PAUL SCHERRER INSTITUT

PSI

D. Araujo, B. Auchmann, A. Brem, H. Garcia, T. Michlmayr, C. Müller and D. Sotnikov

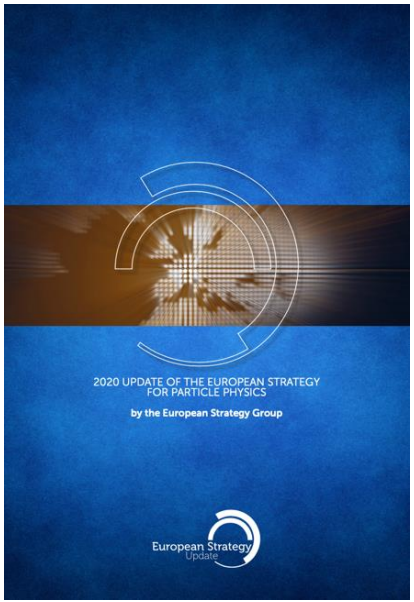
PSI CHART Superconducting Magnets Roadmap: from Powered Samples to Hybrid Magnets

Joint Annual Meeting of the Swiss and Austrian Physical Societies, September 2023

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

From the European Strategy for Particles Physics to the CHART/MagDev Project

Update of the European strategy for particle physics, 2020



http://cds.cern.ch/record/2721370

HFM R&D Program

Hosted at CERN

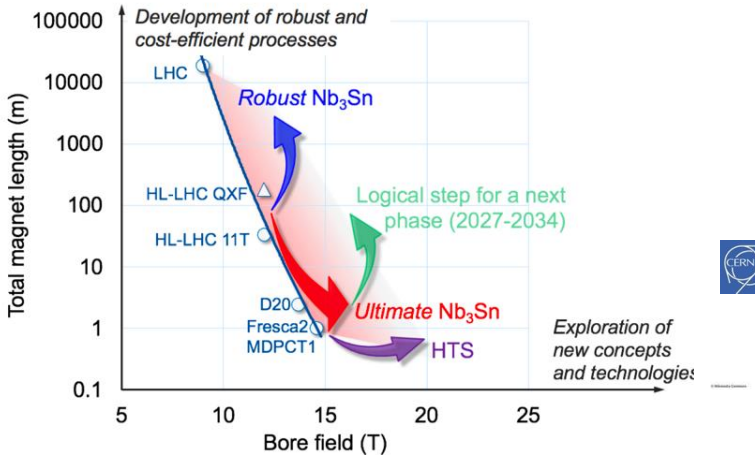
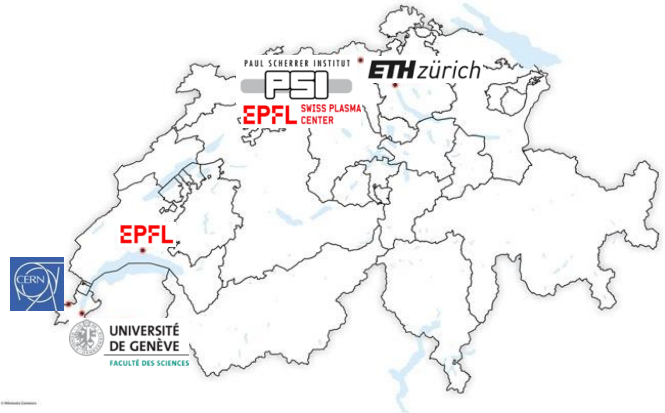


Fig. 2.7: Graphical representation of the objectives of the HFM R&D programme from 2021–2027. Both fronts of maximum field (red for Nb_3Sn, purple for HTS) and large-scale production (blue) will be advanced. Also represented, in green, is a possible evolution for the longer term, 2027–2034.

Accelerator R&D Roadmap published in Jan 2022.
https://arxiv.org/abs/2201.07895

CHART

Hosted at PSI



http://chart.ch

MagDev1 & 2

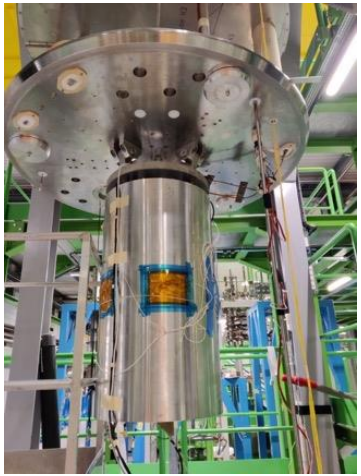
https://www.psi.ch/en/gfa/chart-magdev

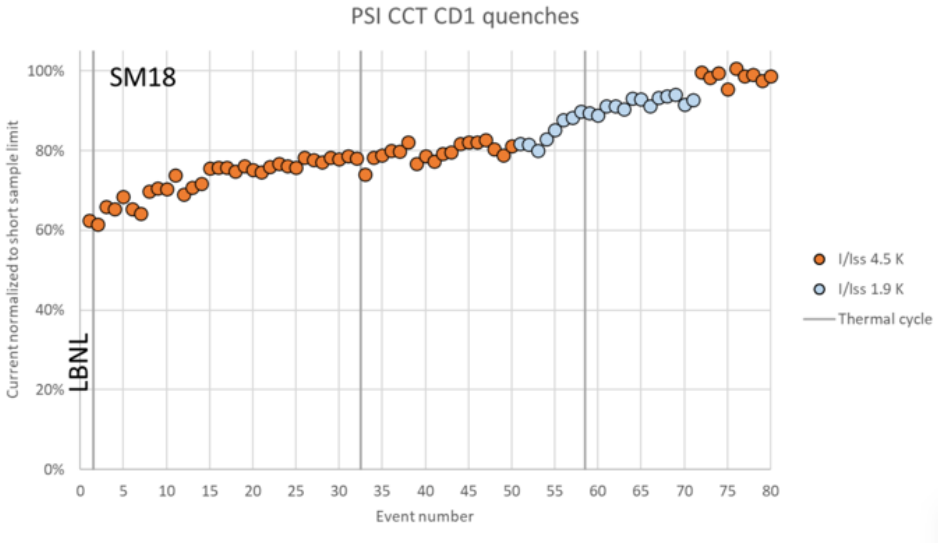
Overview

- CD1 Magnet test campaign (MagDev1)
- Roadmap overview
- Progress on the Roadmap
  - Enabling Technologies
  - LTS Powered Samples – Box and compression Box
  - LTS Stress-managed Coil – BigBOX
- Ongoing: Subscale Platform for LTS and Hybrid Magnets
- Collaborative Integration with CHART Projects

CD1 Testing Results and CCT Conclusions

- Canted-Cosine-Theta Magnet CD1 and Overview of the testing campaign of January 2023





Courtesy F. Mangiarotti (CERN) and M. Daly (PSI).

Training behavior:

the magnet trained a lot. How can we make it training less?

Nb_3Sn limit:

The magnet reached 100% of the maximum field at 4.5 K

Degradation:

After 80 quenches and thermal cycles the magnet shows no degradation

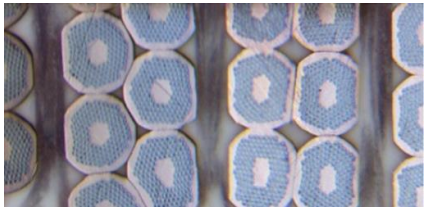
Stress-management works!

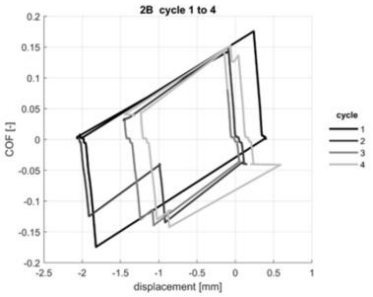
How can we take advantage of the CD1 (and the team) experience to go further?

G. Montenero et al., *Coil Manufacturing Process of the First 1-m-Long Canted-Cosine-Theta (CCT) Model Magnet at PSI*, IEEE Trans. on App. SC., Vol 29(5), 2019.
G. Montenero et al., *Mechanical Structure for the PSI Canted-Cosine-Theta (CCT) Magnet Program*, IEEE Trans. on Appl. SC., Vol 28(3), 2018.

Roadmap overview: The funnel approach

Wax, filled wax / epoxy process development, HT elimination of residues and sliding interfaces, A. Brem





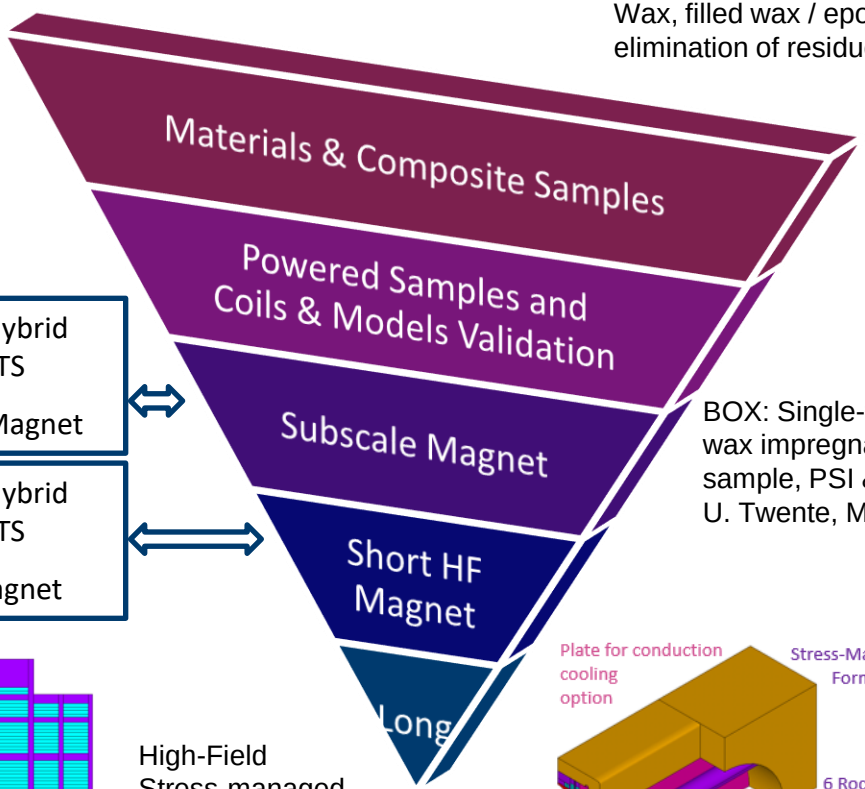
D. Sotnikov,
H. Garcia

LTS and Hybrid LTS/HTS

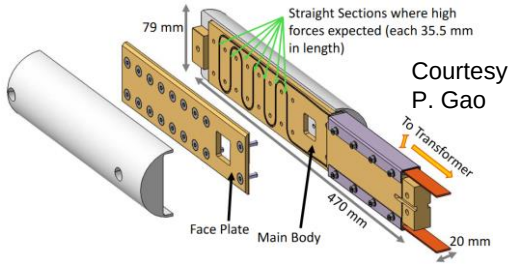
Subscale Magnet

LTS and Hybrid LTS/HTS

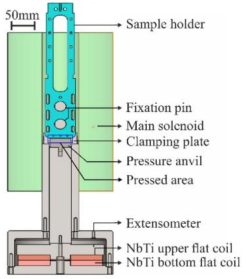
Short Magnet

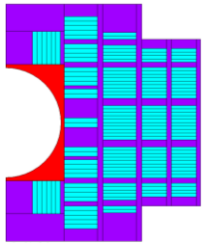


BOX: Single-turn wax impregnated sample, PSI & U. Twente, M. Daly

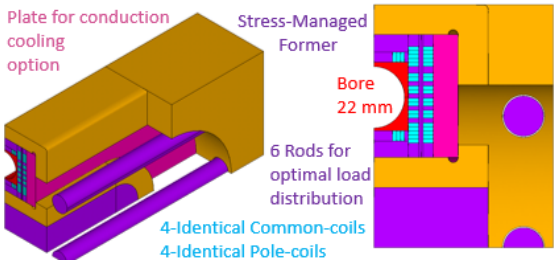


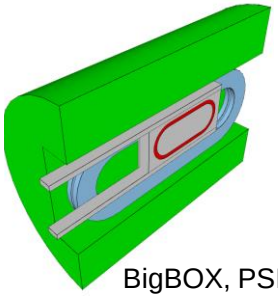
Courtesy P. Gao

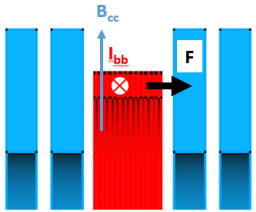




High-Field Stress-managed common coils







BigBOX, PSI & US-MDP/BNL

Enabling Technologies (two among many others)

- Particle filled impregnation systems and glass fiber insulated conductor

find a particles size which allows for high filler volume and goes throug the glass-fiber braid

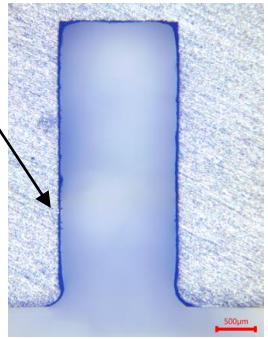
- higher modulus and heat capacity
- lower CTE

in a commercial filled epoxy the particles are filtered by the glass fiber braid

A. Brem

- High temperature glass-ceramic coatings – optimized processing

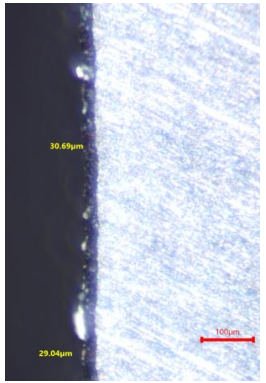
coating



Deep channels, aspect ratio 1:2.5

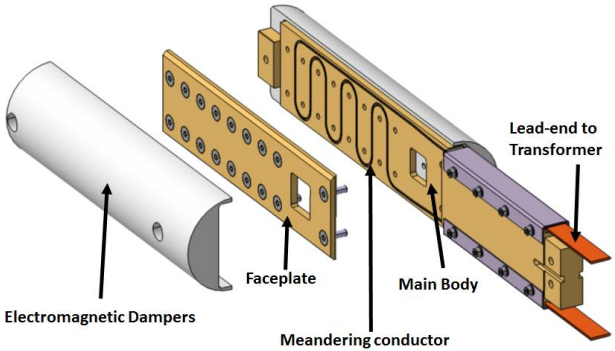
Even coating and controllable thickness

Ceramic coating on box channel

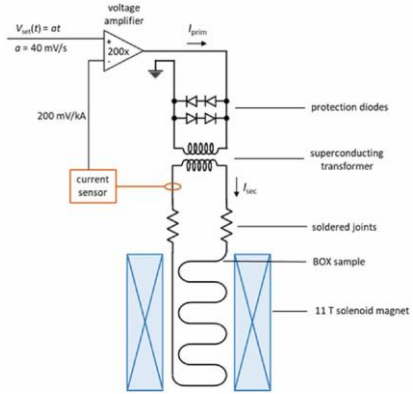


LTS Powered Samples
BOX: BOnding eXperiment

BOX Conceptual View



UT Test Facility



Fast Turn Around

Matrix Systems and Training Behavior Platform

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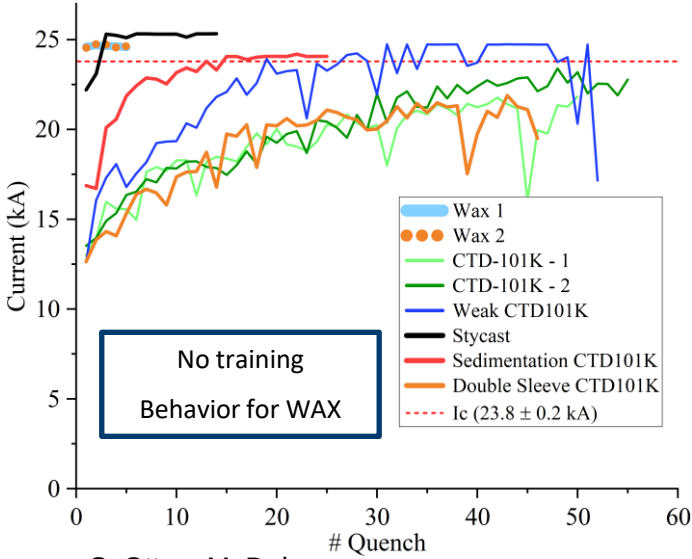
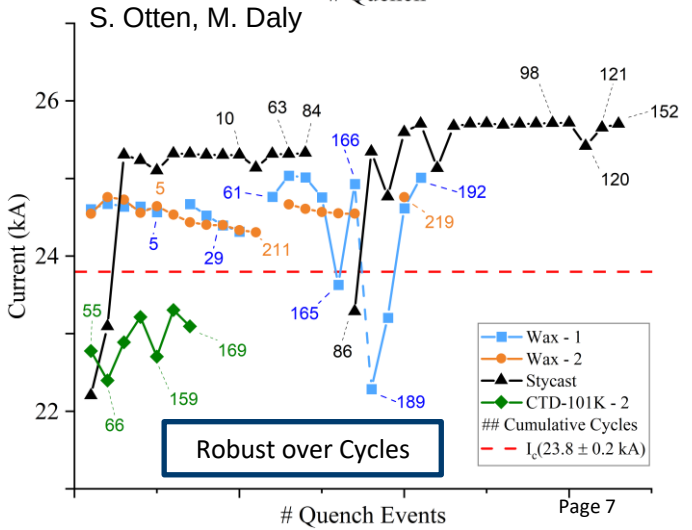


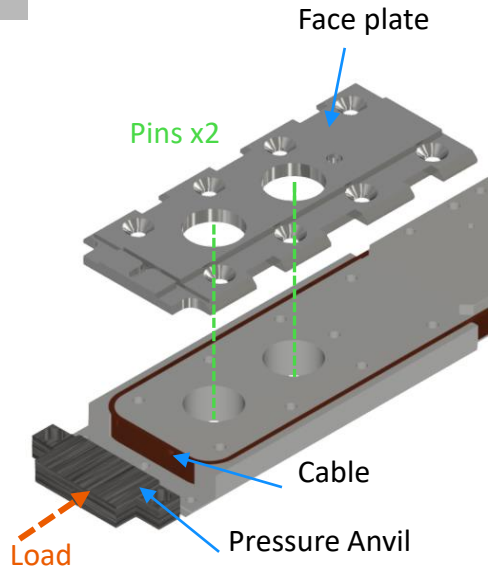
S. Otten, M. Daly



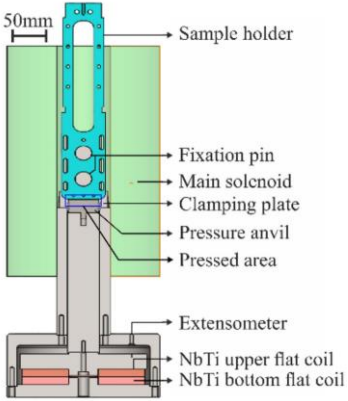
M. Daly *et al.*, "BOX: an efficient benchmark facility for the study and mitigation of interface-induced training in accelerator type high-field superconducting magnets," *Supercond. Sci. Technol.*, vol. 34, no. 11, p. 115008, Sep. 2021, doi: 10.1088/1361-6668/ac2002.

LTS Powered Samples Compression BOX

BOX Conceptual View



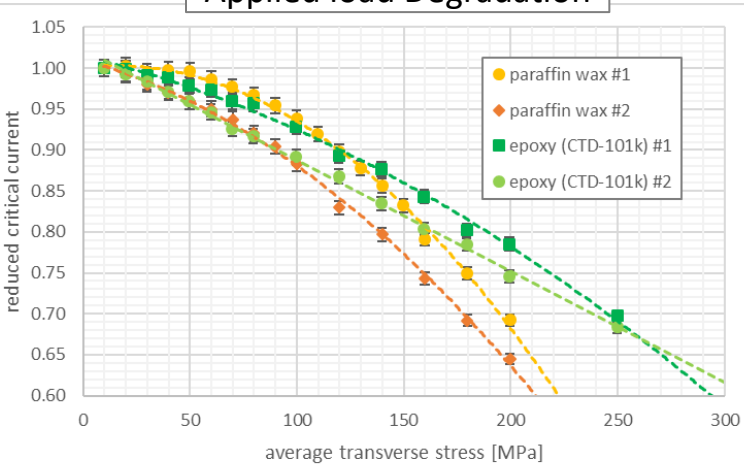
UT Test Facility



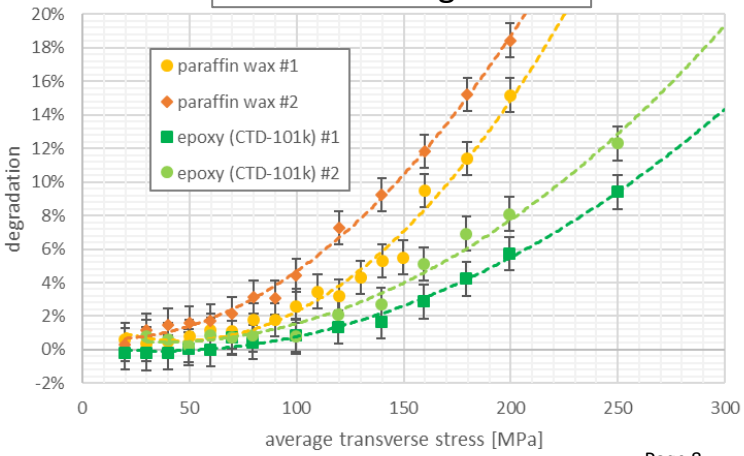
Peng Gao

UNIVERSITY OF TWENTE.

Applied load Degradation



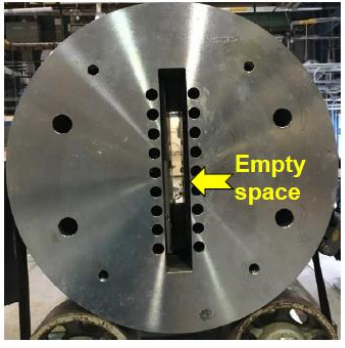
Permanent Degradation



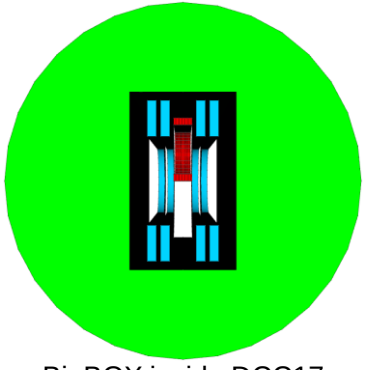
ASC2022 - 1LOr1C-07: Effect of Transverse Pressure up to 200 MPa on a Wax impregnated Nb3Sn Rutherford cable. M. Daly et Al.

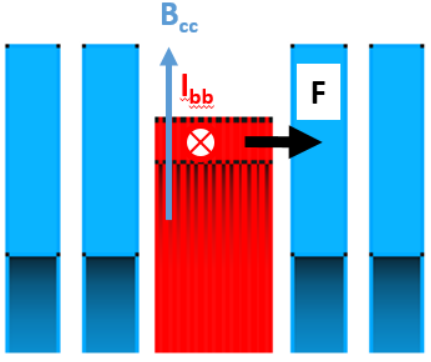
LTS Stress-managed Coil – BigBOX Goals and Manufacturing 1/3

- Assessing coil performance
  - Superconductor margin
  - Conductor degradation
  - Coil training behaviour
- Validating technologies
  - Preload free coil
  - Interface conditions
  - Wax impregnated coils
  - Stress-management
  - Ceramic Insulation Coating



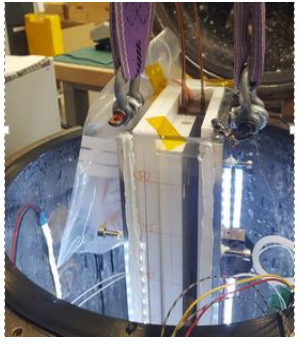
DCC17 Magnet

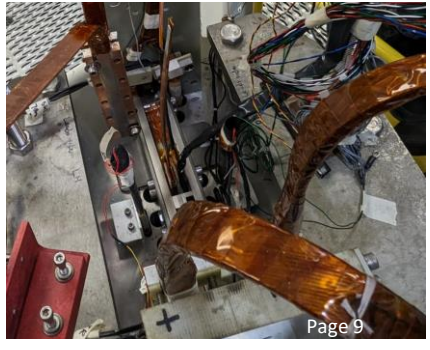

BigBOX inside DCC17



Cross-section illustration

Processes: Winding | Impregnation | Electrical Tests | Integration



LTS Stress-managed Coil – BigBOX Modelling and Integration 2/3

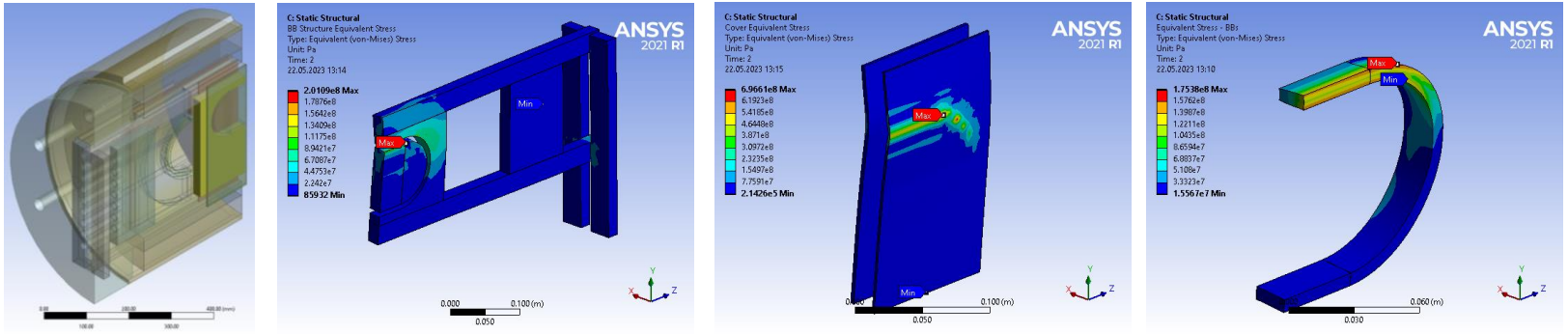
- 3D Modelling and Stress-Management Concept

BigBOX and DCC17 Model

Coil Structure

Stress-managed component

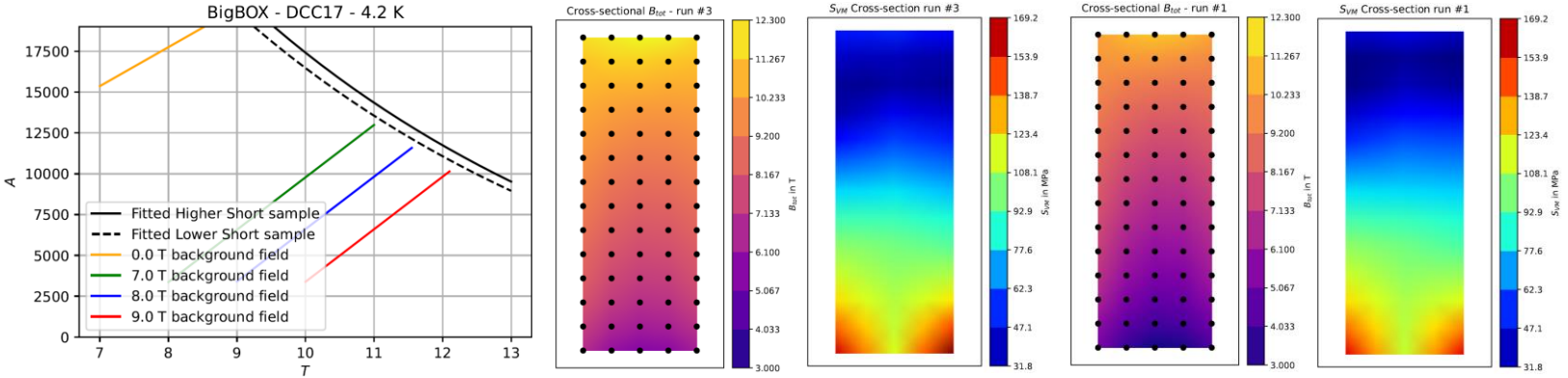
Coil - Powering



BigBOX load lines for several background fields

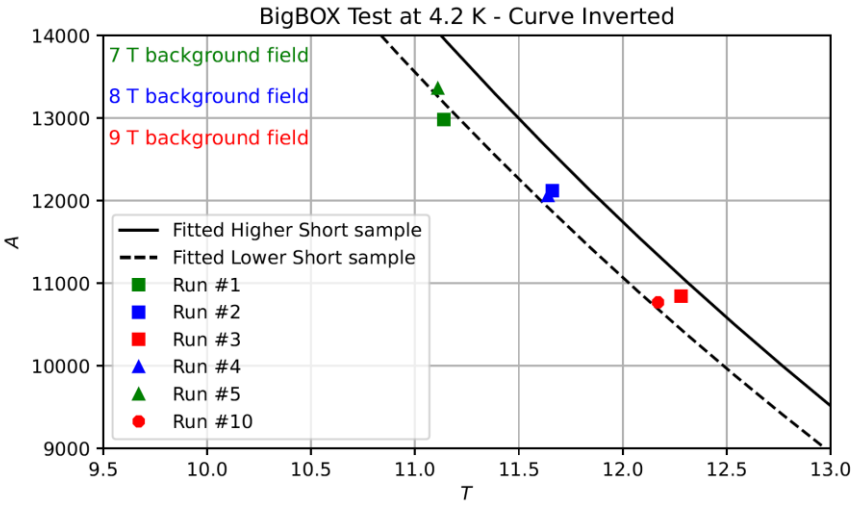
Stress and field with 7 T bg field

Stress and field with 9 T bg field



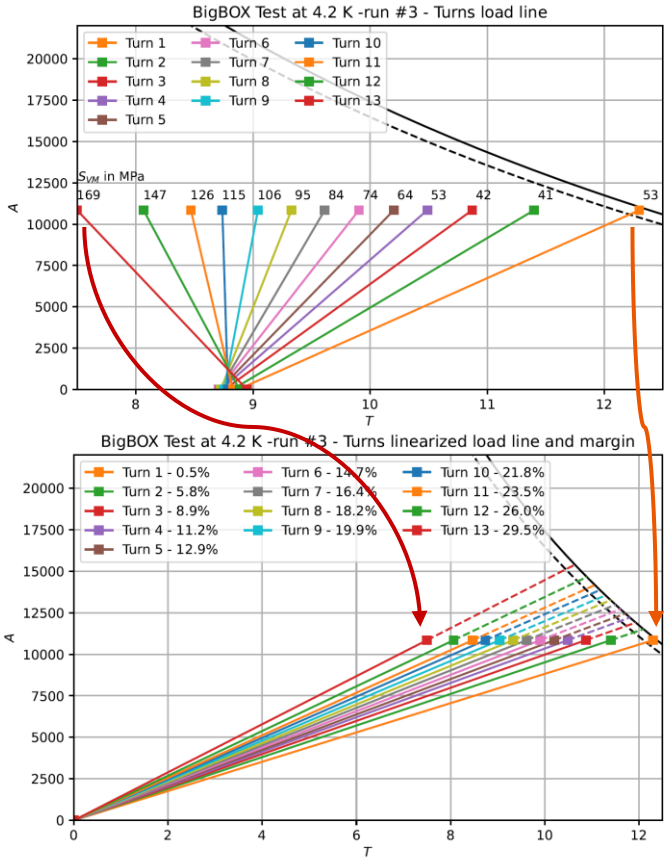
LTS Stress-managed Coil – BigBOX 3/3

- Test Results: 6 times power-up to short sample limit without training behavior



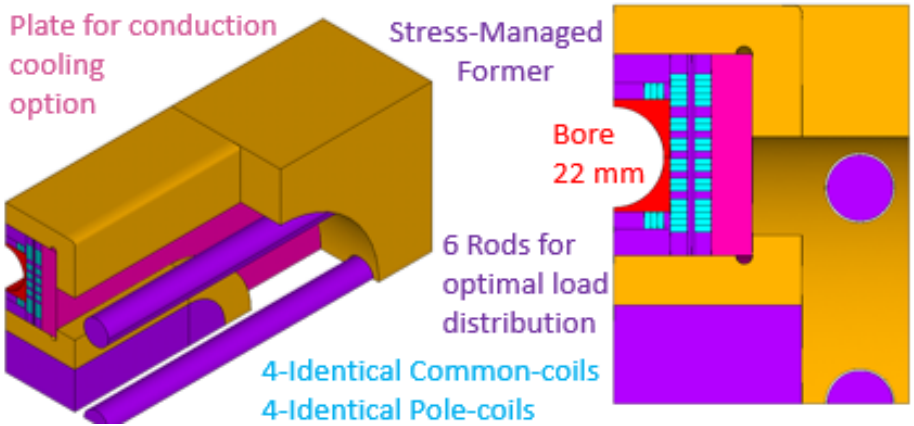
- How we can take advantage of this results on the superconducting magnet design phase?

The engineering margin is inferred from the computed magnetic field and mechanical stress and the applied electrical current.



Ongoing: Subscale Platform for LTS and Hybrid Magnets 1/2

- Validating manufacturing process and introducing advanced concepts: pre-load free, at room temperature, magnet; stress-management structure and grading.
- Fast turn-around platform for testing matrix systems; protection concepts and cooling options.

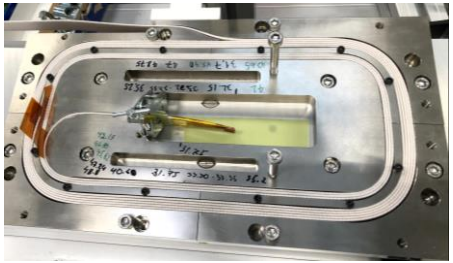


Magnet parameters for testing all coils or the common-coils. The coils straight section is 150 mm. The values refer to the fitted wire Ic curve at 4.2 K values.

Parameter	All coils	CCs
B_0 in T	5.15	5.1
B_{peak} in T	6.45	6.3
I_{op} in kA	8.25	9.2
E_{mag} in kJ	15.2	16.4

Ongoing: Subscale Platform for LTS and Hybrid Magnets 2/2

- Progress on R&D and engineering design (goal of testing in 2024)

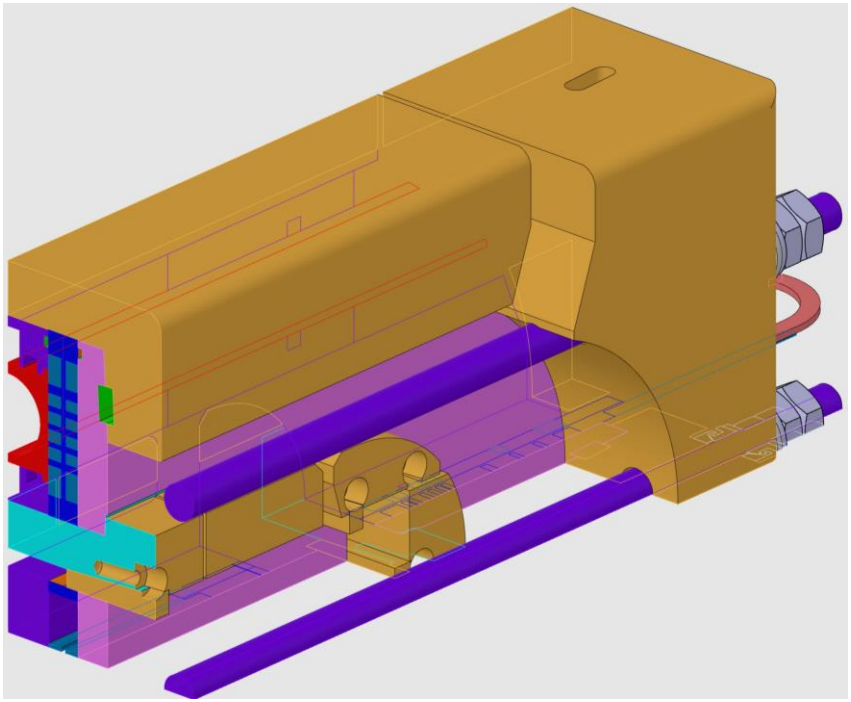


Winding method validation

Instrumented mock-up for assembling validation

Pre-scaled paper after disassembling the Mock-up

3D Detailed CAD model



C. Müller, A. Brem

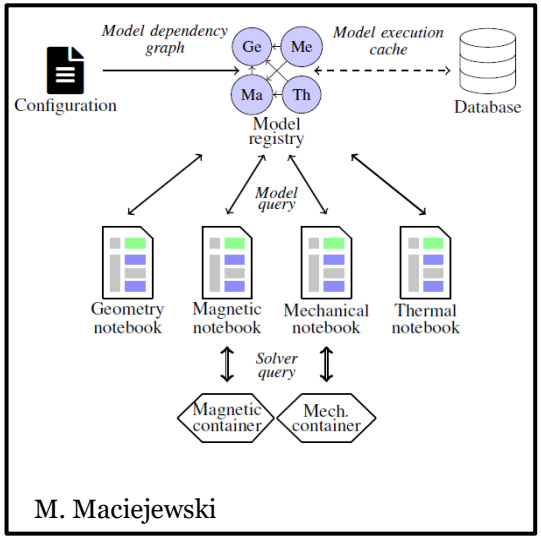
T. Michlmayr

Collaborative Integration with CHART Projects

https://chart.ch/chart-projects/

ETH zürich

- MagRes
- WireChar
- MagComp
- MagAM
- MagNum

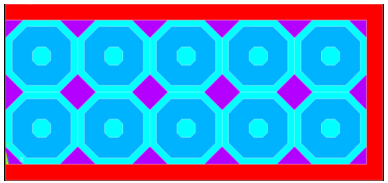


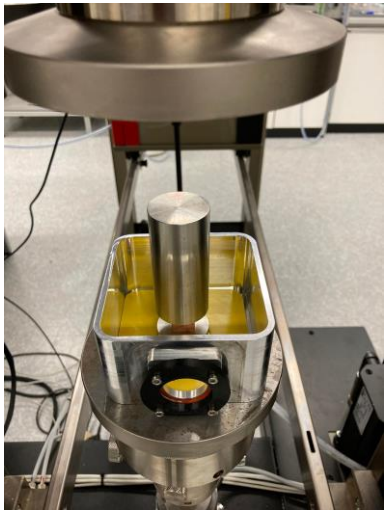
M. Maciejewski

A. Brem

C. Senatore

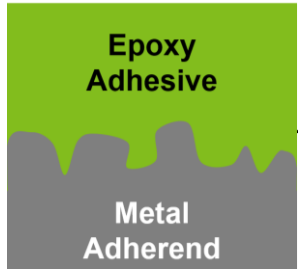
UNIVERSITÉ DE GENÈVE

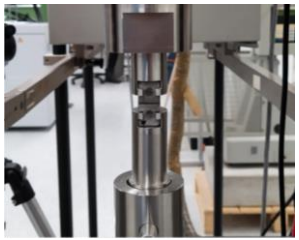




X. Kong

J. Ferchow



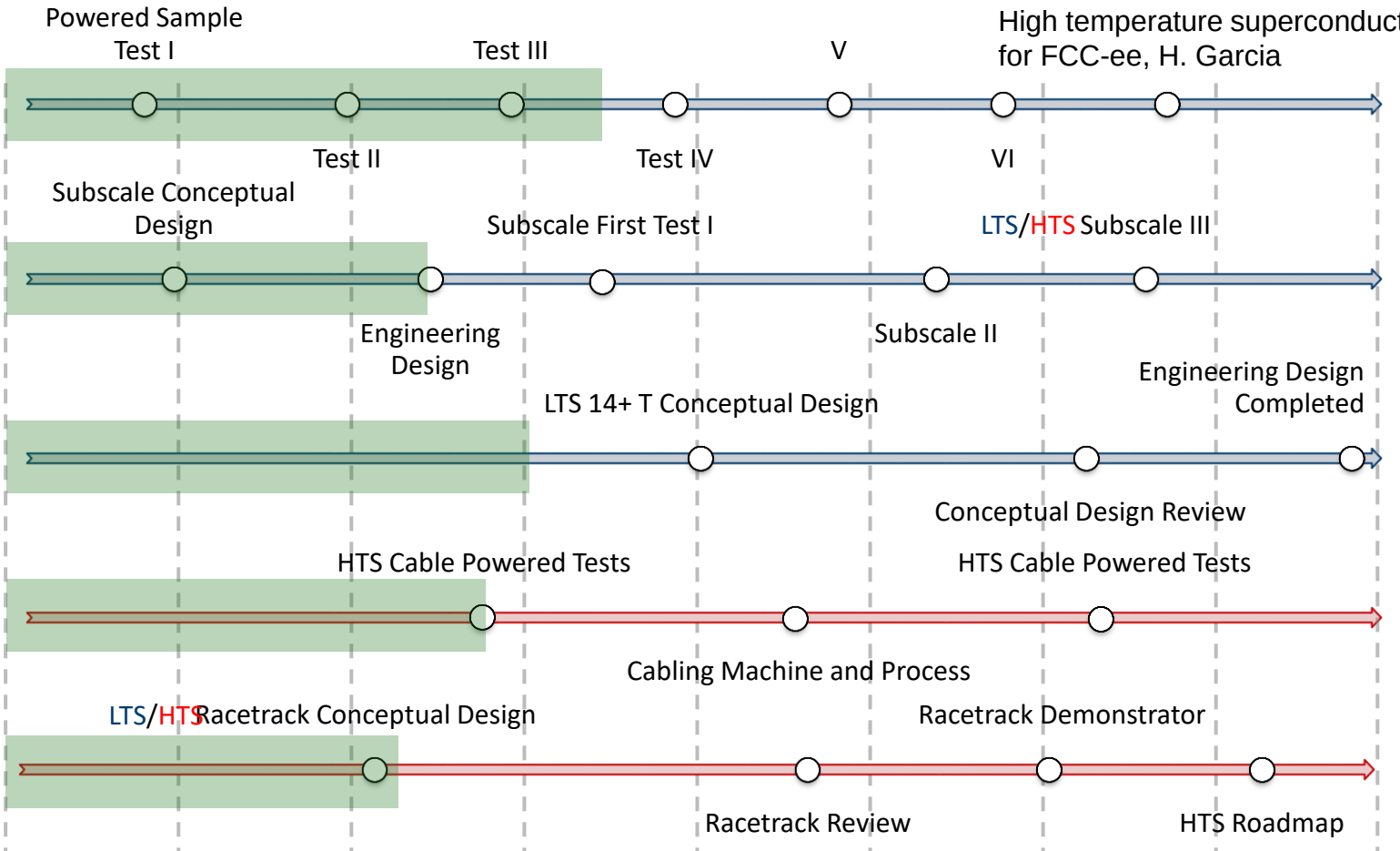


P. Müller

CHART/MagDev2 Timeline

ReBCO High-Temperature Superconductors for Application in High Field Accelerator Magnets. B. Auchmann

High temperature superconducting magnets for FCC-ee, H. Garcia



Q2 2023

Q3 2025