PAUL SCHERRER INSTITUT PSI

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S. Sanfilippo PSI, S. Sidorov PSI, L. Brouwer LBNL, S. Caspi LBNL

CCT Assembly and Impregnation at PSI

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

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Overview

- CCT @ PSI in collaboration with LBNL
- Goal: Address insights from LBNLs CCT3/4 diagnostics:
  - Cracking
  - Cable-to-channel interface
  - Layer-to-layer interface
- Impregnation infrastructure at PSI
- Impregnation process at PSI

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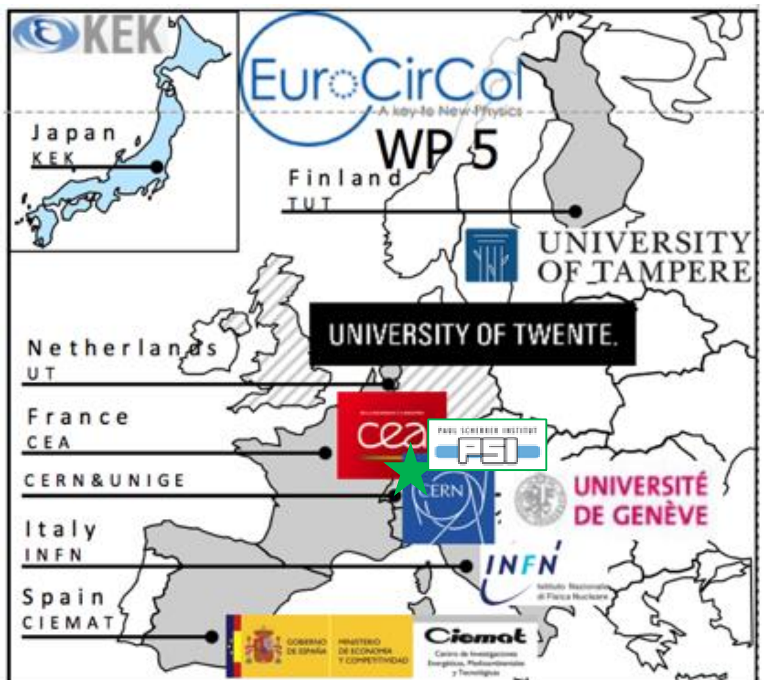
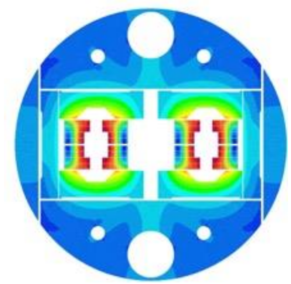
EuroCirCol WP5

- European Circular Energy-Frontier Collider Study started 2015
- PSI joined the effort in 2016 as an “associate member” of WP5
- Magnets fulfill specs for both, FCC-hh and HE-LHC.

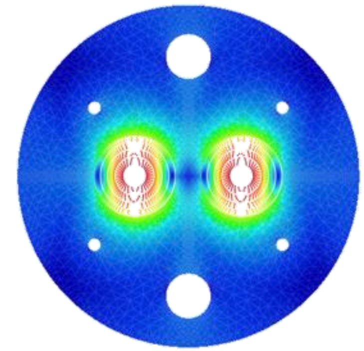


[D. Tommasini, http://cern.ch/fcc/eurocircol]

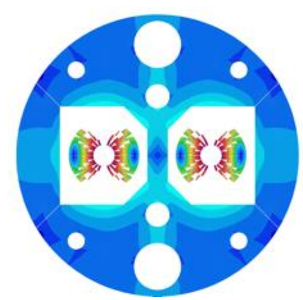
Block coil



Canted Cosine Theta



Cos-theta



Common coils

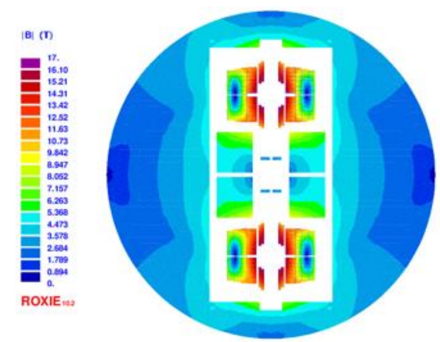


CHART (Swiss Accelerator Research and Technology Center) – Magnet Activities

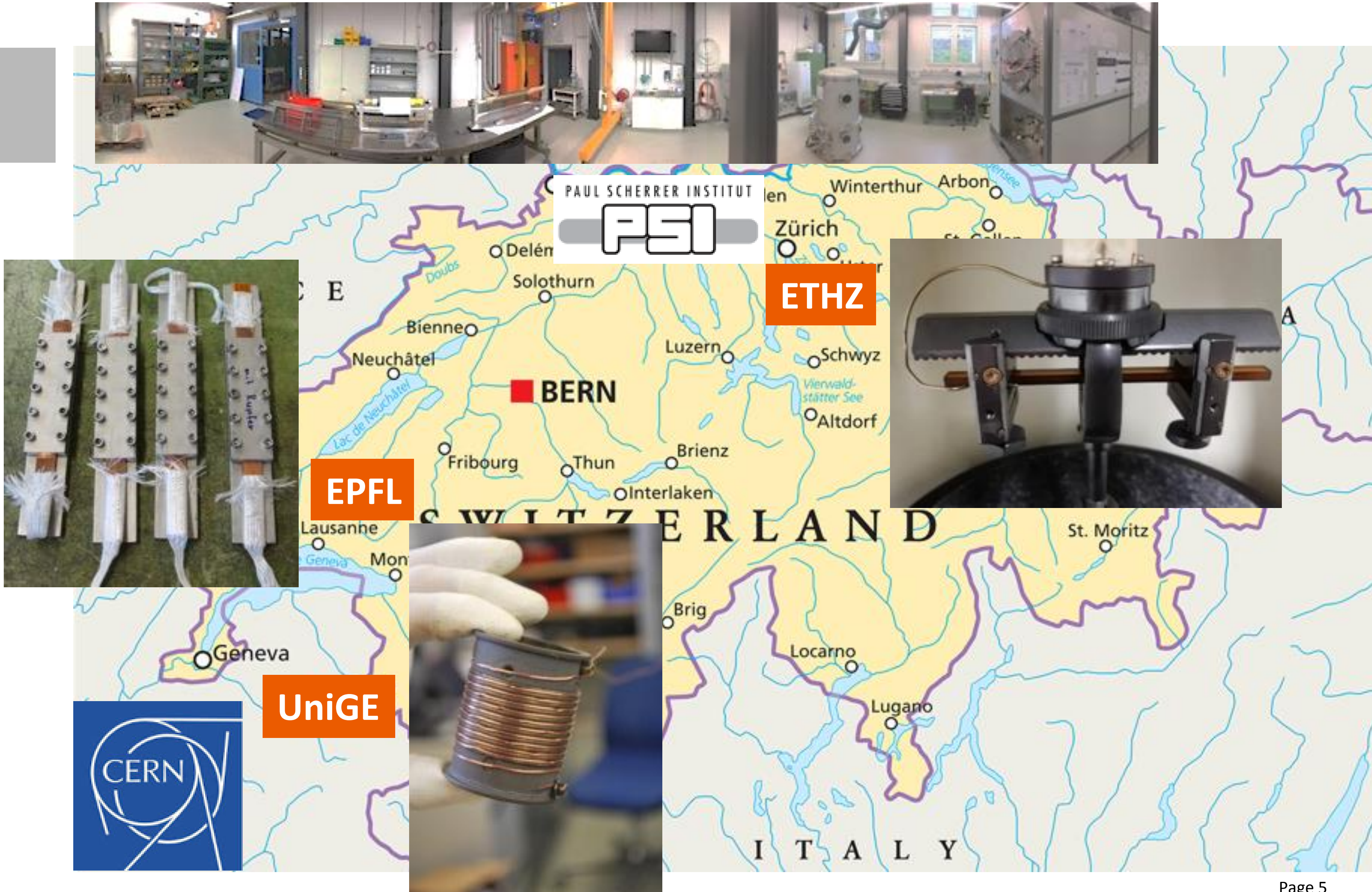
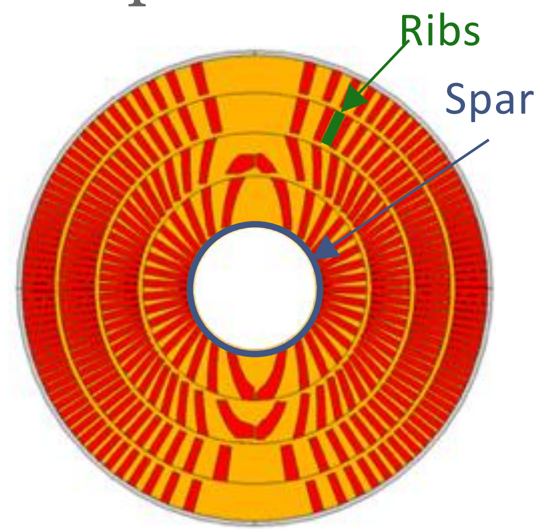


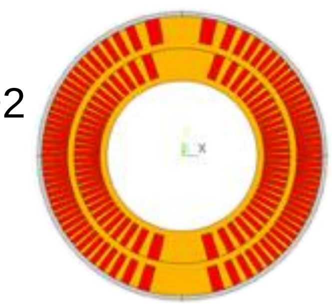
CHART-PSI Goals towards FCC Requirements



- 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.

(First three items: CD1; all six items: CD2)



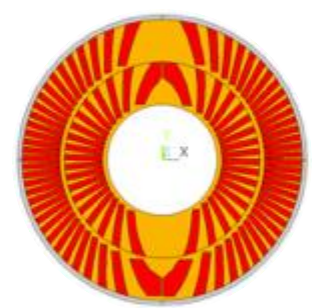
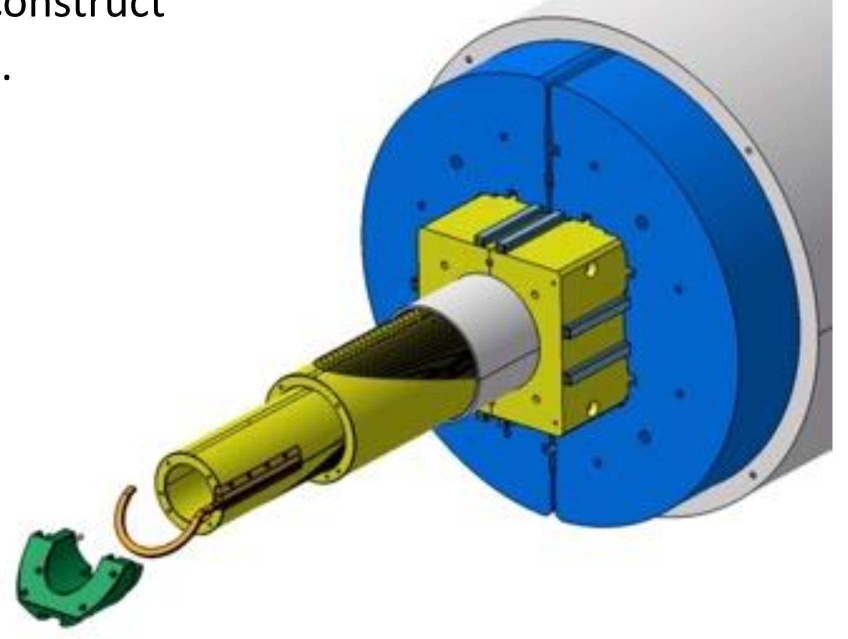


CHART-PSI Status Overview

- Status:
  - Reaction and impregnation infrastructure commissioned.
  - All magnet components and tooling designed and procured.
  - Epoxy-resin R&D with ETHZ started.
  - Production Readiness Review successfully passed on Aug. 28.
  - Coil winding to start next week.
- Next year we plan to finalize the construction of CD1, perform the test at LBNL, and construct a second set of coils called CD2.



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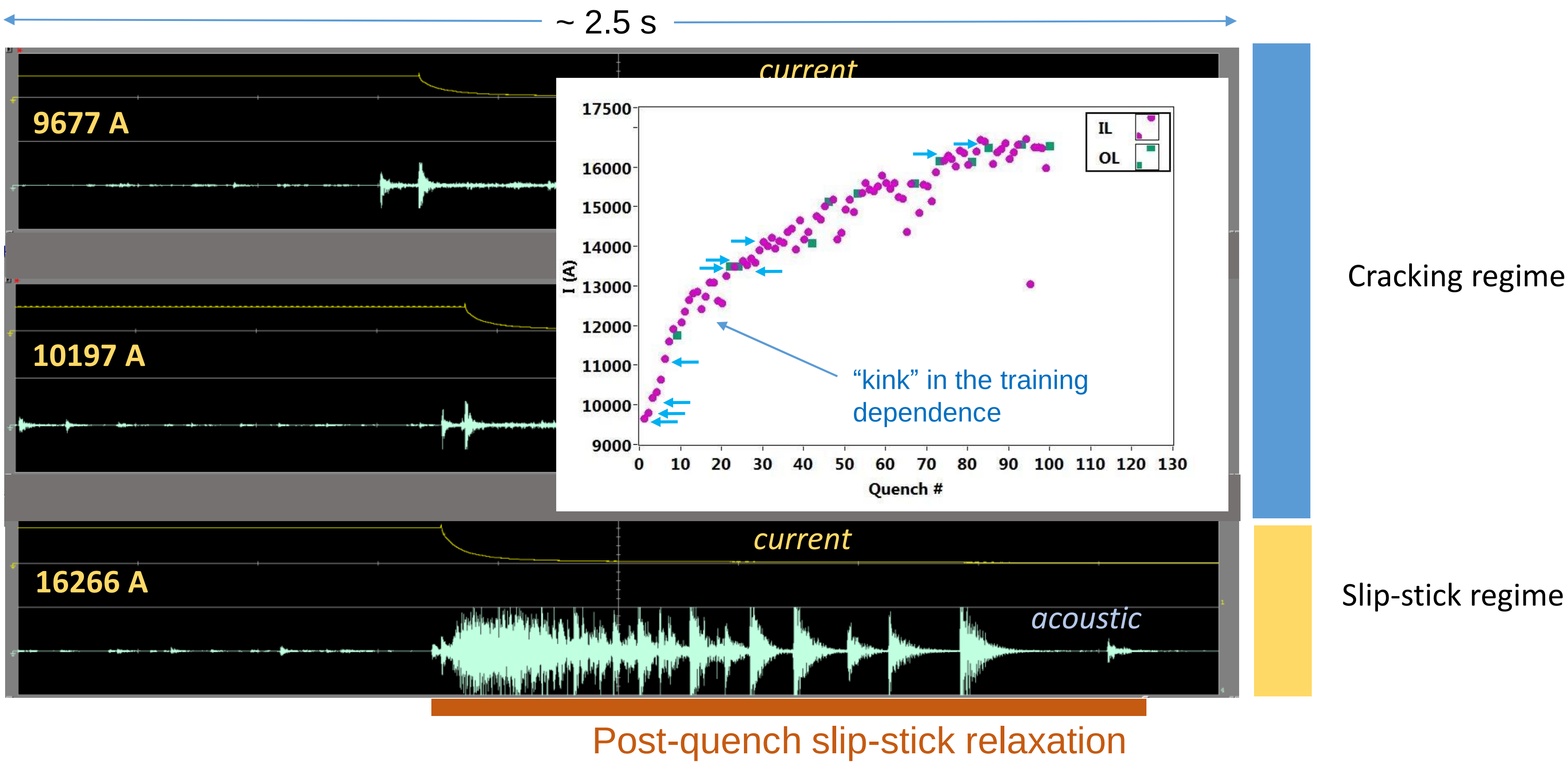
LBNL CCT4 Experience

U.S. MAGNET DEVELOPMENT PROGRAM

Mechanical relaxation after the quench

BERKELEY LAB

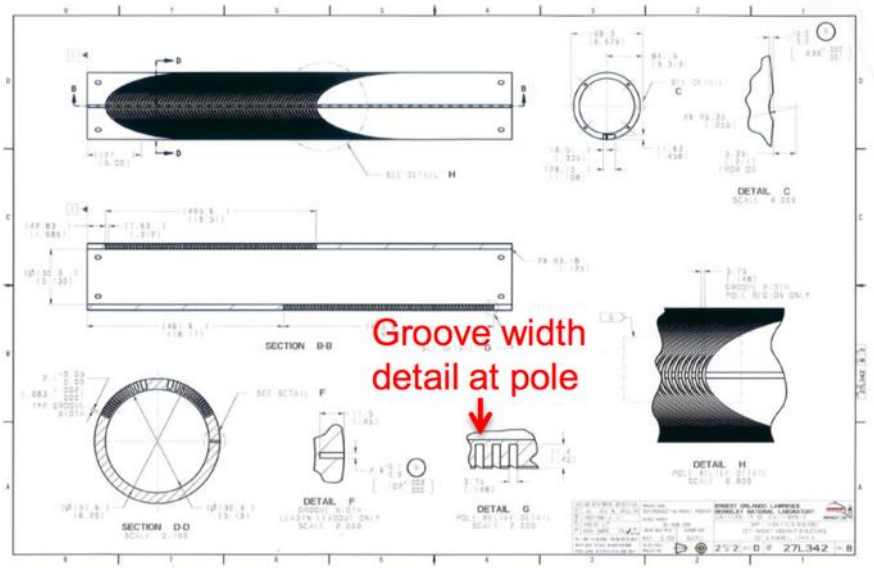


Courtesy M. Marchevsky (LBNL)

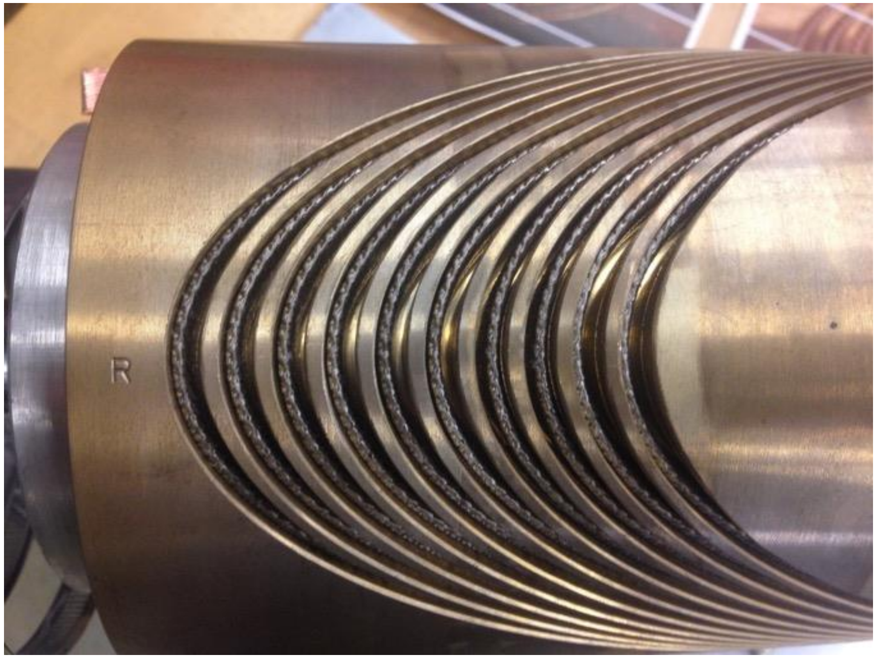
LBNL CCT4 Experience

Courtesy D. Arbelaez (LBNL)

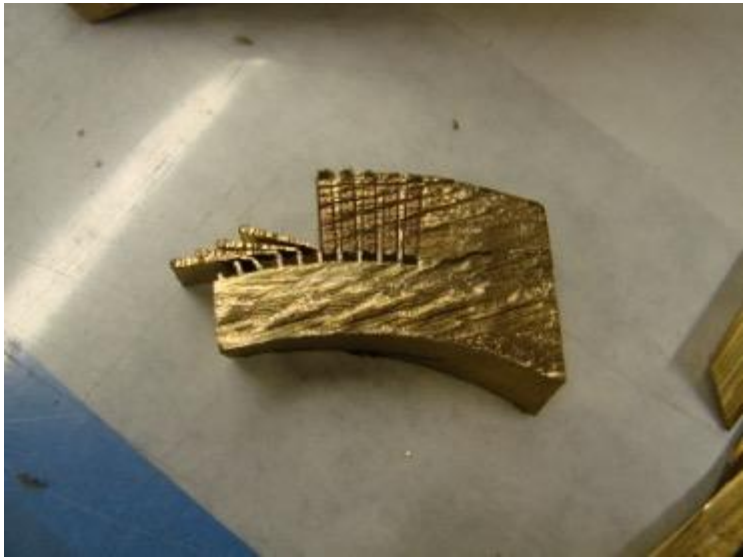
- Channel width must increase on the pole → extra 1.6 mm width.
- CCT3/4 gaps were filled as best they could with glass and impregnated with CTD 101-K.



Gap in photos is larger than in real magnets.



LBNL CCT4 Experience



Courtesy L. Brouwer.

- **CCT3 delamination between layers**
- Impregnated **cable delaminating** easily from channel walls.

Goals

- We need to:
  - ***Avoid cracking*.**
  - ***Improve cable/channel bonding.***
  - ***Improve the layer-to-layer contact*** (either fully glued or fully sliding).
- Fixing these problems one by one, performance issues should be solved.

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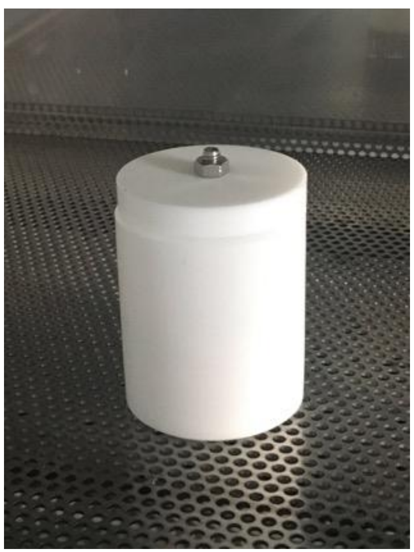
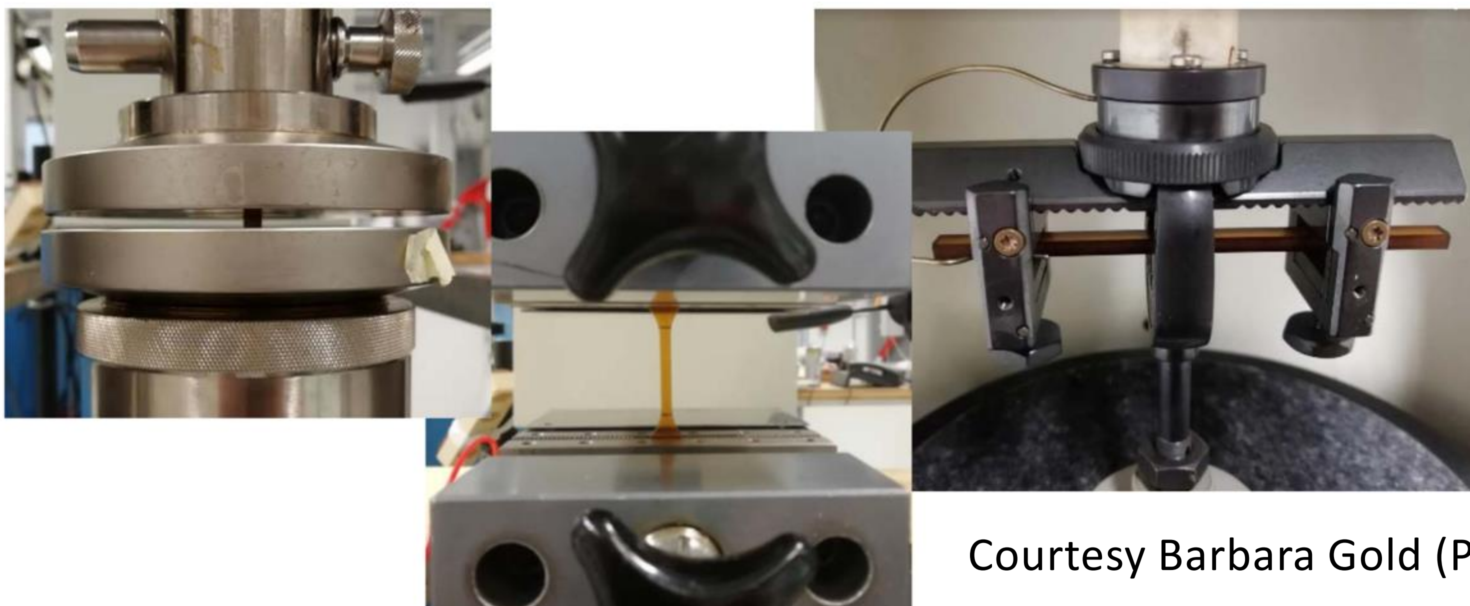
Cracking – The Bolt Tests

- Bolt suspended in epoxy-filled cup
  - CTD 101-K: loud banging noise during shock-freezing in LN2; large part expulsed by ~15 cm during warm-up at RT.
  - CTD 101-G: hair-like fissures, increasing in number and size with repeated thermal shocks.
  - Mix 61: no sign of cracking after three thermal shocks.
- We choose to impregnate with Mix 61, developed and recommended by FSU.



Cracking – R&D at ETHZ

- ETHZ, PSI, and CERN have started a thorough characterization of four epoxies for SC accelerator magnets:
  - CTD 101-K (complete at RT)
  - Mix 61 (FSU) (sample plates produced)
  - Huntsman Araldite MY740 and 750 systems
- Characterization at RT, LN and LHe temperatures in terms of compressive modulus, tensile modulus, fracture toughness, viscosity and pot life.
- Future work: re-test after irradiation; improve on existing systems.



Courtesy Barbara Gold (PSI/ETHZ)

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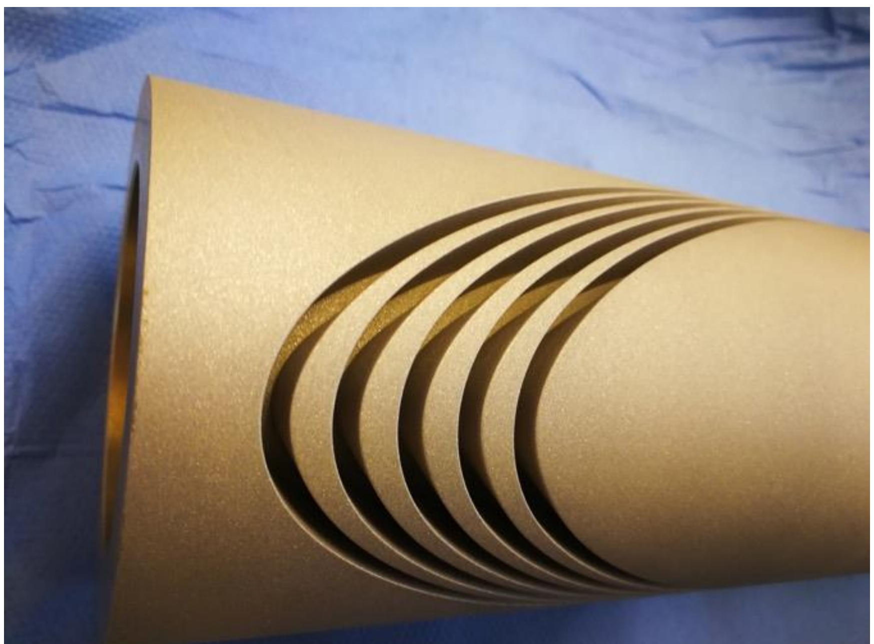
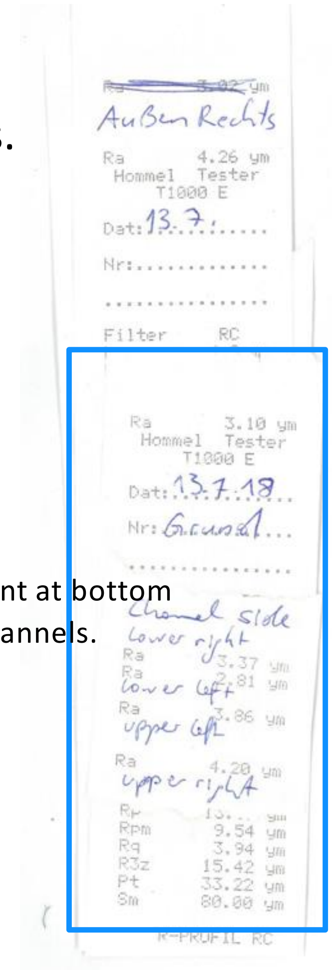
Cable/Channel Interface

- Sandblasted winding former to Ra 3 µm.
- Ultrasound cleaned winding former after sandblasting.
- Stored formers in vacuum up until winding starts to minimize oxidation.
- Ideas beyond:
  - Insulated-cable ultrasound cleaning prior to winding.
    Has been practiced at FSU in the past to reduce reaction residues.



Ra measurement at bottom and sides of channels.



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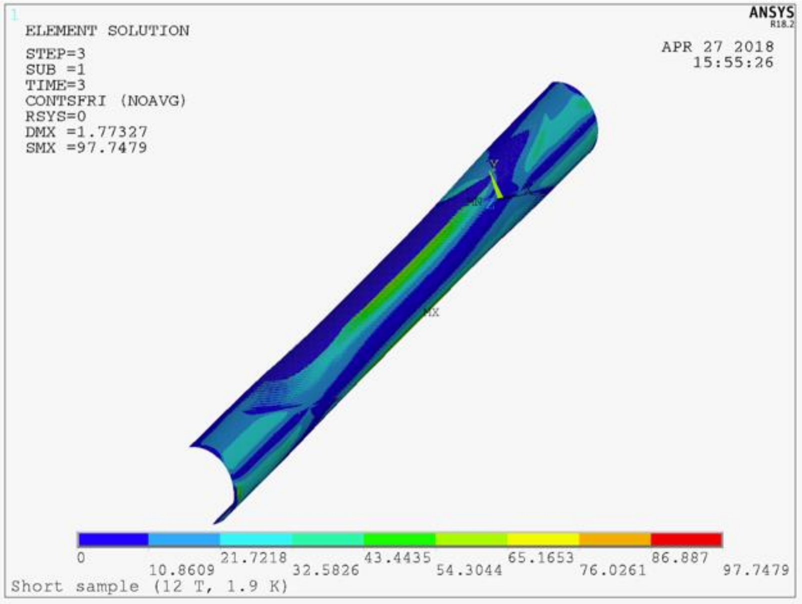
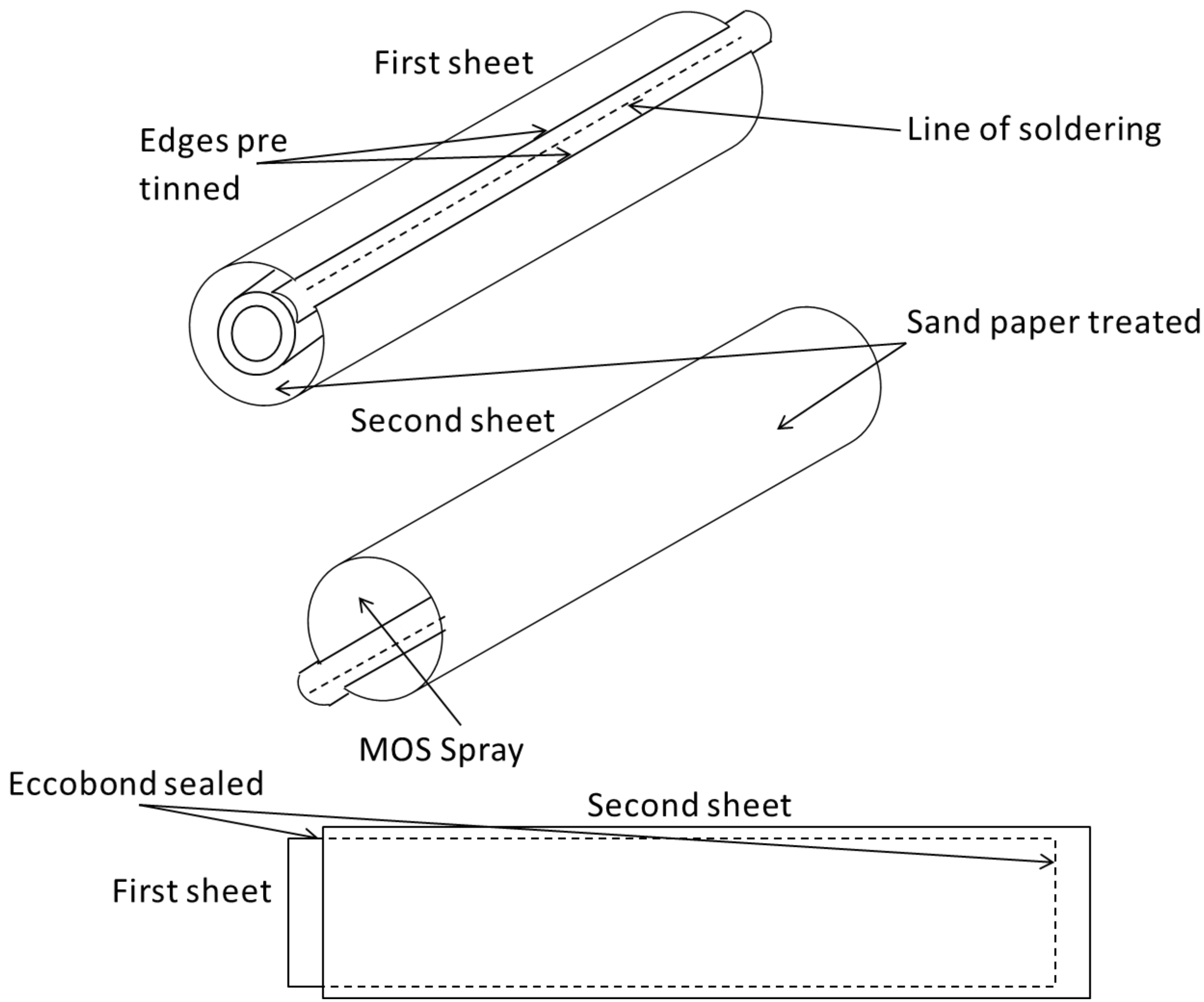
Layer/Layer Interface

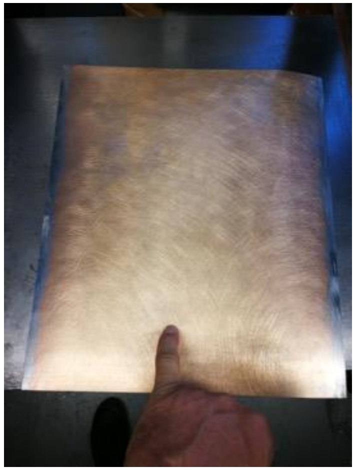
- ANSYS simulation of the full magnet model suggest shear stresses on a bonded layer/layer interface are too high to confidently glue.
- PSI solution: implement a dedicated sliding plane, inspired by MSUT (H. ten Kate et al.).

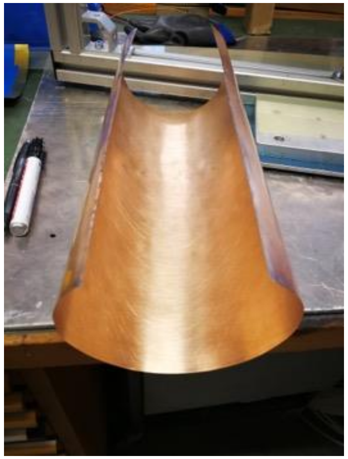


Sliding-Plane Assembly Schematic



Tests





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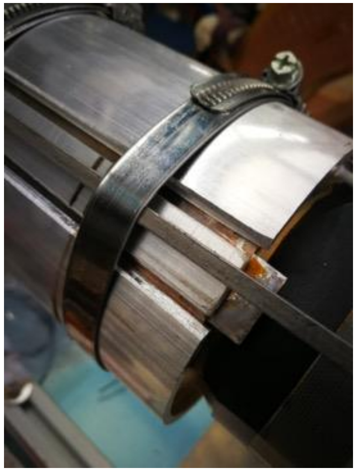



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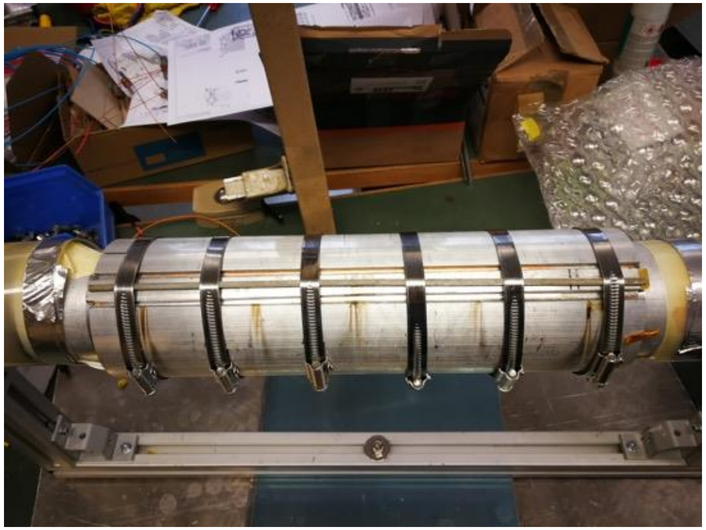
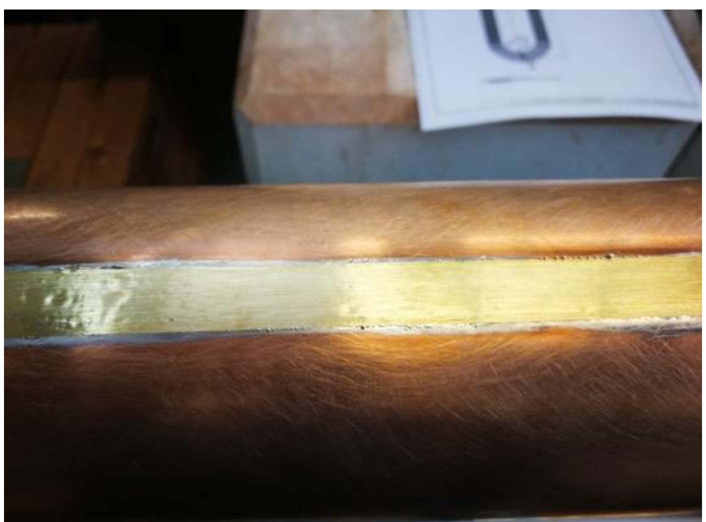
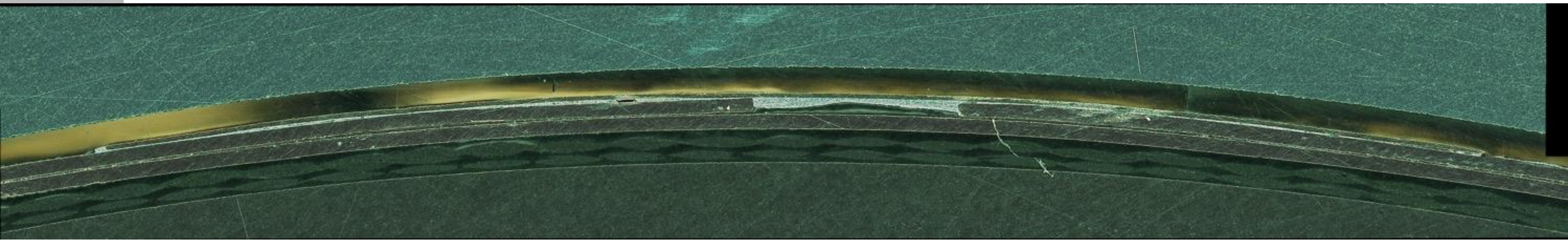


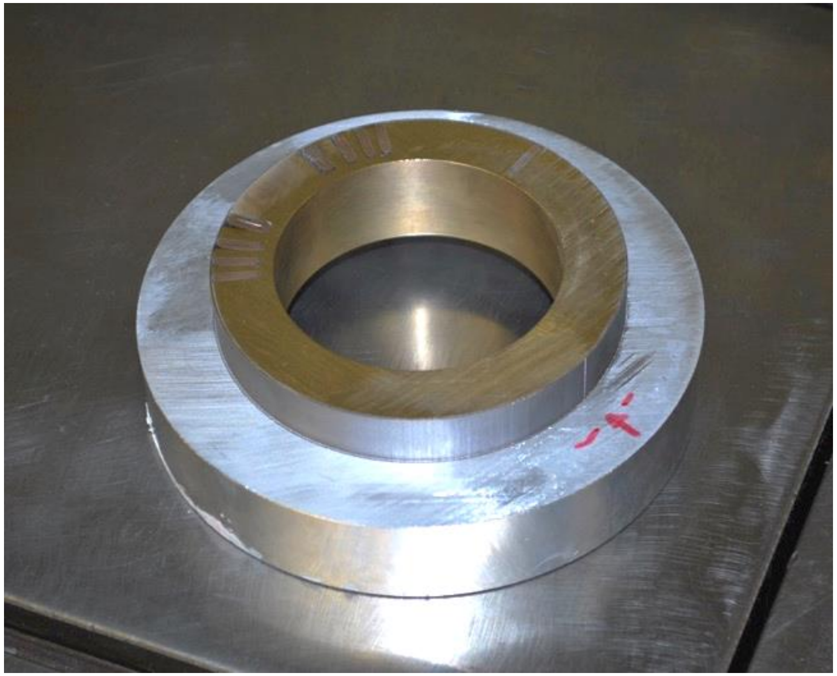


Sliding Plane Tests

- 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:



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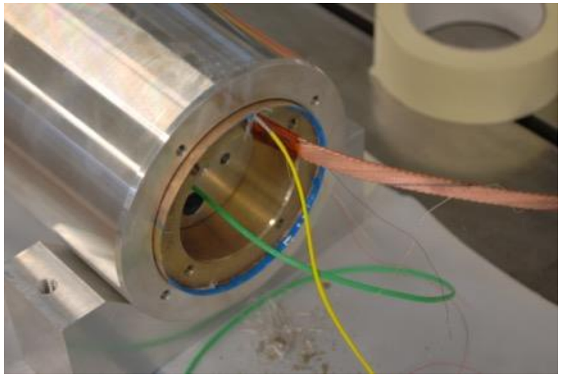
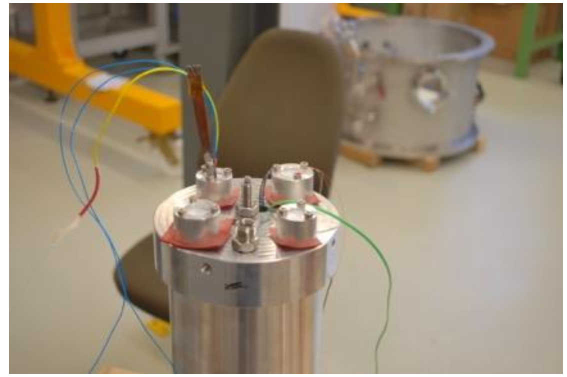
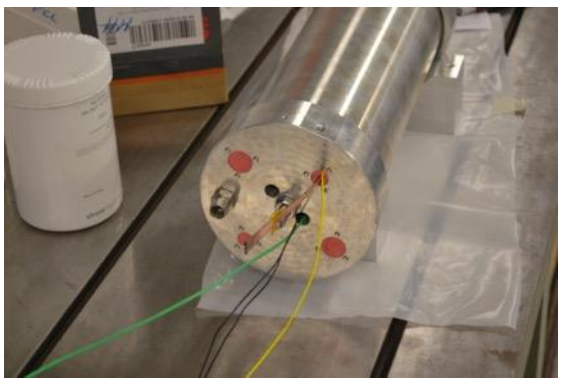
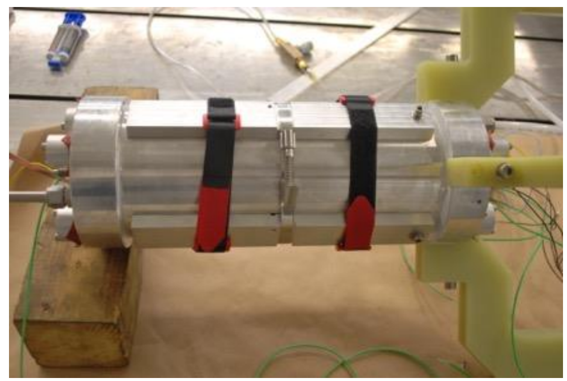
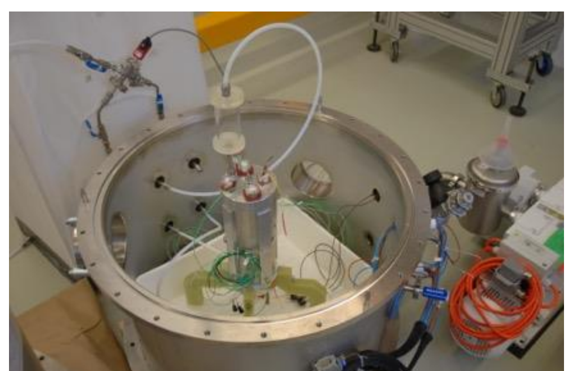
5-Turn Sample Preparation, CD1 Mold

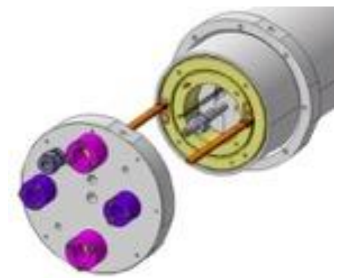












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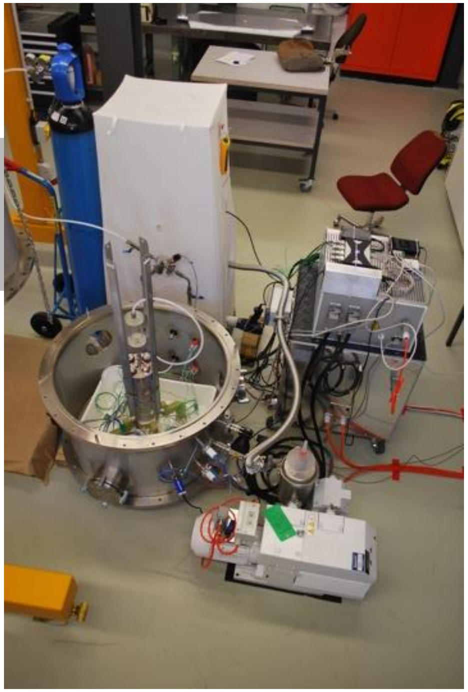
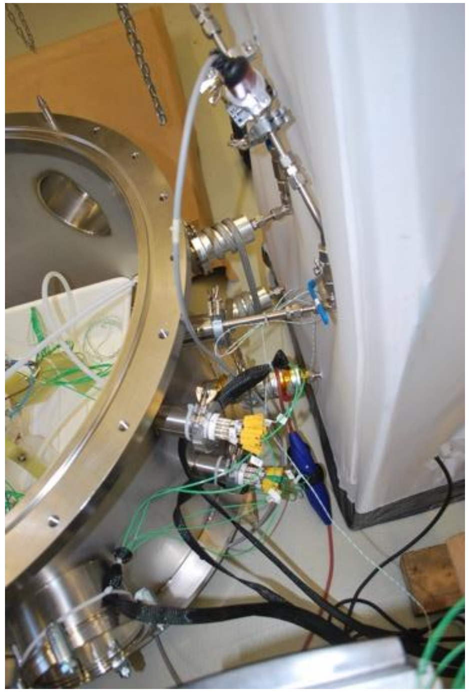
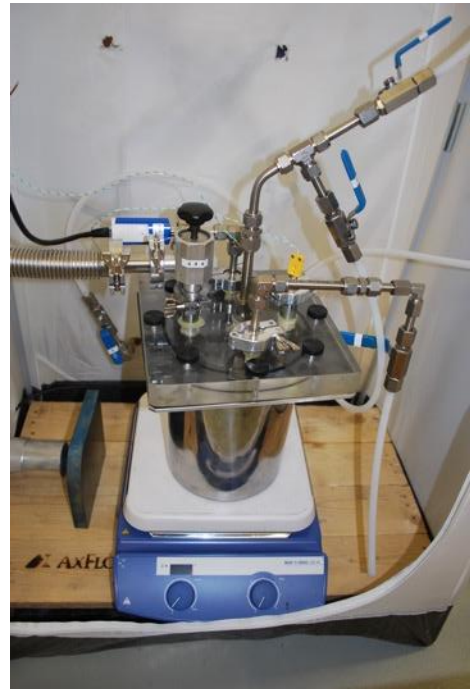
Impregnation Infrastructure







- 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

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Impregnation Procedure

- **Coil drying**
  - Heating coil to 100ºC (full voltage in air, then reduced voltage when pumping) and mixing pot to 60ºC.
  - Repeated purging and pumping with N_2 until vac. pressure rise is close to that of the empty vessel.
  - De-gassing of all valves.
  - Continued pumping (~two days) while cooling to injection temperature 50ºC.
- **Mixing, de-gassing**
  - Pre-heat components.
  - Suck mix into mixing pot at moderate under-pressure, then start mixing.
  - Carefully lower pressure.
  - Stop degassing if pressure rise by 1 mbar takes longer than 3 min (while mixing).

Impregnation Procedure

- **Injection**
  - Observe temperature (hotter to cooler) and pressure gradients (coil pressure higher than lowest pressure during de-gassing) to avoid bubble formation.
  - First resin into bypass, set flow velocity (system not yet mature).
  - Filling observing capacity variation (needs LabView read-out and filtering).
  - Break vessel vacuum, fill more if reservoir level falls.
  - Apply 1 bar over-pressure (N_2 bottle) until reservoir level is stable. (Tightness confirmed up to >1.6 bar. Mild leakage at prolonged 2 bar. Reservoir level change towards 1 bar.)
  - Relax over-pressure and start curing cycle.
- **Curing**
  - Launch curing cycle in ambient pressure with temperature alarms (sending SMS to on-call list).

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Conclusion

- High-field CCTs may well work if the key issues are resolved: cracking, cable/channel interface, and layer/layer interface.
- PSI and LBNL select similar approaches for the cracking (Mix 61) and cable/channel interfaces (sandblasting, cleaning), while exploring different solutions for the layer/layer interface (see next talk).
- LBNL CCT5 test is imminent. CD1 test is planned for April '19 at LBNL. We hope for more insight to realize the promise of CCT mechanics advantages.

- ***Thanks*** to all our partners for trying to get us on the right track with regard to impregnation:
  - LBNL Diego Arbelaez, Lucas Brouwer, Shlomo Caspi, Ray Hafalia, Jim Swanson, Soren Prestemon
  - FSU Ian Dixon, Denis Markiewicz
  - CERN Paolo Ferracin, Herman ten Kate, Glyn Kirby, Jacky Mazet, Juan Carlos Perez, David Smekens, Davide Tommasini
  - ETHZ Theo Tervoort