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High Field Magnet Roadmap at PSI/CHART

Roadmap overview and progress report

Douglas Araujo[1], Bernhard Auchmann[1,2], Andre Brem[1], Michal Duda[1], Jaap Kosse[1], Thomas Michlmayr[1], Colin Müller[1], Henrique Garcia[1], Dmitry Sotnikov[1], Anna Stampfli[1], J. Van den Eijnden [1], and Ariel Haziot[2]

[1]Paul Scherrer Institute [2]CERN

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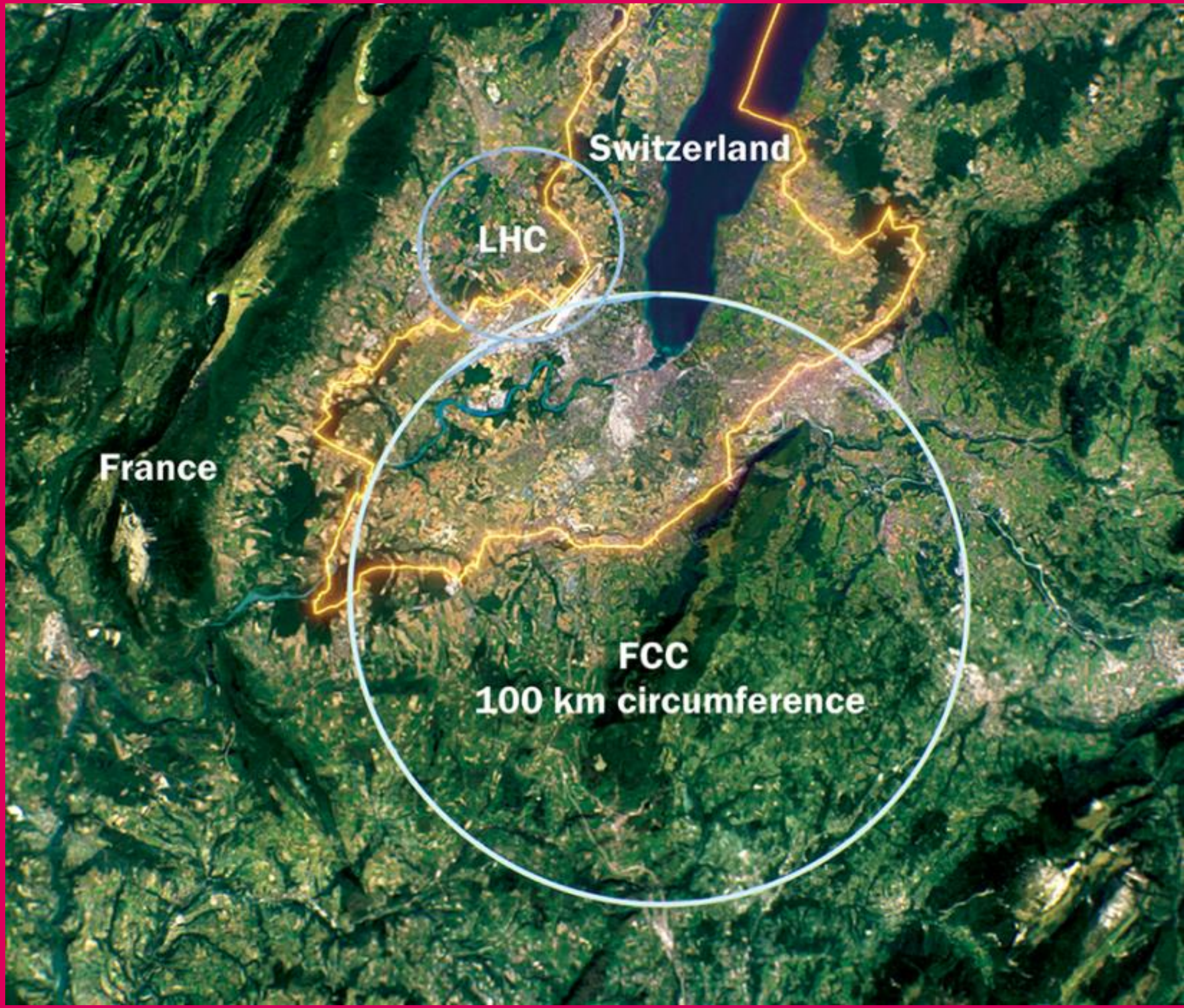
SPS Annual Meeting, Zürich, September 2024

Agenda

- High Field Magnets
- Roadmap
- Progress
- High Temperature Superconductors
- Coming soon…



High Field Magnets

FCC-hh: summary of main machine parameters for pp and physics potential

parameter	FCC-hh	HL-LHC	LHC
collision energy cms [TeV]	81 - 115	14	
dipole field [T]	14 (Nb_3Sn) - 20 (HTS)	8.33	
circumference [km]	90.7	26.7	
arc length [km]	76.9	22.5	
beam current [A]	0.5	1.1	0.58
bunch intensity [10^{11}]	1	2.2	1.15
bunch spacing [ns]	25	25	
synchr. rad. power / ring [kW]	1020 - 4250	7.3	3.6
SR power / length [W/m/ap.]	13 - 54	0.33	0.17
long. emit. damping time [h]	0.77 – 0.26	12.9	
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	~30	5 (lev.)	1
events/bunch crossing	~1000	132	27
stored energy/beam [GJ]	6.1 - 8.9	0.7	0.36
Integrated luminosity/main IP [fb^{-1}]	20000	3000	300

If FCC-hh after FCC-ee: significantly more time for high-field magnet R&D aiming at highest possible energies (HTS) and lowest electricity consumption

HFM High Field Magnets Programme

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Formidable challenges:
- ❑ high-field superconducting magnets: 14 - 20 T
- ❑ power load in arcs from synchrotron radiation: 4 MW → cryogenics, vacuum
- ❑ stored beam energy: up to 9 GJ → machine protection
- ❑ pile-up in the detectors: ~1000 events/xing
- ❑ energy consumption: 4 TWh/year → R&D on cryo, HTS, beam current, …

Formidable physics reach, including:
- ❑ Direct discovery potential up to ~ 40 TeV
- ❑ Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- ❑ High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays (γγ, Zγ, μμ)
- ❑ Final word about WIMP dark matter
- ❑ Insight into EW phase transition in early universe

MagDev

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

https://indico.cern.ch/event/1298458/timetable/

Roadmap | CHART Environment

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

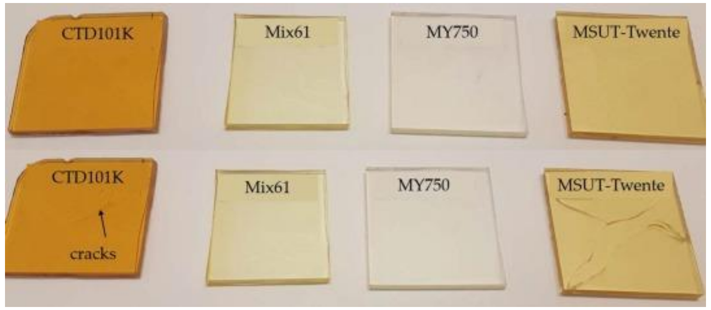
MagRes: resins

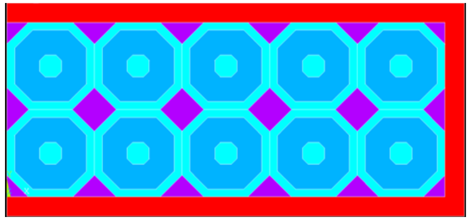
WireChar: conductor

MagComp: mechanics

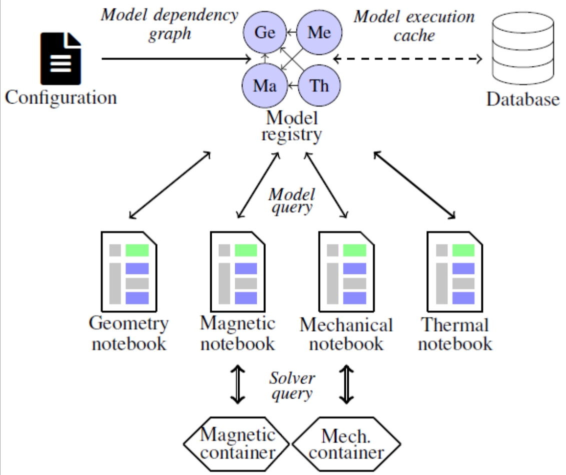
MagAM: 3D printing

MagNum: numerics

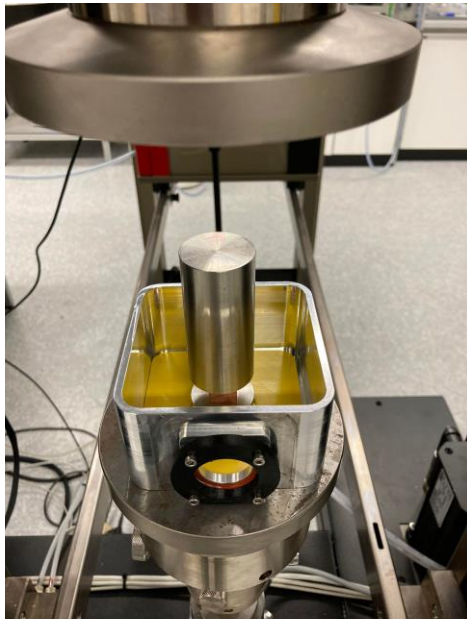




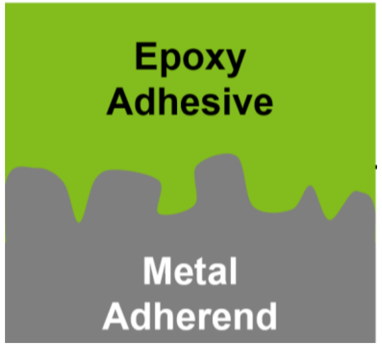
J. Ferchow



M. Maciejewski



X. Kong



P. Müller

C. Senatore UNIVERSITÉ DE GENÈVE

ETH zürich

Roadmap | R&D Vehicles small samples

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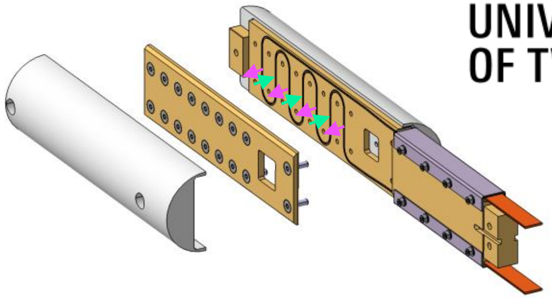
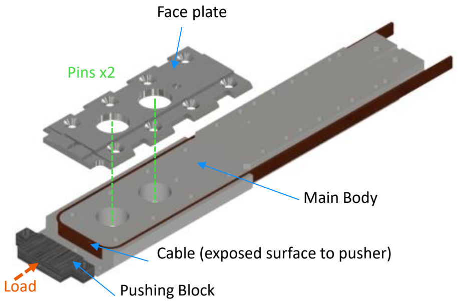
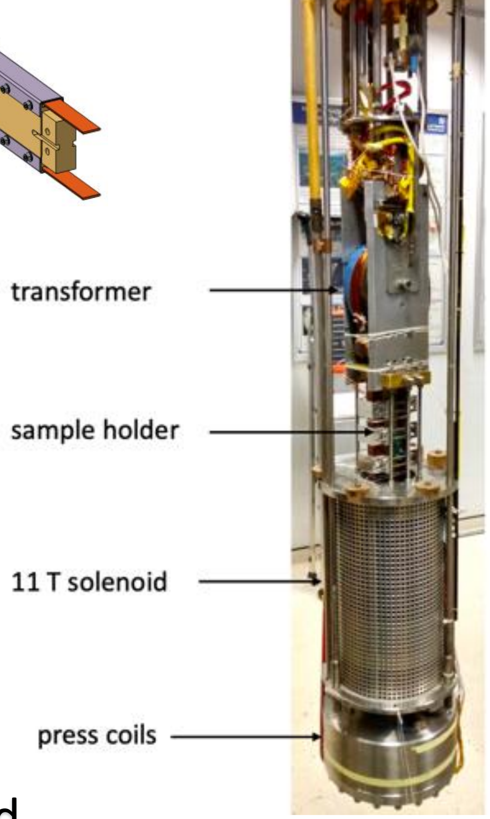


BOX and cBOX





11 T background field
Assessing training and degradation

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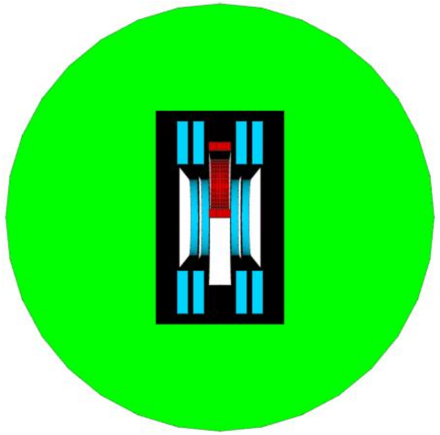
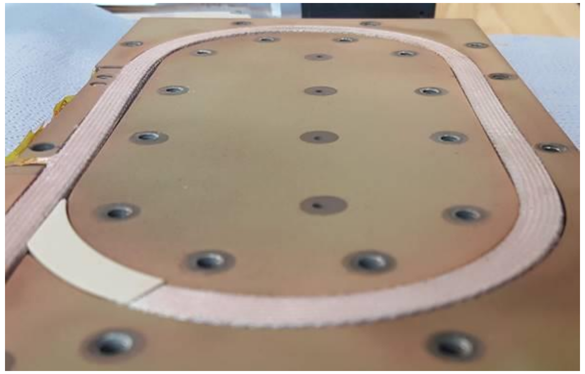
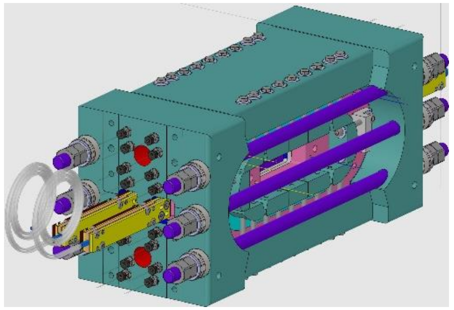
Big BOX



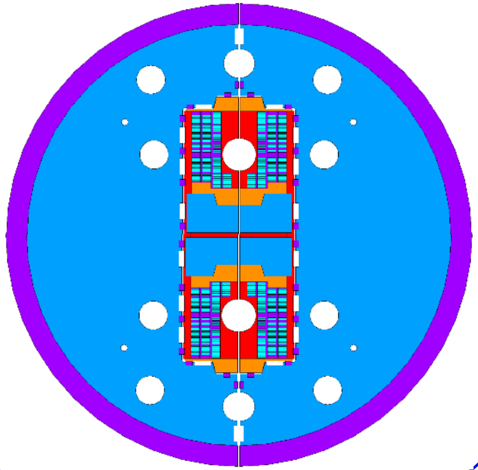
Multi turn
9 T background field, assessing training and degradation



Sub scale SMCC



SMACC 13 T



Standard BOX – addressing training in Nb_3Sn

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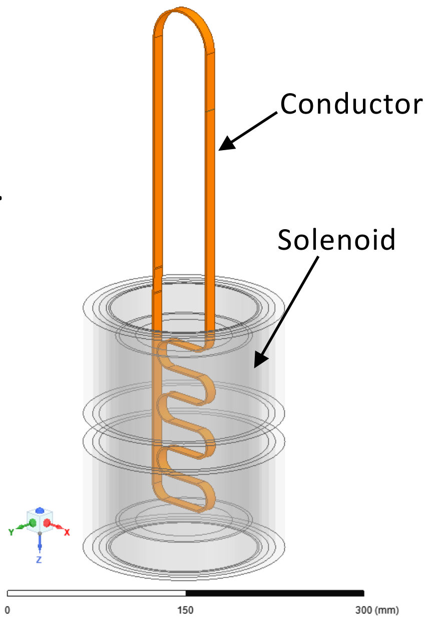
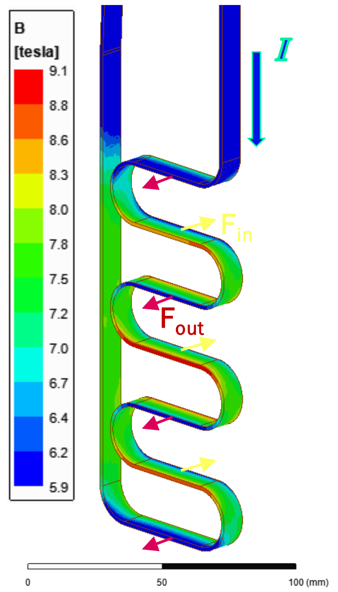
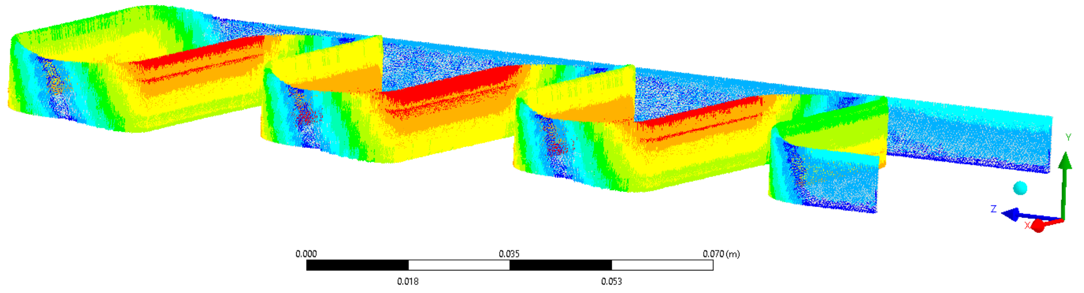
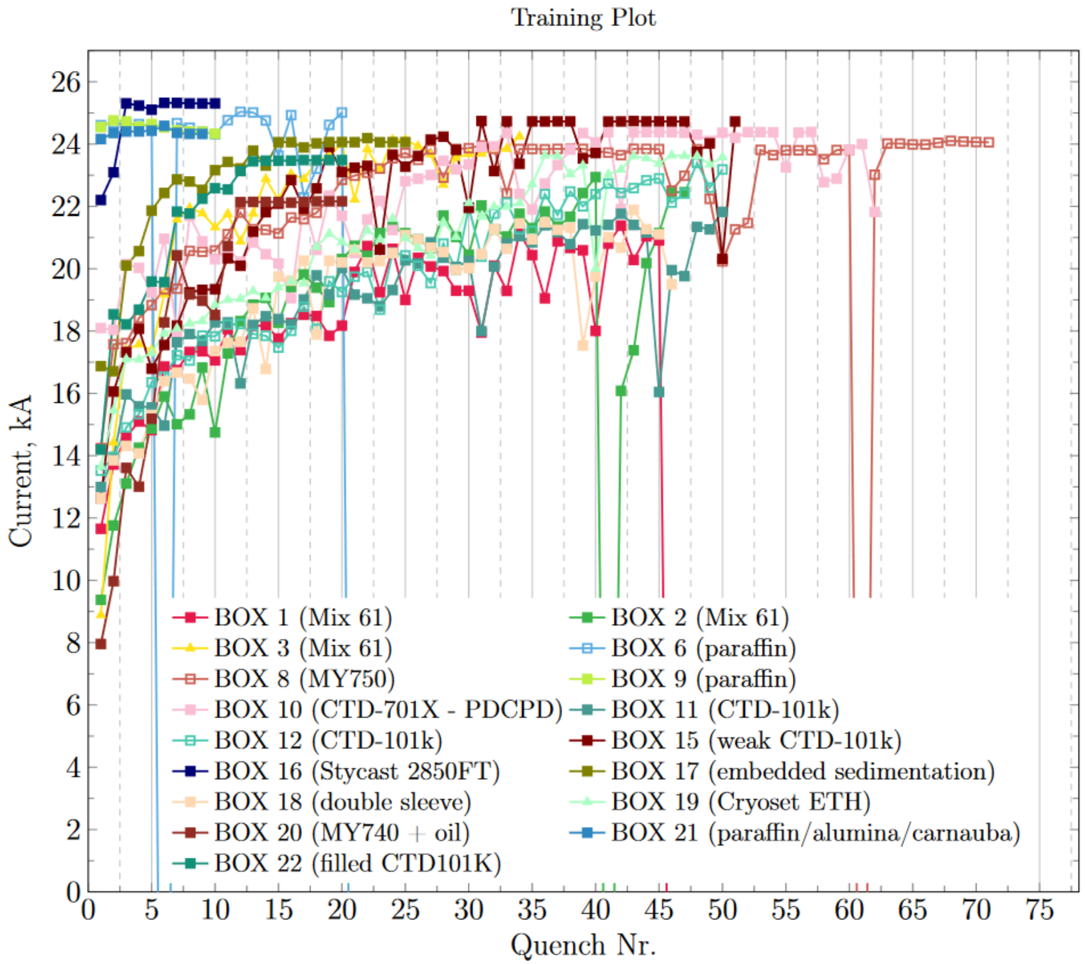


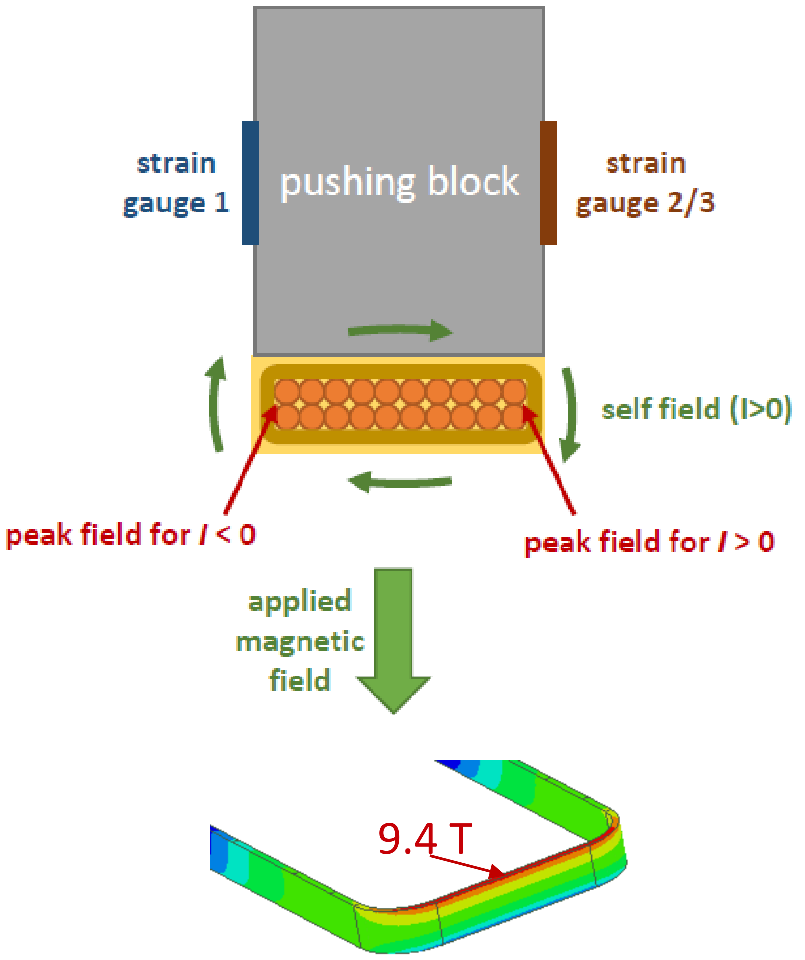


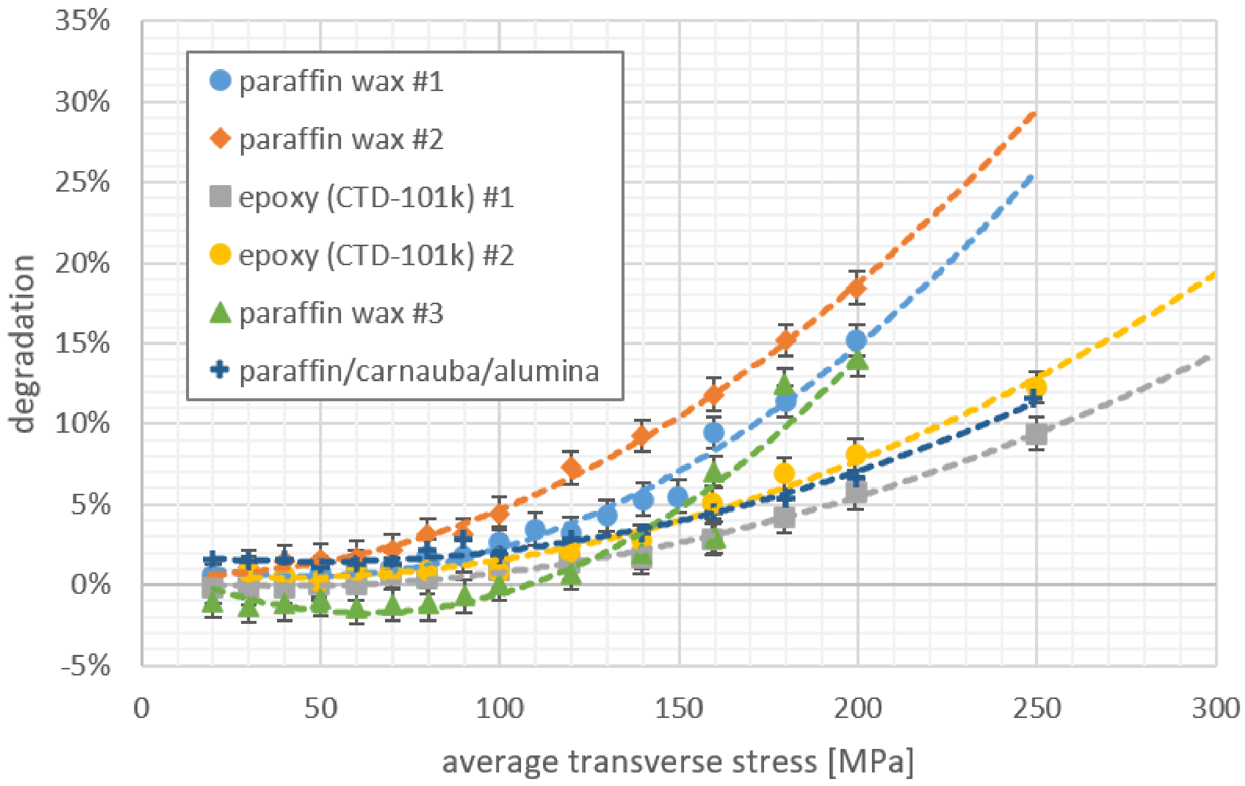




- ➢ evaluate impregnation systems
- ➢ 22 samples tested in the last 3 years

Compression BOX – degradation due to stress





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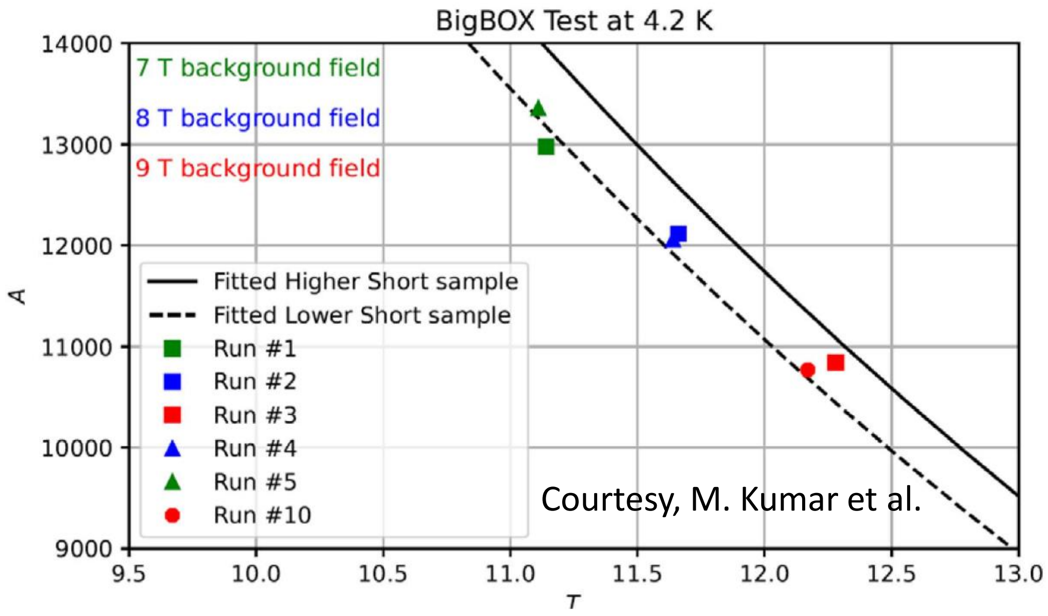
- evaluate impregnation systems
- reversible and irreversible degradation in external field
- 6 samples tested, 2 currently under testing

BigBOX: multi turn Nb_3Sn coil

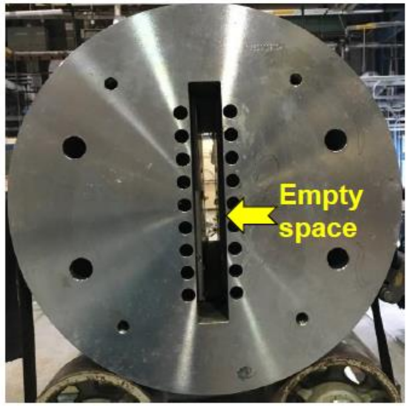
Assessing coil performance
- Superconductor margin
- Conductor degradation
- Coil training behaviour

Validating technologies
- Preload free coil
- Interface conditions
- Wax and filled wax impregnated coils
- Stress-management
- Ceramic Insulation Coating



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

BigBOX2 (impregnated with filled-wax)was manufactured, delivered to BNL and it is waiting to be tested



DCC17 Magnet

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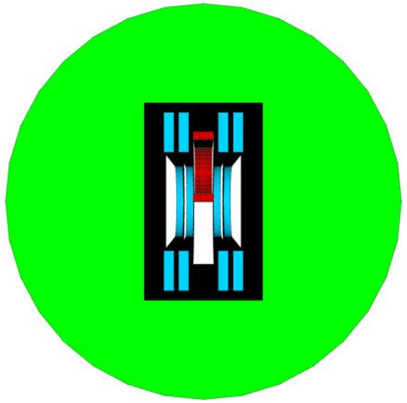
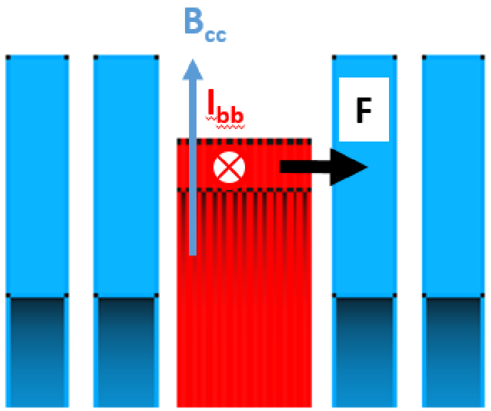
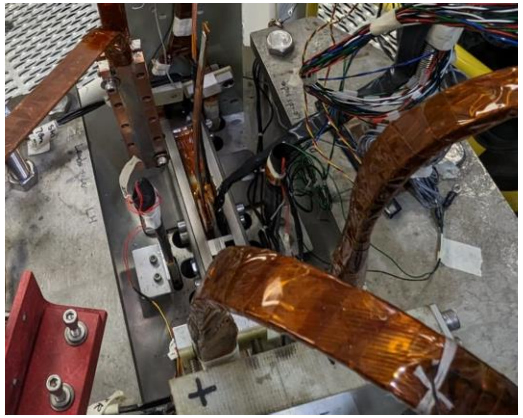


BigBOX inside DCC17



Cross-section illustration



Subscale SMCC | Concept

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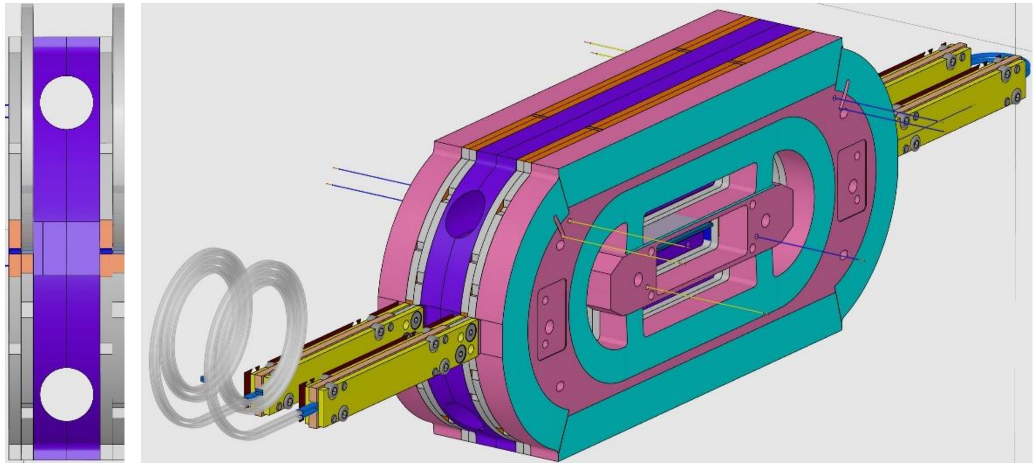
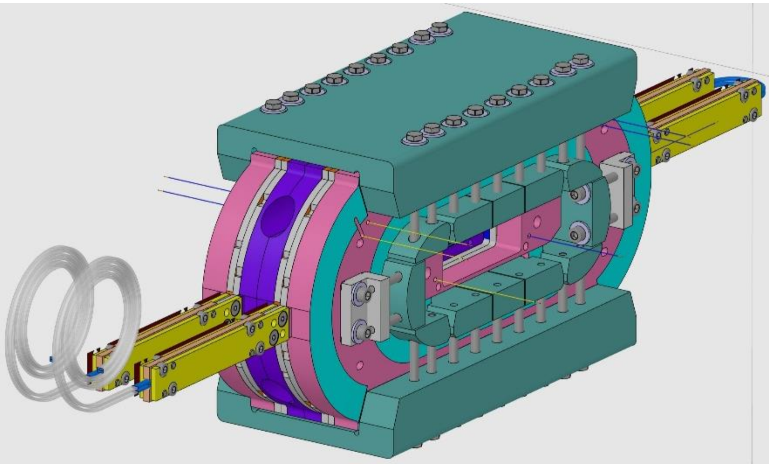
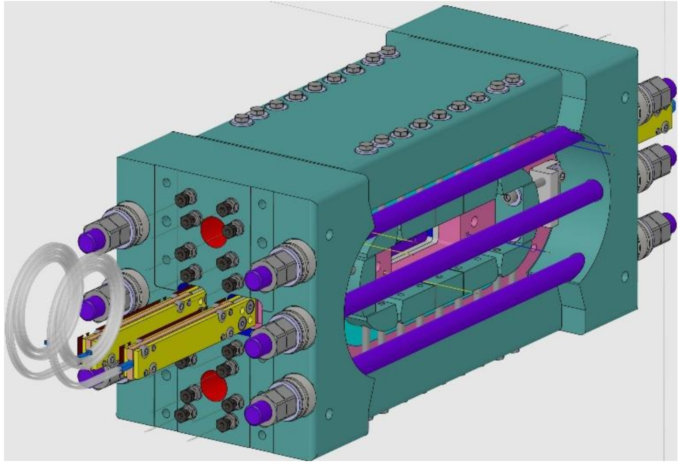


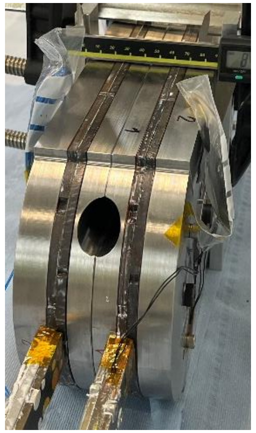
4 common-coils, coil-pack assembly and splice region

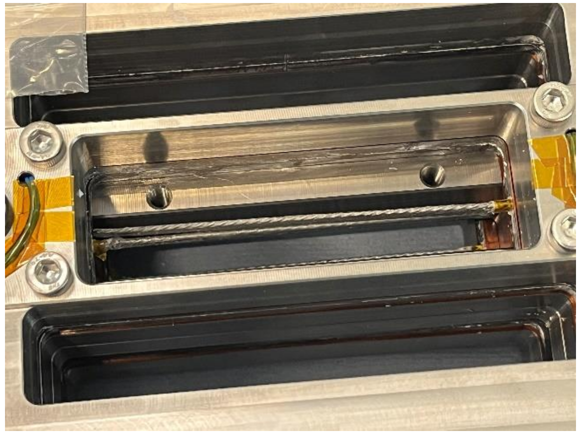


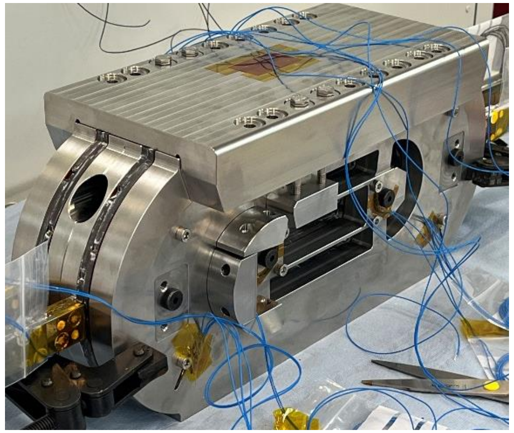
Outer pads

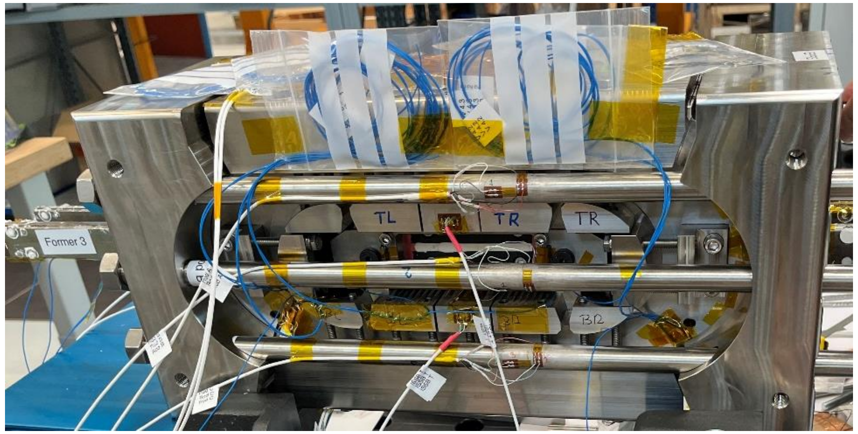


End pads









Cable manufactured by LBNL

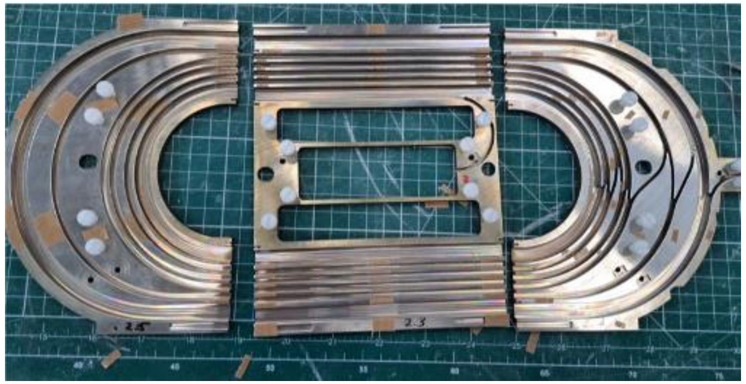
BERKELEY LAB

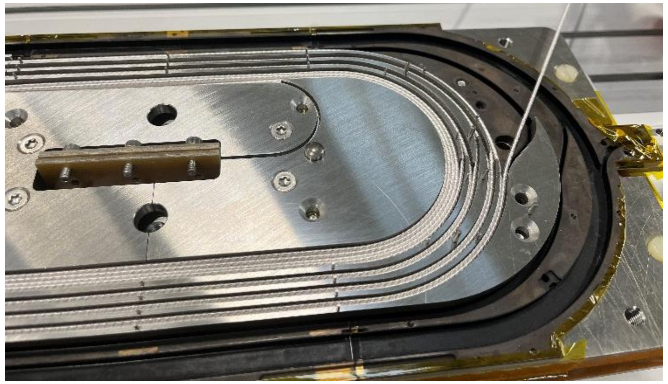
Subscale SMCC | Innovations

Stress-Management
Common-Coils Former

Winding Technique

Instrumentation routing



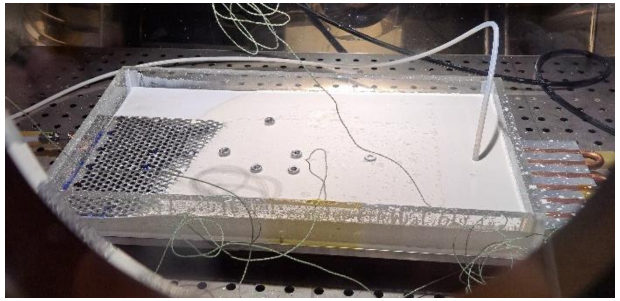


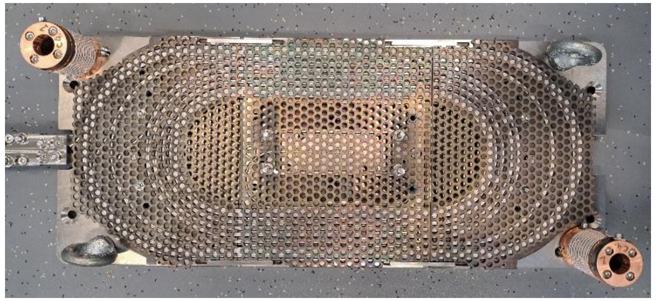
First stand alone impregnated with
Filled Wax system to be tested

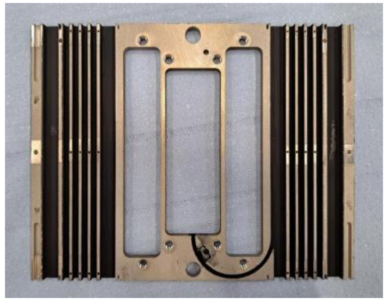
Impregnation Technique

Re-use of tooling through winding,
reaction and impregnation

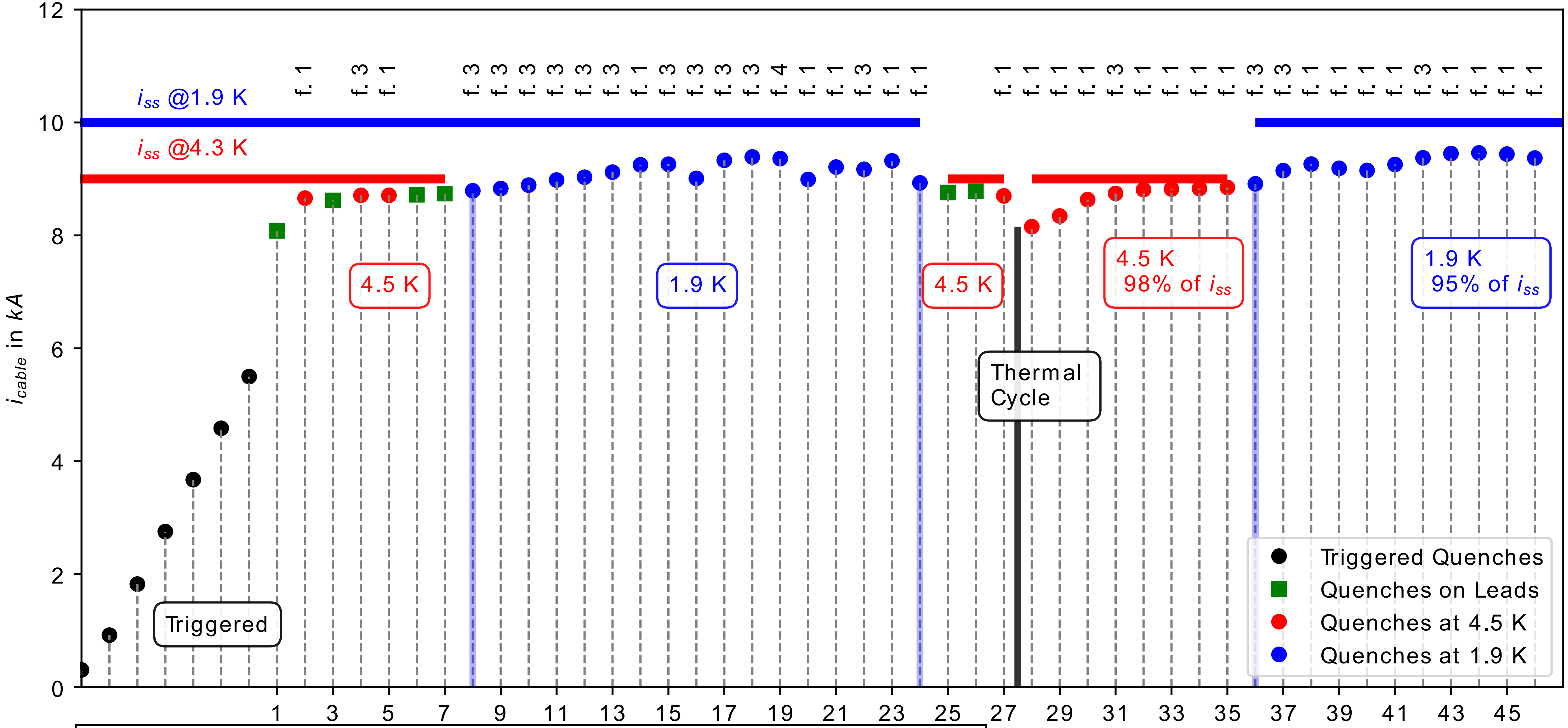
Former Coating







2 coils reacted at CERN, SMT Section
2 coils reacted at PSI



Performance					
T = 4.5 K	i_{ss} = 9.0 kA	i_{max} = 8.85 kA	B_0 = 4.9 T	B_{peak} = 6.04 T	I_{max}/i_{ss} = 0.98
T = 1.9 K	i_{ss} = 10.0 kA	i_{max} = 9.39 kA	B_0 = 5.2 T	B_{peak} = 6.41 T	I_{max}/i_{ss} = 0.94

Courtesy, G. Willering et al.

HTS Challenges and Opportunities

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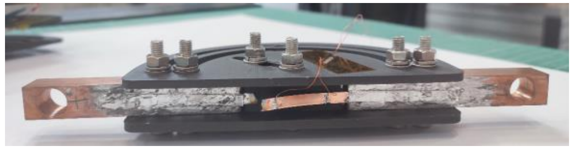
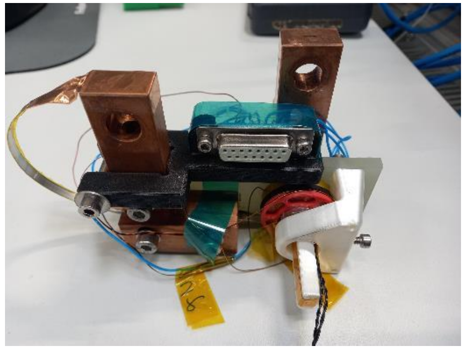
HTS technology

sensitive to mechanical strain
sensitive to thermal load



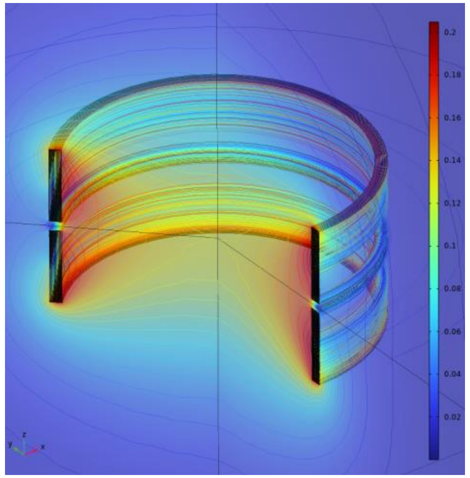
HTS coil manufacturing

HTS tape operation
Noise cancellation and Protection
Modelling validation

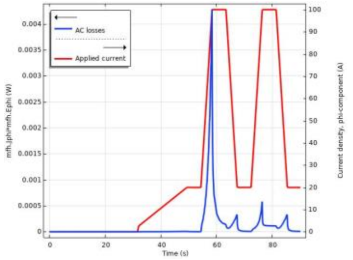


Modelling

FEM software for electro-magnetics
postprocessing measured data

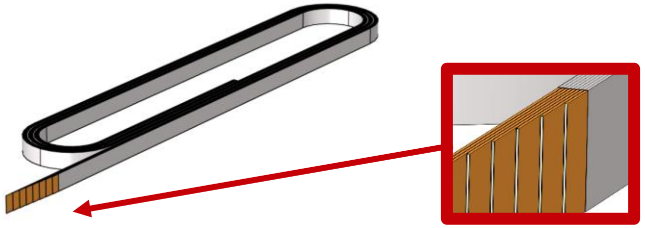


AC losses prediction



HTS cable models

Soldered stack based - HTS cable



HFM concepts

14 T at 20 K
16 T at 20 K

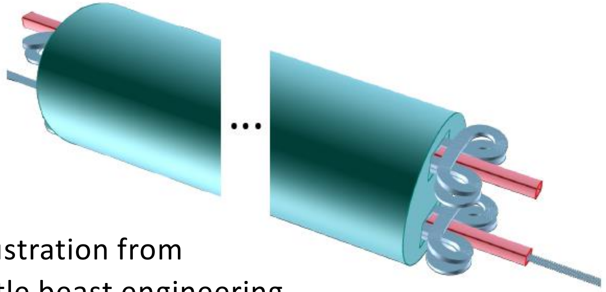


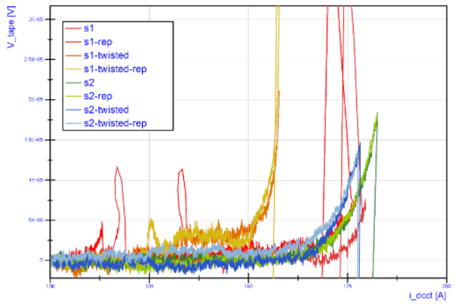
Illustration from
Little beast engineering

Production and measurements

Single tape

Bending and twisting of tape:

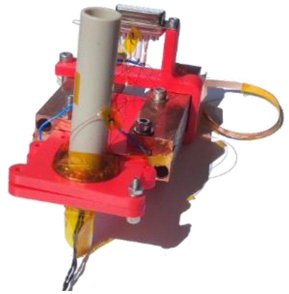
- Set of bending experiments showed degradation of HTS tapes
- Twisting on 15-mm former for double pancake with 4-mm twist pitch (tape width)

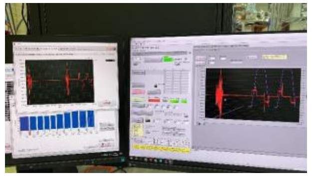


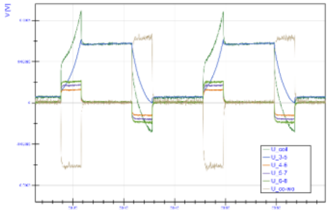
Pancake coils

Several samples of pancake production:

- 1 single tape pancake
- 2 double-tape stack pancake
- 1 single tape double pancake







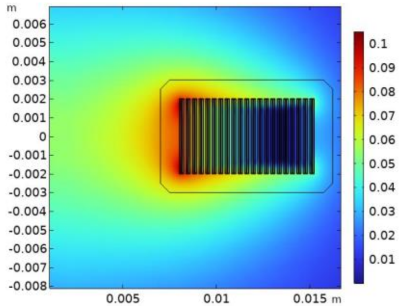
Results:

- 48 measurements done in LN2
- Co-wound coil works for protection
- Signal recorded to 1 uV

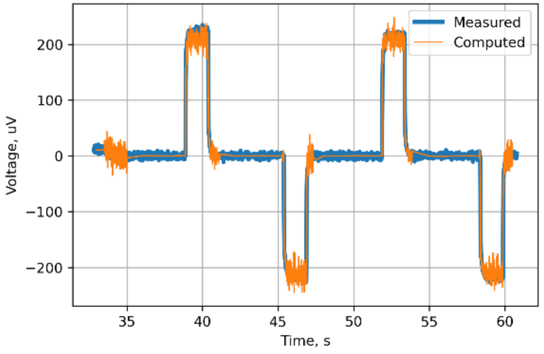
Validation (w/ U. Twente)

Criteria for validation:

- Voltage on coil (done)
- AC losses (ongoing)
- Magnetic field (ongoing)



Coil voltage validation

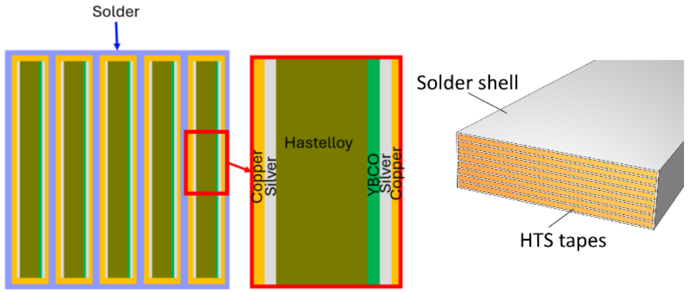


Modelling

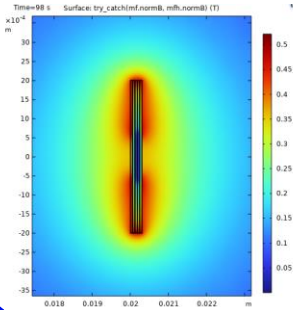
HTS cable

HTS straight soldered stack cable has several benefits:

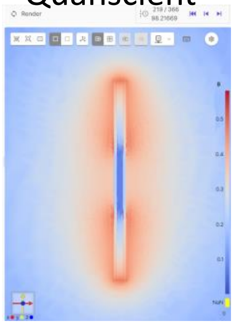
- Shape fits to racetrack design
- Fits to Block-coil and Common coil
- Highest packing factor
- Highest oriented critical current



Comsol



Quanscient



14 T HTS dipole

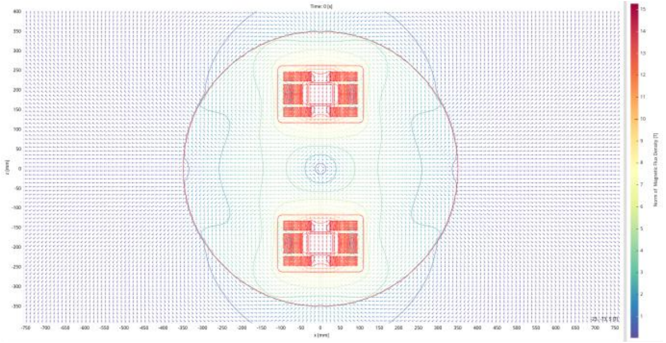
Little Beast collaboration

Type: Block coil

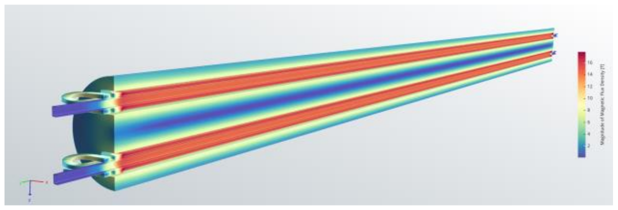
Target field: 14 T

Temperature: 20 K

Goal: comparison with LTS projects



Courtesy J. van Nugteren



16 T HTS dipole

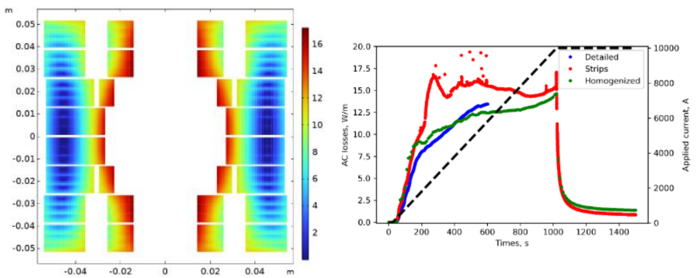
AC losses optimization

Type: Block coil

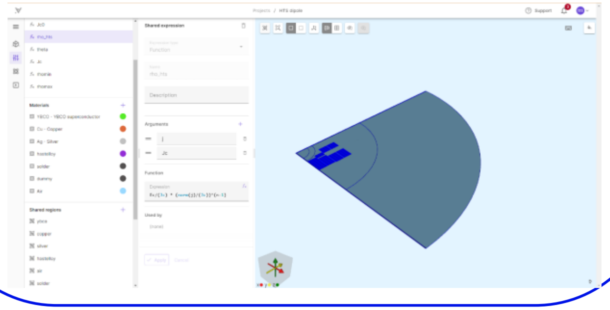
Target field: 16 T

Temperature: 20 K

Goal: getting AC losses prediction with different computation software



QUANSCIENT



Coming soon…

- LTS and HTS samples for testing new impregnation systems, AC losses study and modelling validation
- 2024: LTS subSMCC2: testing new protection systems that could be suitable for both LTS and HTS
- 2025: HTS subSMCC3: insulated ReBCO - based cable
- 2025: SMACC: 13 T demonstrator with field quality