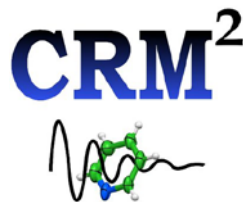




New Experimental Test Rig for Pulsed Field Magnetization of Bulk HTS with Small Coils

Kévin Berger,
Sébastien Leclerc, Pierre-Louis Marande, Bruno Douine,
Jacques Noudem, Michael Rudolf Koblischka, and Jean Lévêque



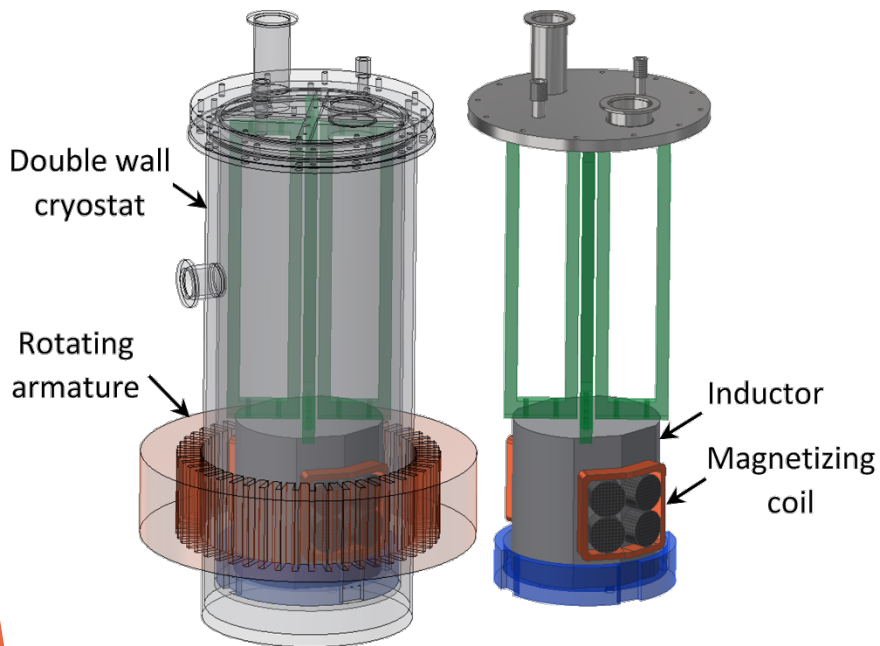
Bulk HTS rotating machines

- ▶ Rotating machines with HTS are attracting considerable interest
- ▶ Higher magnetic flux supplied by HTS / conventional
 - ▶ increased power/torque density
 - ▶ resulting in a smaller size and a lighter weight

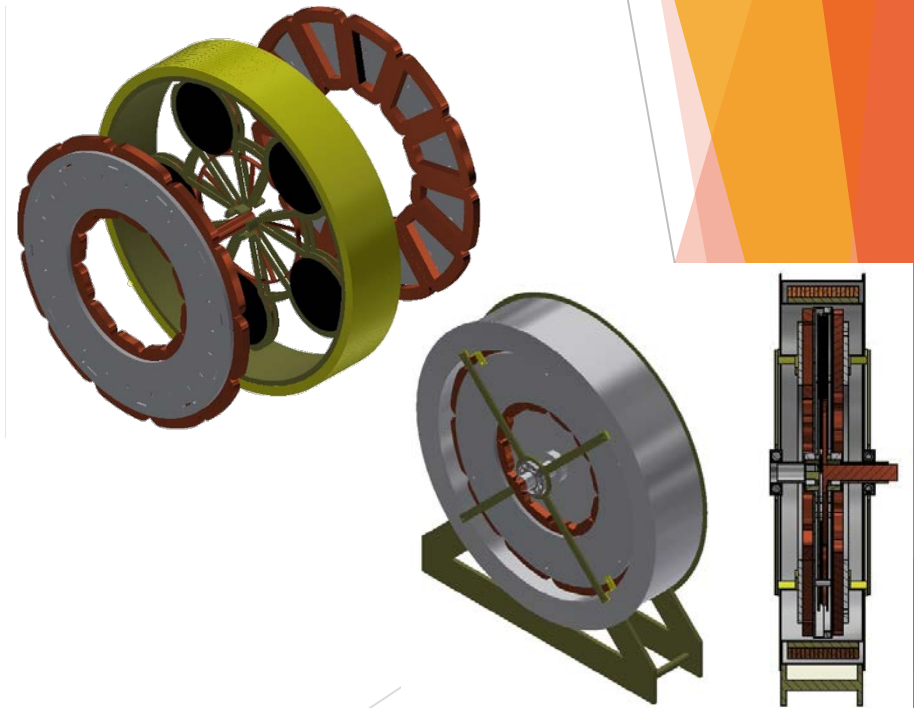
} airborne applications
- ▶ Compared with HTS windings, bulk HTS can trap an even higher magnetic flux, leading to higher power densities
- ▶ Record trapped field by FC: 17.6 T @ 26 K
 - ▶ Centre of 2 x 25 mm diameter Gd-Ba-Cu-O
J. Durrell *et al.*, *Supercond. Sci. Technol.* 2014

Bulk HTS rotating machines @ GREEN

- ▶ One-pole pair radial flux machine with magnetized bulks (poster THU-B44)



- ▶ Axial flux machine with bulks used as magnetic screens



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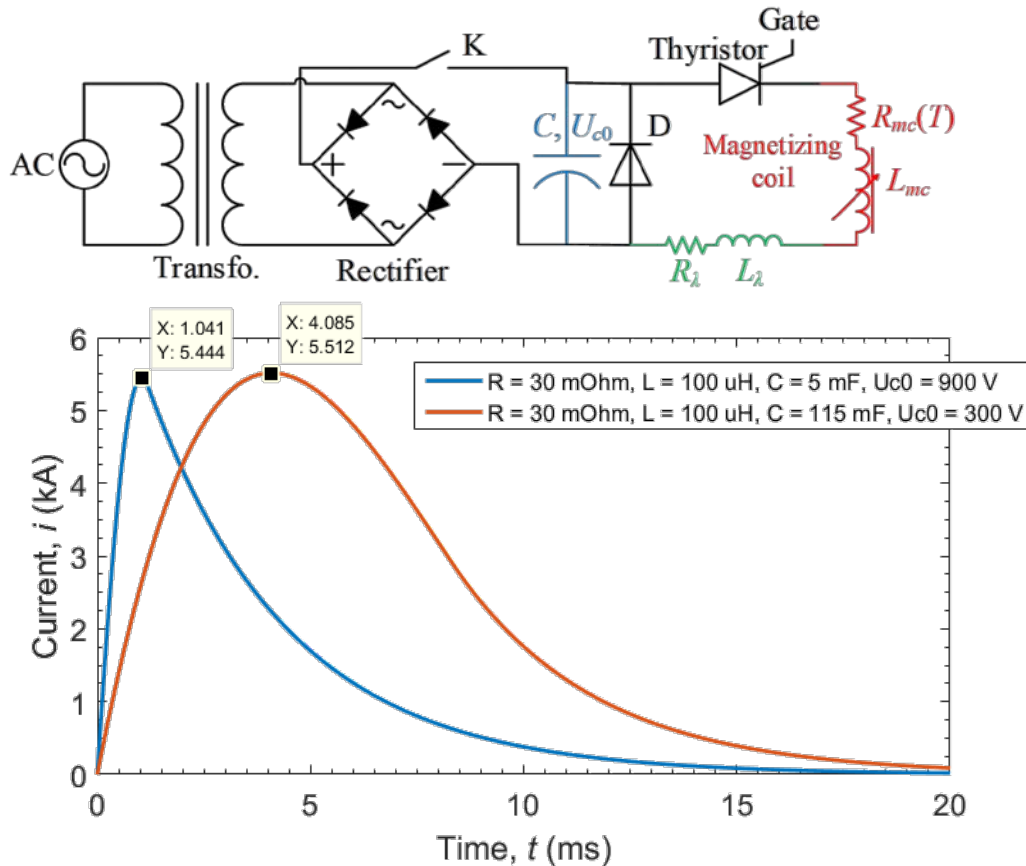
Presentation outline

- ▶ Pulsed field magnetization (PFM) of bulk HTS
 - ▶ Description
 - ▶ Electrical diagram
 - ▶ Examples of setups (Japan, U.K.)
- ▶ Operational test rig @ GREEN - University of Lorraine
 - ▶ Description and samples
 - ▶ Magnetizing coils
 - ▶ Thermal design
 - ▶ Learning from its failures
 - ▶ Trapped field results

Pulsed field magnetization of bulk HTS

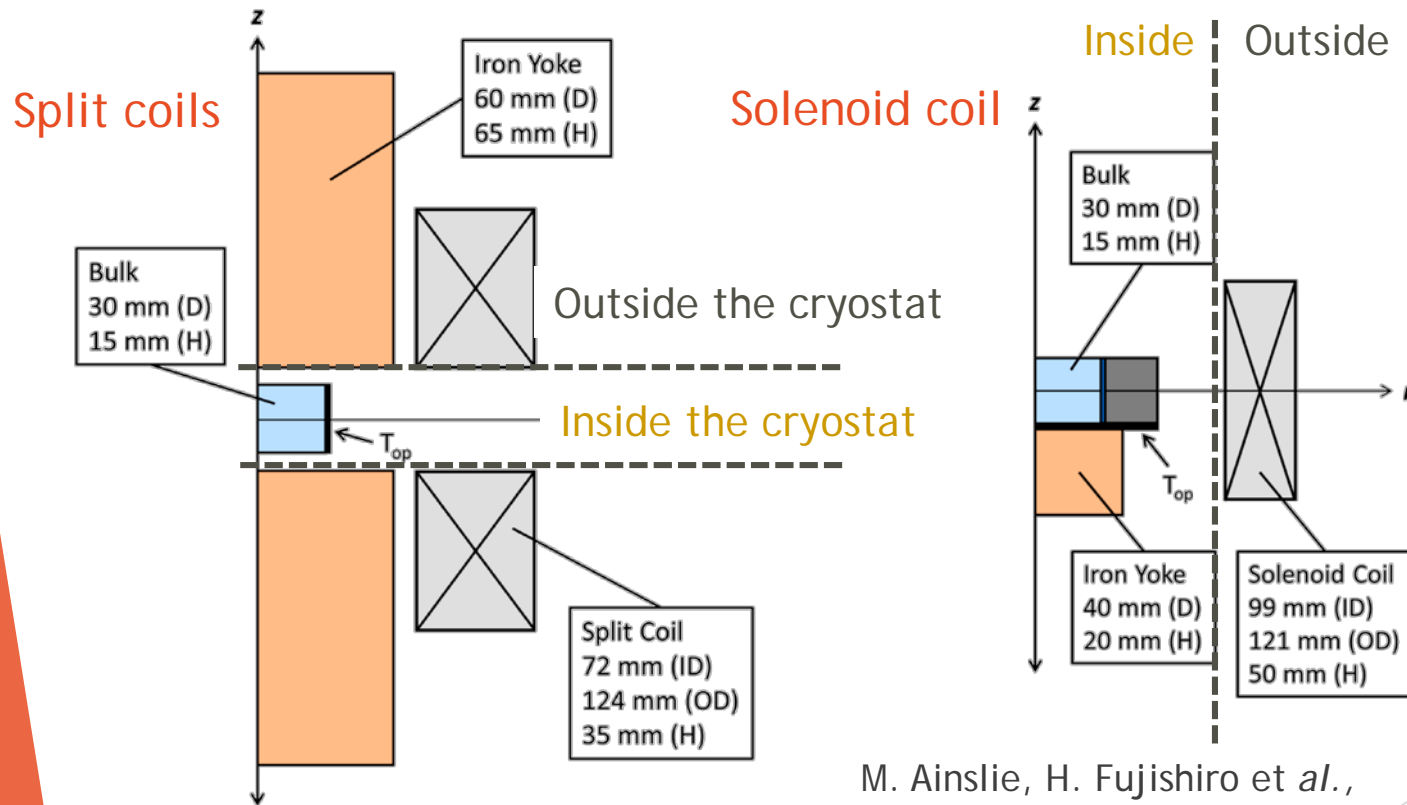
- ▶ PFM allows *in situ* magnetization
 - ▶ No need of large and/or superconducting coils
 - ▶ Compact and mobile system
- ▶ PFM process strongly depends on
 - ▶ The primary source of energy (usually a capacitor bank)
 - ▶ The inductance value of the magnetizing coil (w or w/o iron)
- ▶ Many considerations to take into account
 - ▶ Pulse magnitude, pulse duration, temperature, etc.
- ▶ Record PFM trapped field: 5.2 T @ 29 K
 - ▶ Top surface of 45 mm diameter Gd-Ba-Cu-O
H. Fujishiro et al., *Physica C* 2006

PFM source and electrical diagram



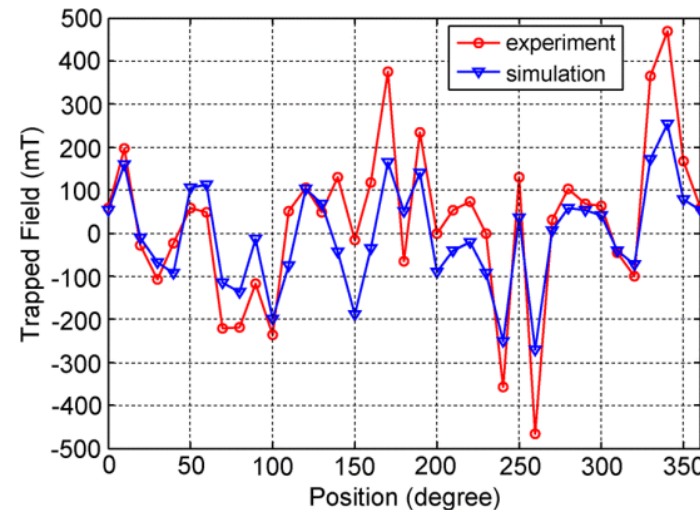
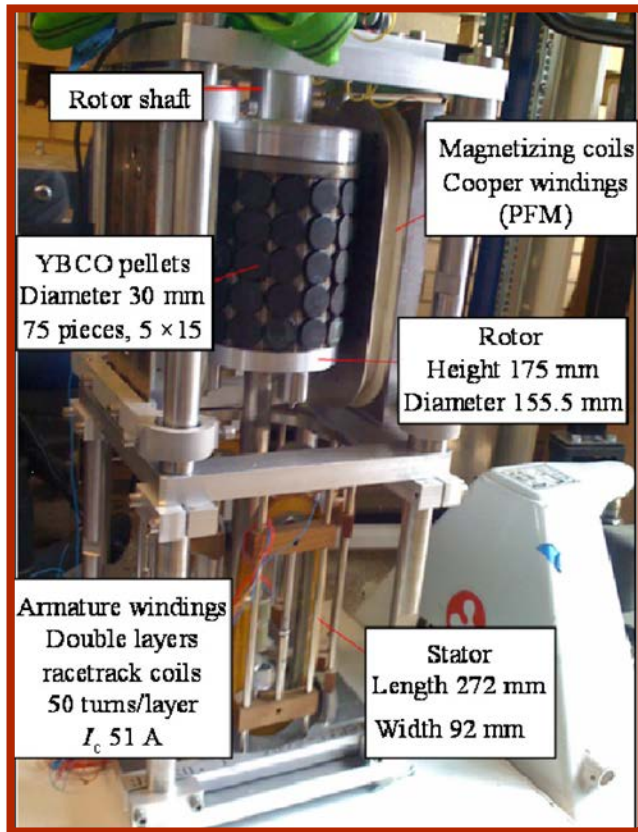
10 kJ - 2 kV - 25 kA

Examples of operational setups for PFM



M. Ainslie, H. Fujishiro et al.,
Supercond. Sci. Technol. 29 (2016) 074003

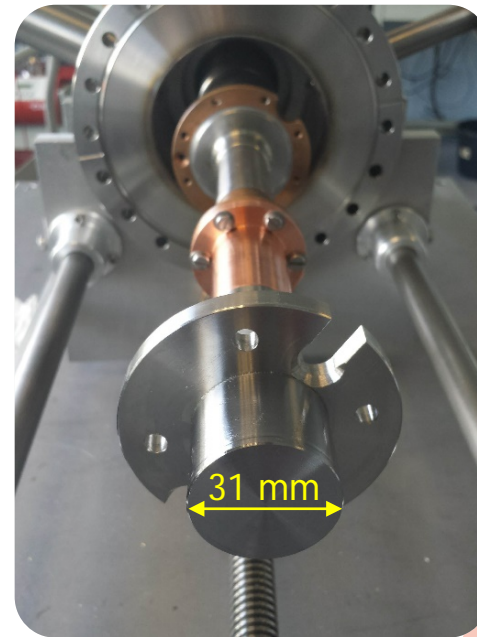
Magnetization by stator windings or equivalent



W. Xian, Y. Yan, W. Yuan, R. Pei, T. A. Coombs
IEEE TASC, Vol. 21 (3), June 2011, pp. 1171-1174.

Operational test rig @ GREEN *in situ* magnetization

VACODUR® 50
49% Co, 1.9% V, rest Fe
from VACUUMSCHMELZE GmbH



$B_{sat} > 2.3 \text{ T}$
 $H_c < 200 \text{ A/m}$
 $\rho = 4 \cdot 10^{-7} \Omega \cdot \text{m}$
density 8120 kg/m^3
 $\alpha = 10 \cdot 10^{-6} \text{ K}^{-1}$

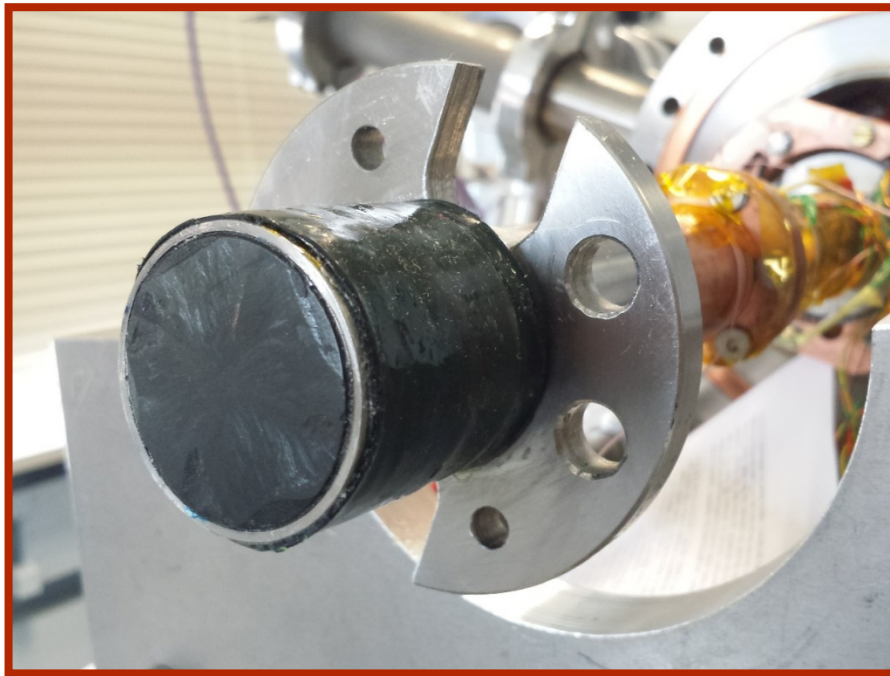
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YBaCuO samples with SUS Ring

- ▶ Sample and SUS ring are glued together with Stycast 2850 FT

35 mm diameter - 12 mm high
from CAN SUPERCONDUCTORS s.r.o.



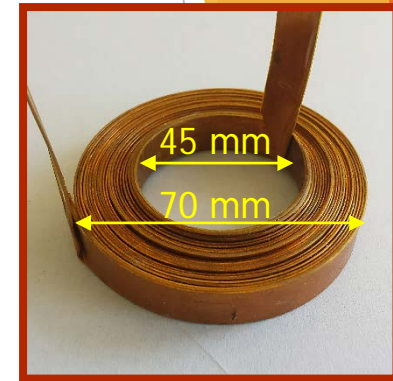
31 mm diam. - 17 mm high
from ATZ GmbH



Coil design and realization

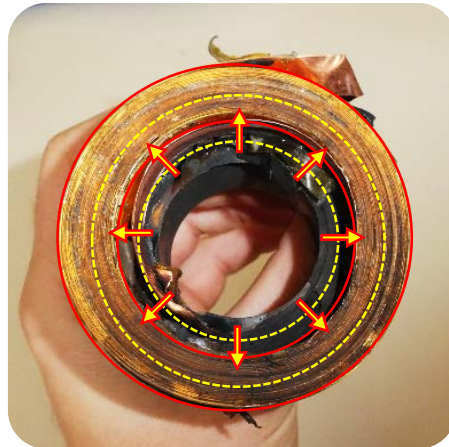
- ▶ Coil should be as close as possible to the sample
 - ▶ Better magnetic coupling and optimized size
 - ▶ Copper foils of 0.2 mm thick
 - ▶ Kapton tape for turn-to-turn insulation

- ▶ Our first aim was to thermalize the coil with the 2nd stage of the crycooler using Stycast molding
 - ▶ Easy to manufacture and mount

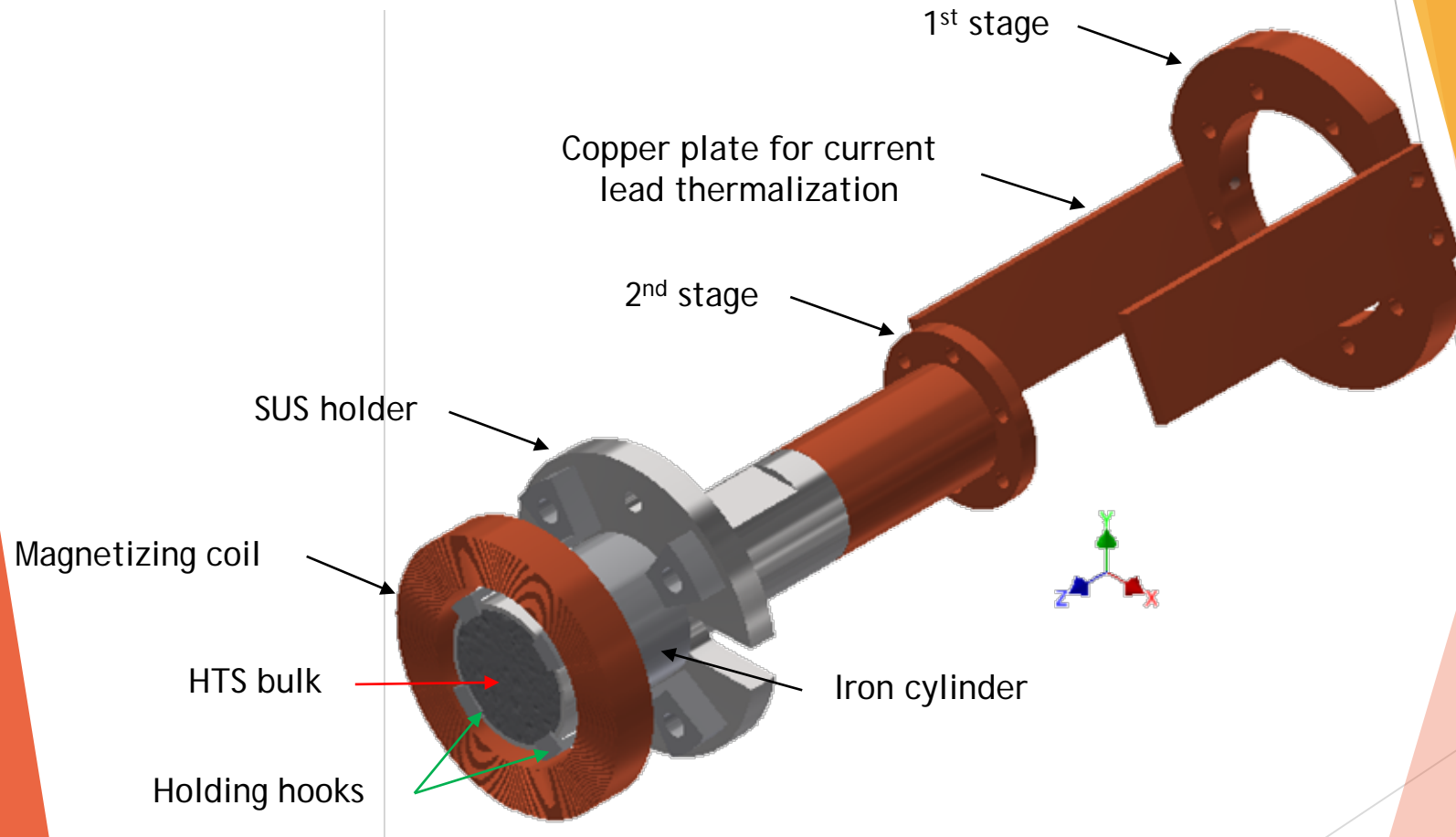


Coil design and realization

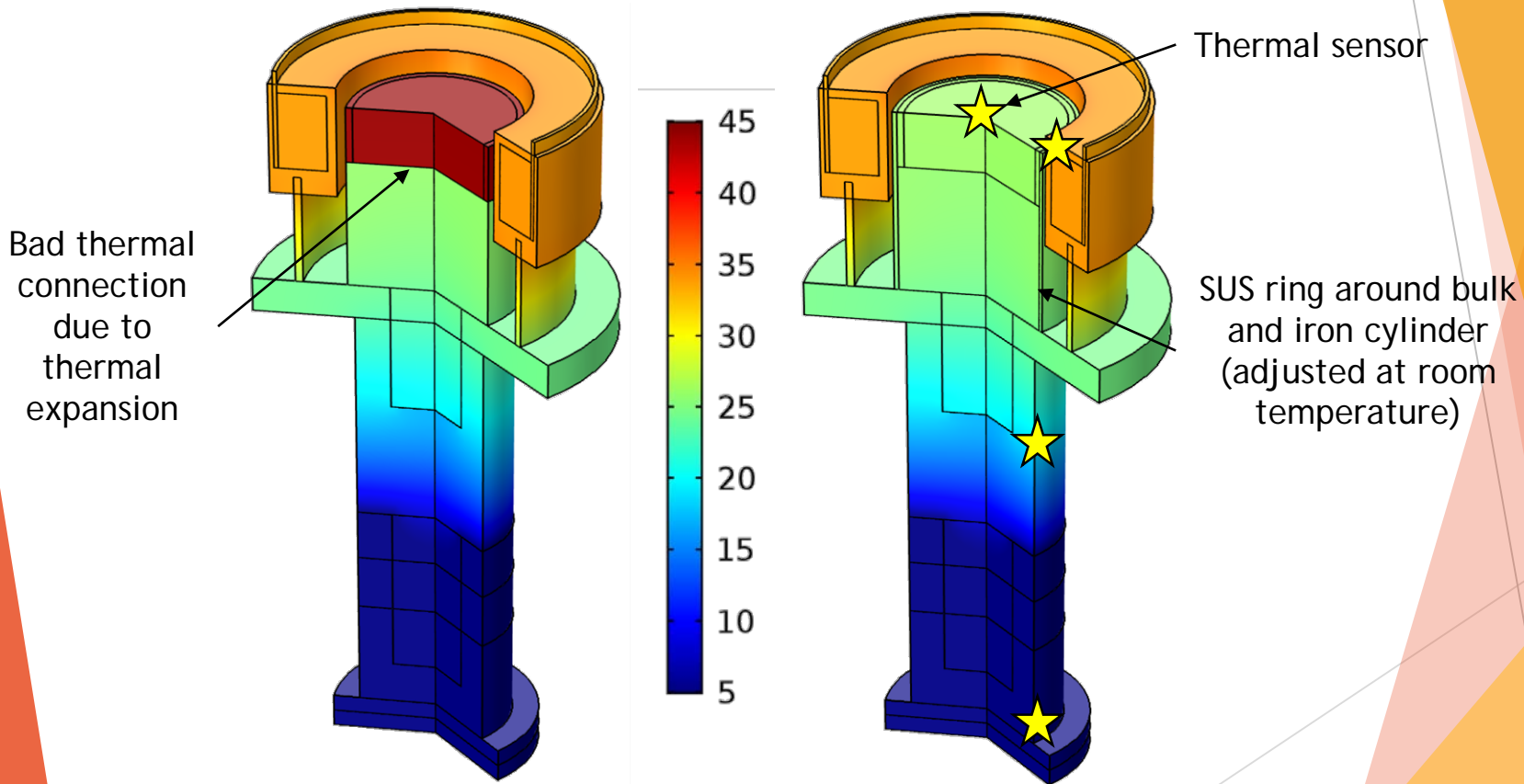
- ▶ Some problems occurred during the experiences
 - ▶ Stycast can not handle the Lorentz force during the pulse magnetization (~ 2.5 GPa @ 10 kA)
 - ▶ Heat is not well extracted (it's still epoxy resin...)
- ▶ Fiber glass + Araldite impregnation
- ▶ Cooling using the 1st stage of the cryocooler



Thermal design



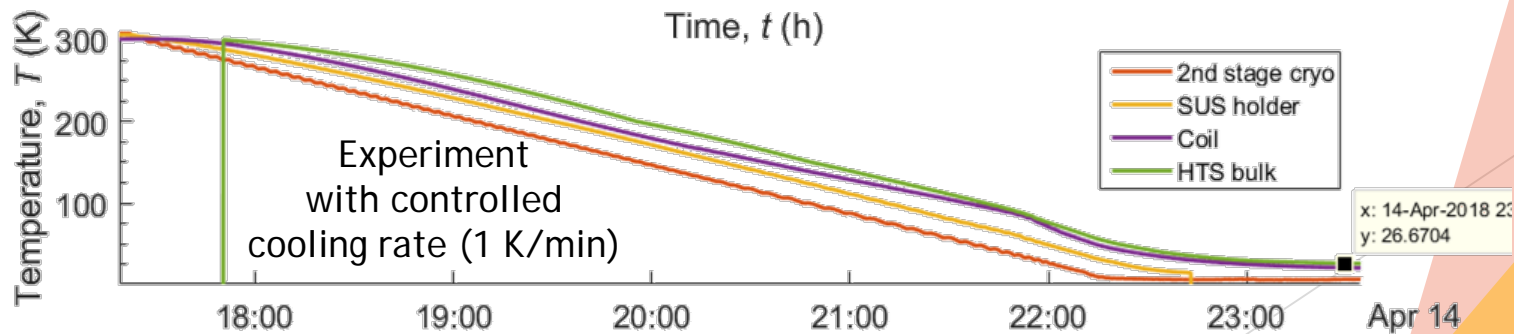
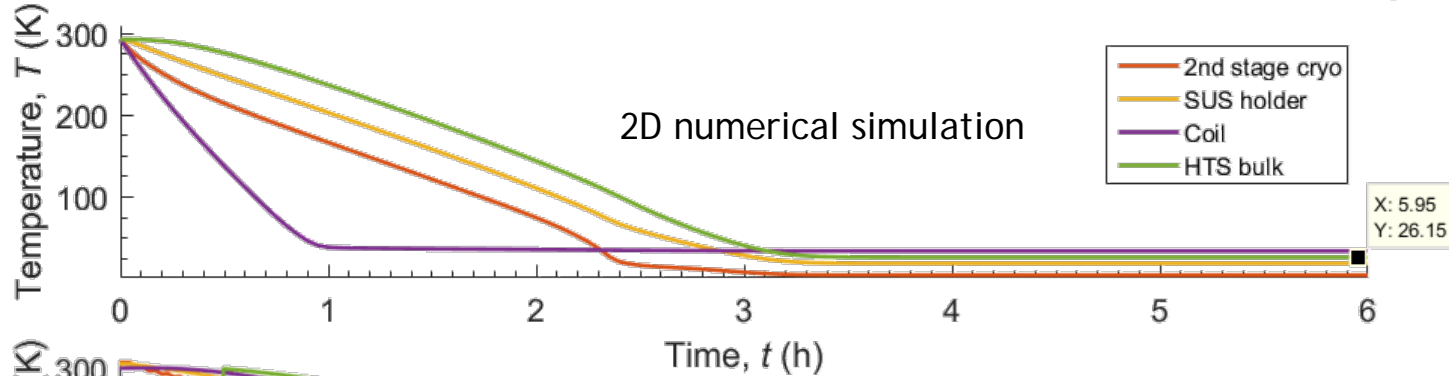
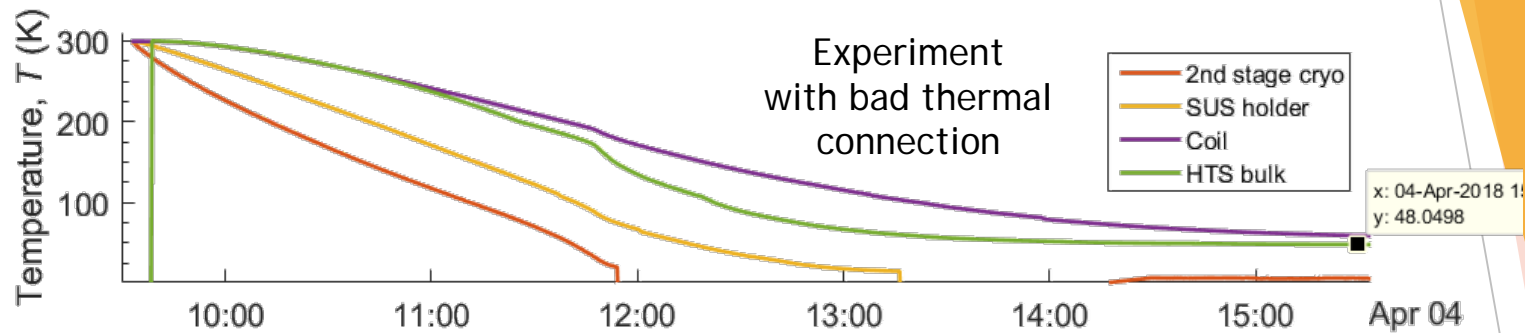
2D thermal simulation after experiment feedback



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Cool-down



Other issues

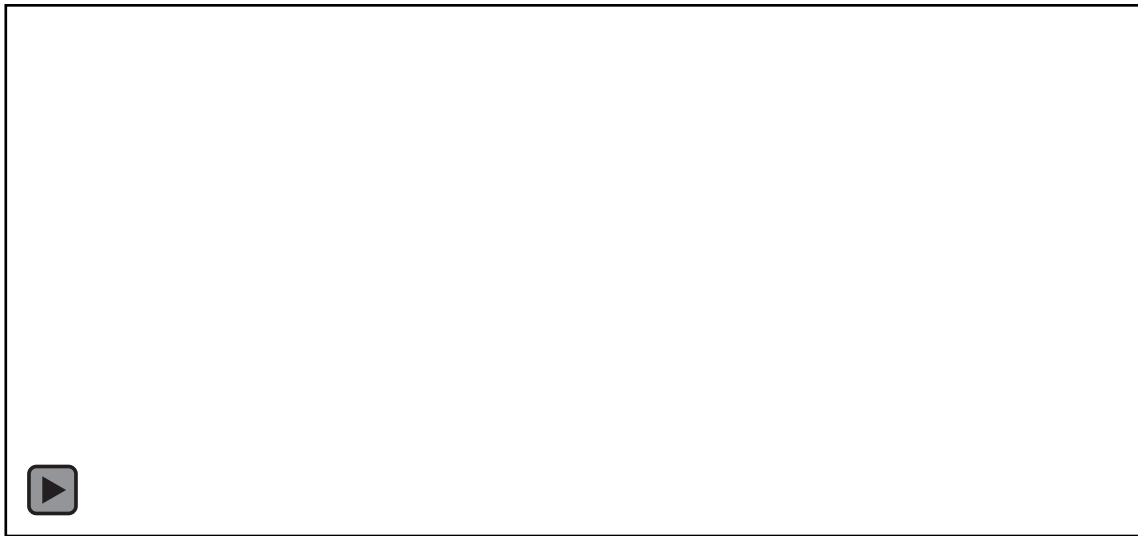
- ▶ High voltage up to 2 kV and high current densities $> 1 \text{ kA/mm}^2$
 - ▶ Working with HV in small environment that requires good thermal connections and compactness is not easy...



- ▶ Thermalization of the coil leads through the 1st stage of the cryocooler was made with Aluminium Nitride
 - ▶ (Cu / AlN / Cu) sandwich with copper plates of 20 mm x 80 mm
 - ▶ AlN properties: $k > 150 \text{ W/(m.K)}$, $\rho > 10^{10} \Omega.m$, $E_d = 15 \text{ kV/mm}$
density of 3300 kg/m^3 , $\alpha = 4.6 \cdot 10^{-6} \text{ K}^{-1}$

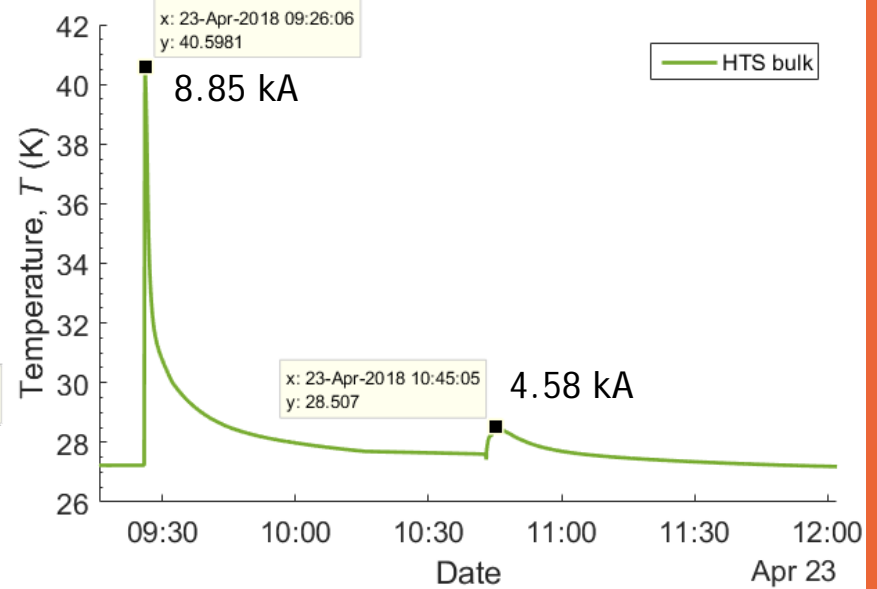
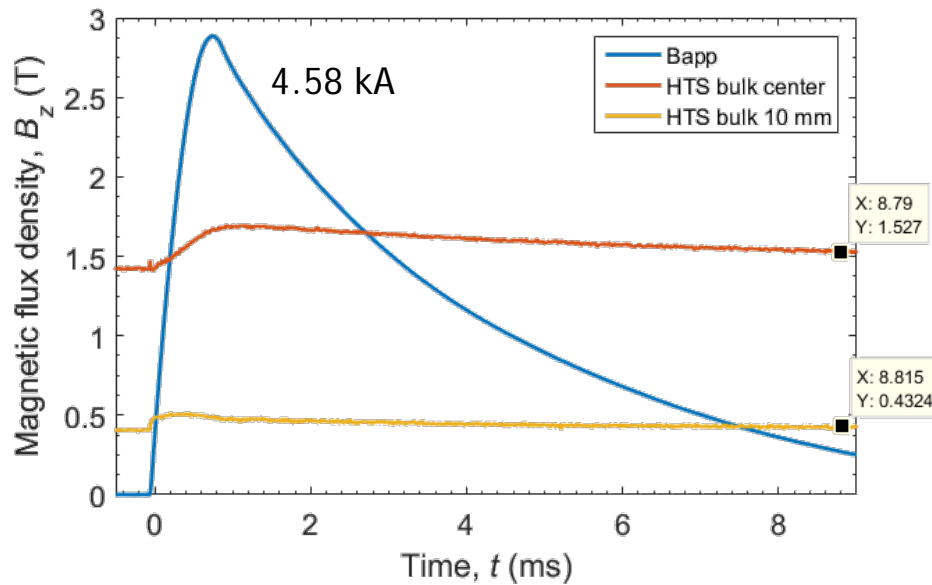
Other issues

- ▶ During PFM, the coil attempts to place at the center of the iron cylinder
 - ▶ The resulting force on the coil holder @ 10 kA reaches 13 kN ~ the weight of a Peugeot 5008



Trapped magnetic field

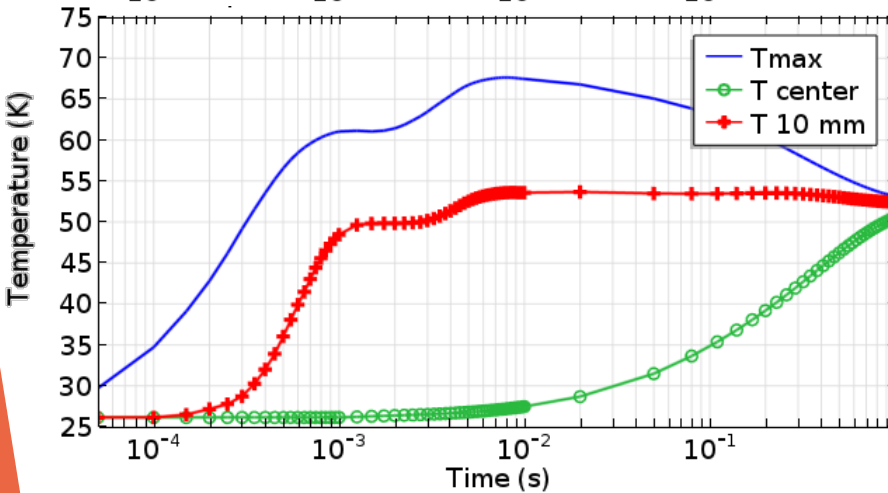
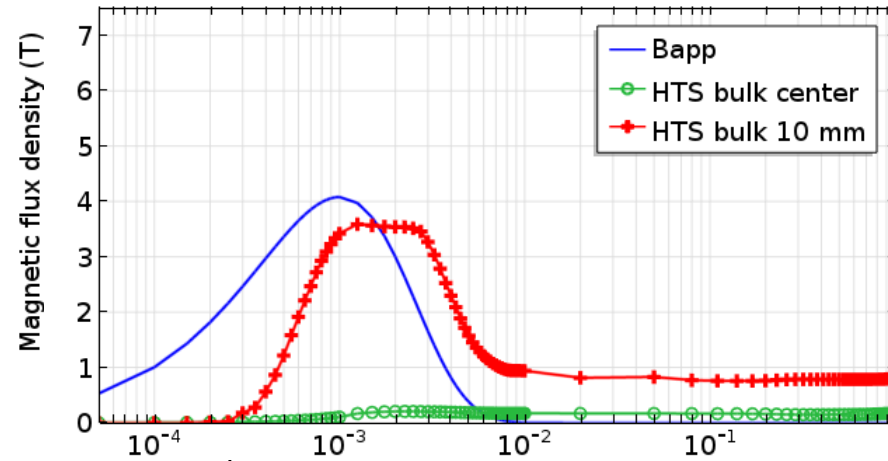
- ▶ Iteratively Magnetizing pulsed-field with Reducing Amplitude (IMRA) and Multi-Pulse with Step-wise Cooling (MPSC)



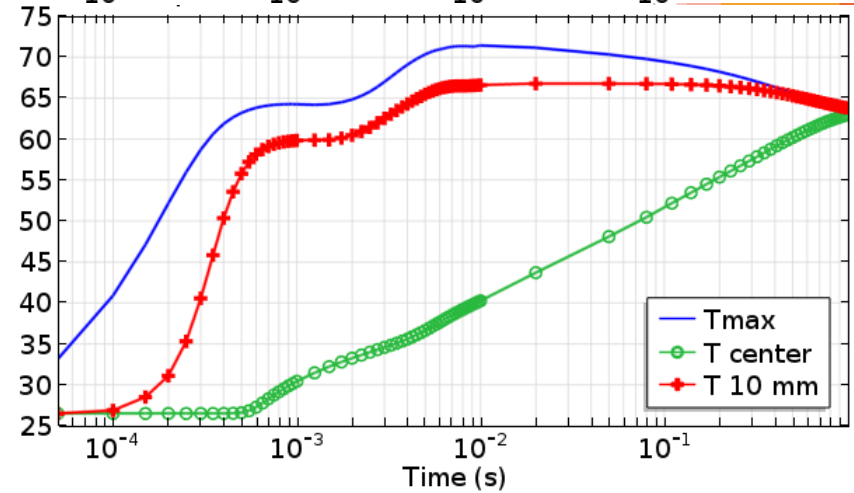
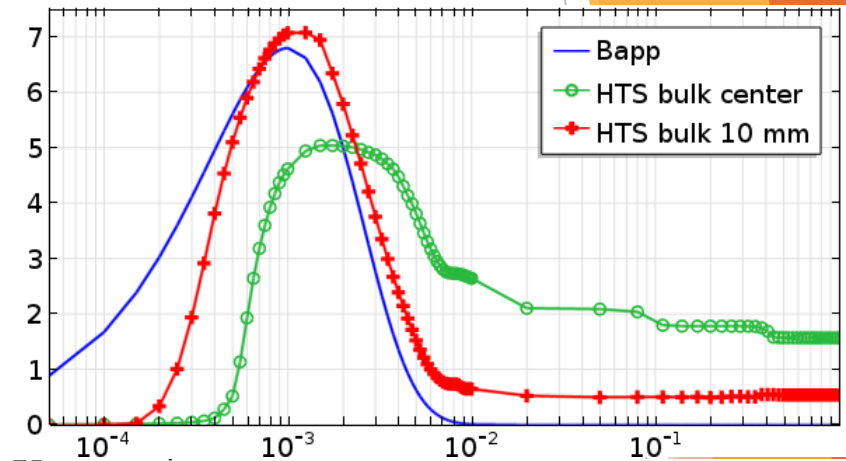
0.60 T @ LN²
1.29 T @ 45 K
1.47 T @ 27.5 K

Trapped magnetic field simulation

$I_{\max} = 6 \text{ kA}$



$I_{\max} = 10 \text{ kA}$

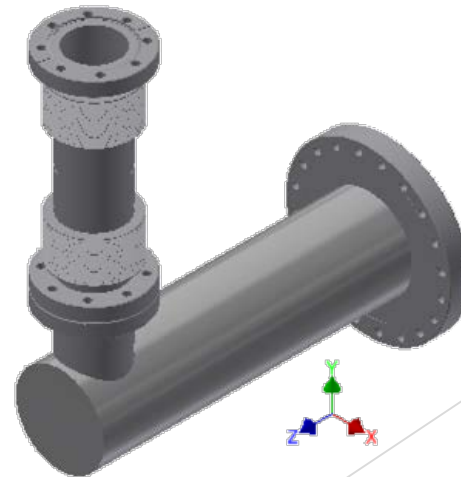
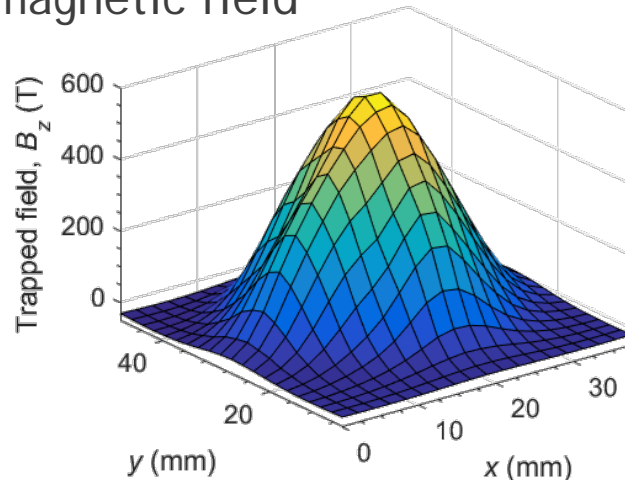


Conclusion

- ▶ A new test rig for PFM with cryocooler was successfully build
- ▶ Multi-constrained system
 - ▶ Thermal, mechanical, high-voltage, high current densities...
- ▶ Fast improvement of knowledge through experience feedback and numerical simulations
- ▶ Trapped field results show a strong impact of heat generation during PFM
 - ▶ Because of the low specific heat of YBaCuO at low temperature ~ 30 K

Outlook

- ▶ New samples (LRE)-Ba-Cu-O are coming soon from Pr. M. Muralidhar (Japan)
- ▶ New coil designs
- ▶ We will move forward in the PFM of several bulks at the same time
- ▶ Field mapping setup for a global view of trapped magnetic field





İlginiz için teşekkür ederim

Thanks for listening

We are looking for 'good' samples...

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