PSI Center for Accelerator Science and Engineering

HFM
High Field Magnets Programme

CHART
Swiss Accelerator Research and Technology

CERN

Status of HFM development at PSI

D. Araujo, B. Auchmann, A. Brem, C. Lindner, T. Michlmayr, C. Müller,
A. Stampfli and D. Sotnikov (PSI)
A. Ballarino, A. Haziot (CERN)

FCC Week, 23 May 2025, Vienna

This work was performed under the auspices of and with support from the Swiss Accelerator Research and Technology (CHART) program, http://chart.ch.

MagDev Laboratory

André Brem
Material Scientist

Anna Stampfli
Technician Processes

Colin Müller
Mechanic

Christina Lindner
Technician HTS, CAD

Douglas Araujo
Magnet Engineer

Dmitry Sotnikovs
Engineer ReBCO

Inês S. P. Peixoto
Magnet Engineer

Thomas Michlmayr
CAD, Technical Design

Joep Van den Eijnden
ETHZ PhD Student

LTS R&D

Fast-Turnaround Stress-Management R&D

Goal: Build industrializable Nb_3Sn high-field magnets that "just work".

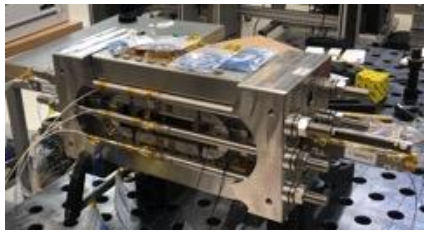
ETH zürich

First deliverable

2019

2020

2024

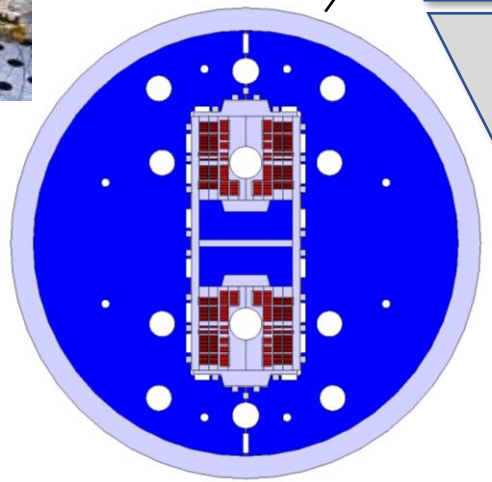


2025/26

Courtesy D. Araujo

BERKELEY LAB

CERN



Long-magnet infrastructure available only at CERN.

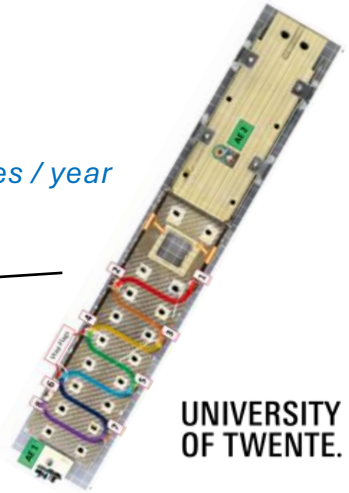
#Deliverables / year

100s

10

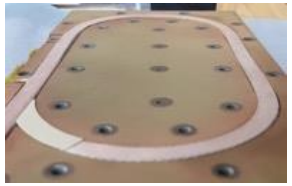
2-3

0.5-1



UNIVERSITY OF TWENTE.

Courtesy M. Daly



Courtesy D. Araujo

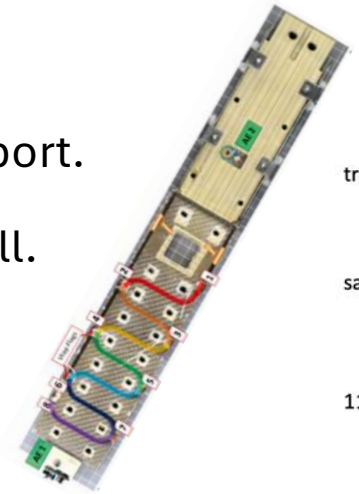
Brookhaven National Laboratory

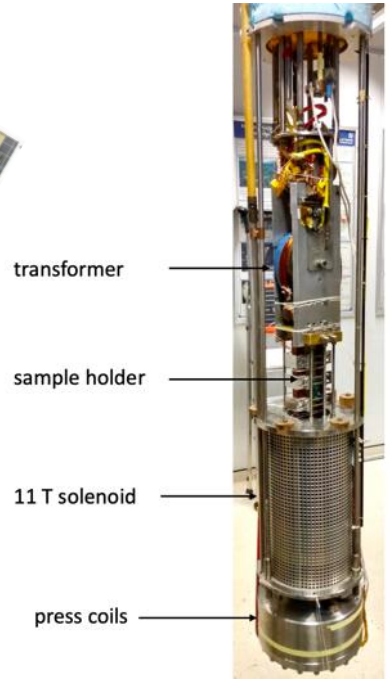
Compression BOX

Filled wax reaches CTD 101-K level of support.

SMACC1/R2D2 HF cable performs very well.

Ic values as expected from strand measurements (S. Hopkins)

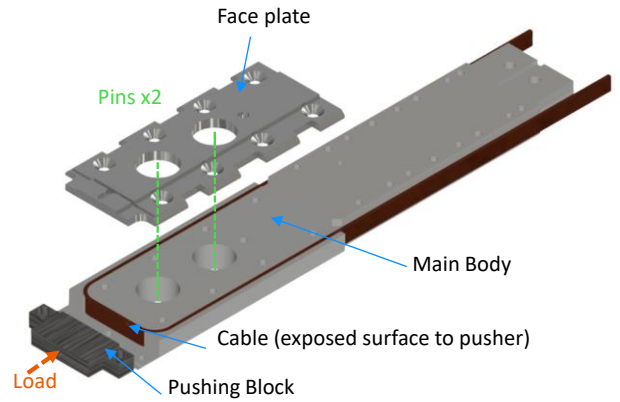




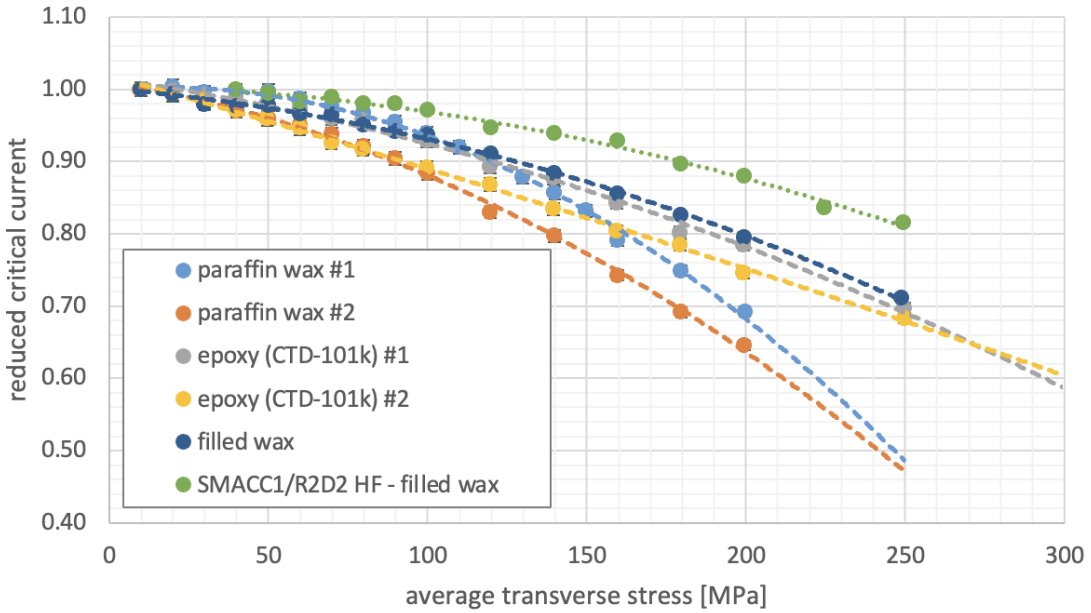
UNIVERSITY OF TWENTE.

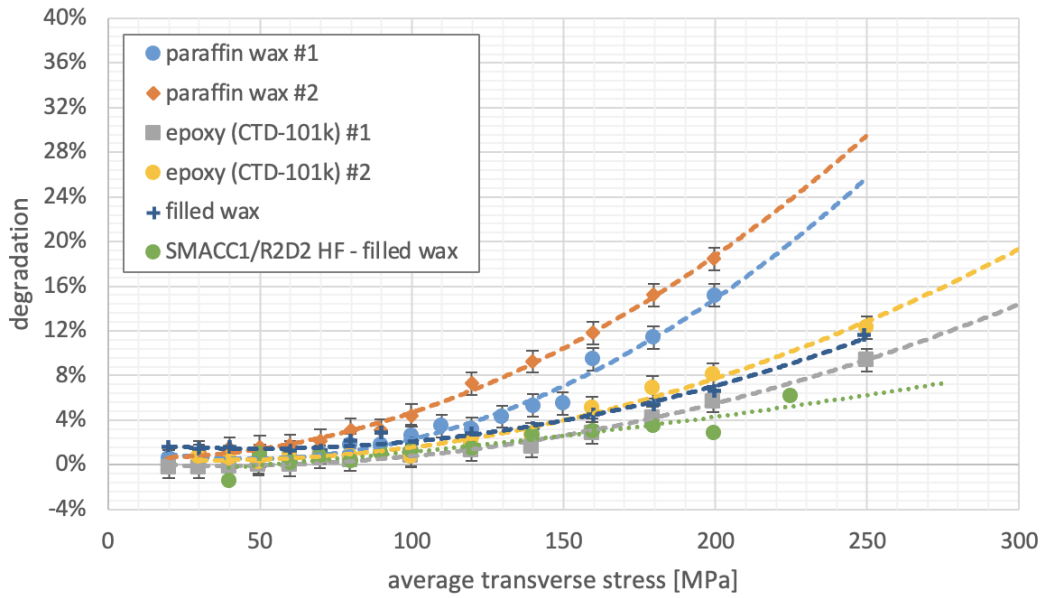
CHART Swiss Accelerator Research and Technology

PSI



Courtesy M. Daly



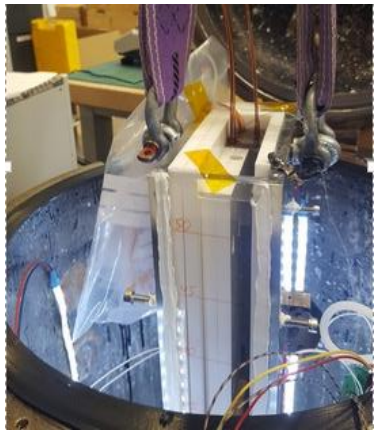


Courtesy, A. Brem, M. Daly, S. Otten, S. Sidorov

BigBOX1: Manufacturing Steps and Results

Winding

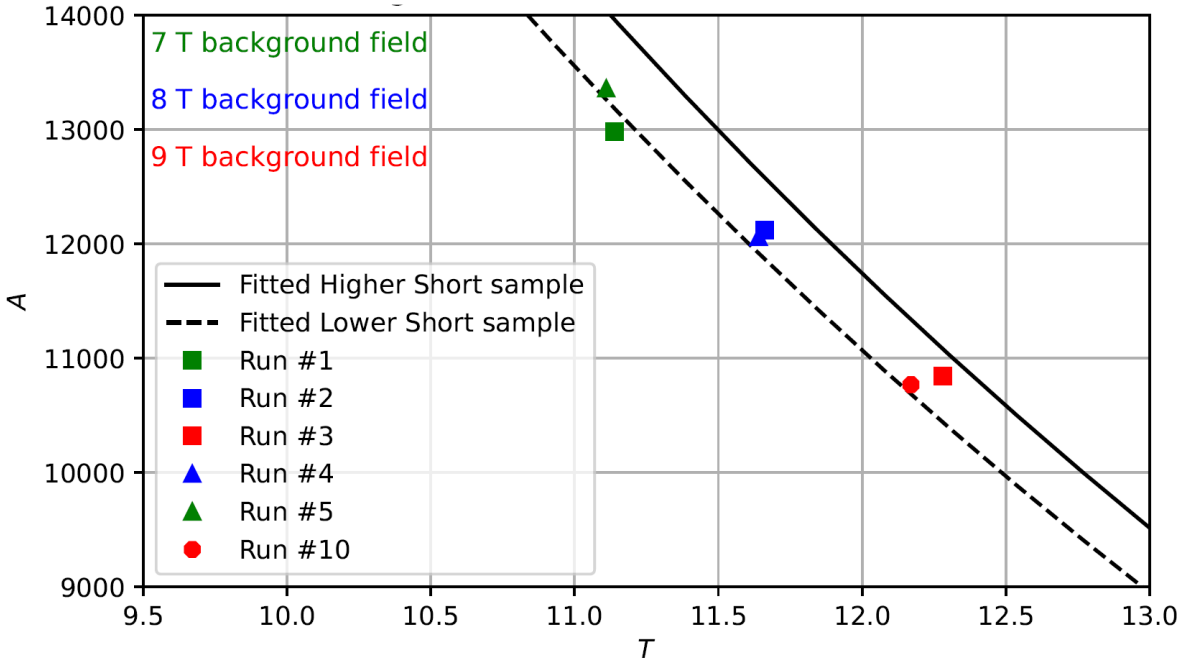
Impregnation (Wax)



Electrical Tests

Integration

6 times power-up to short sample limit without training



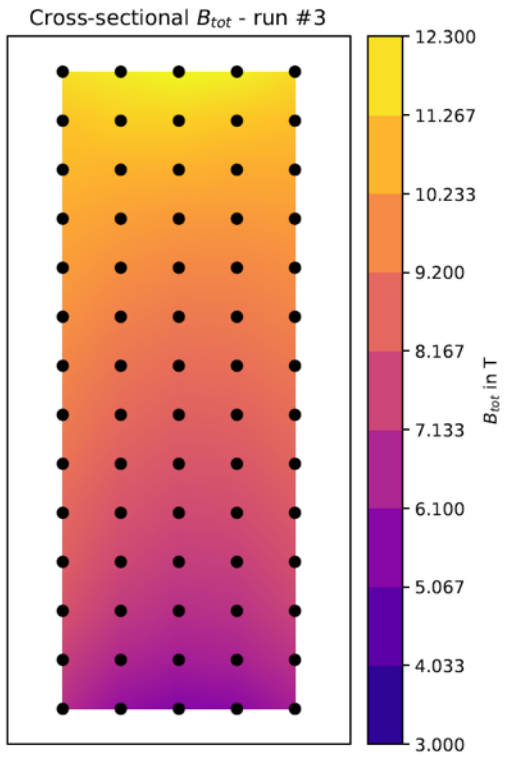
Test Results: courtesy R. Gupta, P. Joshi and M. Kumar

D. M. Araujo *et al.*, "Assessment of Training Performance, Degradation and Robustness of Paraffin-Wax Impregnated Nb_3Sn Demonstrator Under High Magnetic Field," *IEEE Trans. Appl. Supercond.*, vol. 34, no. 5, pp. 1–8, Aug. 2024, doi: 10.1109/TASC.2024.3368995.

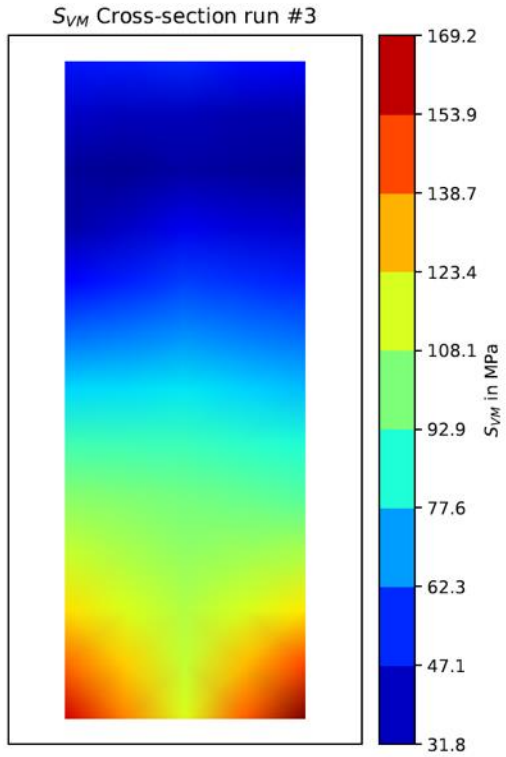
From BigBOX1 to BigBOX2

BigBOX1: powered in a single direction

Impregnation system: paraffin wax



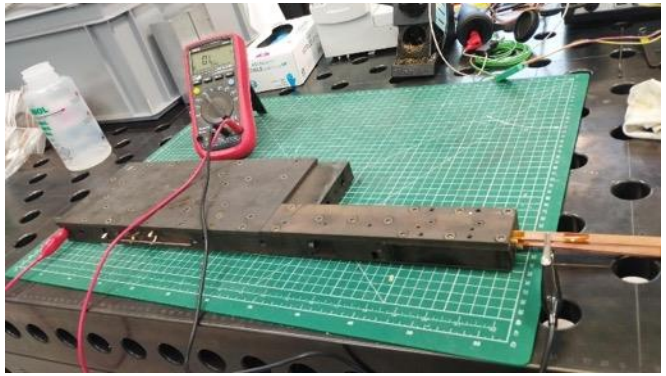
Peak field of 12.3 T



Peak of Stress of 170 MPa

BigBOX2: powering in two direction (assessment of degradation) and Impregnation System: filled paraffin Wax comparable to BOX 7 and 8.

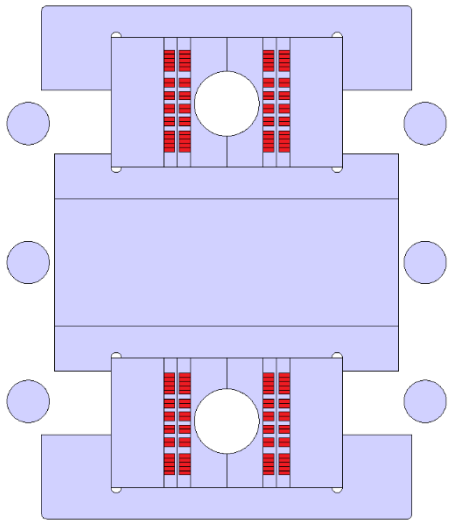
BigBOX2 was manufactured and delivered to BNL in 2024

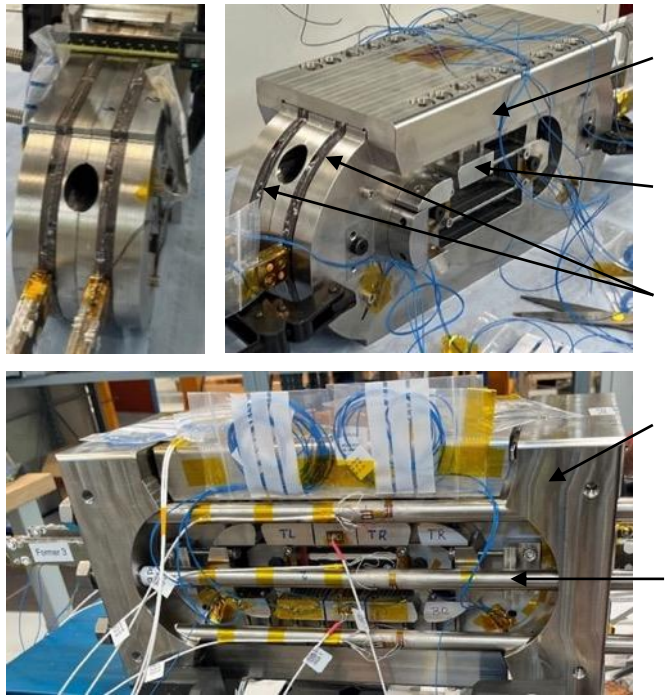


BigBOX2 is scheduled to be tested in May 2025

Subscale Stress-Managed Common Coil Magnet (subscale SMCC1)

- Stress-managed common coil concept
- Validating manufacturing processes and technologies: re-use of tooling from winding to the final assembly, layer to layer splicing, impregnation system, ceramic coating





Magnet Concept, design and manufacturing by PSI

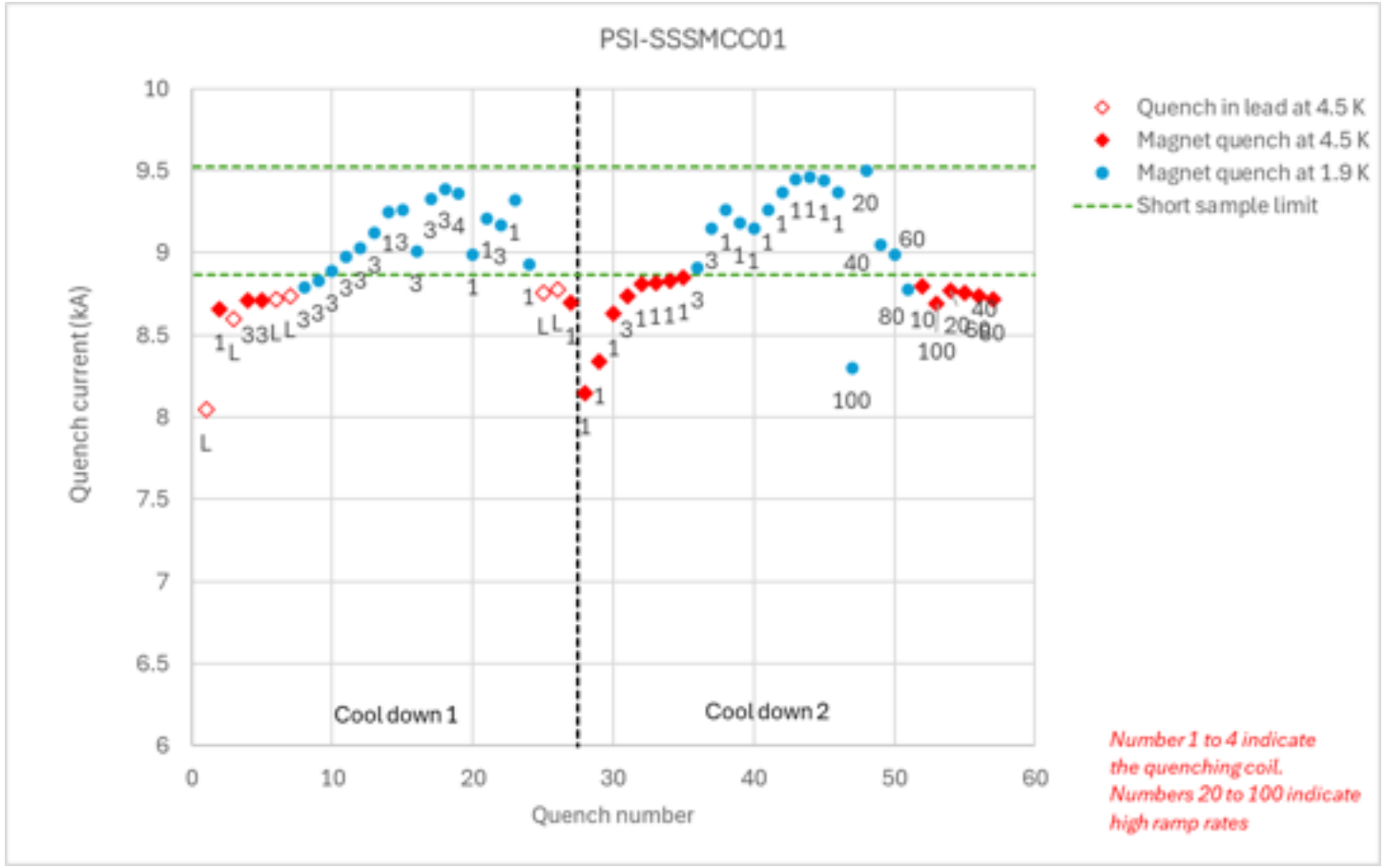
Cable manufactured at LBNL

Heat Treatment of 2 of 4 coils and testing campaign

TABLE I
MAGNET PARAMETERS

PARAMETER	VALUE	UNIT
Strand diameter	0.6	mm
Number of strands	11	
Ins. cable thickness	1.6	mm
Ins. cable width	4.1	mm
Bore	22	mm
Straight-section	150	mm
Intra-beam	120	mm
T_{op}	4.5	K
$I_{short\ sample}$	9.0	kA
B_0, I = 9.0 kA	5.0	T
B_{peak}, I = 9.0 kA	6.1	T
Energy	16	kJ
L	0.39	mH
F_x	270	kN
F_y	-5.1	kN
F_z	51.7	kN
j_{cu}	5.6	kA/mm^2
j_{sc}	6.6	kA/mm^2
$j_{overall}$	1.4	kA/mm^2

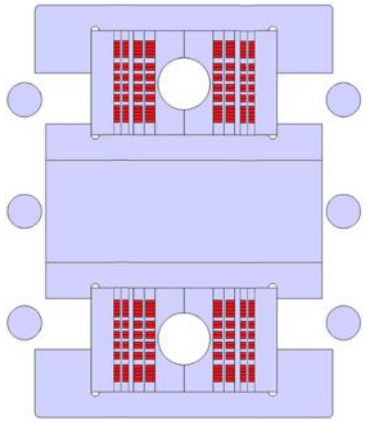
subSMCC1 Performance

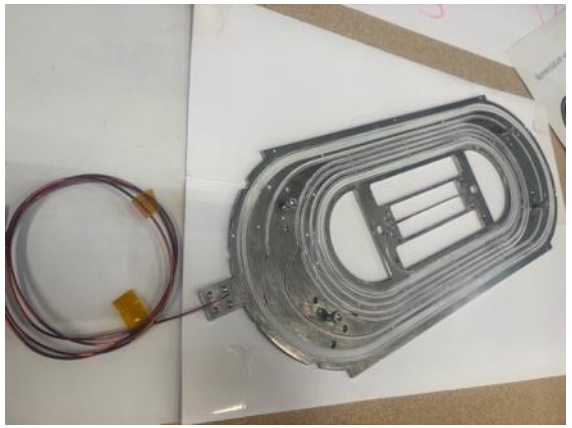


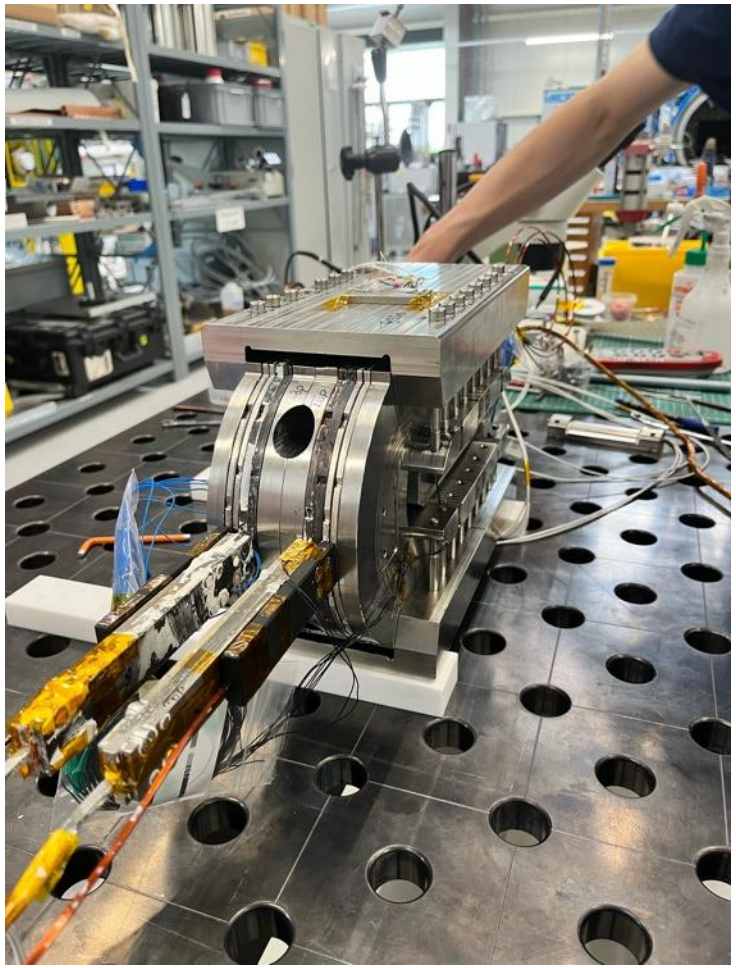
[Test data courtesy of G. Willering, CERN]

subSMCC2

- The second assembly of subSMCC has two new coils (accidental coil damage during subSMCC1 disassembly), as well as four ESC coils.
- With Jcu of 5.6 kA, subSMCC is hard to protect. It overheats even if the entire coil were quenche instantaneously.
- ESC promises to extract energy to the ESC coils and protect subSMCC2 without energy extraction.

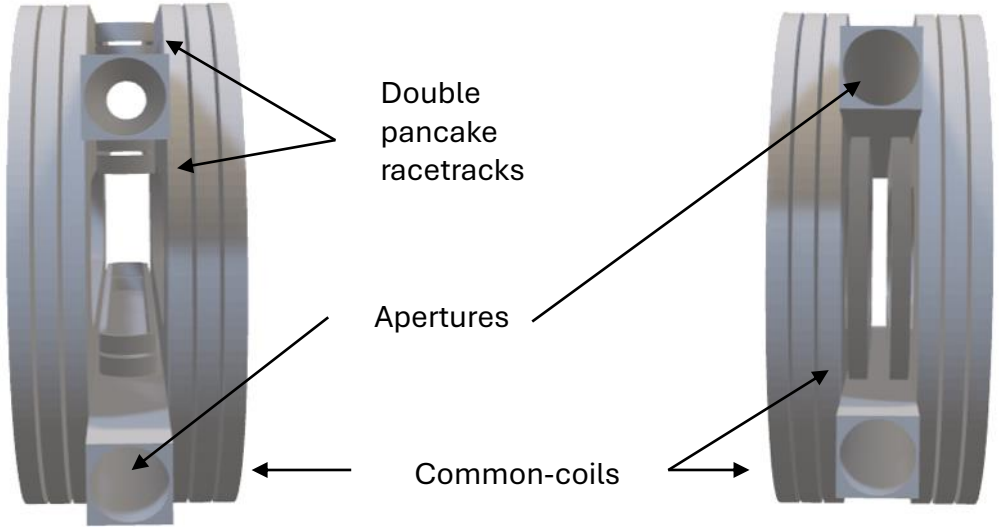




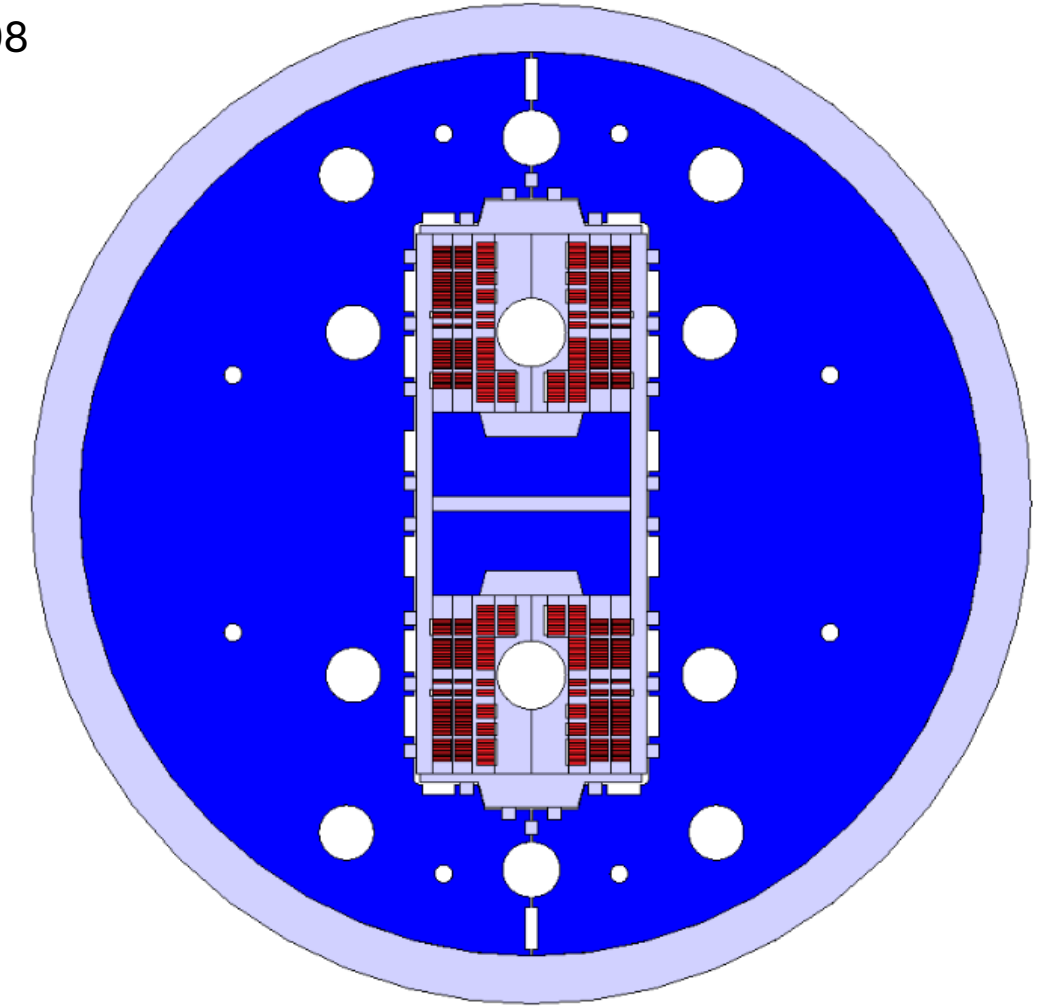


SMACC1:
Stress-Managed Asymmetric Common Coil

Conceptual Design Review: https://indico.psi.ch/event/1698



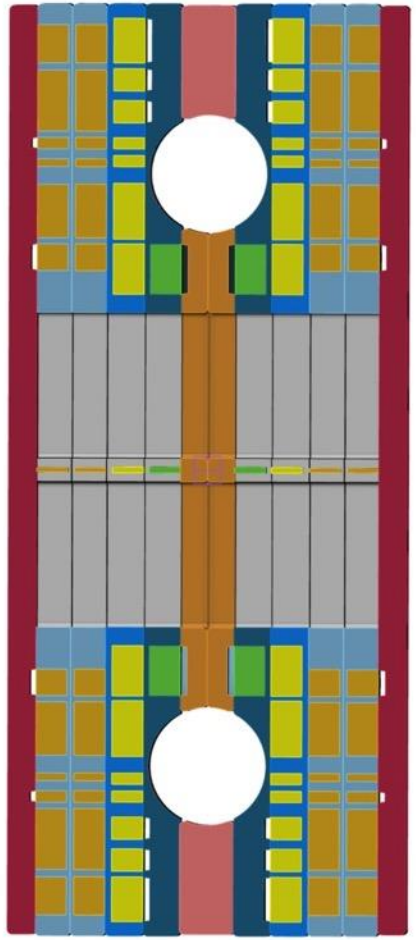
B_0 in T	B_{peak} in T	T_{op} in K	% Margin	I_{op} in kA
12.0	**12.6 (+5%)**	**1.9**	**24.1**	**12.9**
13.0	13.7	1.9	17.1	14.1
14.0	14.7	1.9	10.0	15.3

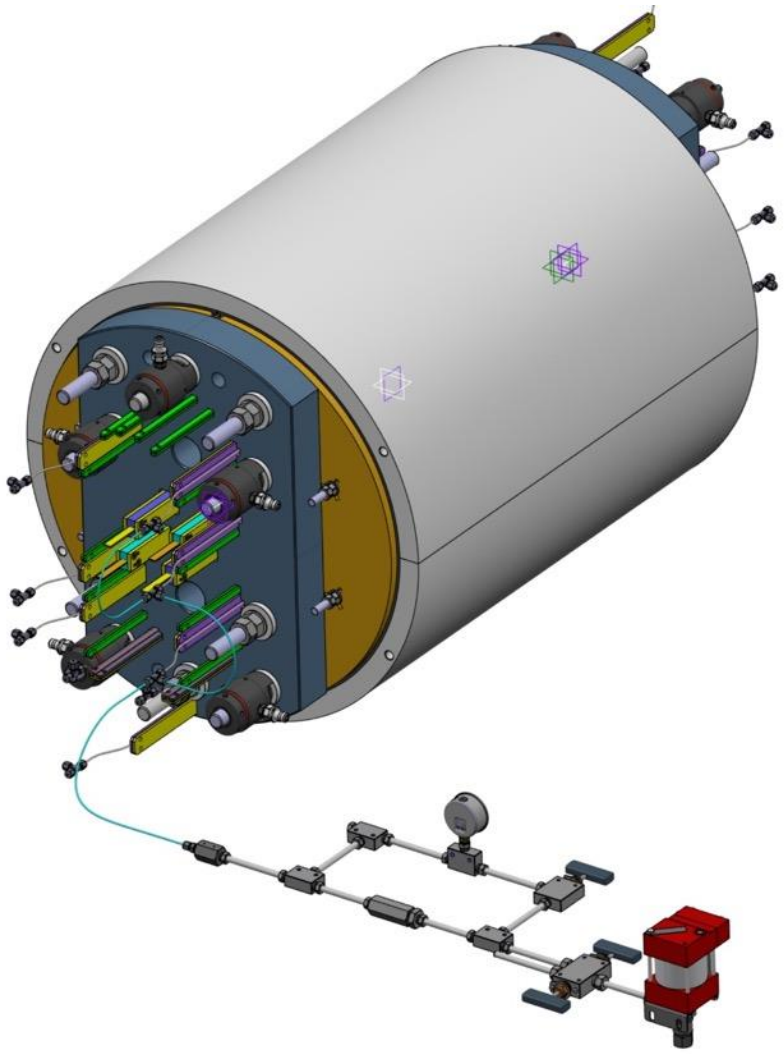


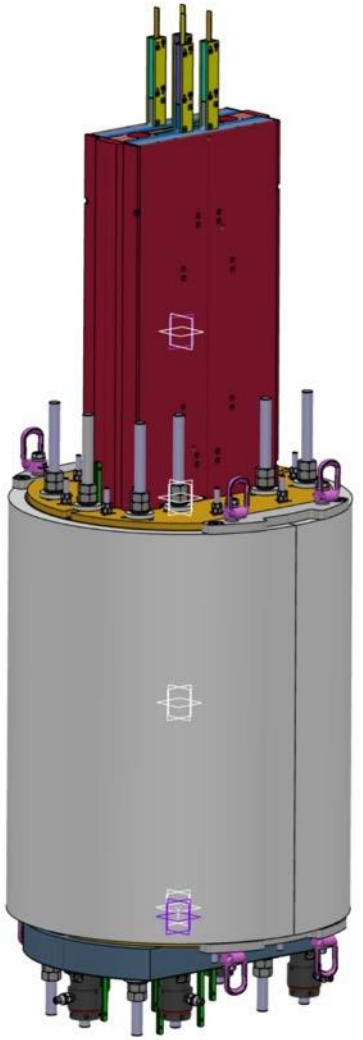
D. Araujo *et al.*, "Electromechanical Design of Nb_3Sn Stress-Managed Asymmetric Common-Coils," *IEEE Transactions on Applied Superconductivity*, 2025.

SMACC1:
Stress-Managed Asymmetric Common Coil

Technical design is complete and procurement under way. Assembly planned for Q2’26.







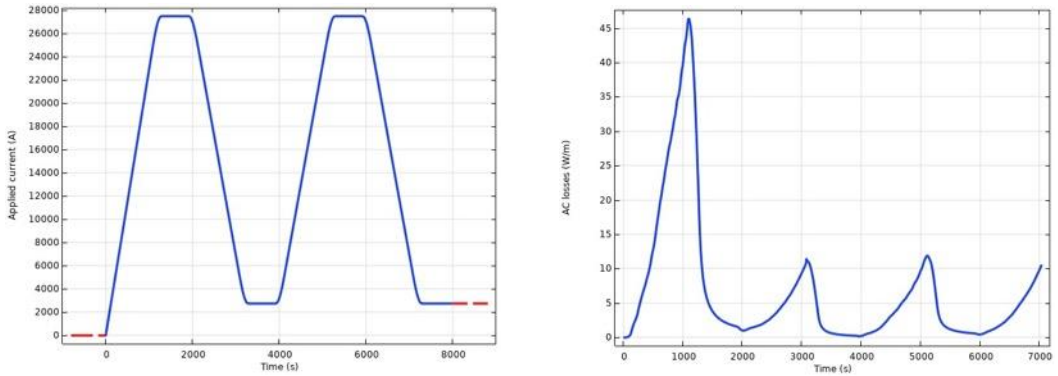
Progress on the engineering design, courtesy T. Michlmayr

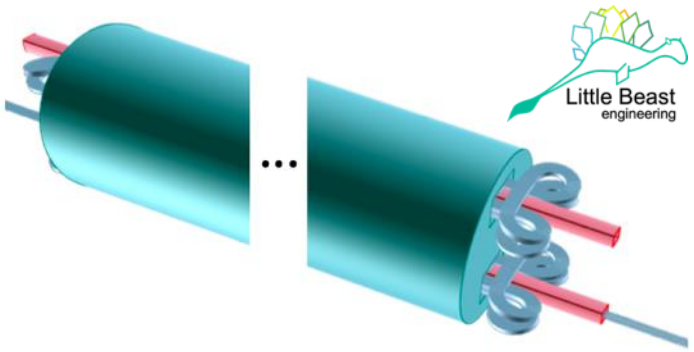
HTS R&D

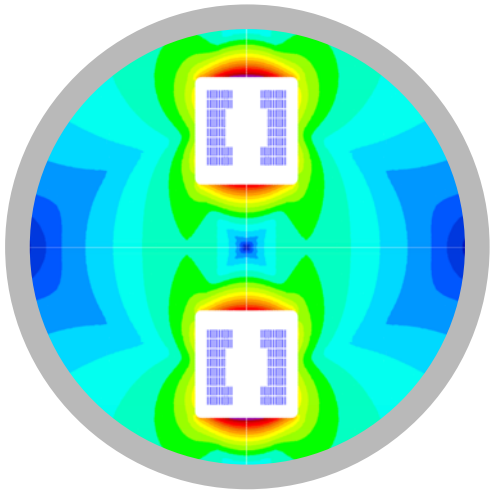
HTS ReBCO Accelerator Magnets for FCC-hh

ReBCO promises more sustainable operation, higher physics reach, and a more credible cost prospect.

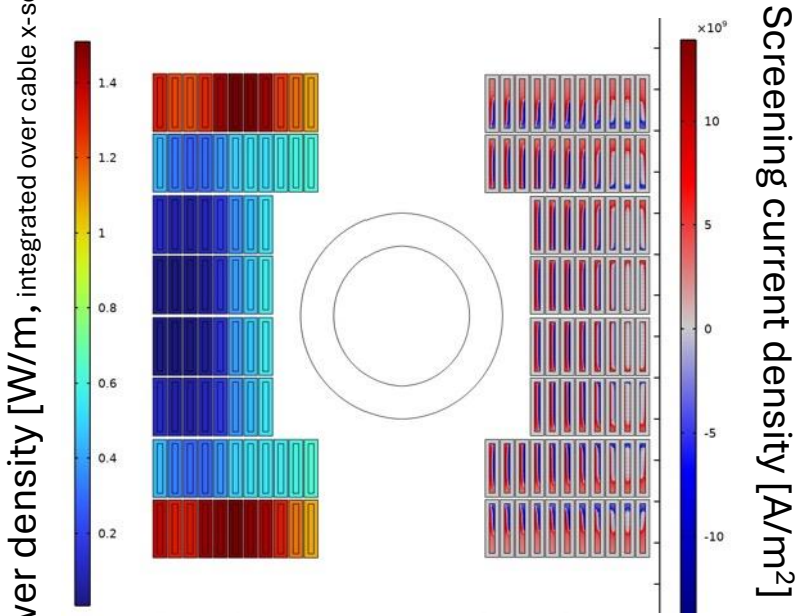
- Higher magnet temperature (20 K) improves power consumption for static and beam-induced losses.
- Higher fields and collision energies could be envisaged but main cryo load for FCC-hh becomes synchrotron radiation (SR) on the beam screen.
- Increased ramp losses may (at least) in part cancel the improved cryogenic efficiency at 20 K.
  - Initial estimates indicate a >2x increase in ramp losses wrt. Nb_3Sn state of the art.







Screening-current and -loss calculation
Courtesy D. Sotnikov, PSI



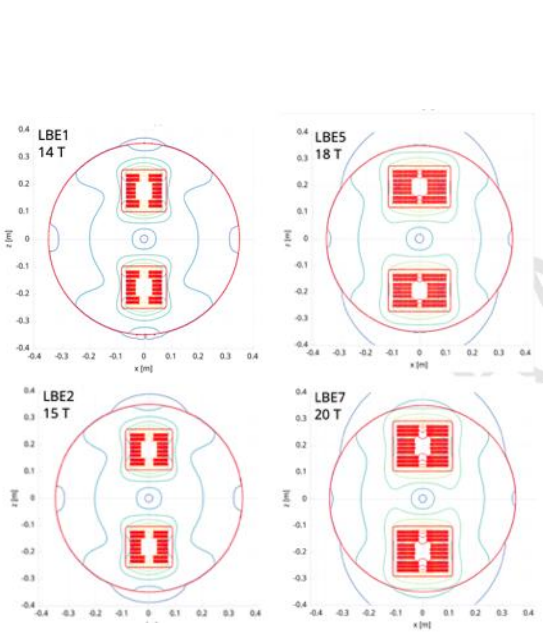
ReBCO FCC-hh Dipole Scaling Exercise

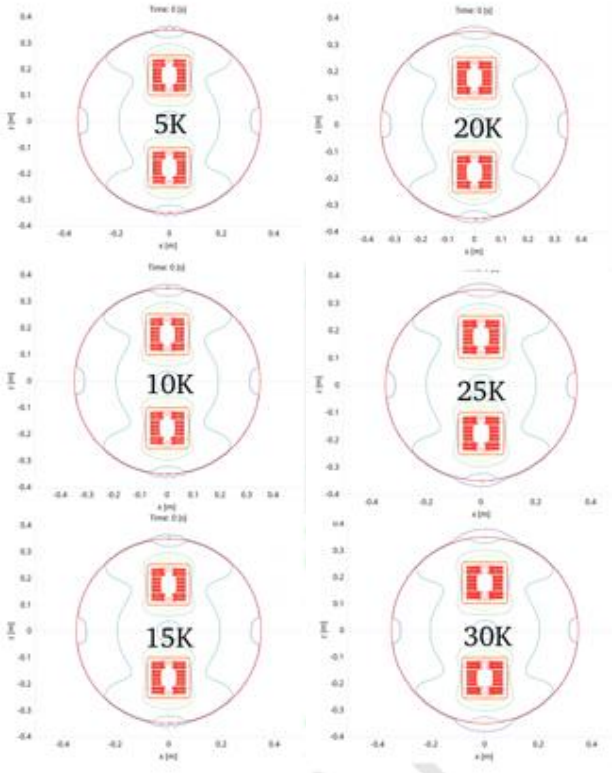
Coil layouts were scaled at 20 K from 14 to 20 T, and at 14 T from 5 K to 30 K.

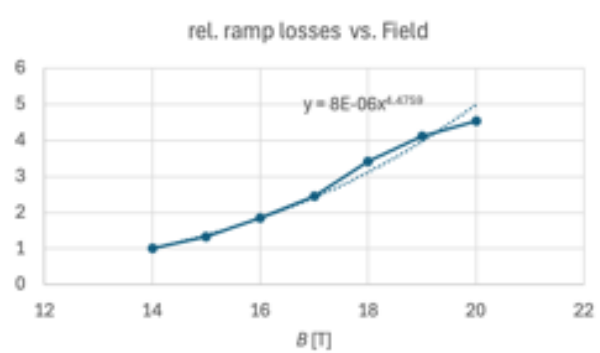
As expected, AC losses grow non-linearly with field due to larger field sweep and growth in coil-size.

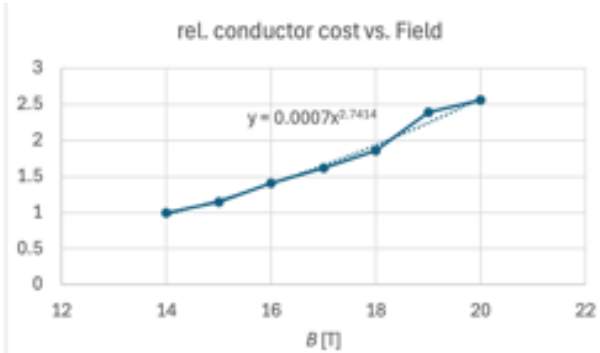
In this study, AC losses increase 4-fold from 14 to 20 T.

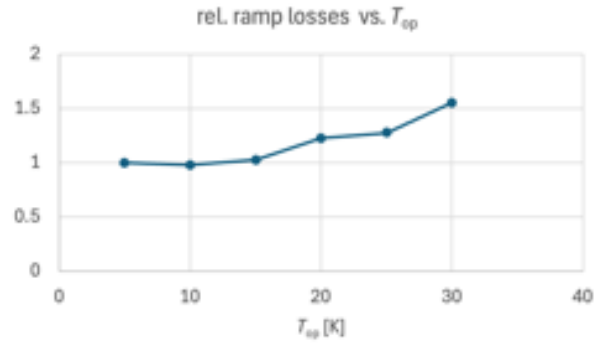
Initial results indicate that losses decrease mildly towards lower temperatures.

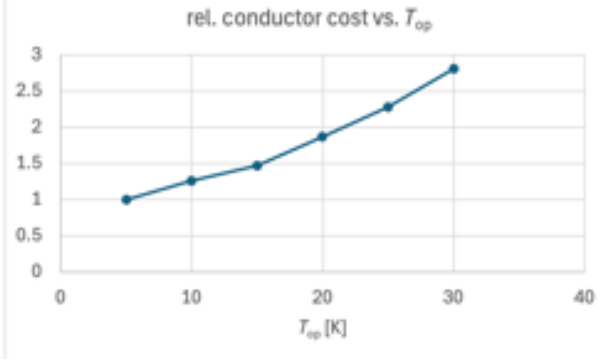






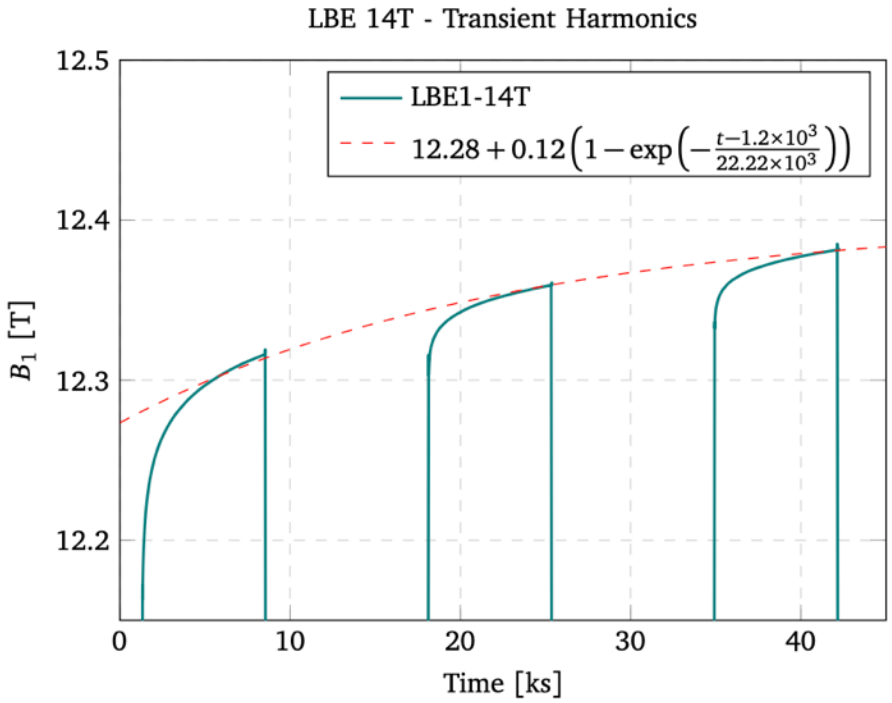


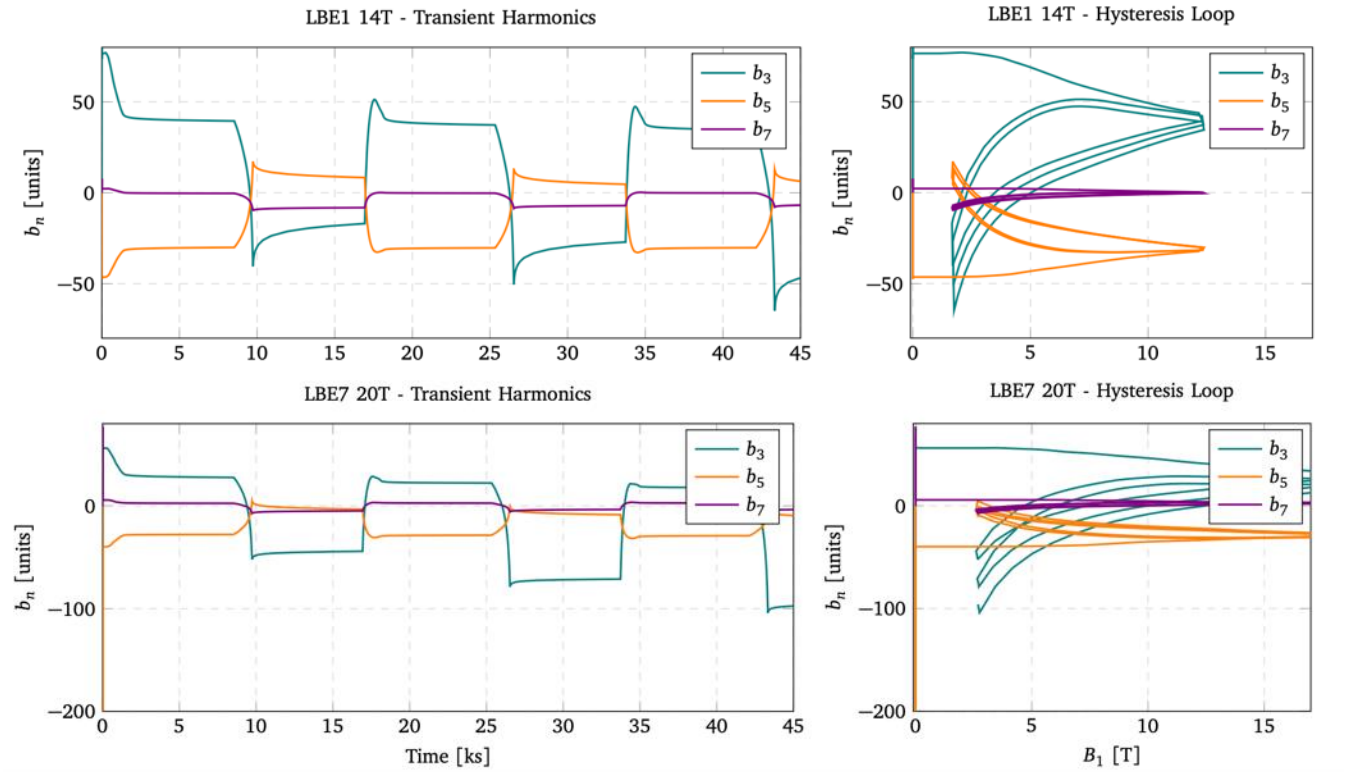




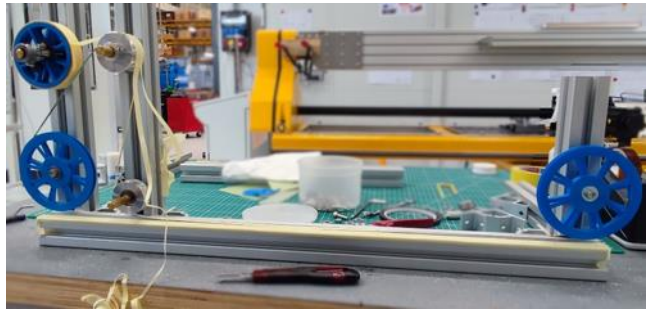
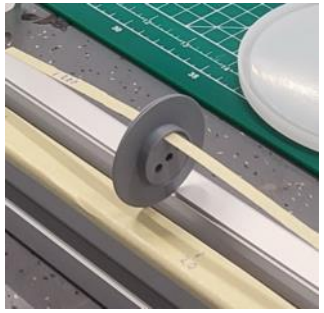
ReBCO FCC-hh Dipole Scaling Exercise

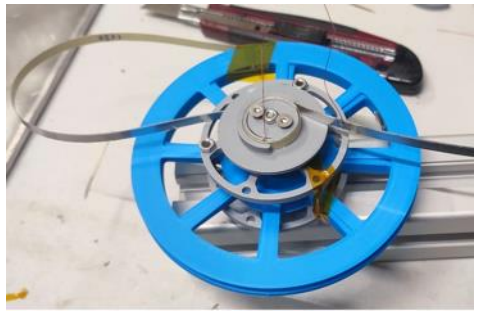
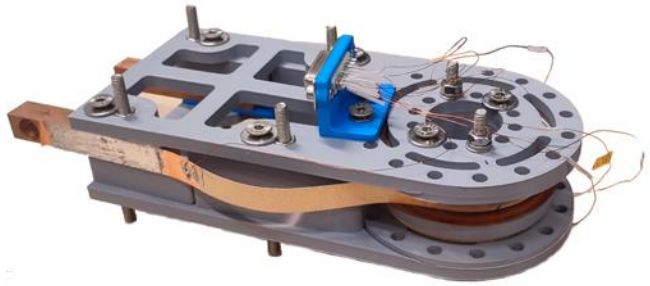
- In this study, a strong screening effect with long time constants is observed. Multiple cycles are needed to reach reproducible conditions.
- Experimental validation is of the essence.





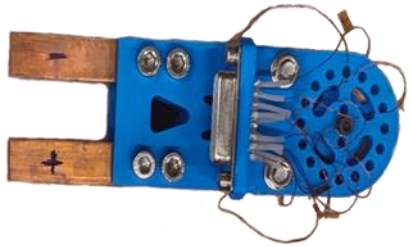
BabyHTS: AC loss model-validation coils

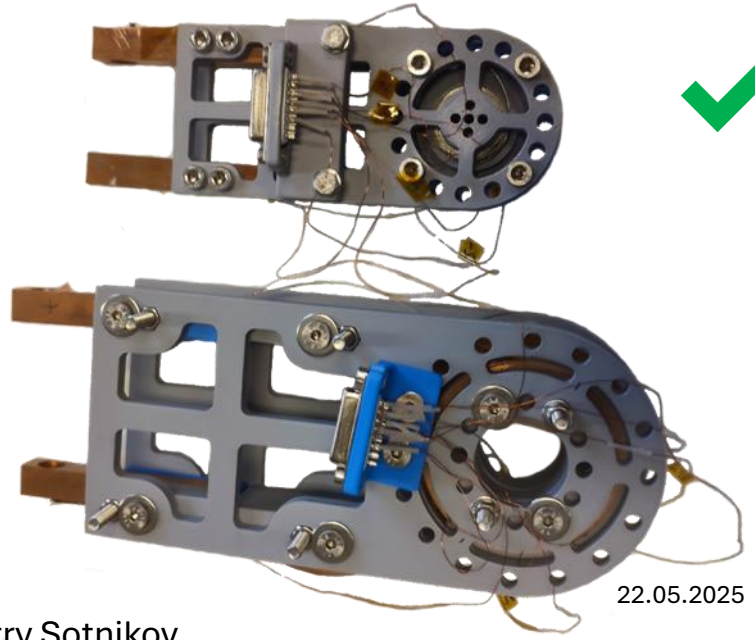




Courtesy: H. Garcia

✗



✗



✓

✓

Paper insulation → double pancake start → winding → v-taps → leads

Coil name	Cable	Inner diameter, Twisting, mm	Inner diameter, Former, mm	Outer diameter, limit, mm	Insulation between windings, mm
blueBerry	4 mm single tape	17	20	30	0.6
greyBerry4d	4 mm soldered 2-stack	17	20	40	0.6
greyBerry12	12 mm single tape	57	60	70	0.6

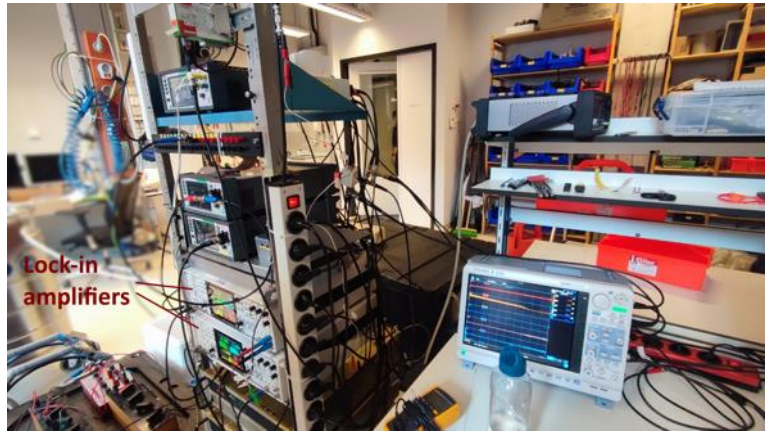
Courtesy: Dmitry Sotnikov

BabyHTS: AC loss model-validation coils

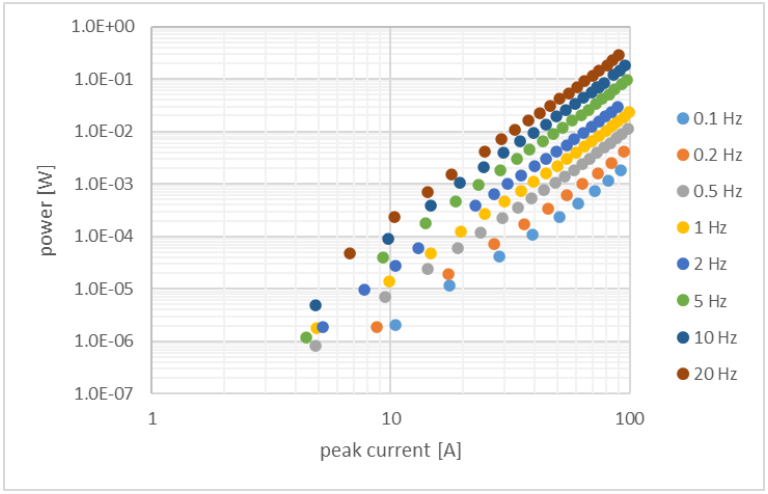
Numerical models resolve the REBCO layer and homogenized the other metal layers (Hastelloy, silver, copper).

Agreement to measurements is good for 4-mm 2-stack and 12-mm 1-stackcable.

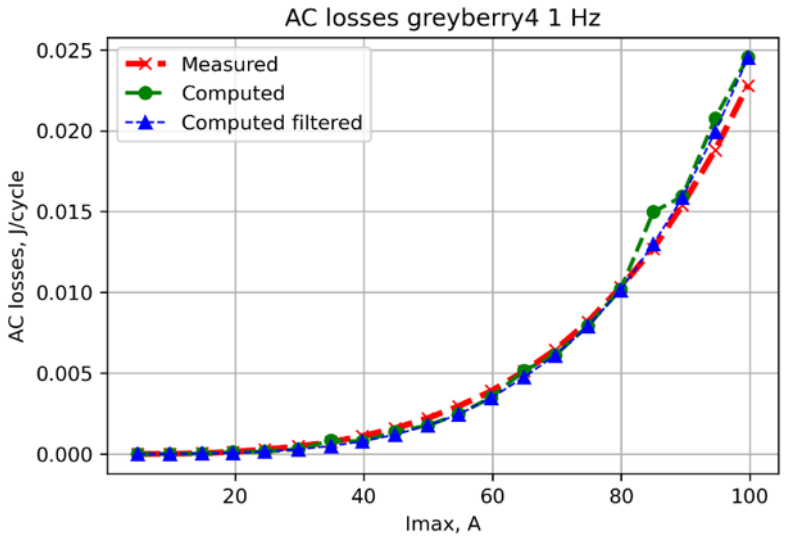
Note: fully homogenized model inaccurate and divergent.

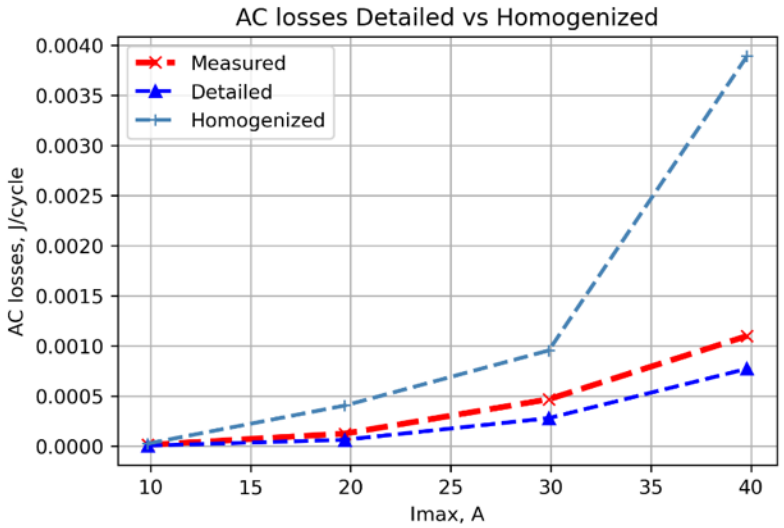


greyBerry4d
Tape: 4mm Turns: 20 P_max = 0.28W



COMSOL

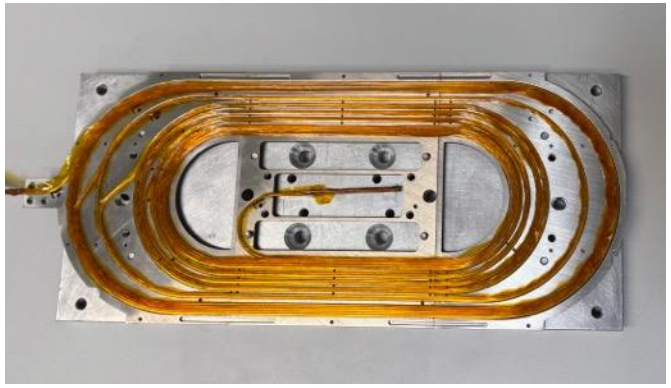


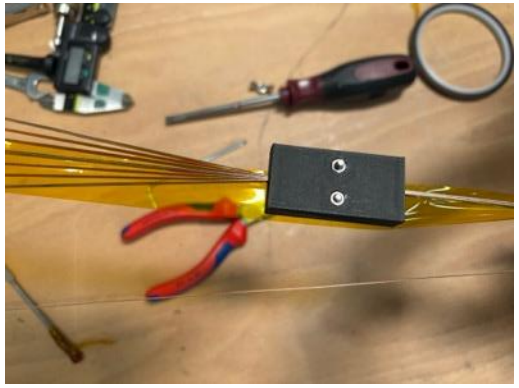


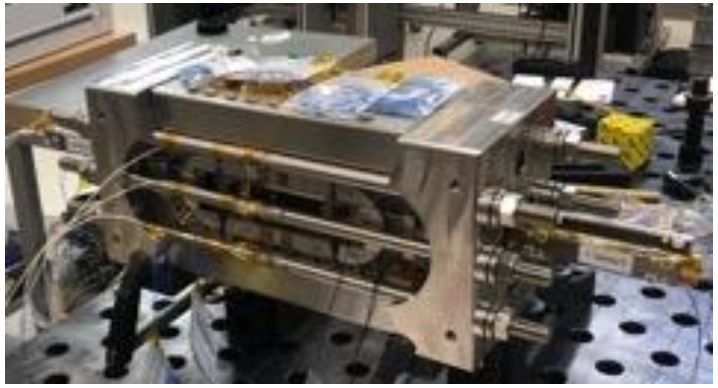
Courtesy: Simon Otten, Thomas Hanhart and Dmitry Sotnikov

HTS subscale preliminary work

- Re-use subSMCC2 design and structure for 4.5 T ReBCO magnet (8x4-mm tapes).
- Insulated REBCO soldered-tape-stack cable.
- SMCC magnet with two apertures for field quality measurements (stability, reproducibility).
- CLIQ and ESC protection studies.
- Coil-manufacturing trials (winding, splicing, soldering) progressing.







Outlook

LTS

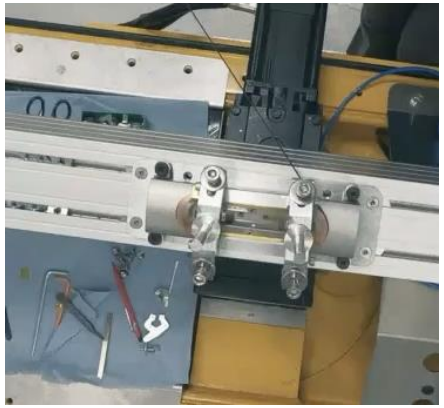
- BigBOX2 test — 2025
- subSMCC2 test
- SMACC1 construction and test — 2025-2026
- subSMACC and SMACC2 focus on 14-T demonstration, scalability, cost-effectiveness.* — 2027-2028

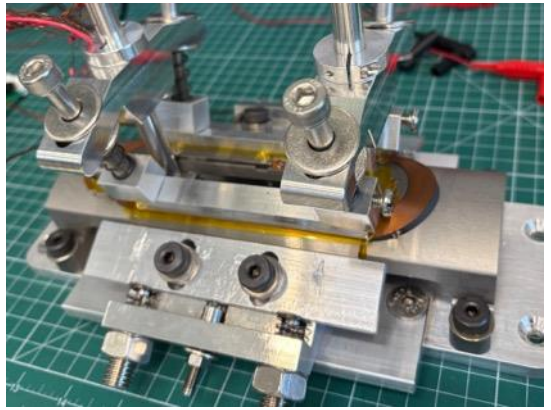
HTS

- REBCO subSMCC with ESC — 2025
- Two additional subscale magnets with differing cable, coil, and protection strategies.*
- Sample coil for testing in 10 T background field.* — 2026-2028

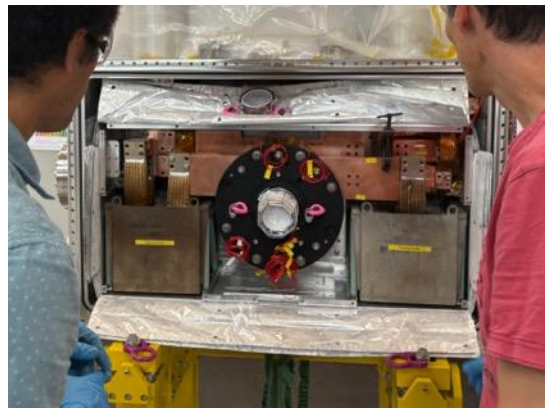
* Subject to deliberations on a new collaboration agreement 2025-28

Other PSI magnets for FCC-ee





[HTS4 Development, M. Koratzinos]



[FCC-ee Injector Overview and Outlook, P. Craievich]