PAUL SCHERRER INSTITUT

Swiss Accelerator Research and Technology

09.06.22 – CHART Workshop 2022

MagDev1

B. Auchmann (PSI/CERN) for the MagDev team: D. M. Araujo, A. Brem, M. Daly, C. Hug, J. Kosse, T. Michlmayr, H. G. Rodrigues
with support from PSI Magnet Section and M. Duda (CHART FCCee Injector Study)

Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI.

Overview

- CHART1: CCT Demonstrator
- CHART2 MagDev1: Technology Development
- CHART2 MagDev2: Stress-Managed Cosine Theta Roadmap
- CHART2 MagDev1/2 HTS Developments
  - NI coil technology and CHART2 FCCee Injector Study project
  - Technology Racetrack and SuperBend Demonstrator
- CHART2 MagDev1 Technical Review and CHART Synergies

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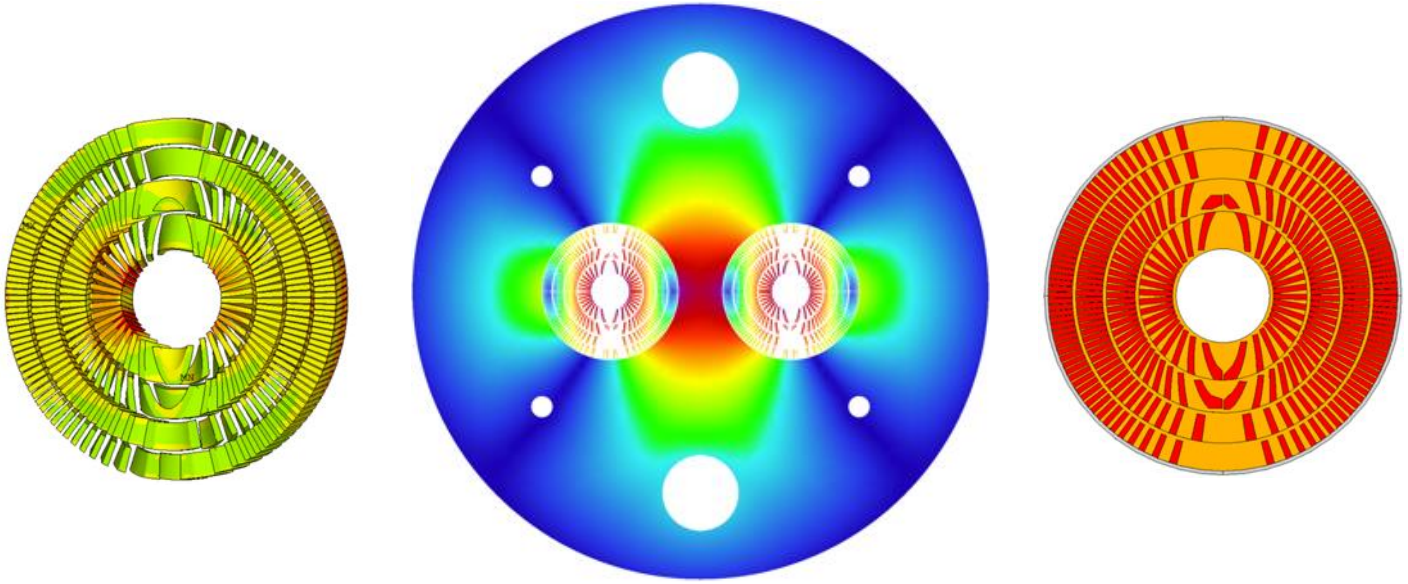
CHART1 MagDev0 Goals

- CHART1 goals (mid-2016 to mid-2019) :
  1. the design of an optimised 16 T Canted Cosine Theta (CCT) dipole magnet, as an option for the FCC hadron collider main magnet;
  2. the development (design and prototype) of a high-field dipole magnet with CCT technology.



[B. Auchmann et al., *Electromechanical Design of a 16-T CCT Twin-Aperture Dipole for FCC*, IEEE Trans. on Appl. SC 28 (April, 2018) no. 3.]

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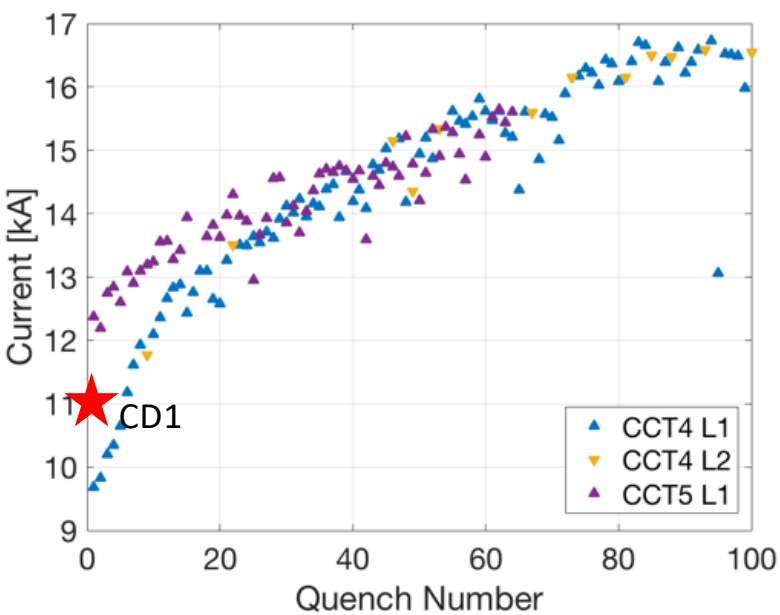
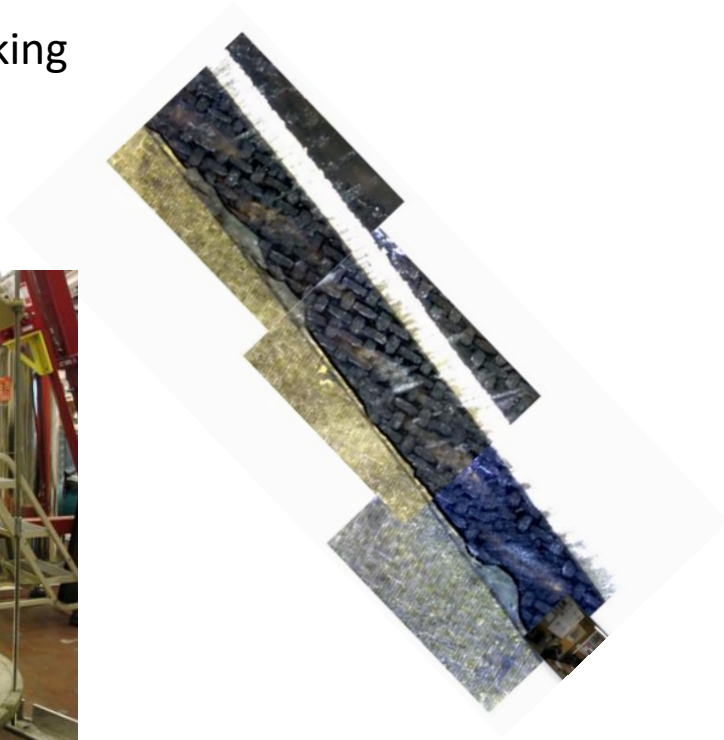
[G. Montenero et al., *Coil Manufacturing Process of the First 1-m-Long Canted-Cosine-Theta (CCT) Model Magnet at PSI*, IEEE Trans. on App. SC., Vol 29(5), 2019.
G. Montenero et al., *Mechanical Structure for the PSI Canted-Cosine-Theta (CCT) Magnet Program*, IEEE Trans. on Appl. SC., Vol 28(3), 2018.]

CD1 Testing Odyssey

- Magnet was shipped to LBNL in Nov. 2019.
- The test preparation was interrupted by COVID 19 and resumed in Aug. 2020.
- Magnet test started in Sept. 2020 but interrupted by cryo problem.
- Max. current after 2 quenches: 11.1 kA or 62.5% of short sample, 6 T in the bore.
- **CHART has built a *magnet*** (no more and no less can be said at this stage).
- **Test to be continued at CERN in Q1 Q2'22**.
- LBNL experience points to a debonding and cracking problem in the impregnated channels, causing excessive training.





Courtesy D. Arbelaez, LBNL.

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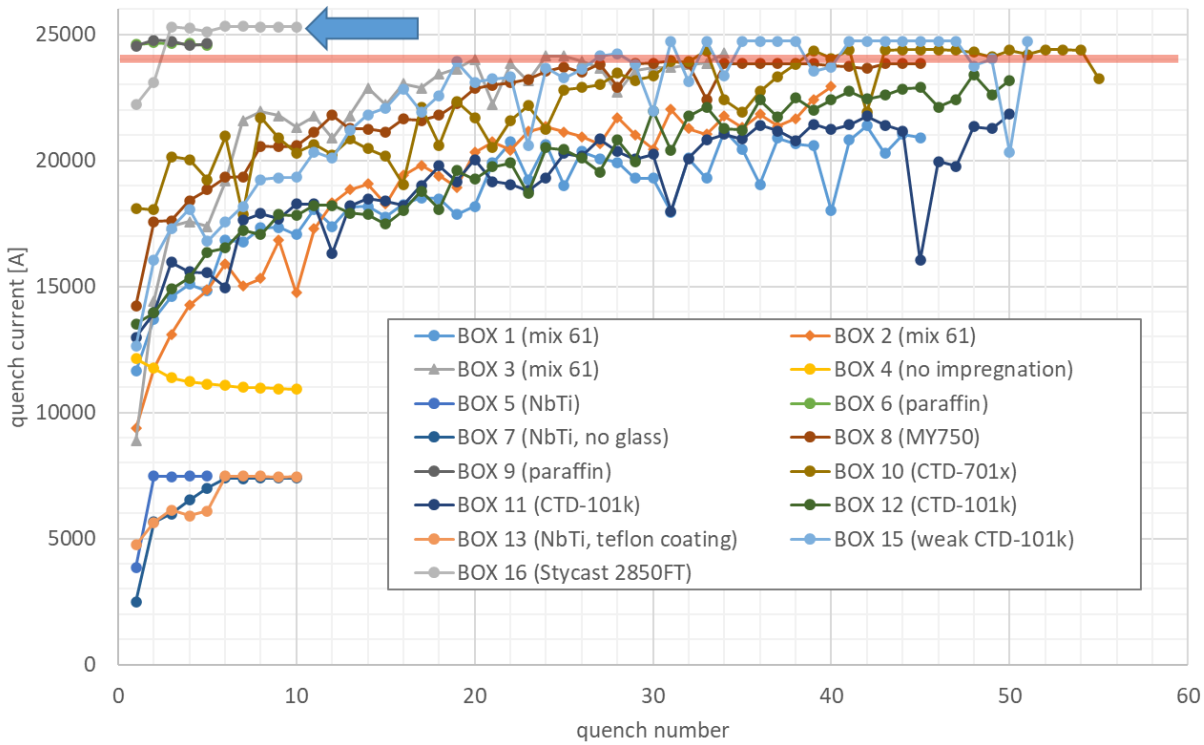
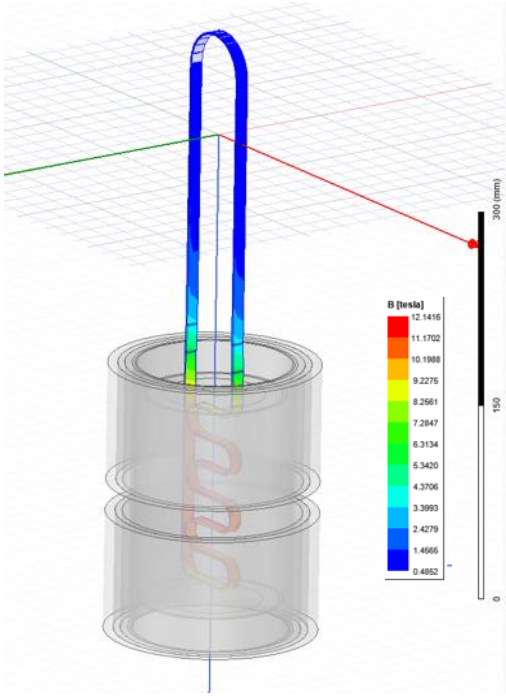
BOX Program





Pictures by M. Daly, S. Sidorov, S. Otten

BOX (BOnding eXperiment) program with uTwente has shown a wide variety of results, from complete conductor ***degradation (no impregnation)*** to substantial ***training (epoxy)*** to ***no-training (wax, Stycast),*** with ***15 BOX samples*** successfully manufactured and tested to date.

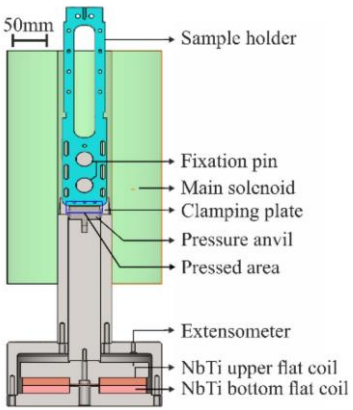
Wax-impregnated CCT subscale magnet ***to be tested at LBNL shortly***. Additional tests in Nb-Ti CCTs under preparation at ***Wigner Institute, INFN, and CERN***.

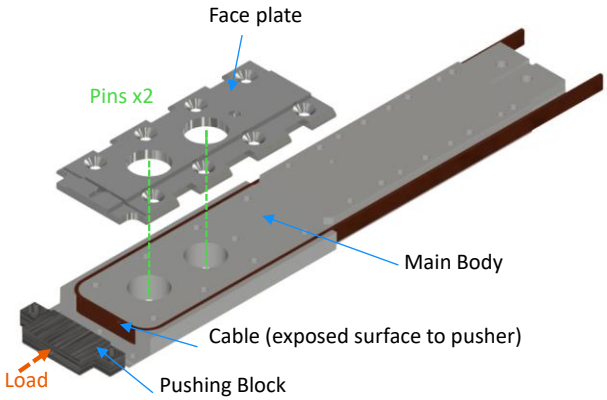
BOX Compression

Successful systems can be characterized and benchmarked against CTD101-K in U Twente's transverse-compression setup.

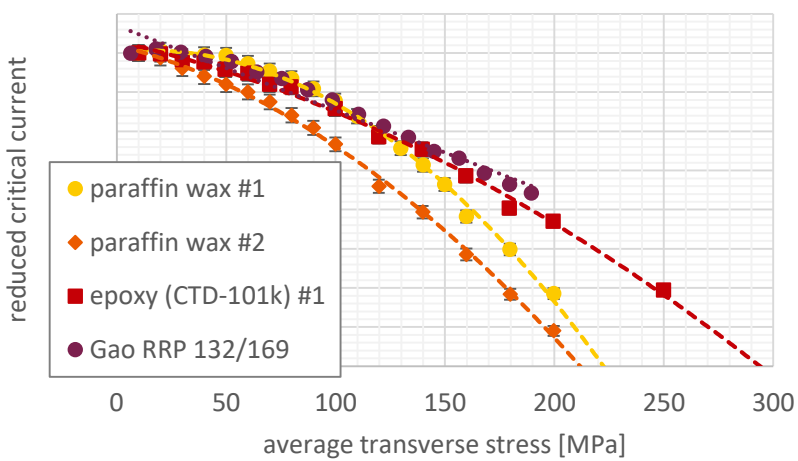
CTD 101-K measurements reproduce previous results.

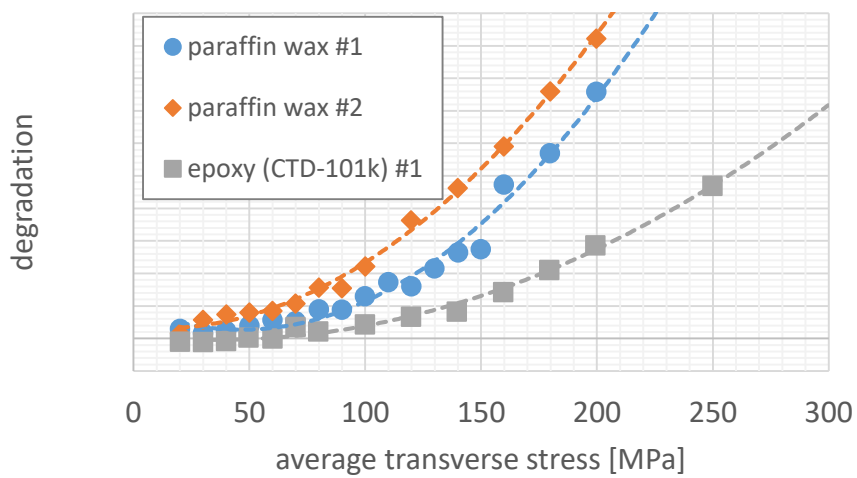
Paraffin wax's lower modulus and yield increase degradation.





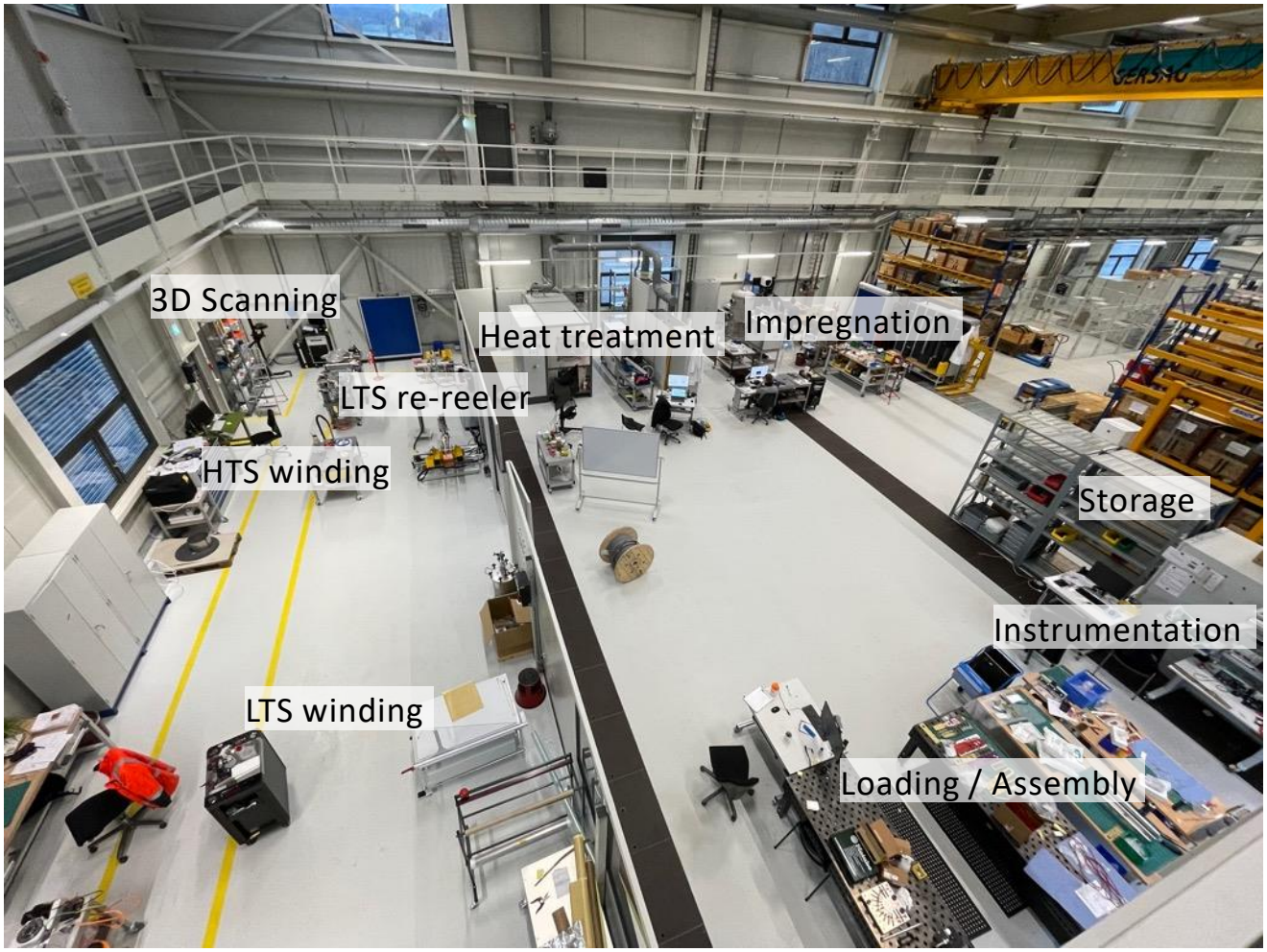
Courtesy M. Daly





Courtesy S. Ott et al.

MagDev Laboratory Layout



MagDev Team and CHART collaborations

Douglas Araujo
Engineer LTS

Michael Daly
Engineer LTS

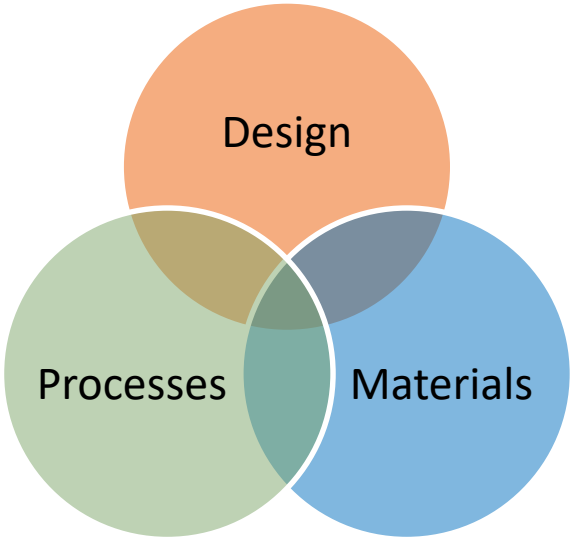
Christoph Hug
Technician LTS

André Brem
Material Scientist

Thomas Michlmayr
CAD, Technical Design

Jaap Kosse
Engineer ReBCO

Henrique Rodrigues
Technician ReBCO



Instrumentation, Protection, Testing

PAUL SCHERRER INSTITUT
P3 Project, Magnet Section

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
WireChar, WireDev

ETH zürich
MagNum (D-ITET)

ETH zürich
MagRes (D-MAT SMG)

ETH zürich
MagAM (pd|z, inspire AG)

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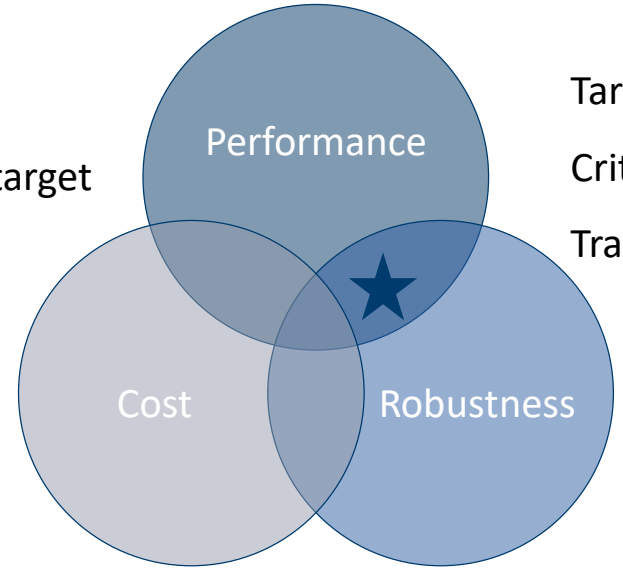
Nb3Sn Driving Questions

ESPPU statement "***Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV".***

The HFM program's efforts in Nb3Sn magnet R&D must demonstrate decisive progress in the areas of performance, robustness, and credible reduction of cost.

Economical field target



Target field for 100 TeV is 16 T.

Critical params and eng. margins tbd.

Training performance tbd.

ALARA, later possibly cost target.

Scalability in units and length.

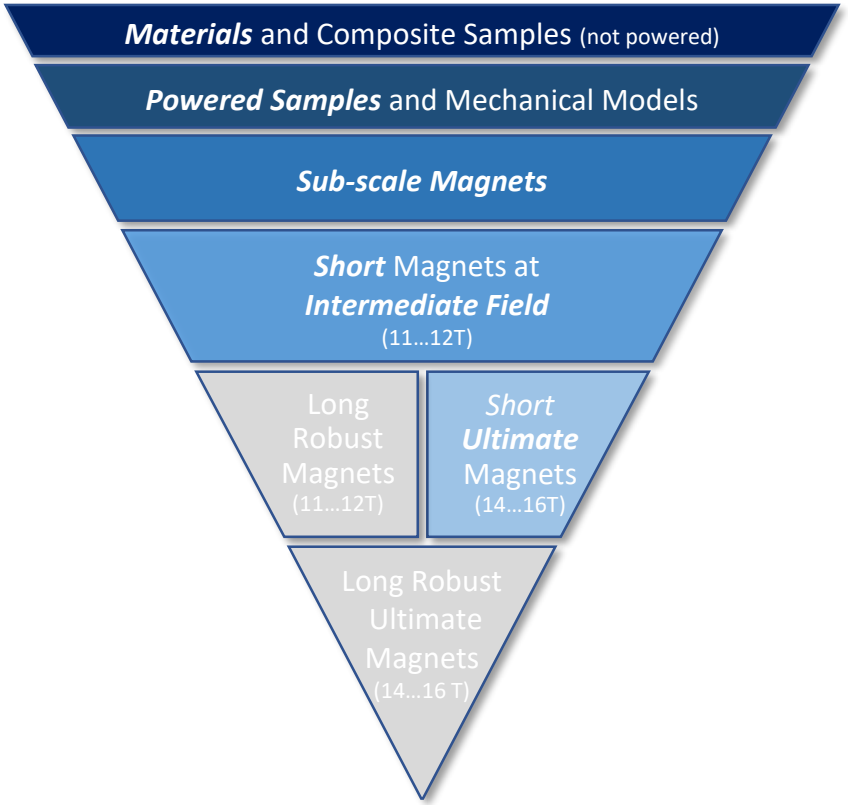
Electrical and thermal cycles.

Optimized production yield.
Industrialization.

First up: show innovation towards robust performance.

Nb3Sn Fast-Turnaround Innovation Funnel

- We suggest the Nb_3Sn Magnet R&D program to use succession of meaningful fast-turnaround R&D vehicles.
- New technologies can be tested under approximately realistic conditions at the earliest possible stage and the smallest permissible scale and cost.



Materials, insulation, interfaces, 10-stacks, etc.

Transverse-pressure tests on strands/cables, joint tests, BOX.

SMC, insert coils, 4-6 T 0.5-m-long accelerator-type magnets

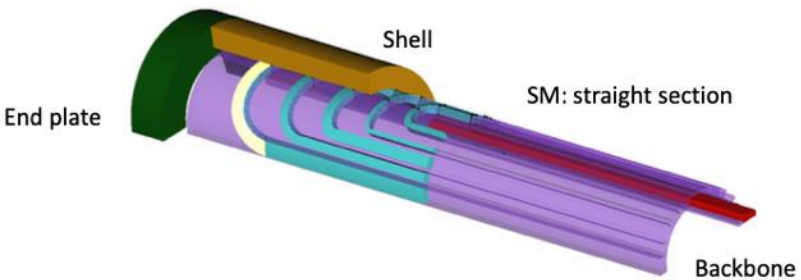
11-12 T nominal field accelerator magnets demonstrating essential technologies of ultimate-field magnet.

4-layer short demonstrator aiming for near-ultimate specifications with available conductor

Adapted from LDG HFM roadmap chapter, P. Vedrine et al.

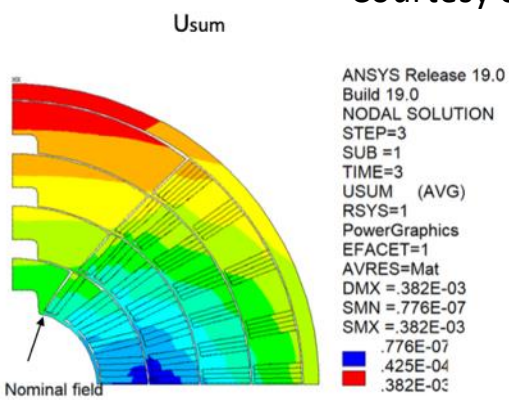
Stress-Management Continued

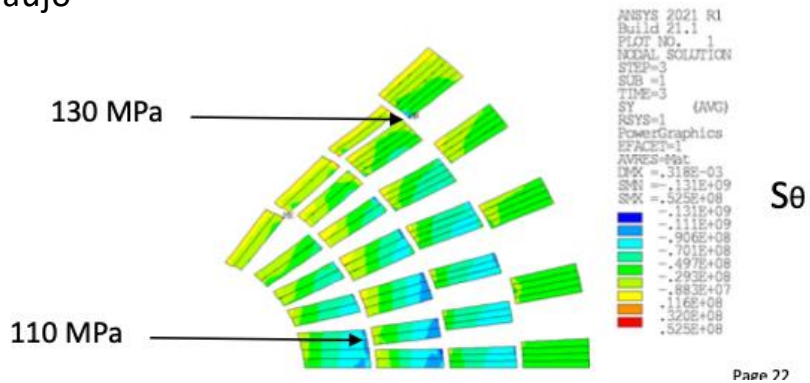
- CCT for Nb_3Sn promised reduced conductor stress by introducing stress management.
- The BOX program provided a handle on the vexing interface problem.
- Other difficulties intrinsic to CCT technology remain for FCC-hh main dipoles.
- **Stress-managed cosine theta geometries promise to combine the benefits of SM with the (relatively) easier manufacturability of half-shell type coils.**



Courtesy of A. Zlobin
FNAL

Courtesy of D. M. Araujo





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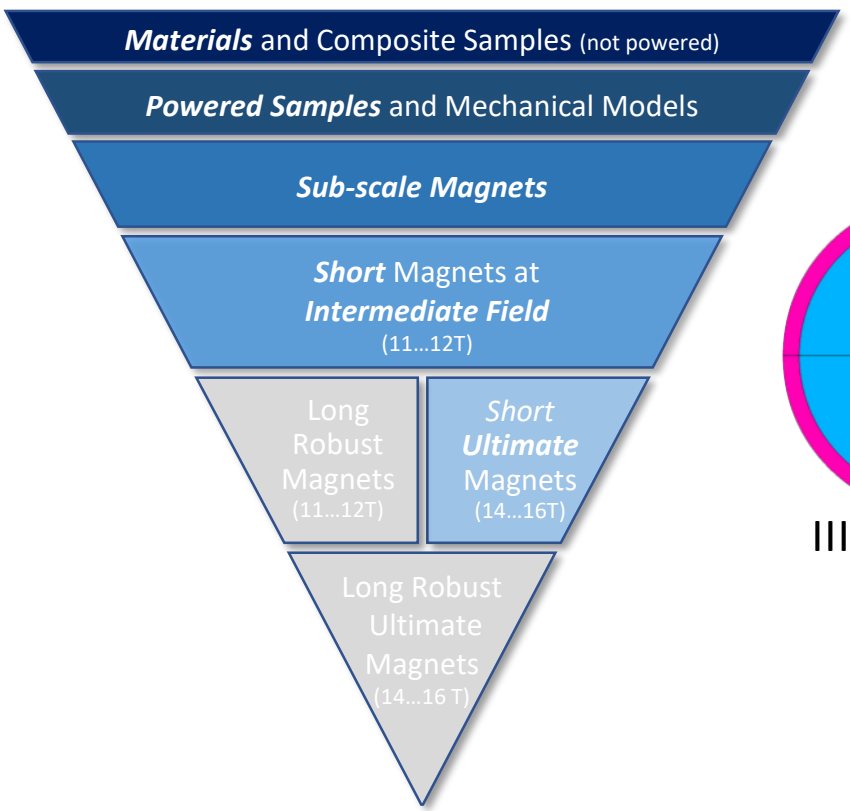

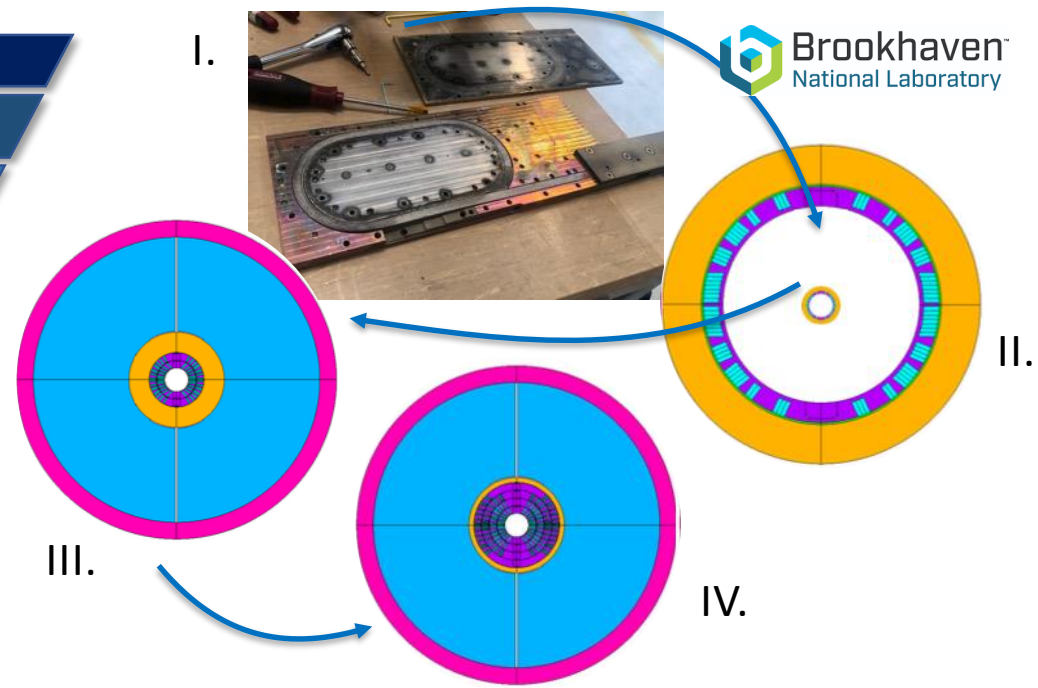

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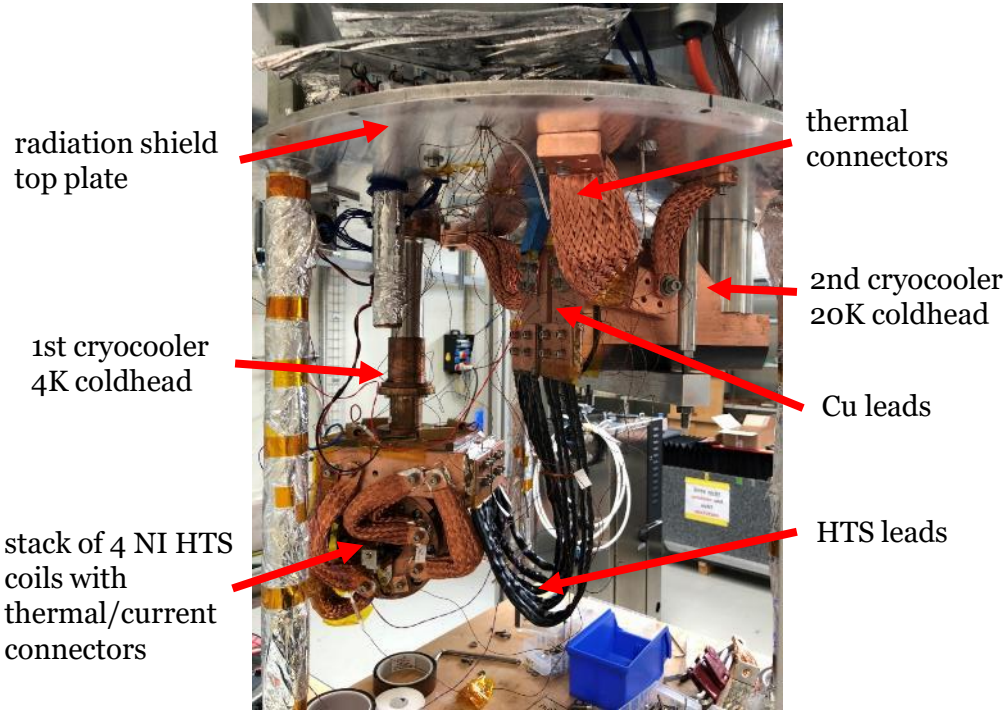
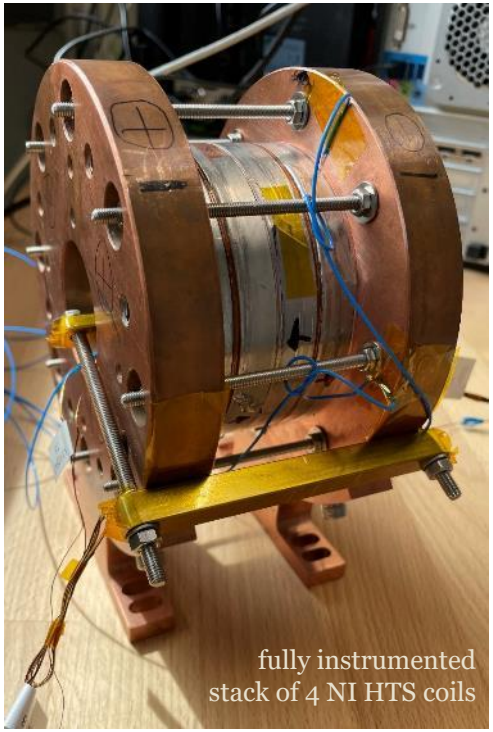
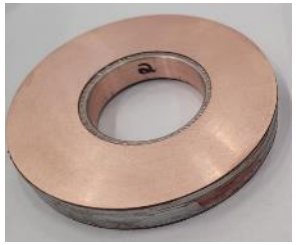
Technology Solenoid in the Cryogen-free test station

- Successful test in cryogen-free test station of 4-pancake HTS NI solenoid, built in-house at PSI and using licensed Tokamak Energy Ltd technology.
- Coil reached **18.2 T** in the center, **20.3 T** on the conductor at the maximum current of the power converter of 2 kA.





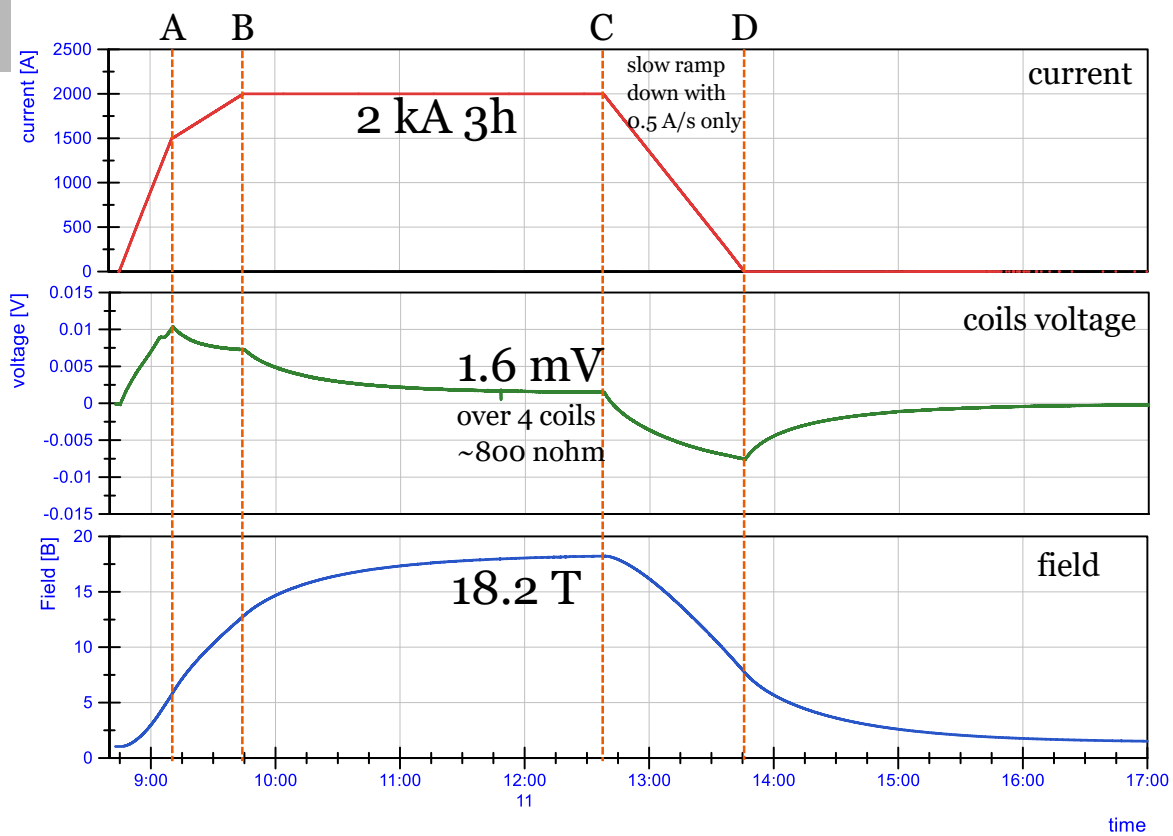


Diameter: 100 mm
Aperture: 50 mm

SC type: ReBCO
tapes: 2
turns: 2 x 170
SC length: 2 x 49 m

Courtesy of M. Duda

4-stack +10 K test results



0-A:
- fast ramp up with 1 A/s
- voltage over coils increasing because of current radial path

A-B:
- slower ramp up with 0.2 A/s to stabilize coils voltage increase

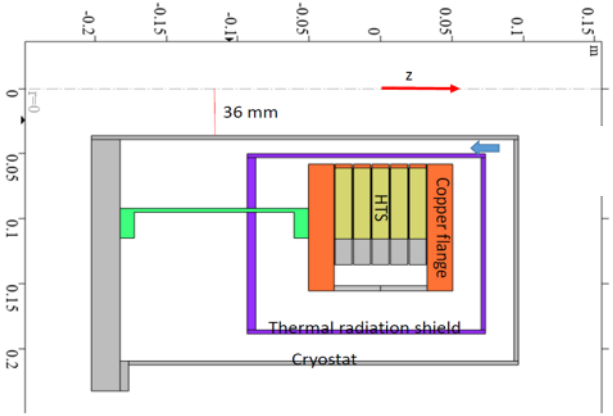
B-C:
- 2 kA 3h plateau
- coils voltage decreasing because of current redistribution
- field is increasing – not reaching plateau

C-D:
- slow ramp down with 0.5 A/s to avoid quench back

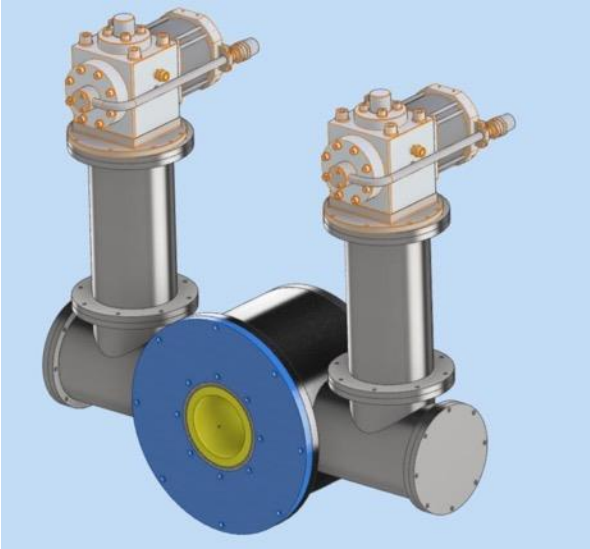
Courtesy of M. Duda

CHART2 FCCee Injector Study: P3 (PSI Positron Production) Project

- Adiabatic Matching Device for the FCCee injector test stand at SwissFEL will be HTS NI coil.
- NI coil technology provides:
  - stable DC operation,
  - high thermal conduction due to solder impregnation to extract heat deposited in coils,
  - radiation robustness due to absence of insulators.
- Direct application of TS experience at larger scale (ID from 50 mm in TS to 100 mm in P3).



Courtesy J. Kosse



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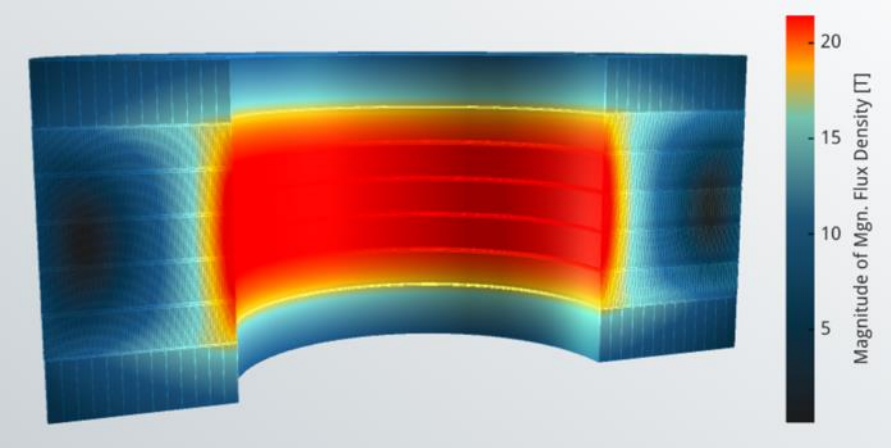

By littlebeastengineering.com.

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MagDev Roadmap Review

- International technical review of MagDev1 and MagDev2 roadmap (http://indico.psi.ch/e/magdev1review).
- LTS, HTS, and Enabling Technologies roadmaps were endorsed and commented.

- The committee is impressed by the **quality and the quantity of the work presented**. All presentations were very well organized and thorough; the computational and experimental work follows a rigorous development approach
- The committee appreciates the **dynamism and motivation of the team** and the **complementary fields of expertise**
- The team has shown to be **well connected to other institutions** through various collaborations - as foreseen by CHART2 - and **open to analyze/implement existing technical solutions**

From review close-out presentation, A. Ballarino (CERN)

CHART Synergies

- **FCCee P3** receives HTS NI solenoid; predicts record positron-production yields.
- **FCCee HTS4** builds upon experience with CCT and SM-CT, as well as cryo-cooled magnet systems.
- **FCCee CPES** uses the cryogen-free test station for demonstrator tests.
- **MagRes**, **MagComp**, and **MagAM** benefit from fast-turnaround testing of novel systems.
- **MagNum** benefits from MagDev alpha- and beta-testers of pyMBSE developments, and from experimental data for collabortion partners at CERN and TU Darmstadt.

- HTS technology **can increase the physics reach** in many experimental setups and contribute to **high-power-efficiency** accelerator infrastructures.