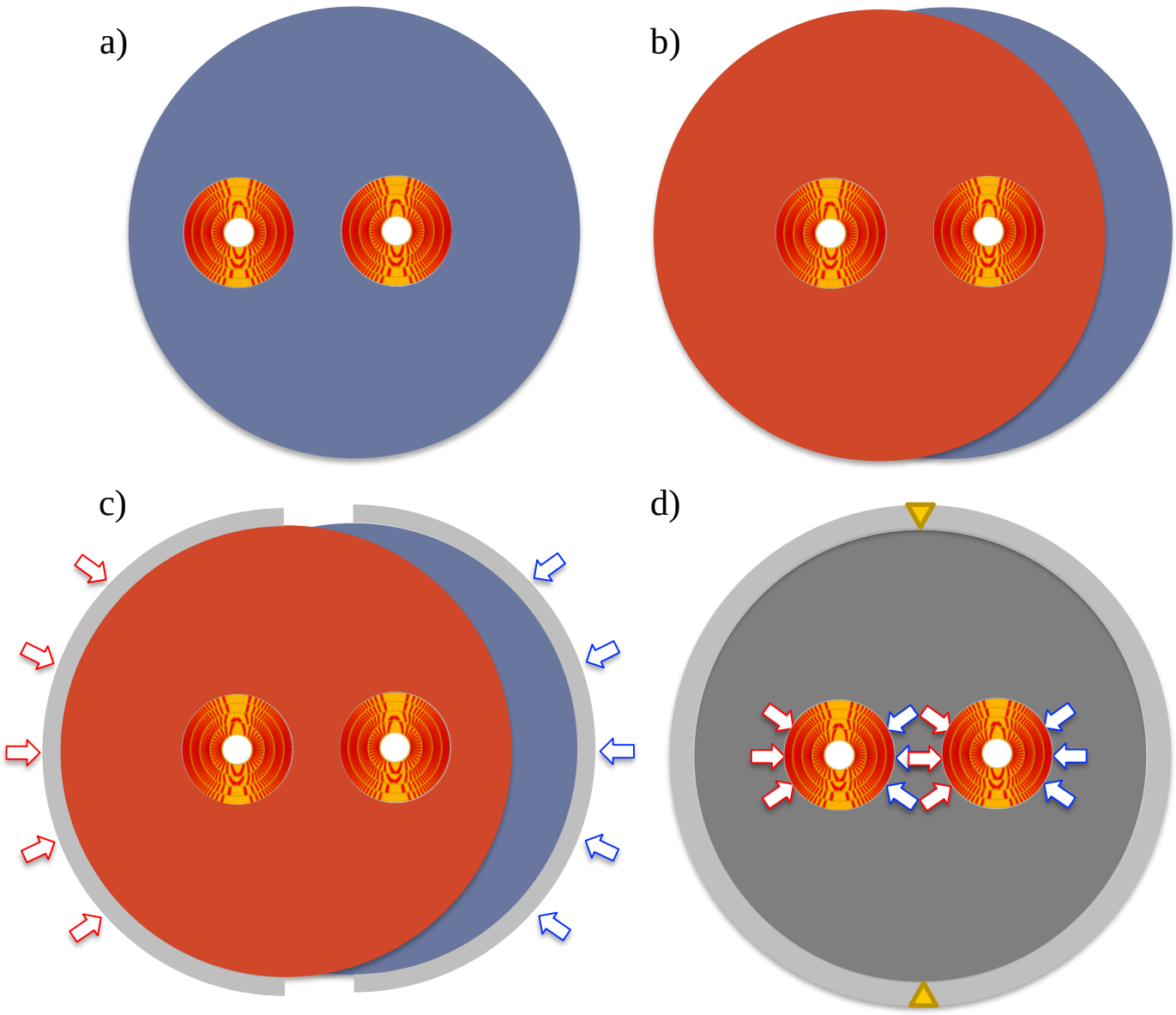
3-D modeling results:

- **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.

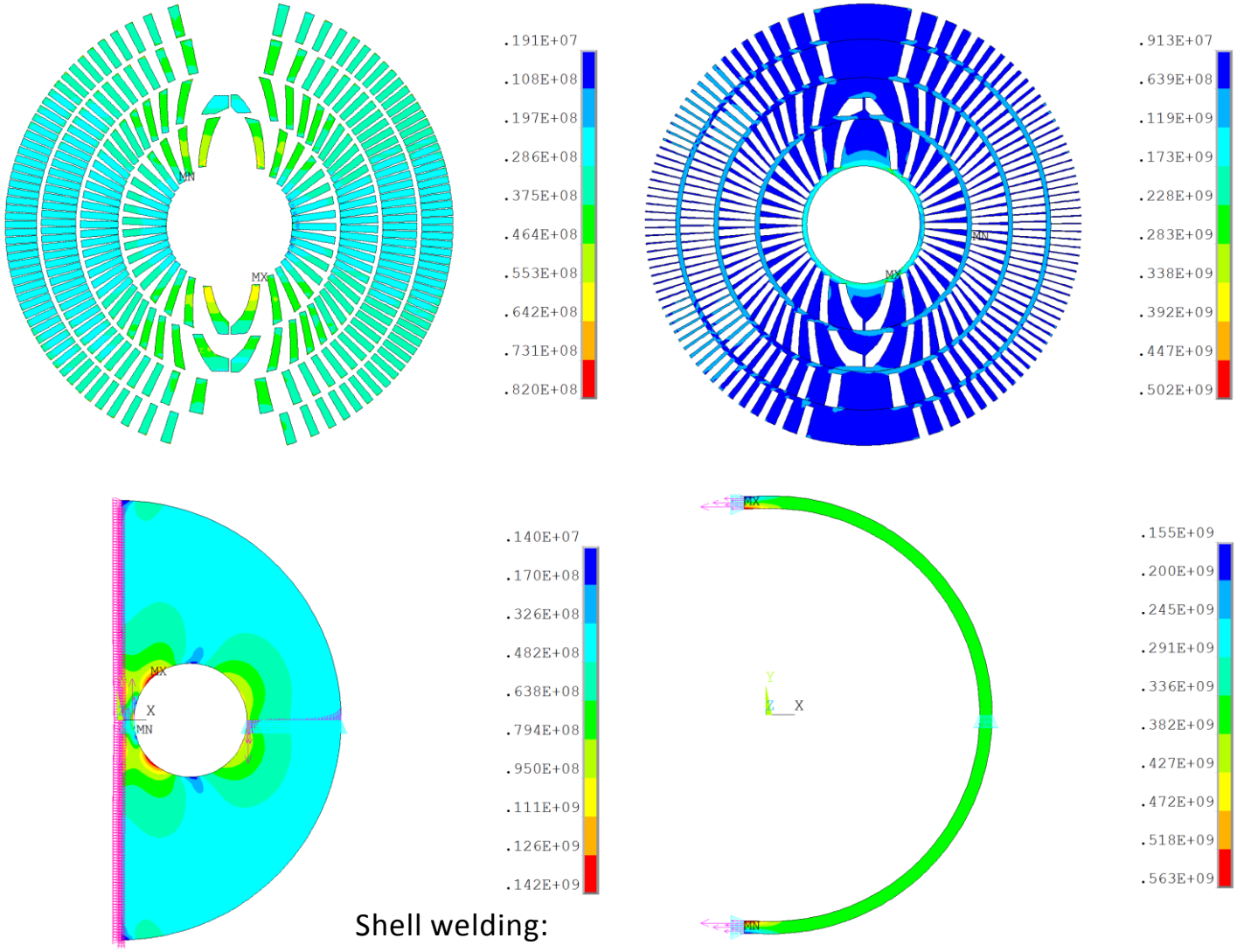




Courtesy M. Negrazus


a)
b)
c)
d)

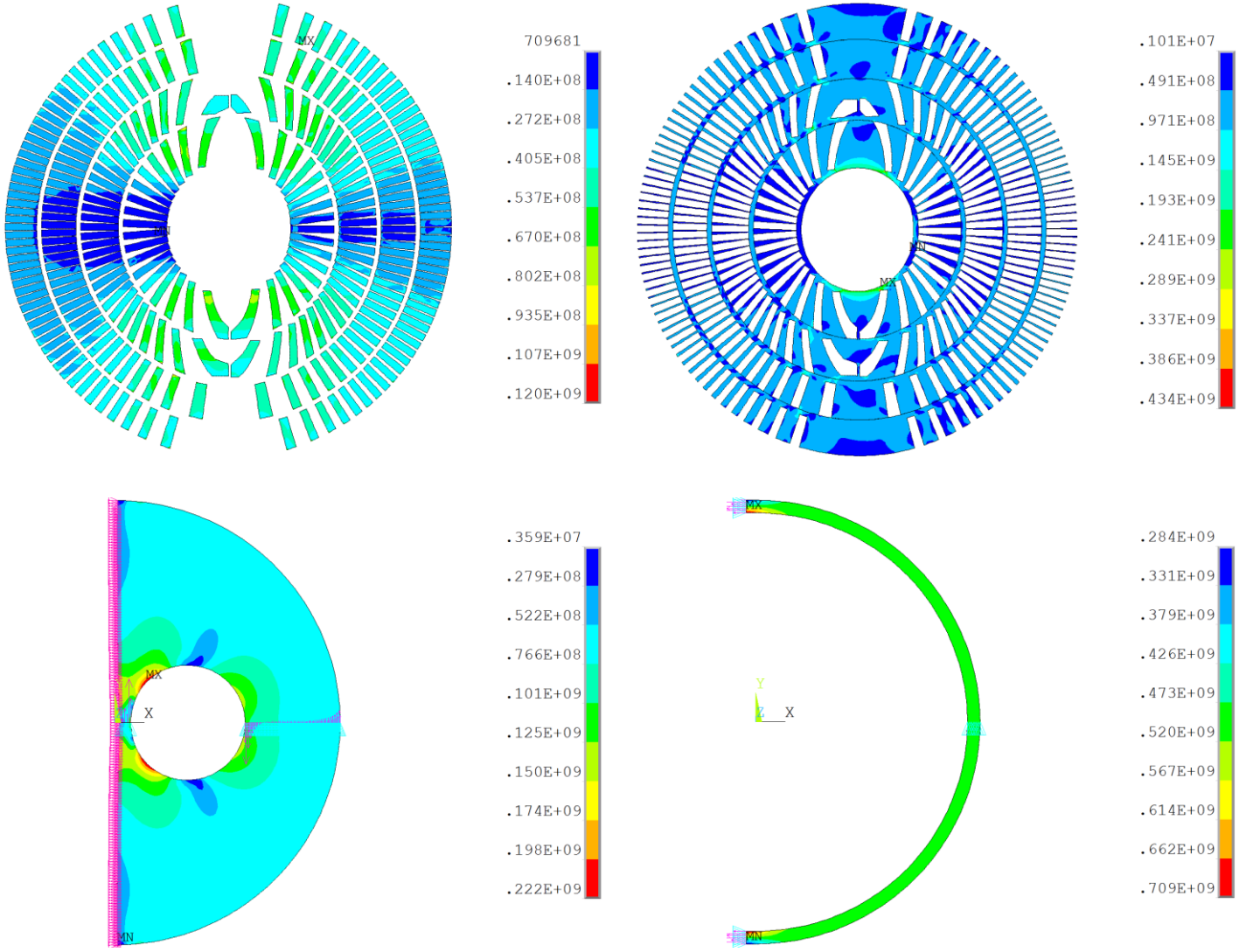
2D Mechanical Design – Room Temperature



Shell welding:

- here displacement constraint (0.9 mm, total 1.8 mm weld shrinkage).
- equivalent to 350 MPa pressure constraint (SS limit).

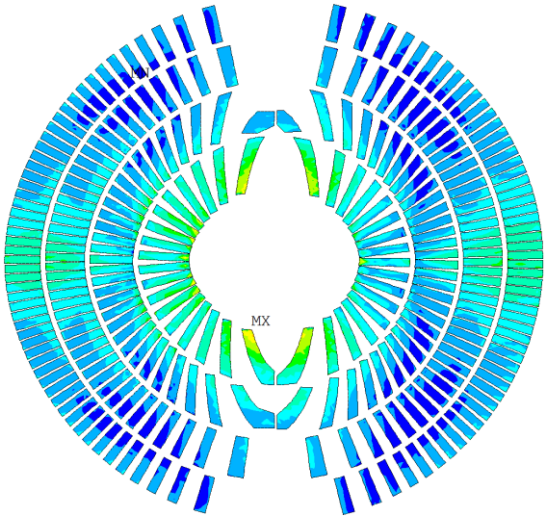
2D Mechanical Design – Cool-Down

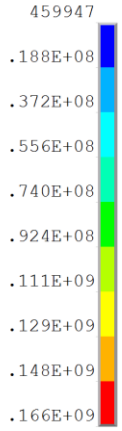


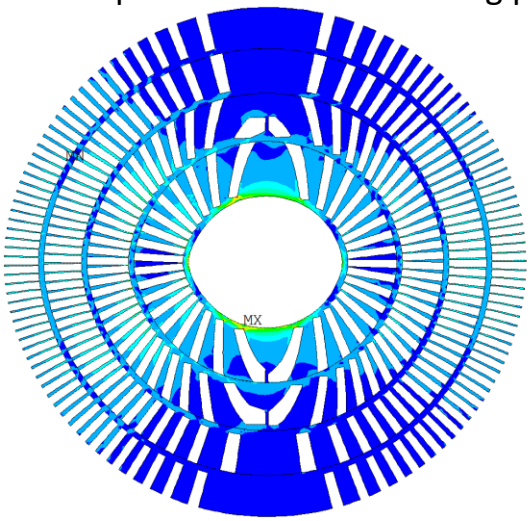
2D Mechanical Design – 16 T

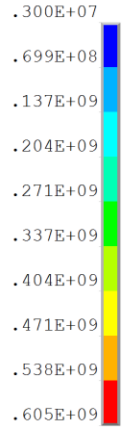
Al-bronze tensile strength measurements after HT under way.

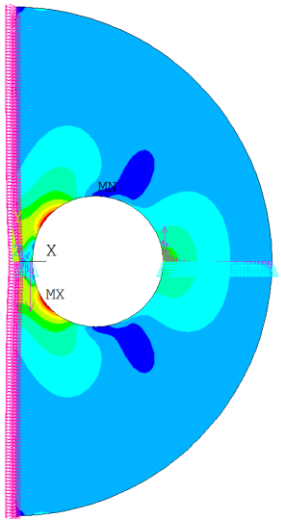
Final former material depends on manufacturing process. Ideally Ti.

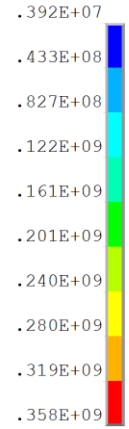


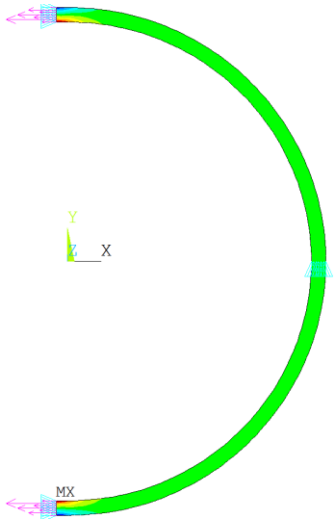


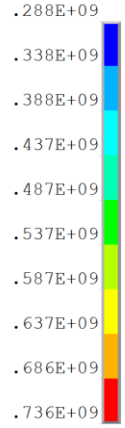






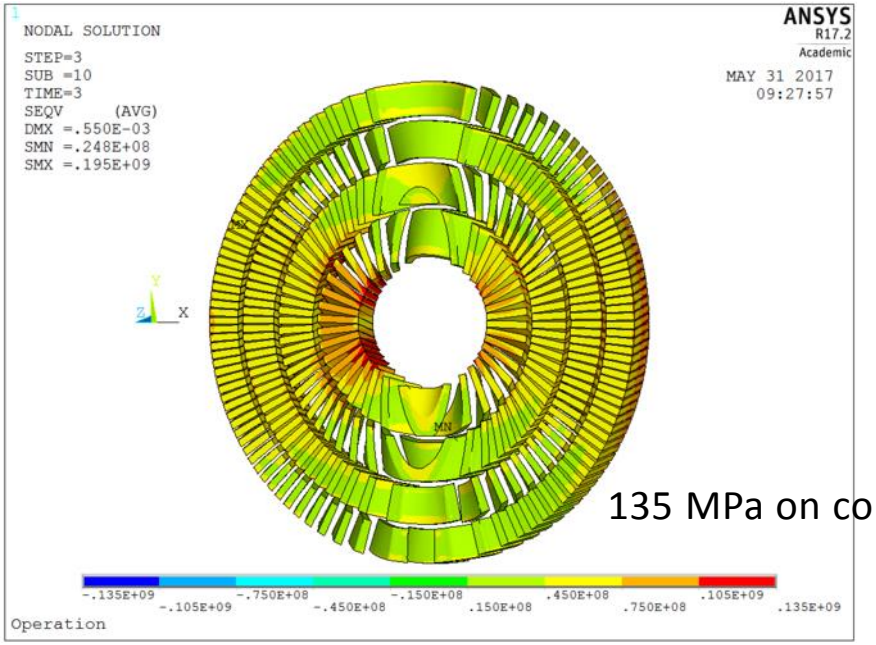




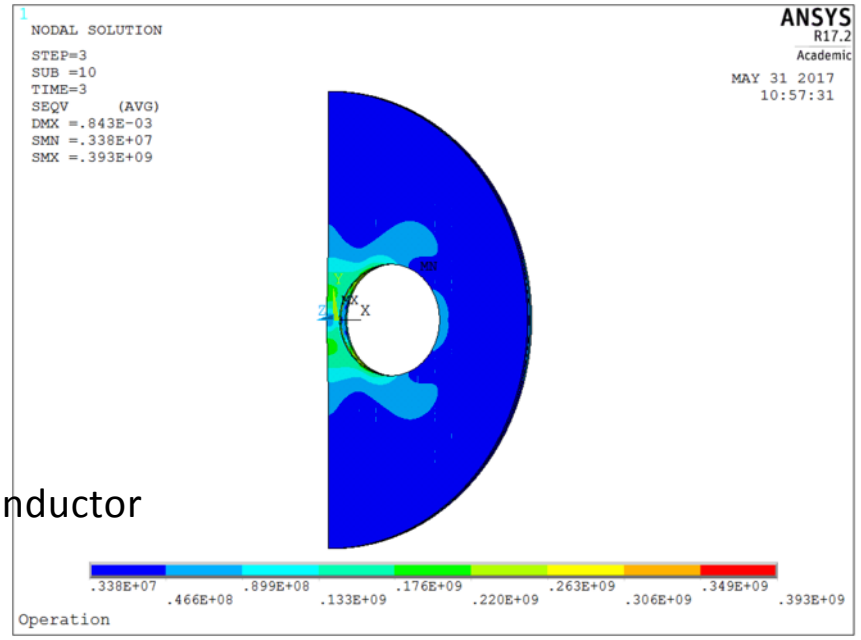


3-D Periodic Simulation

- 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.



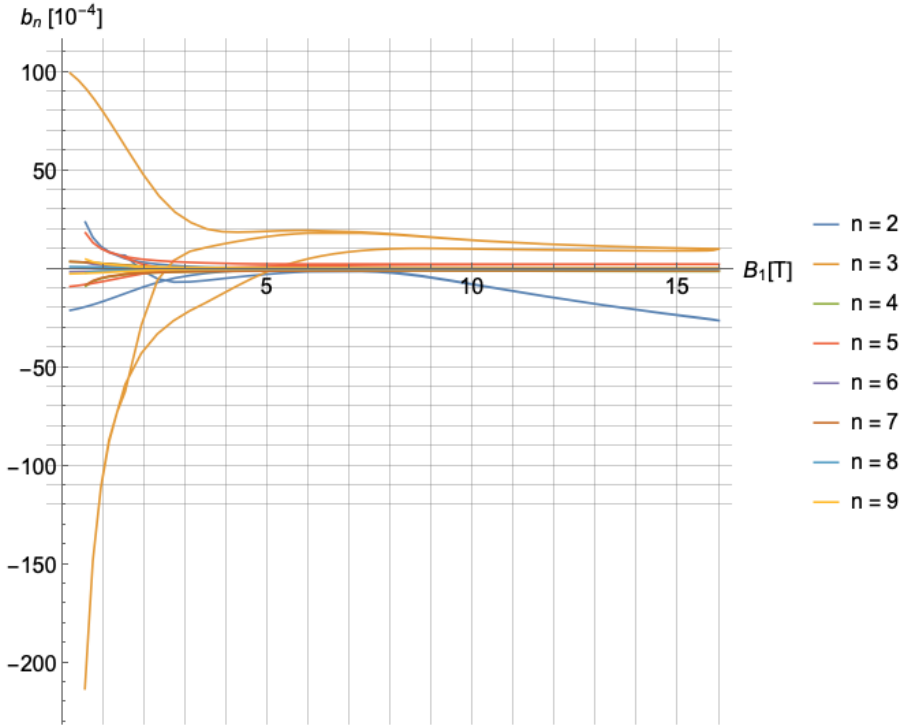
135 MPa on conductor

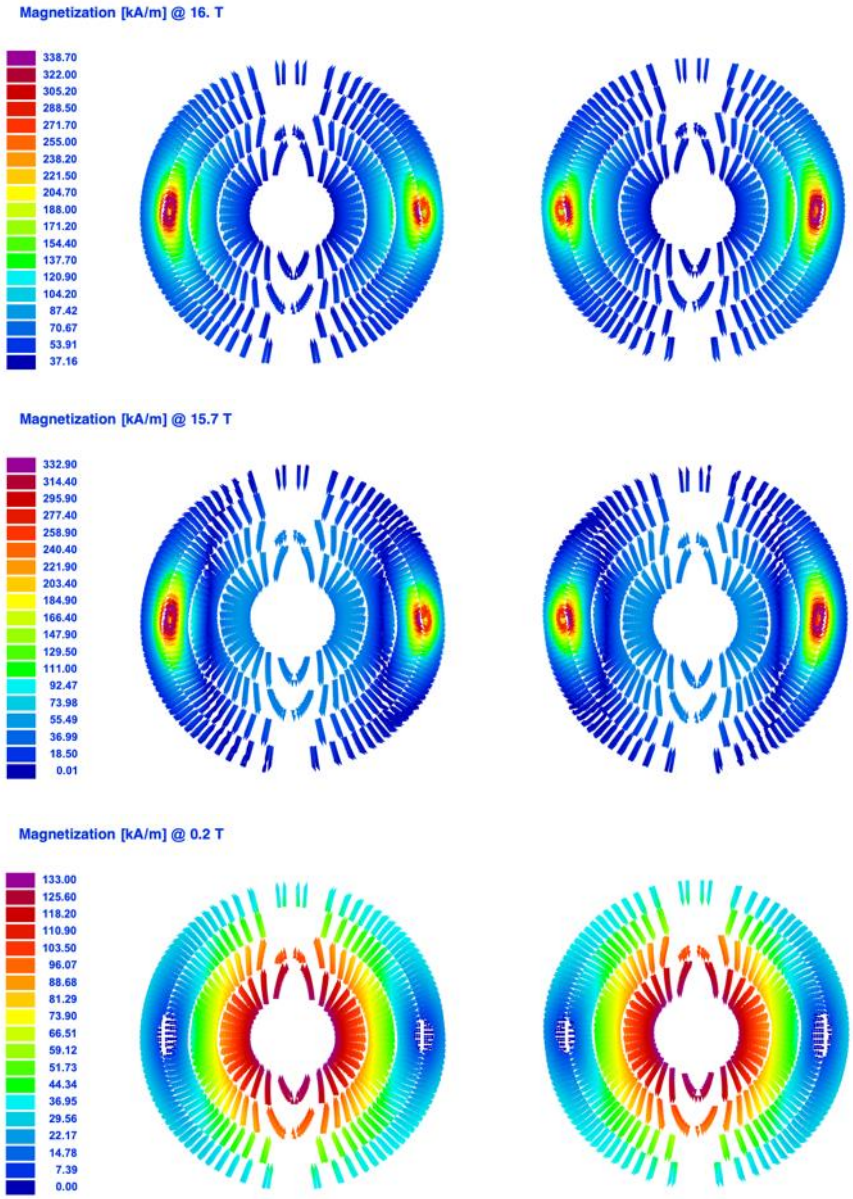


Courtesy G. Rolando

Persistent Currents

- 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.



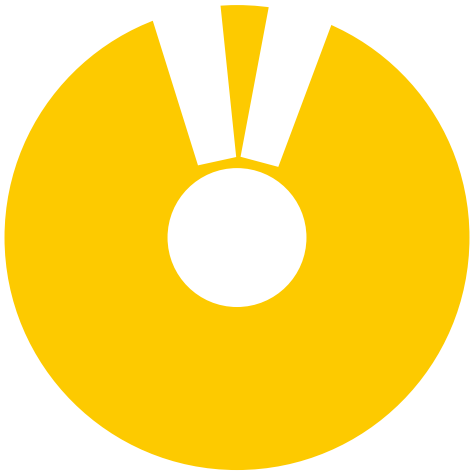


Field Quality

- 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.

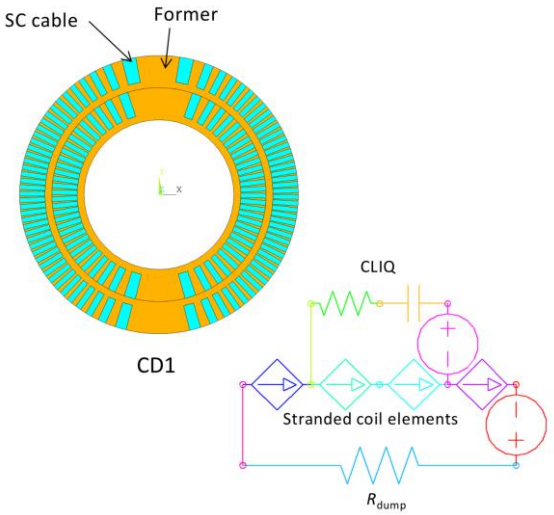
Main Field = 16.0015 T

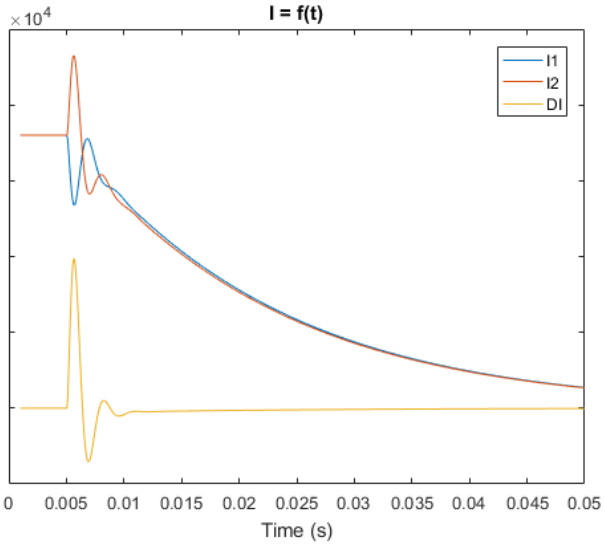
	an	bn
1	-0.458577	10 000.
2	1.46377	-16.9835
3	0.197922	9.41813
4	-0.518893	0.113957
5	0.0145285	2.37396
6	0.675784	-0.202357
7	-0.0930704	-0.985619
8	-0.53873	0.0595043
9	0.0626084	0.295271
10	0.293446	-0.0128189

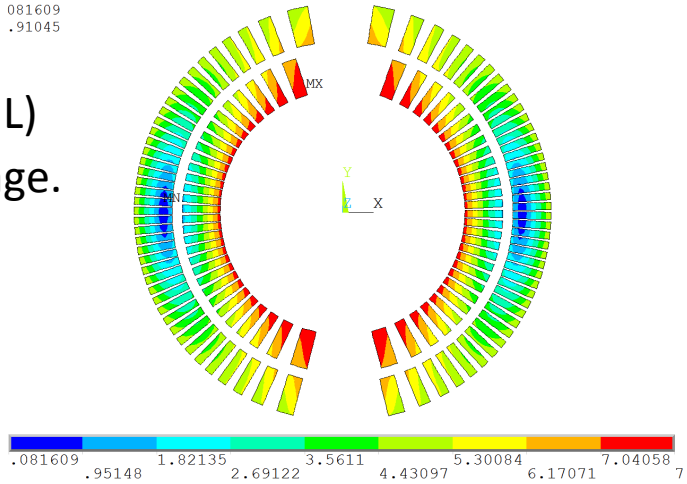


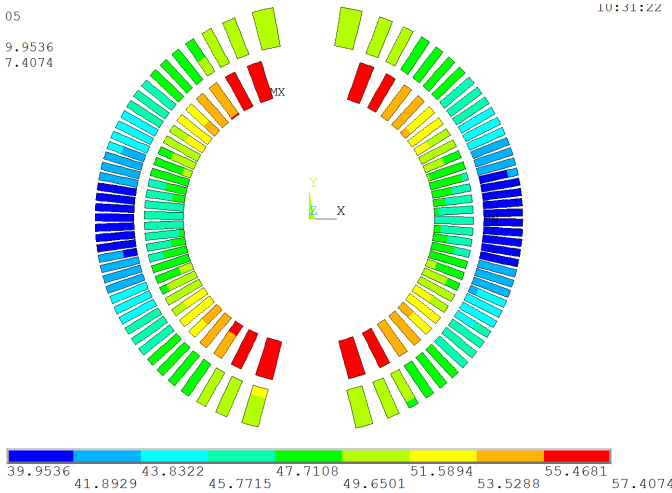
Quench Simulation for CCT

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









Courtesy J. Gao PSI and L. Brouwer LBNL

Overview

- CCT @ FCC
- SC Magnet Lab @ PSI
- CD1 Manufacturing trials

CHART-PSI Goals towards FCC Requirements

- Goal: Demonstrate key technological features of an **efficient** 16-T CCT in two-layer technology model magnets.

- Thin ribs and spars
- Exterior mechanical structure
- Fast quench detection and CLIQ protection.
- Wide Rutherford cable.
- Inclined channels.
- Improved resin mix.

CD1

CD2

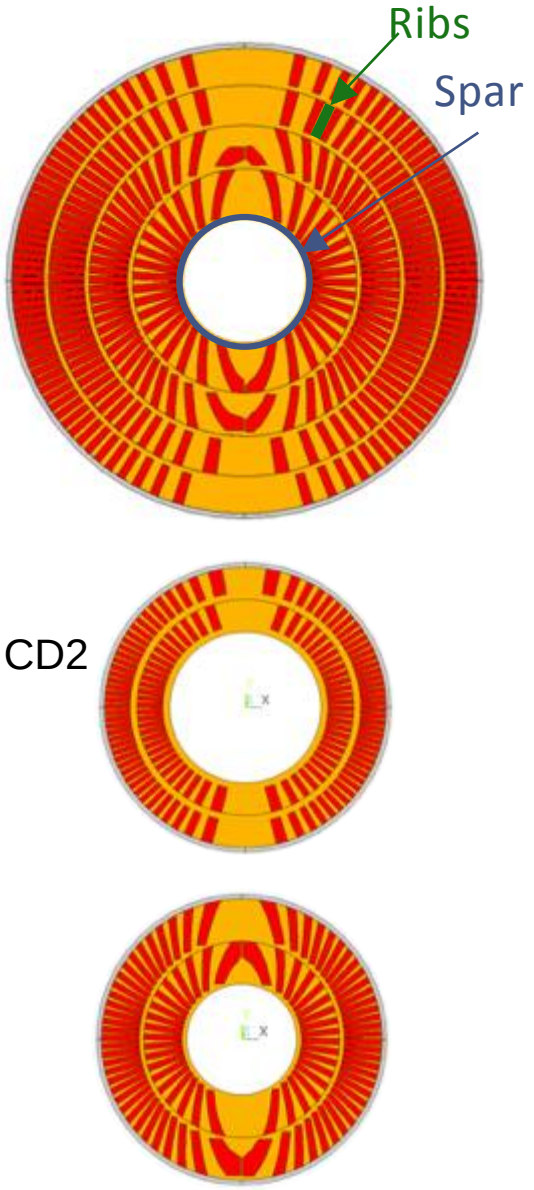
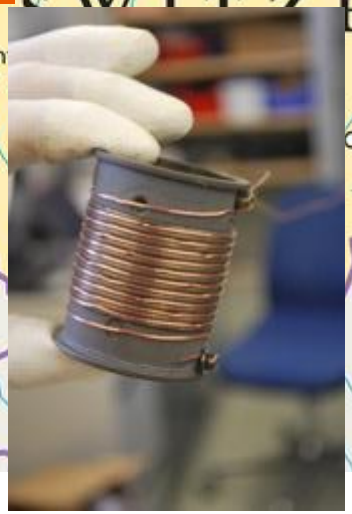


CHART (Swiss Accelerator Research and Technology Center) – Magnet Activities



PAUL SCHERRER INSTITUT

PSI

ETHZ

EPFL

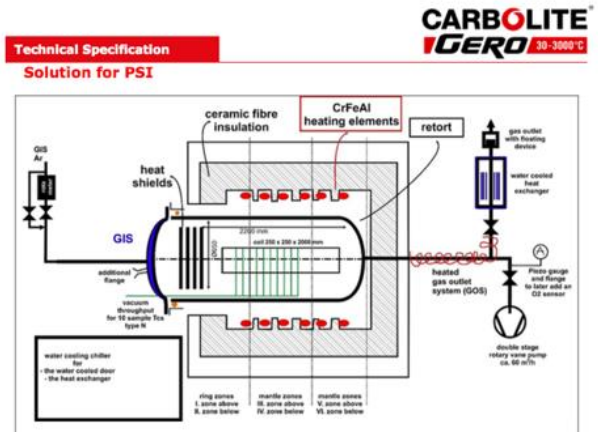
UniGE

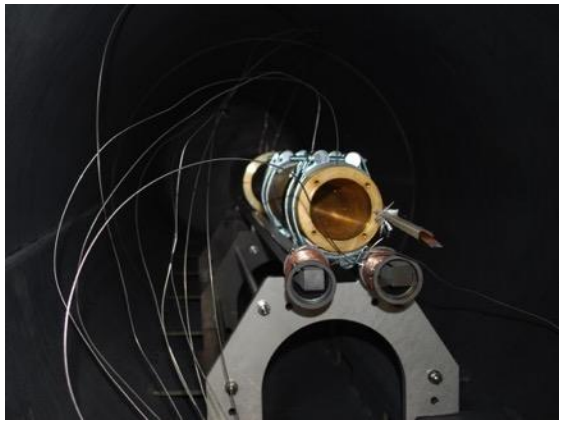
CERN

PSI SC Magnet Lab

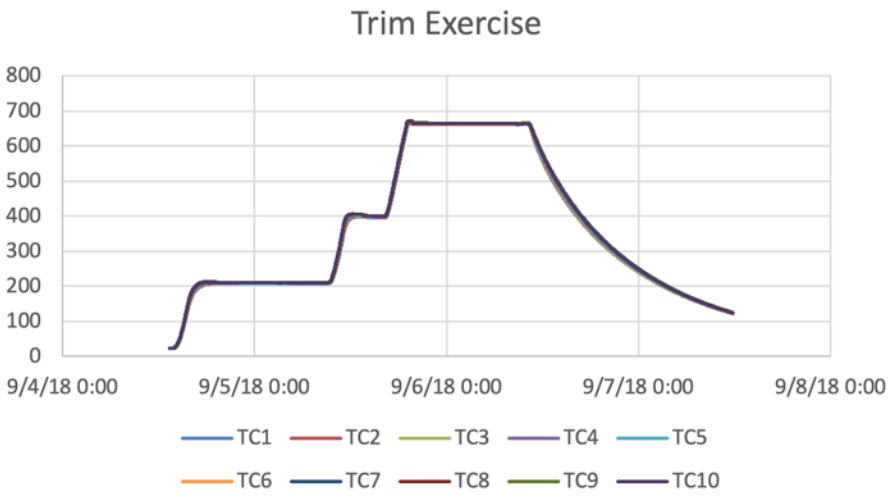
Reaction Commissioning

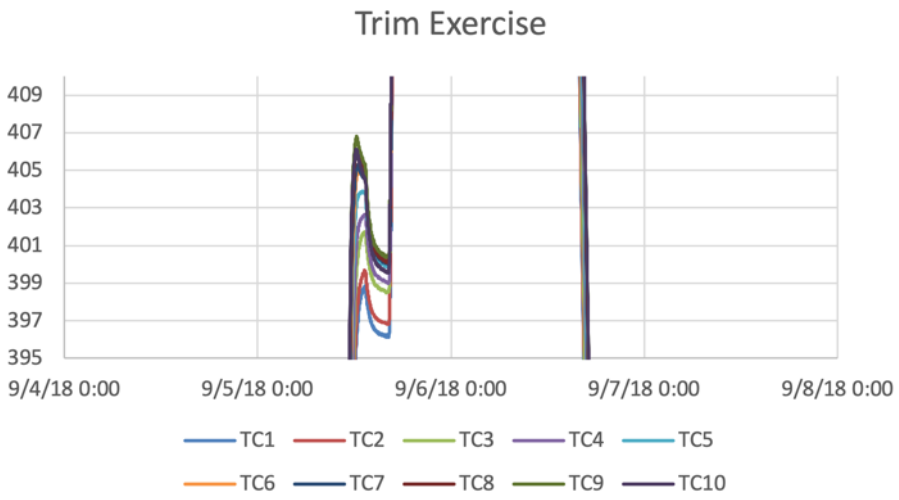
- Furnace fully operational (Ar supply, water chiller, ventilation, electricity, DAQ).
- Loading tooling complete and tested.
- Reaction of 5-turn test former complete.
- Short-sample confirmation by UniGE not before ASC.
- First coil reaction expected for Week 44.

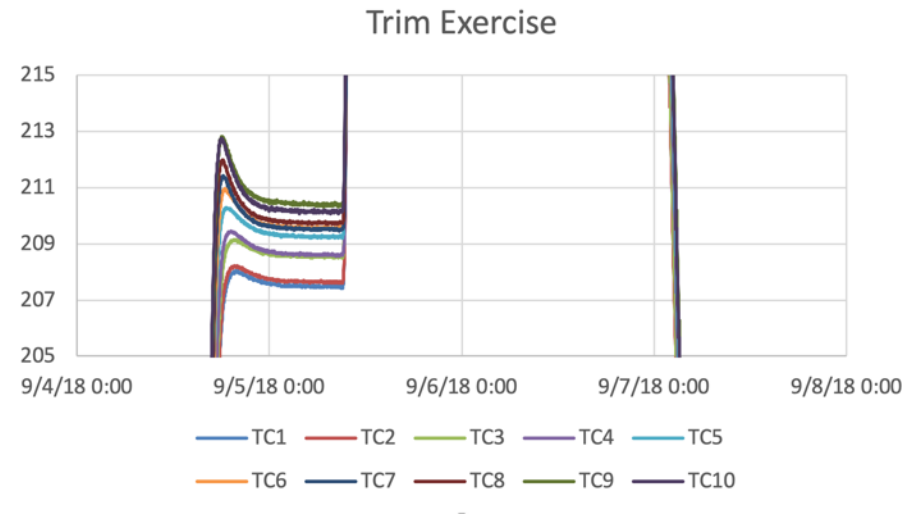


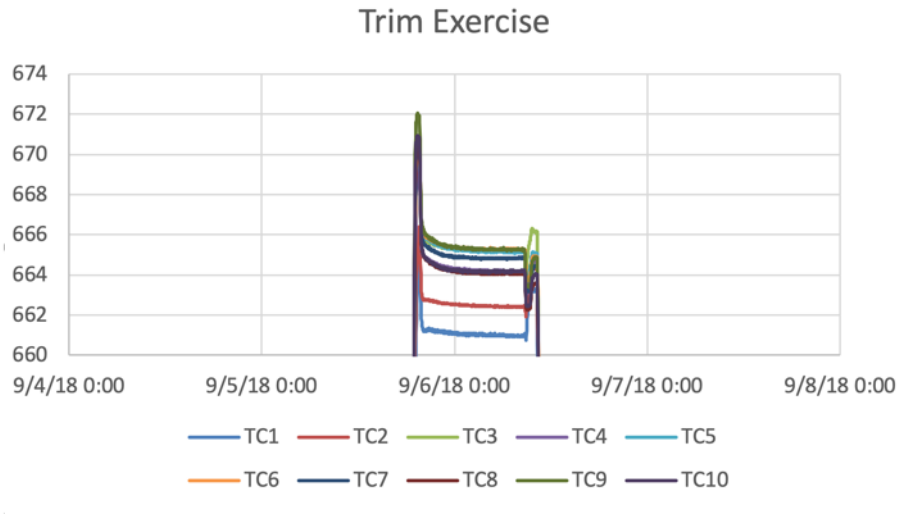


Reaction Furnace Trimming



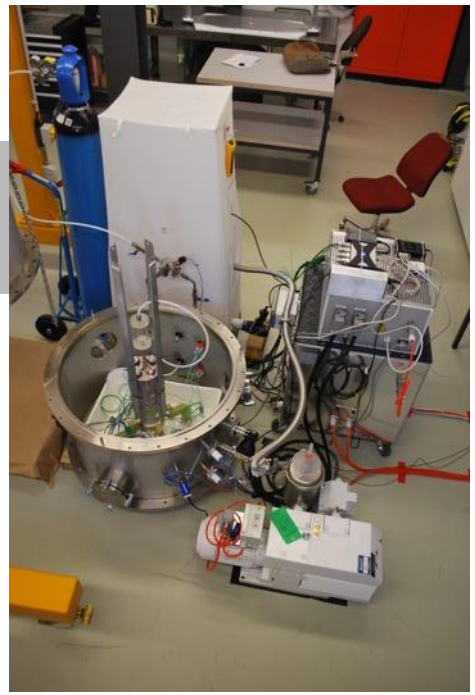






All plateau axial maps within +/- 3 K.

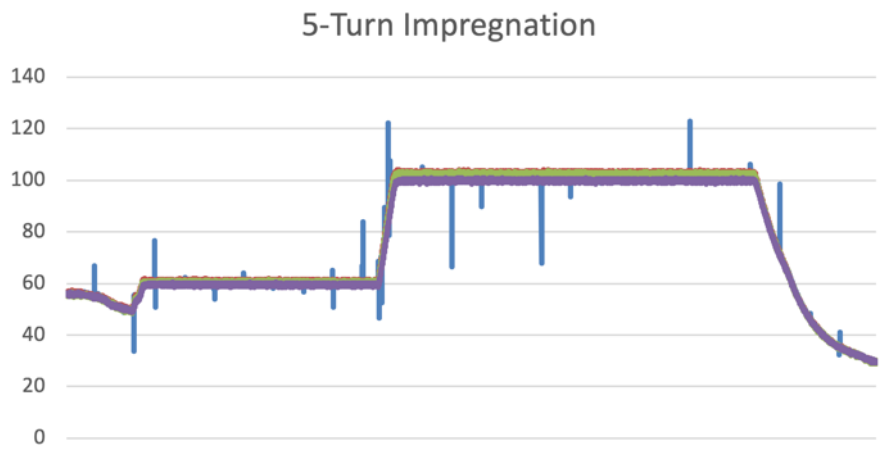
Impregnation Infrastructure

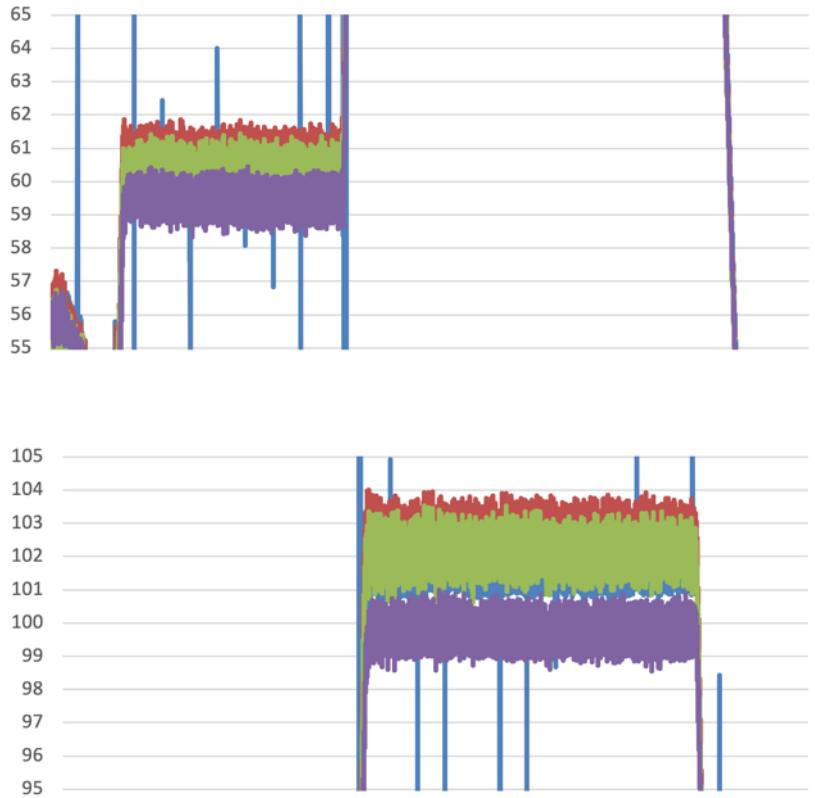



Vacuum vessel with feed-throughs in bottom part.
50 m^3/h vacuum pump with LN_2 trap
N_2 bottle for over-pressure and purging.
Control and powering units with voltage selection
Heated “green-house”
Heated feed-throughs into the vessel
See-through mixing pot
DAQ and alarm PCs
Capacitive monitoring as 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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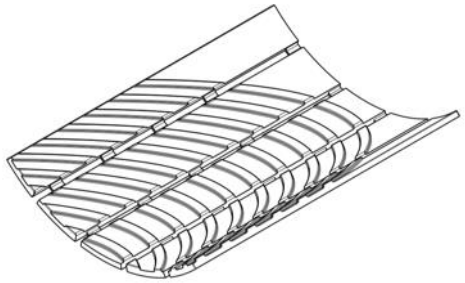
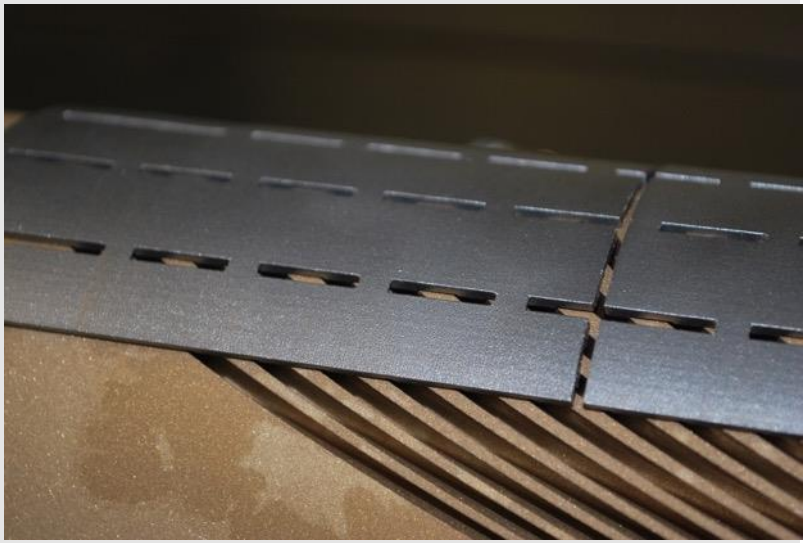
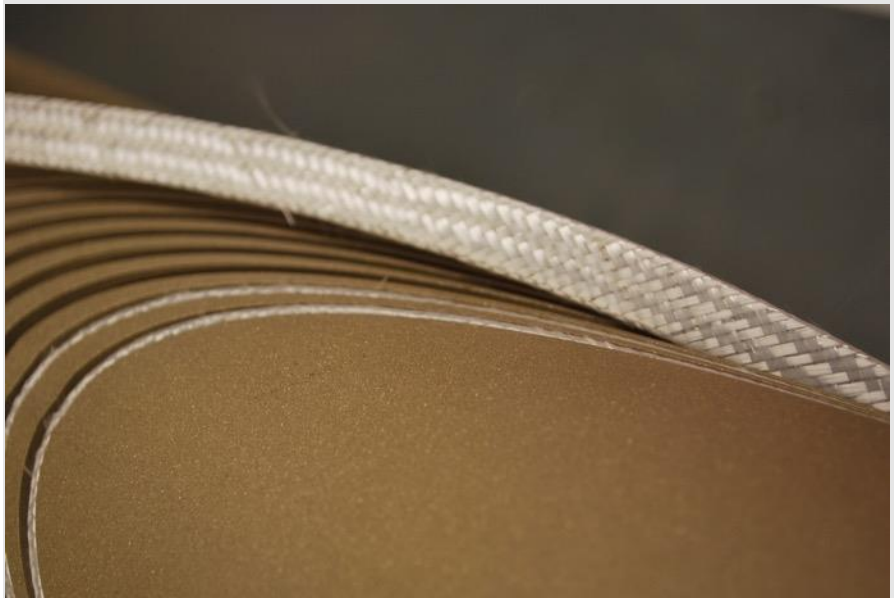
CCT Winding

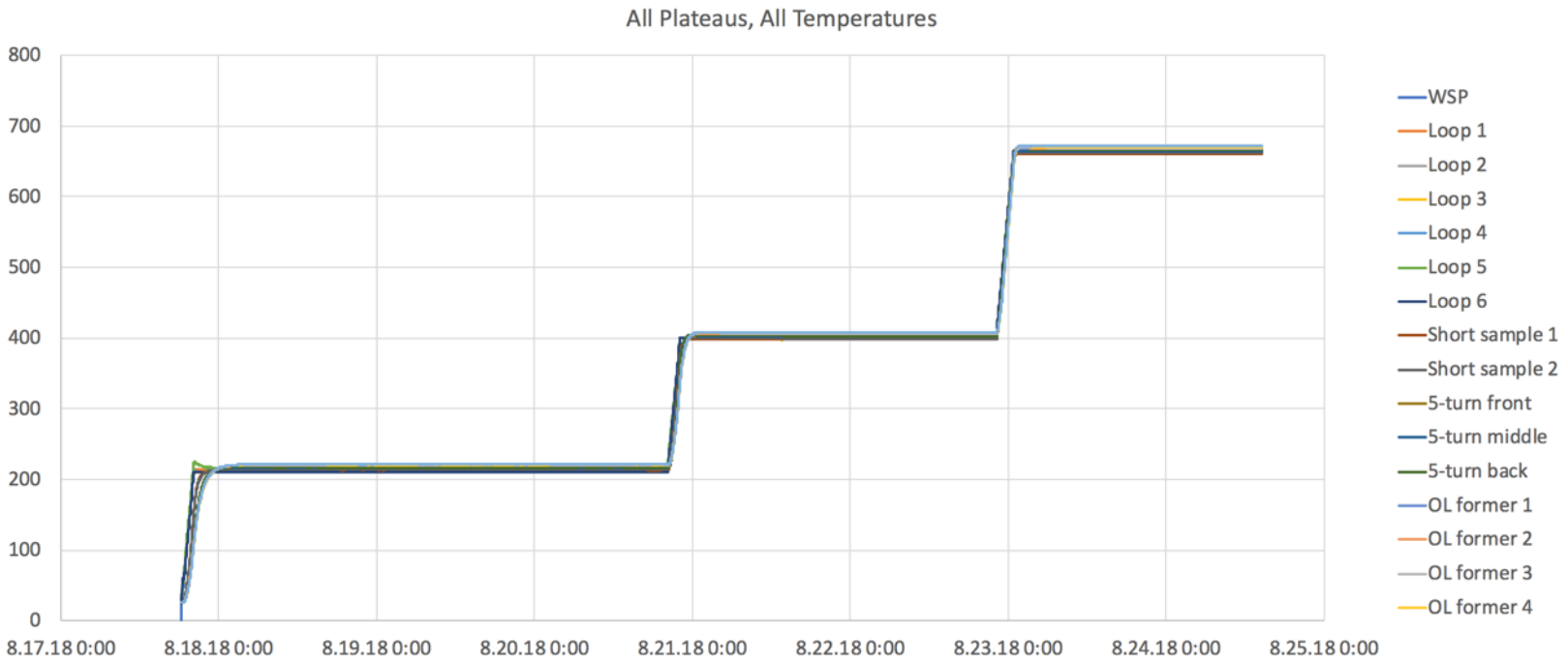


- OL winds easily and without cable popping up (see below).
- IL has tendency to pop up from the channels.
- Cable keepers were designed, tested, and printed in steel for the CD1 IL.





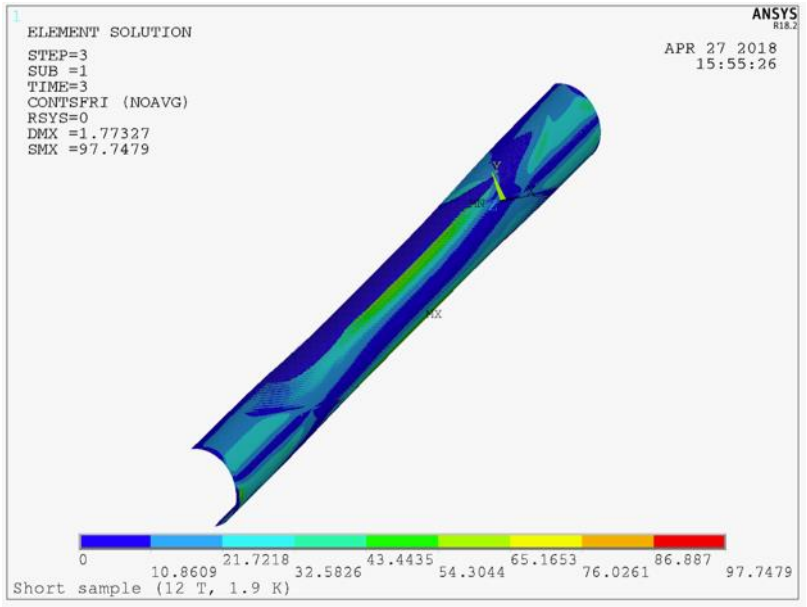
5-Turn Reaction



- 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.

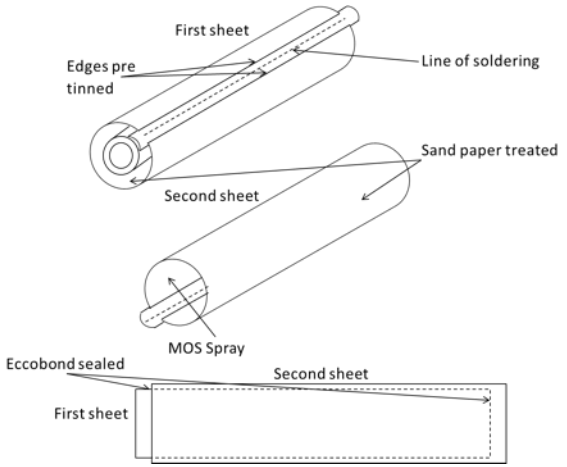
Layer/Layer Interface

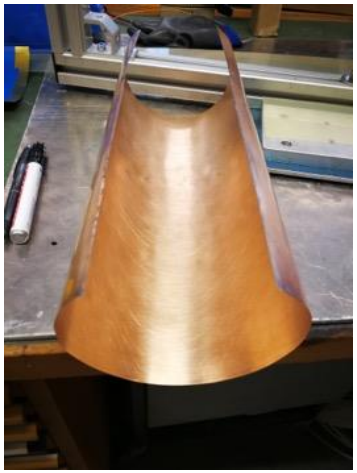
- ANSYS simulation of the full magnet model suggest shear stresses on a bonded layer/layer interface are too high to confidently glue.
- PSI solution: implement a dedicated sliding plane, inspired by MSUT (H. ten Kate et al.).

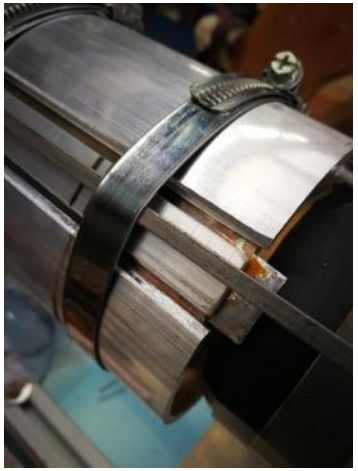


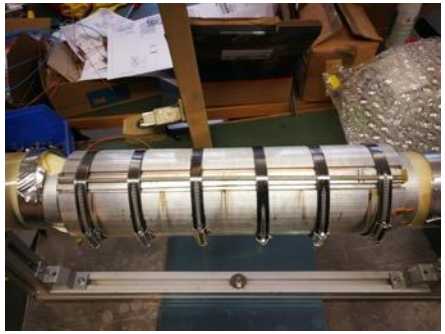
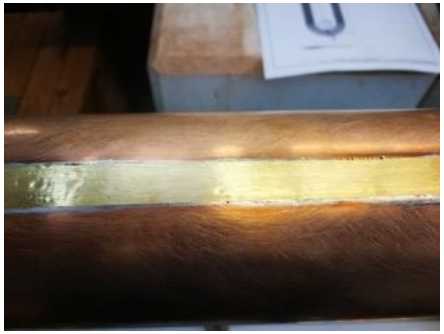
Sliding Plane Installation

- ANSYS simulation of the full magnet model suggest shear stresses on a bonded layer/layer interface are too high to confidently glue.
- PSI solution: implement a dedicated sliding plane, inspired by MSUT (H. ten Kate et al.).

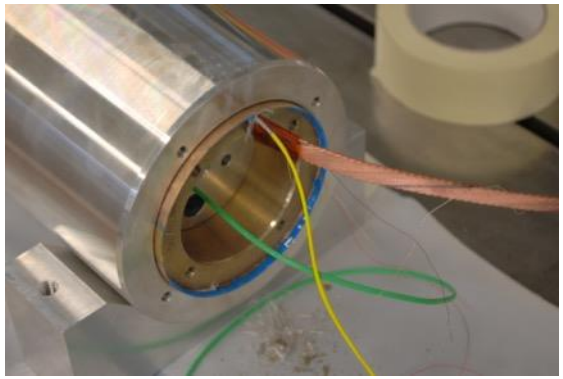
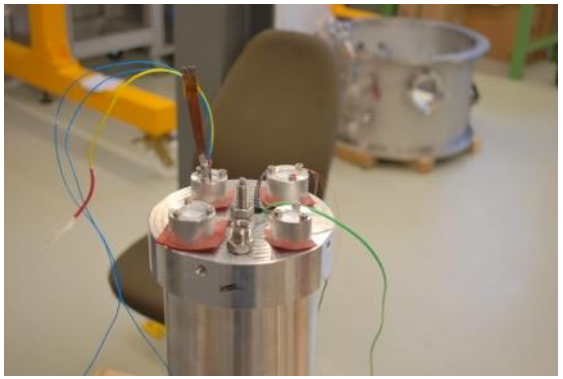
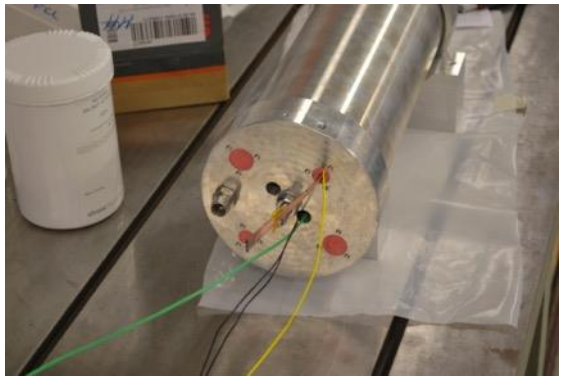
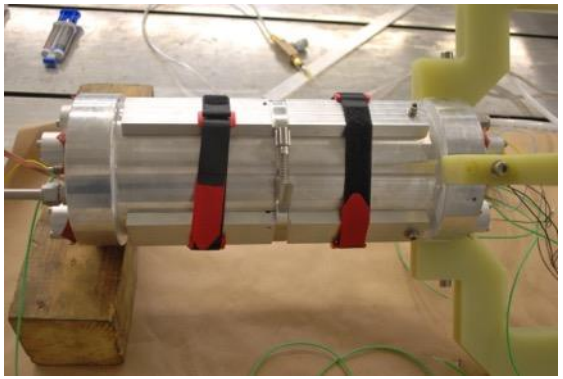
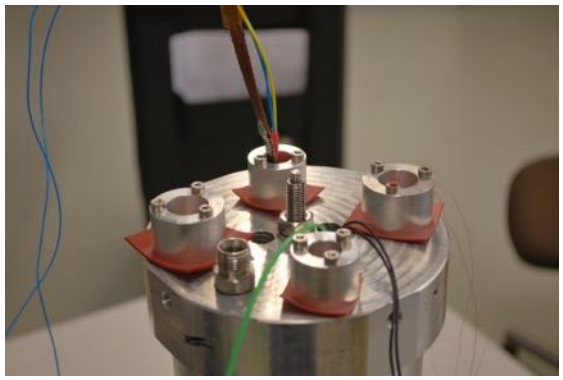
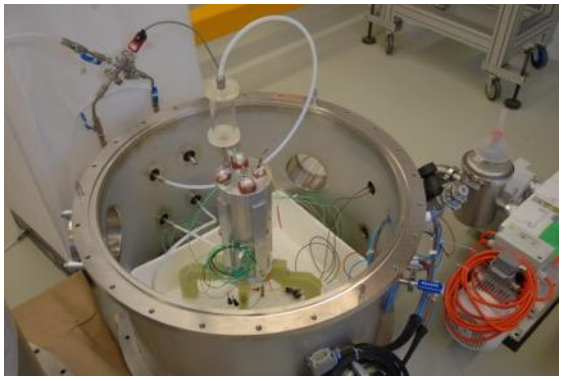


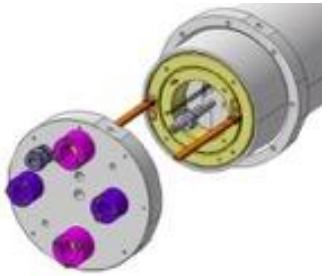


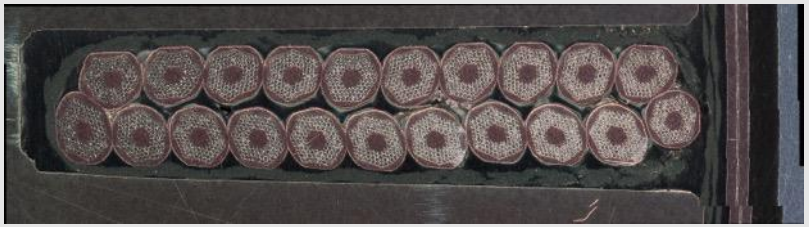

5-Turn Sample Preparation, CD1 Mold

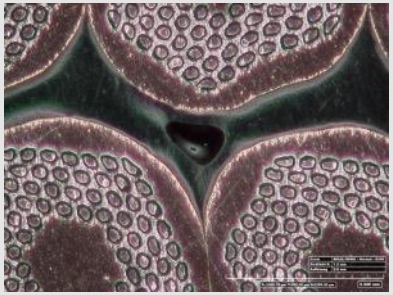







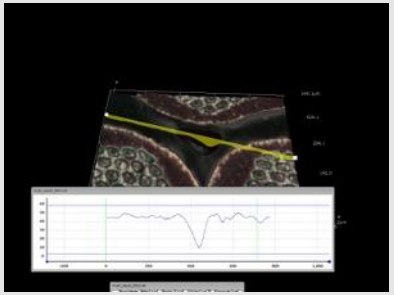



Impregnation Results

- Some potential bubbles visible.



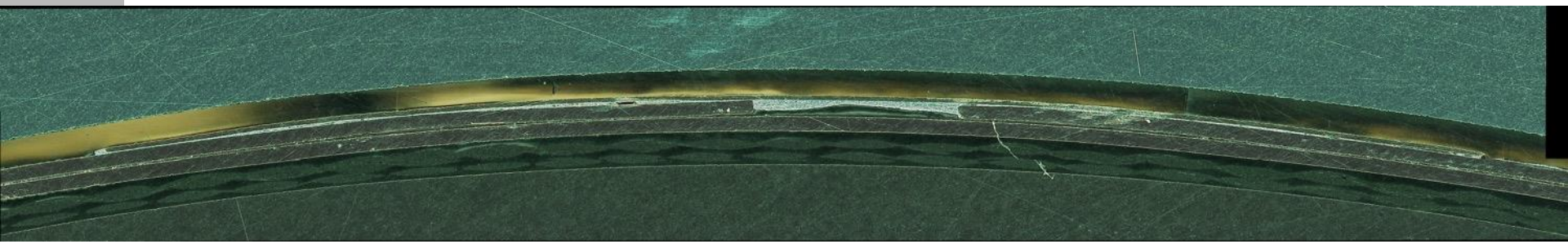




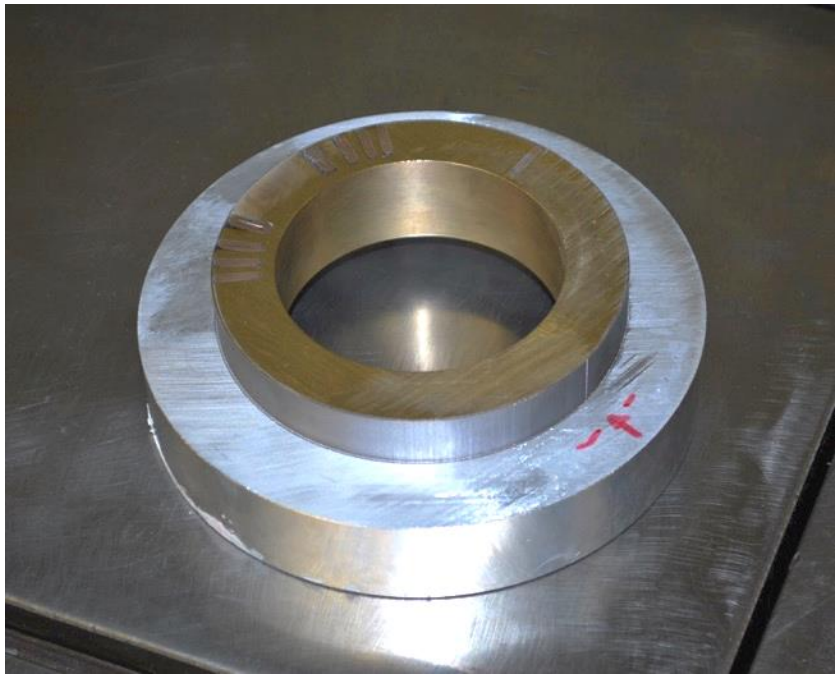
- Next step: improve control of injection flow rate via peristaltic pump.

Sliding Plane Tests

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

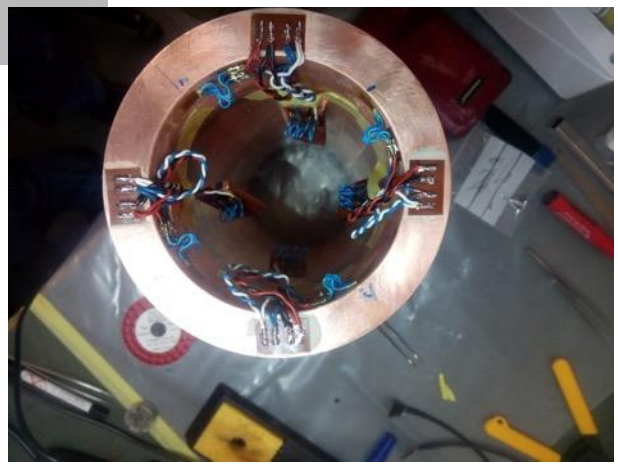


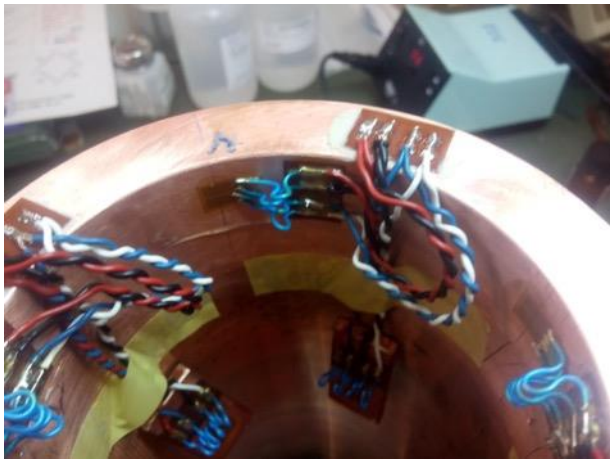
- Separation of layers post impregnation – sliding planes in action:

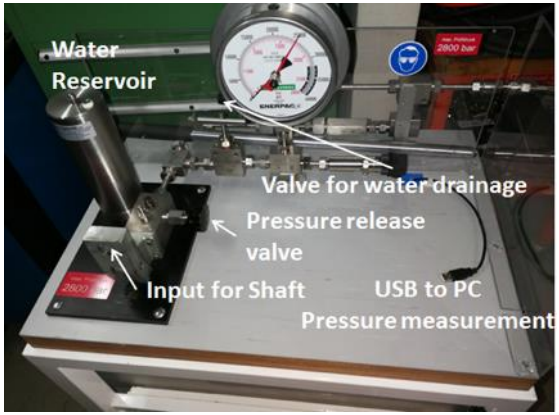


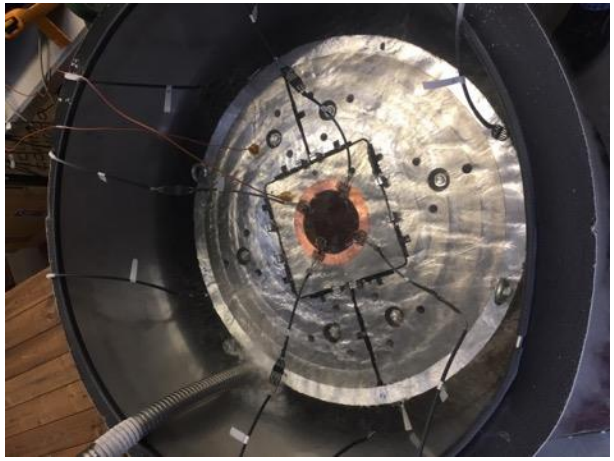
Mechanical Instrumentation and Assembly

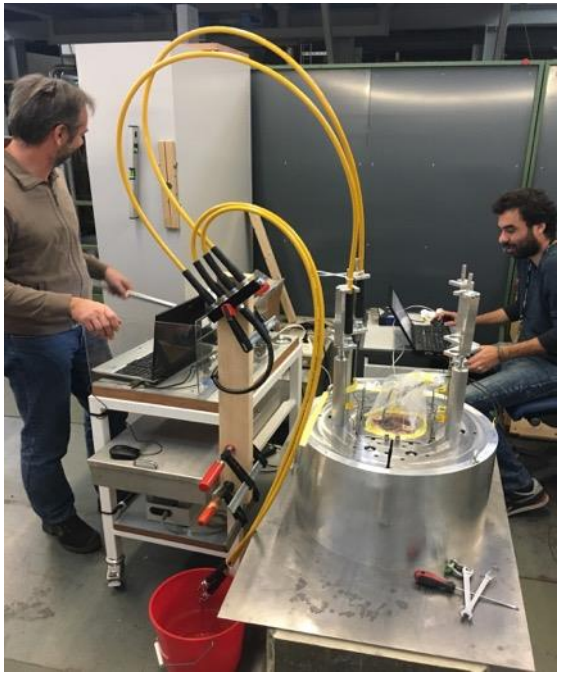
- Mechanical model test in Dec. 2017.





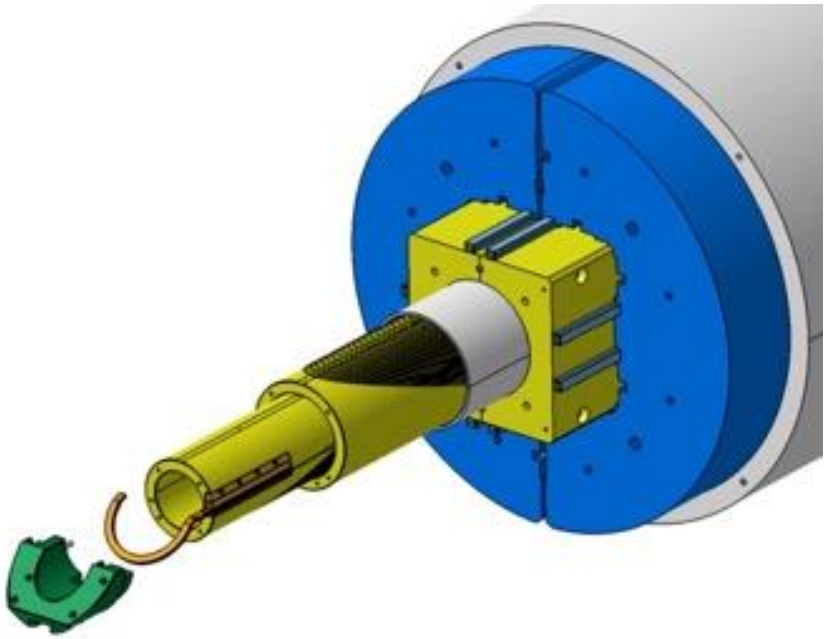






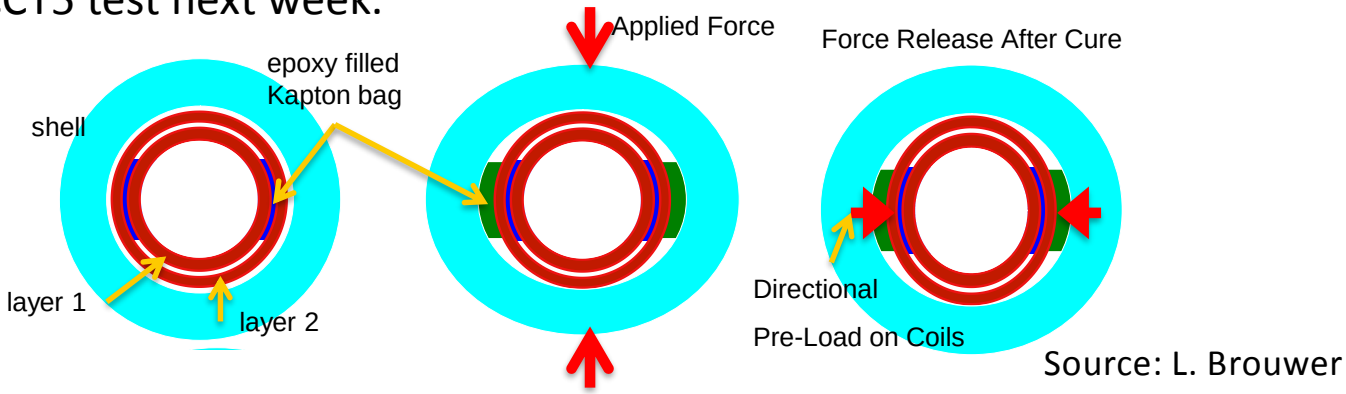
CD1 Status

- Coil winding to start Monday.
- Reaction cycle to launch Friday.
- Splice testing during reaction week.
- Coil manufacturing until end of 2018.
- Mechanical assembly and instrumentation early 2019.
- Magnet test in LBNL by April 2019.



Conclusion

- 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.
  - Coil manufacturing start imminent.
- LBNL's CCT5 test next week.



Source: L. Brouwer

- Hopefully important lessons from CCT5 and CD1 tests for FCC week 2019.