NI HTS magnet projects at PSI

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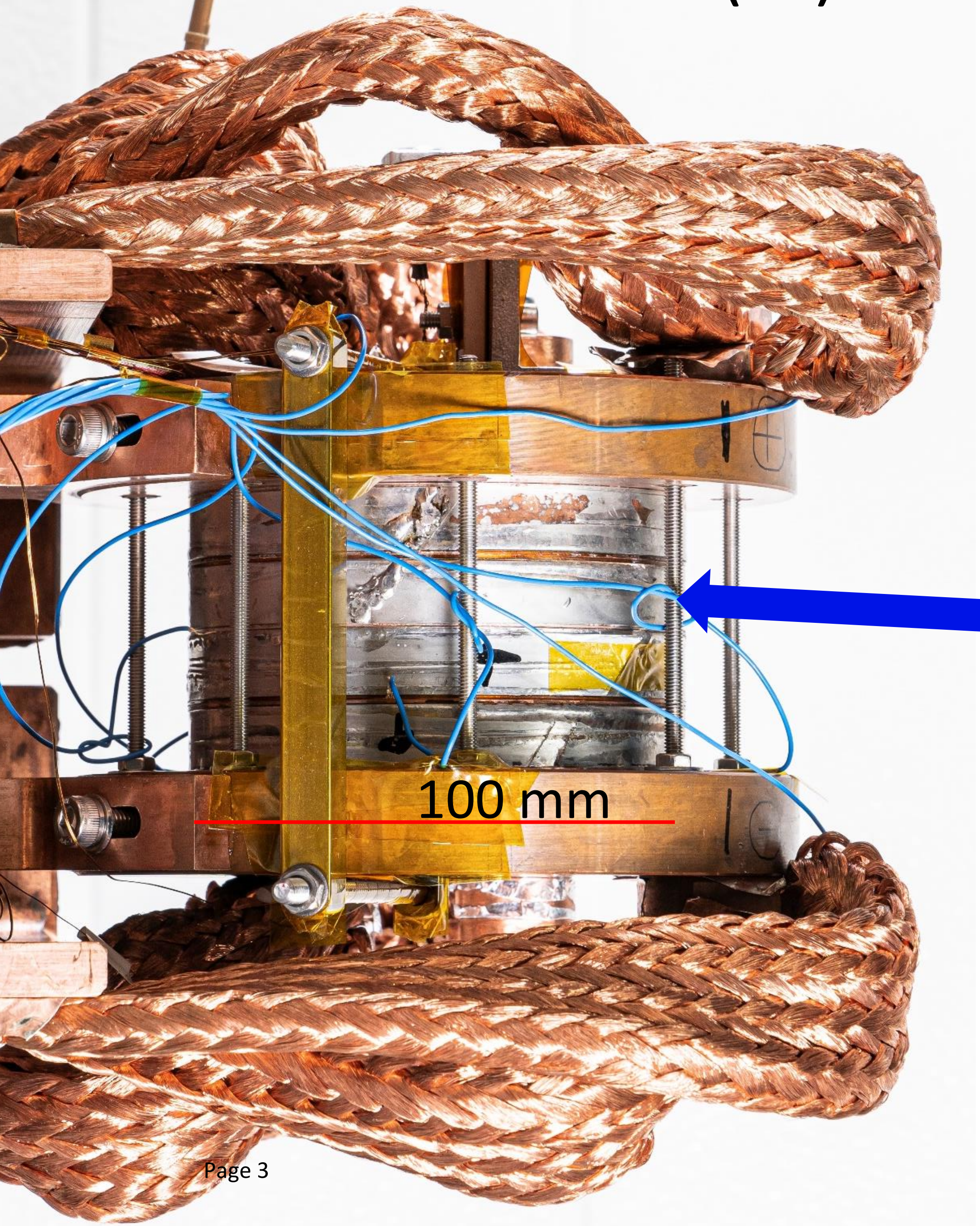
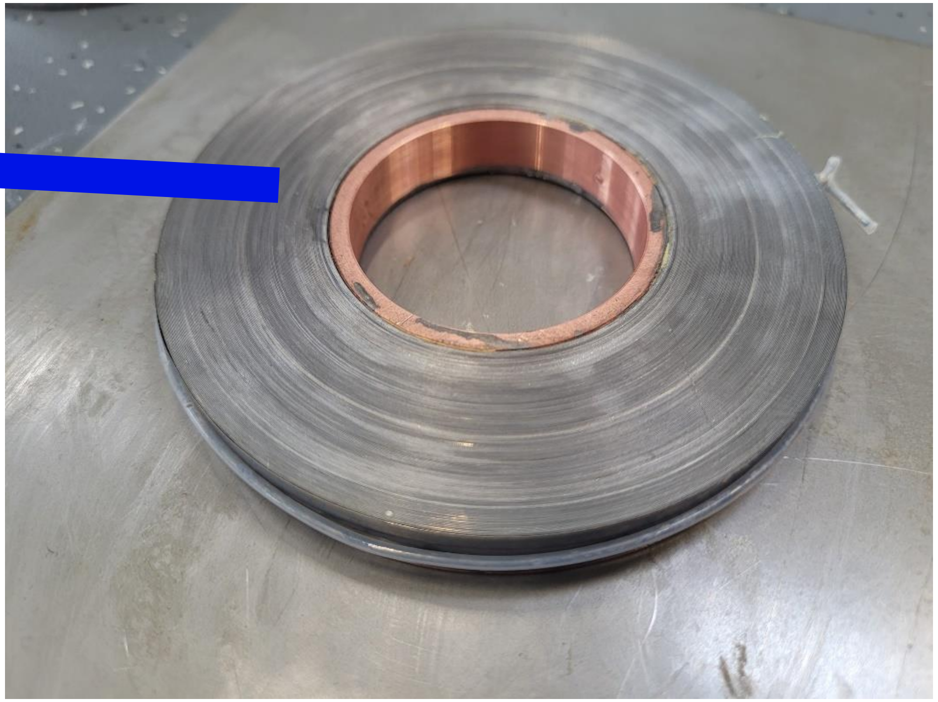
Contents

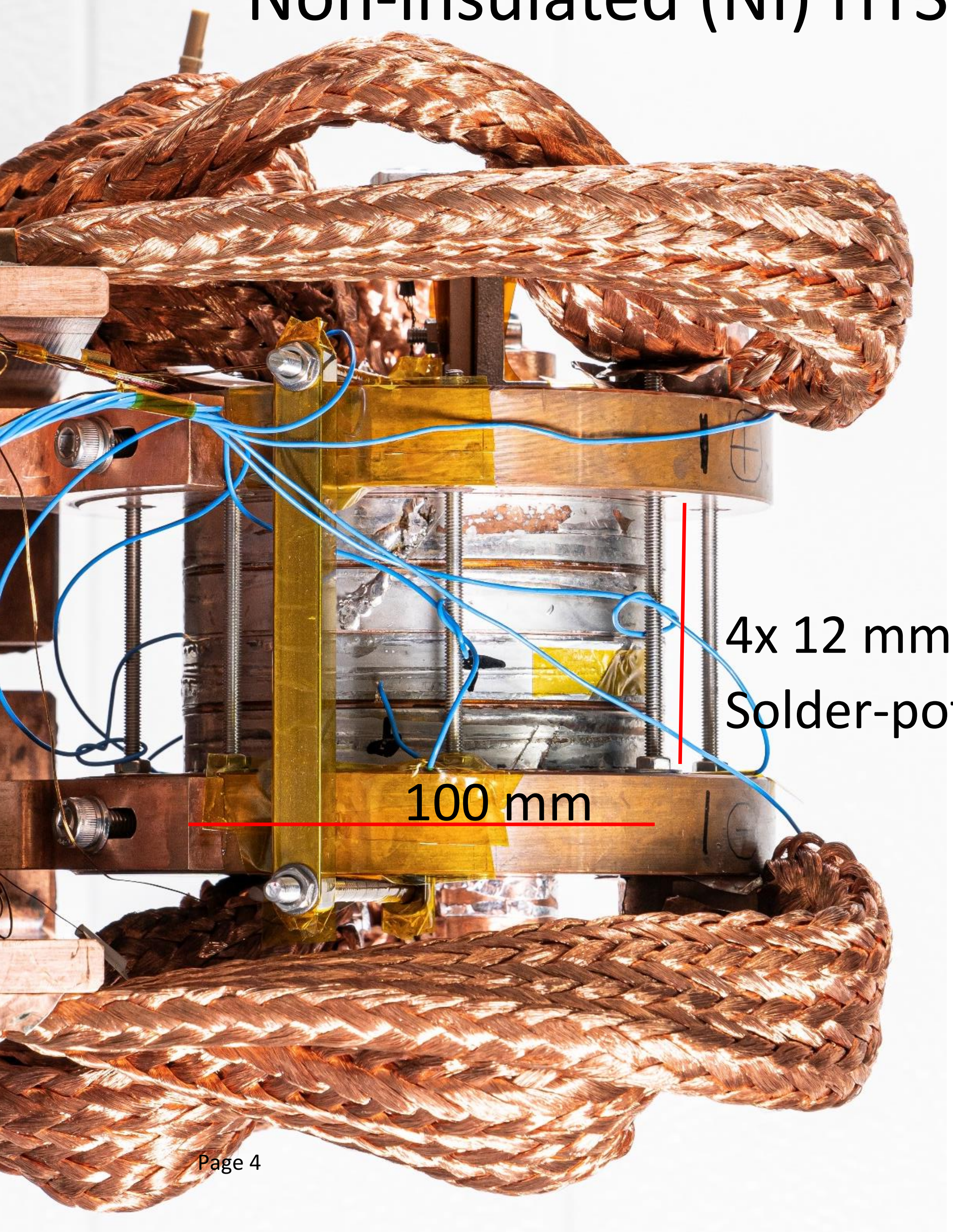
Non-insulated (NI) HTS



Single-layer pancake coil wound from bare HTS tape
Solder-impregnated

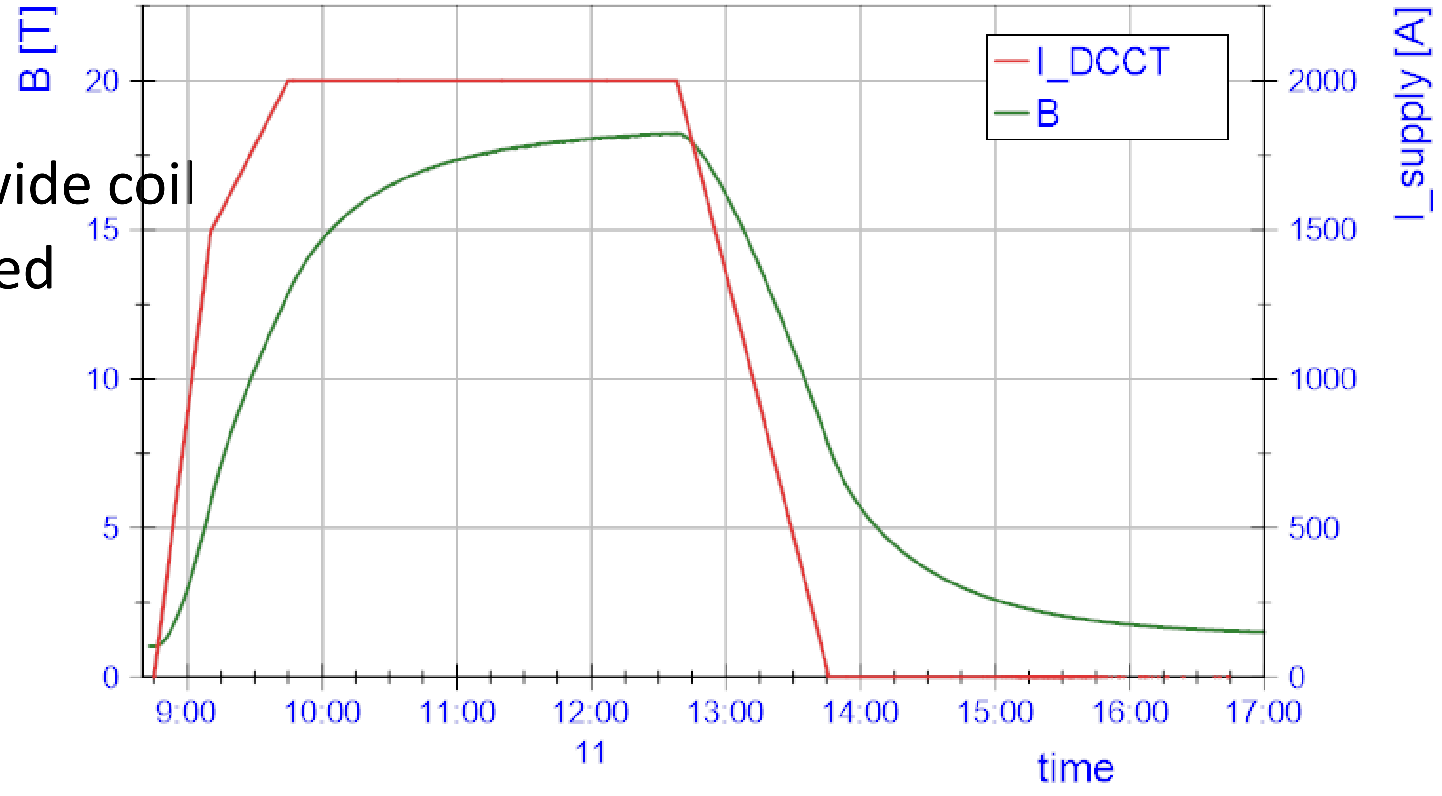


Non-insulated (NI) HTS Technology Solenoid



Rapidly develop infrastructure via license agreement with Tokamak Energy

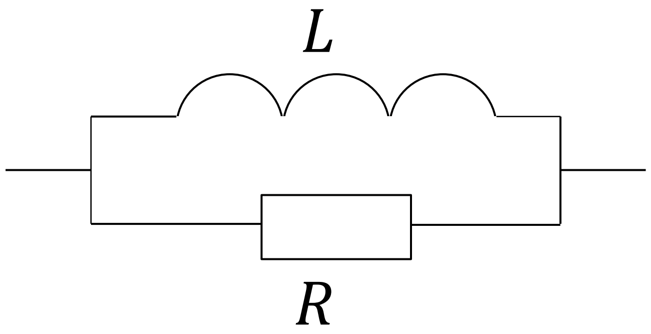
18 T by PSI 4 stack at 2 kA, 12 K



Non-insulated (NI) HTS Technology Solenoid

NI coil electrical representation:

- Inductor (HTS spiral path)
- Resistor (turn-turn contact)



Charging time constant $\tau = L/R$

Large NI magnets (large L) take a long time

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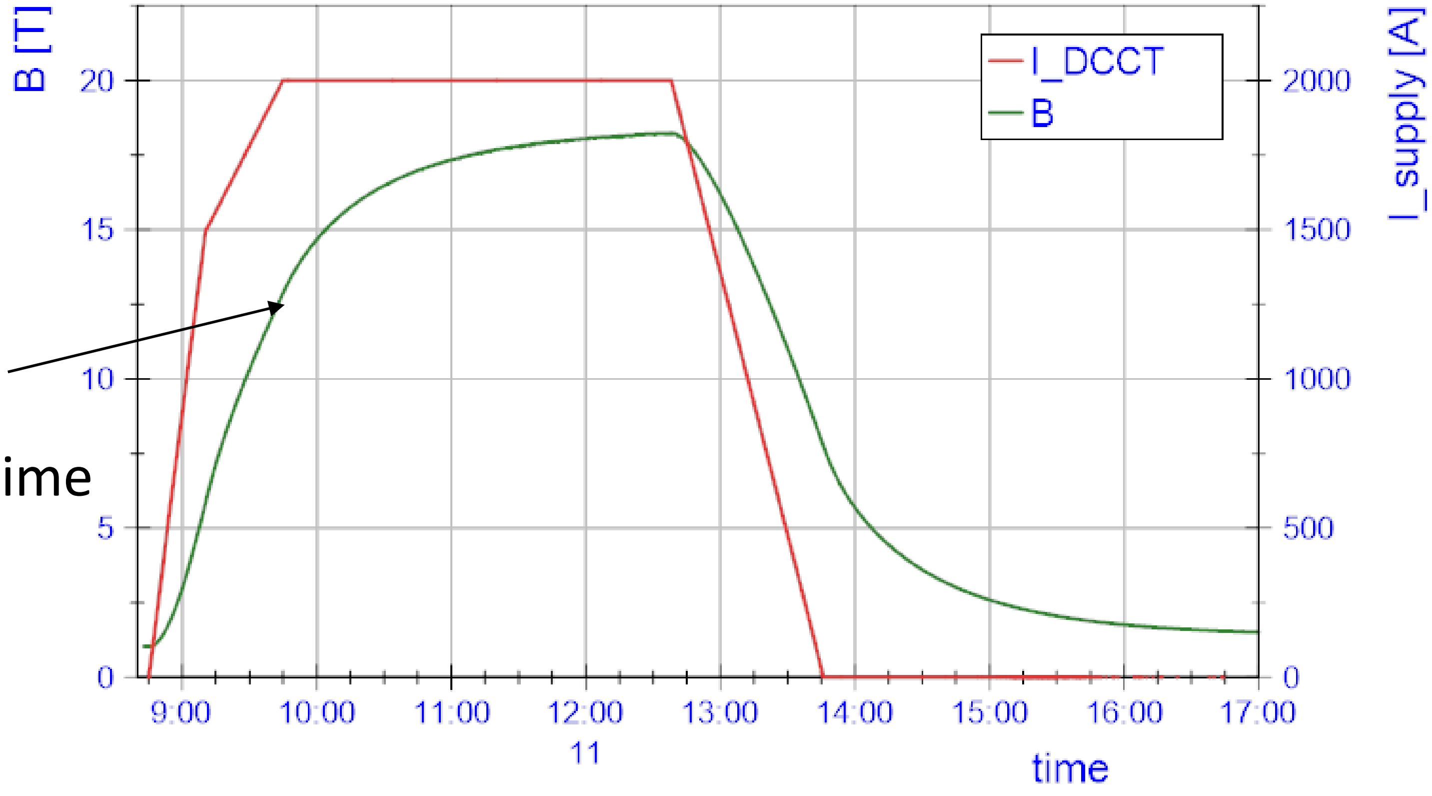

Non-insulated (NI) HTS Technology Solenoid

PSI

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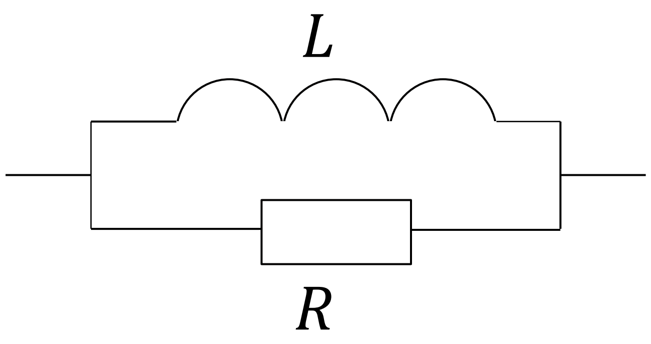

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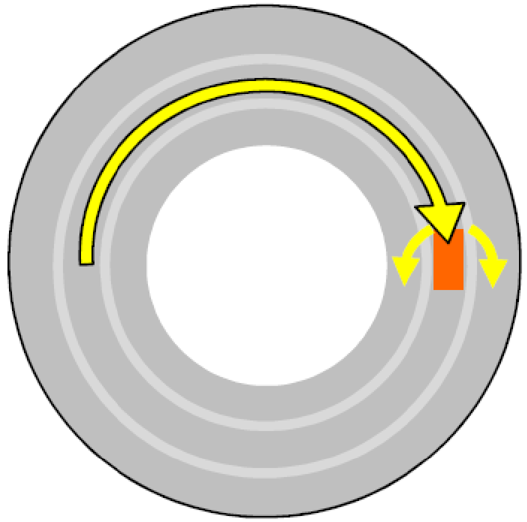
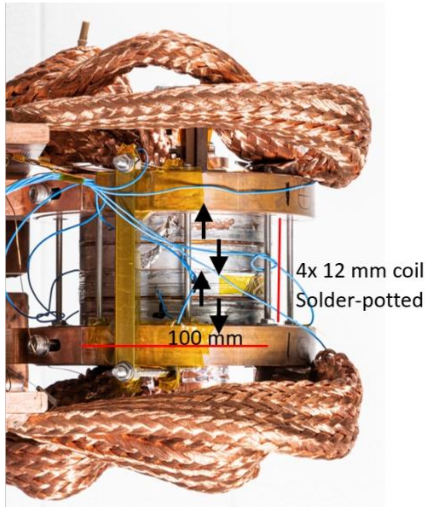


- *Very high current density* magnet → compact winding, lower cost
- Key benefits: compactness, operation reliability, mechanical robustness

S. Hahn, D. Park, J. Bascuñán, and Y. Iwasa,
"HTS Pancake Coil without Turn-to-Turn Insulation," IEEE TAS, 2011.

Experiment vs model

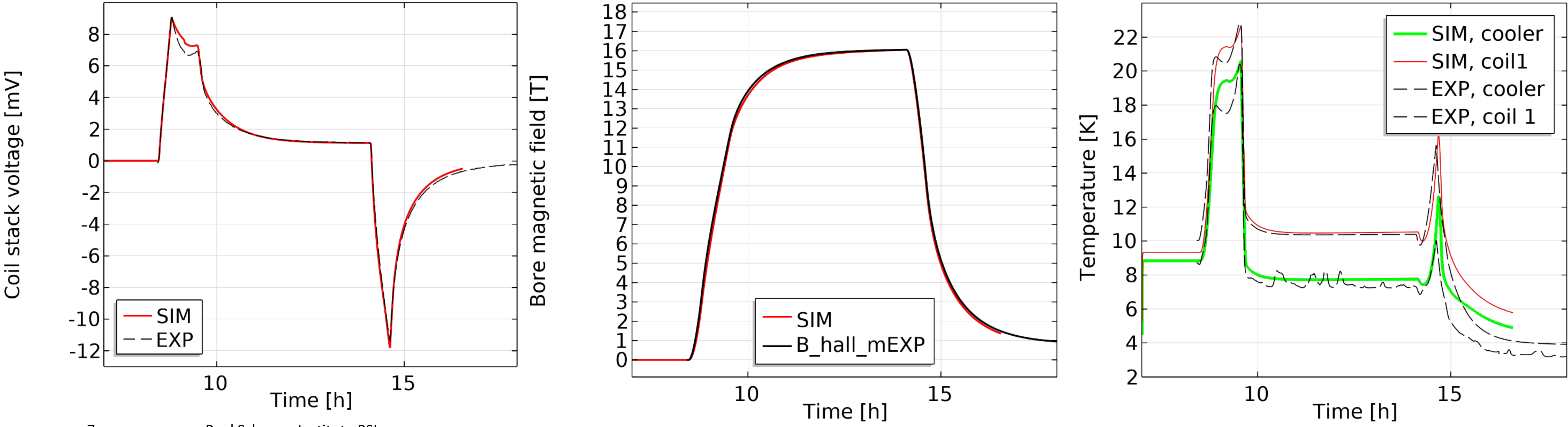


Turn-turn resistance used a fitting parameter

$$\rho_{turnturn} \propto \rho_{copperRRR20}(B,T)$$

Works reasonably over a 15-77 K range

Example: 1.8 kA at 15 K in cryogen-free setup



Contents

- 18 T technology demonstrator
- 18 T split solenoid
- RIXS manipulator head magnet
- Positron capture solenoid

Split Solenoid for Neutron Scattering

18 T NI HTS solenoid → 10 mm split NI HTS solenoid

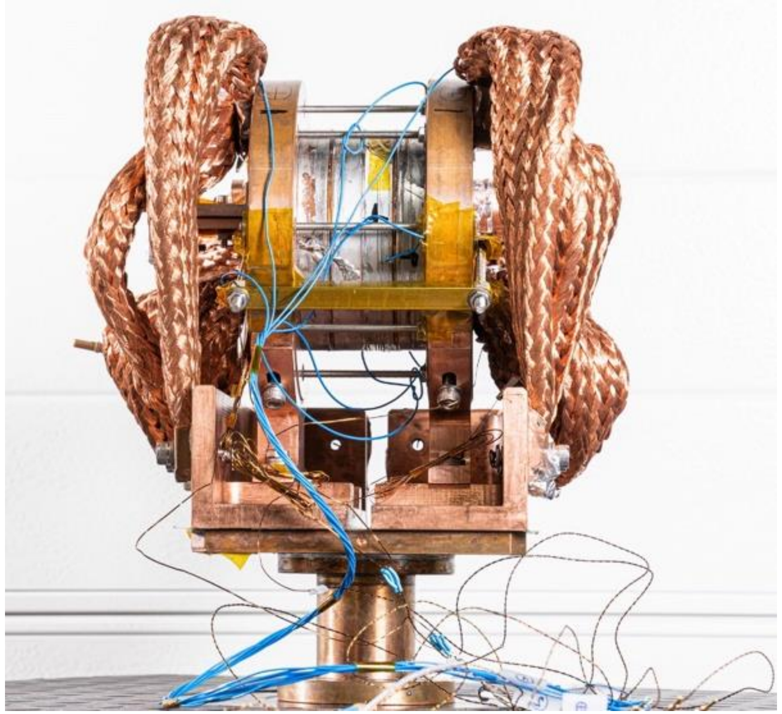
Bore field 18 T at 2 kA, 12 K

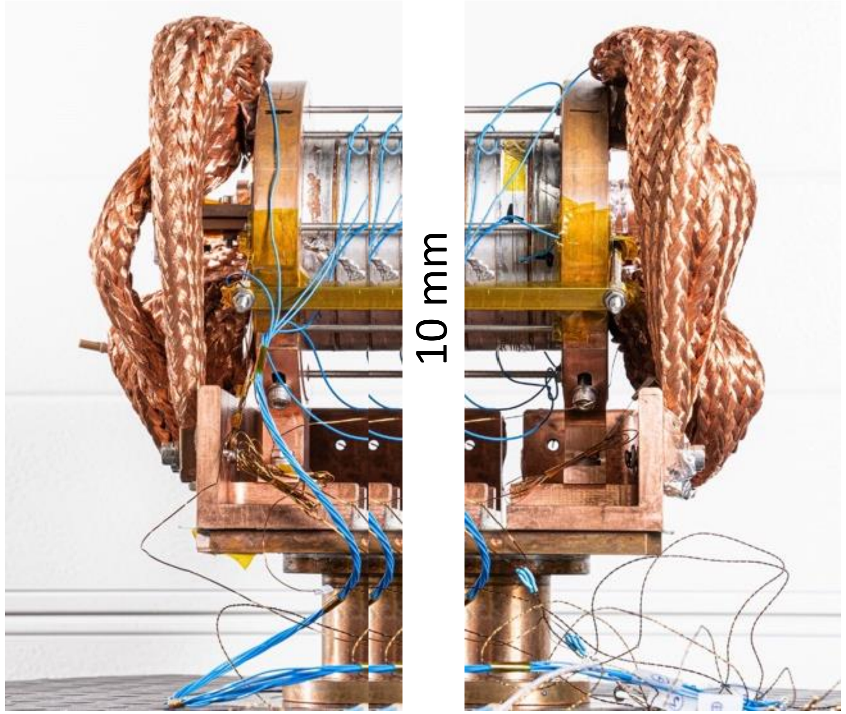
4 coils

Predict with simulation

~Bore field 18 T at 1.8 kA

6 coils





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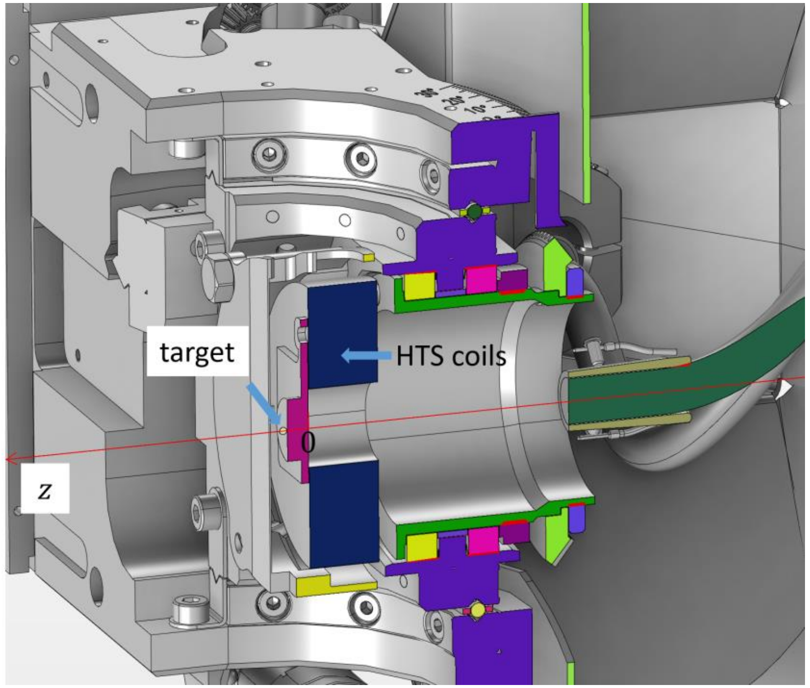
R'Equip RIXS Manipulator Solenoid

- Planned upgrade of the manipulator used in the RIXS beamline at SLS for soft X-ray scattering experiments. Funded, planned to start design 11/24
- Supply a high magnetic field (up to 6 T) on the target via compact solenoid



3.6 cm

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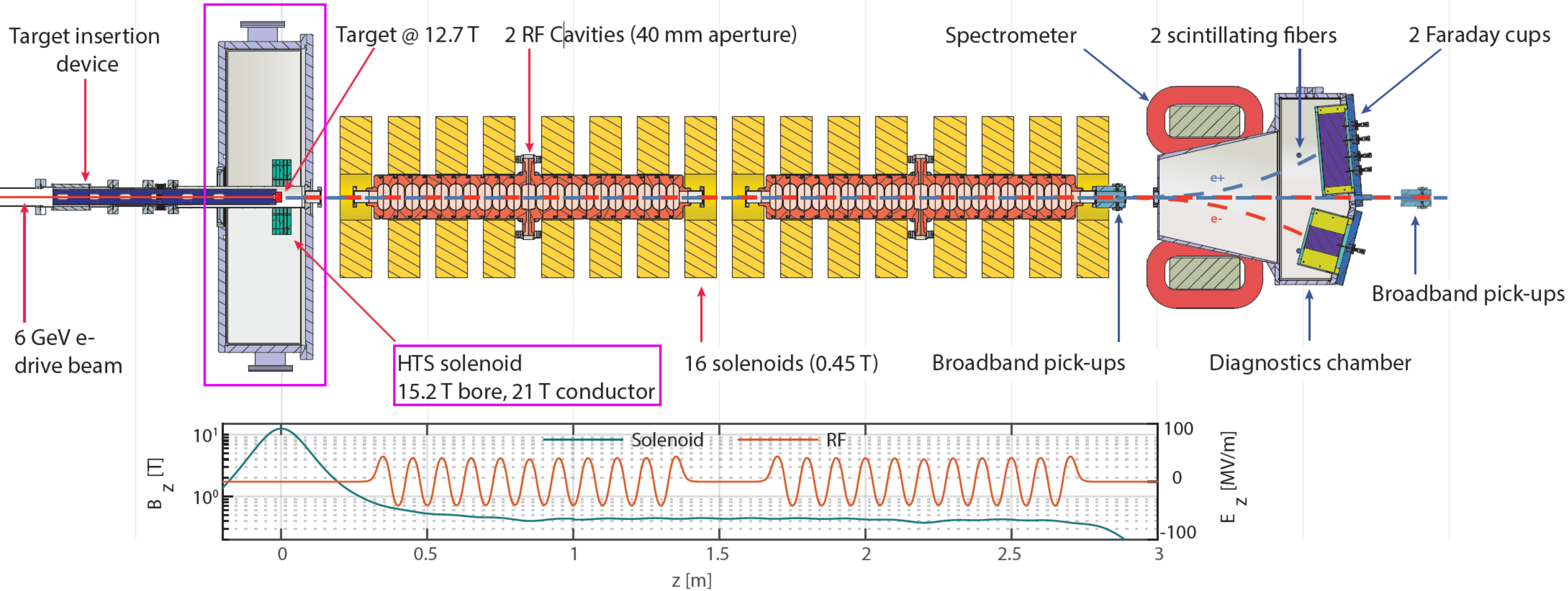
PSI Positron Production (P^3) Experiment @ SwissFEL

Aims to demonstrate high yield positron source in 2026. Relevant for FCC-ee

CHART
Swiss Accelerator Research and Technology

PSI Positron Production (P^3) Experiment

Aims to demonstrate high yield positron source



Magnet to be tested by end of 2024

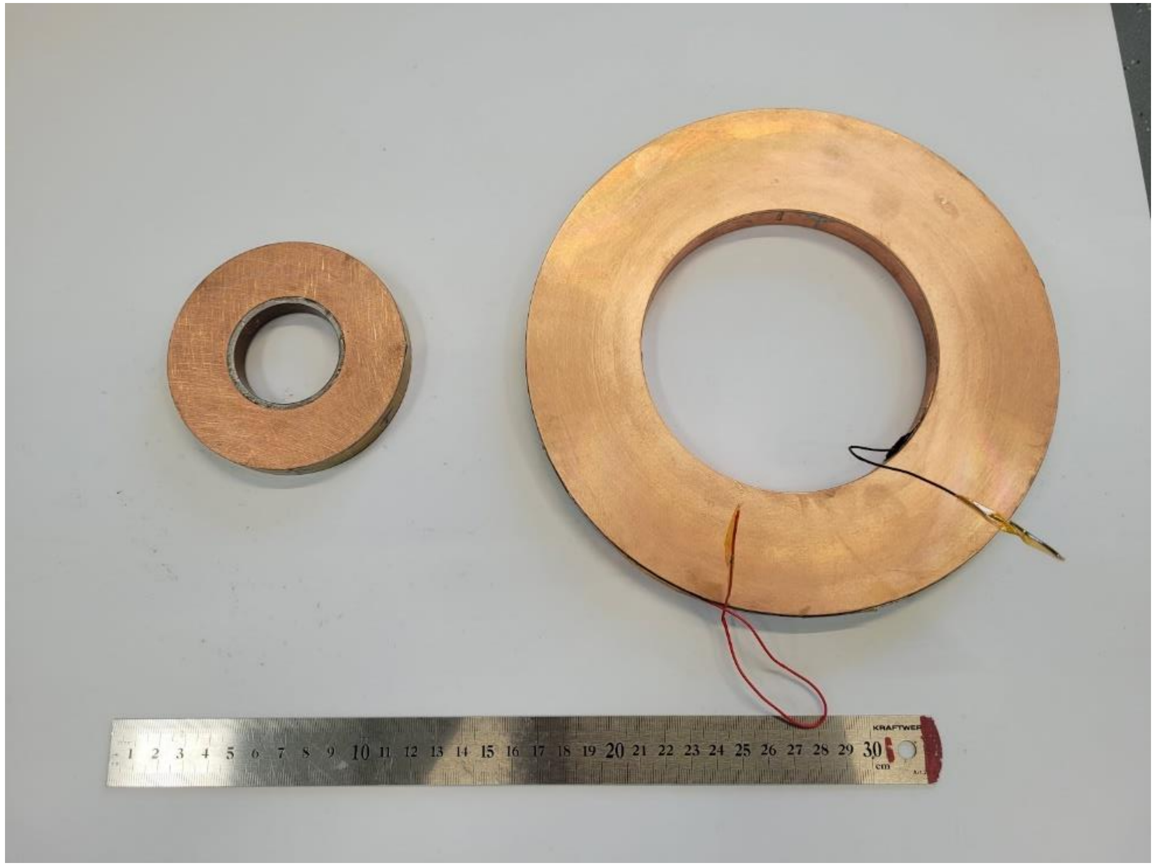
P^3 experiment operational 2026

N. Vallis, https://doi.org/10.1103/PhysRevAccelBeams.27.013401

Upscaled version of 18 T PSI NI solenoid

18 T 50 mm cold bore
4 coils
Built & tested

15 T 72 mm warm bore
5 coils
Under construction



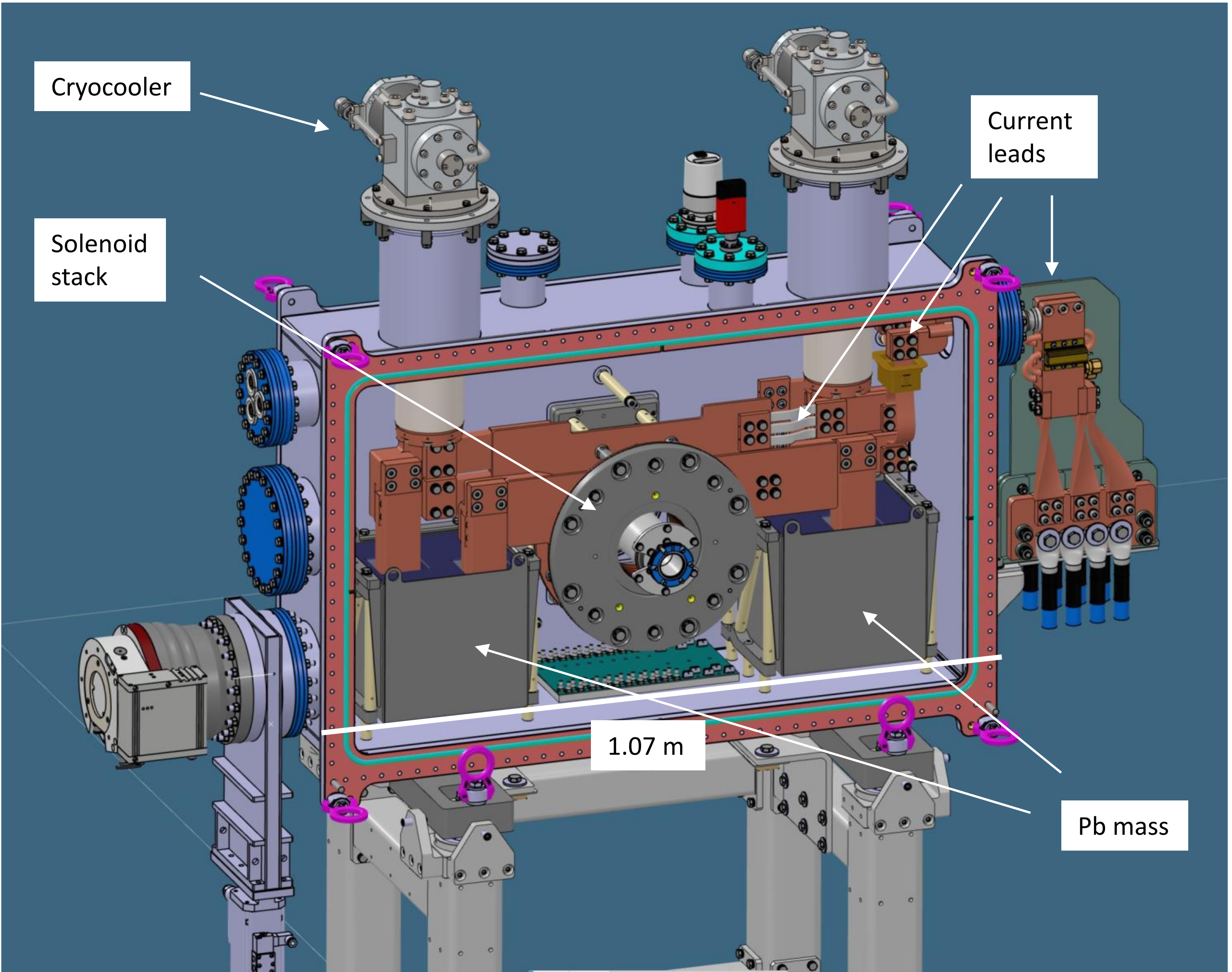
Radiation

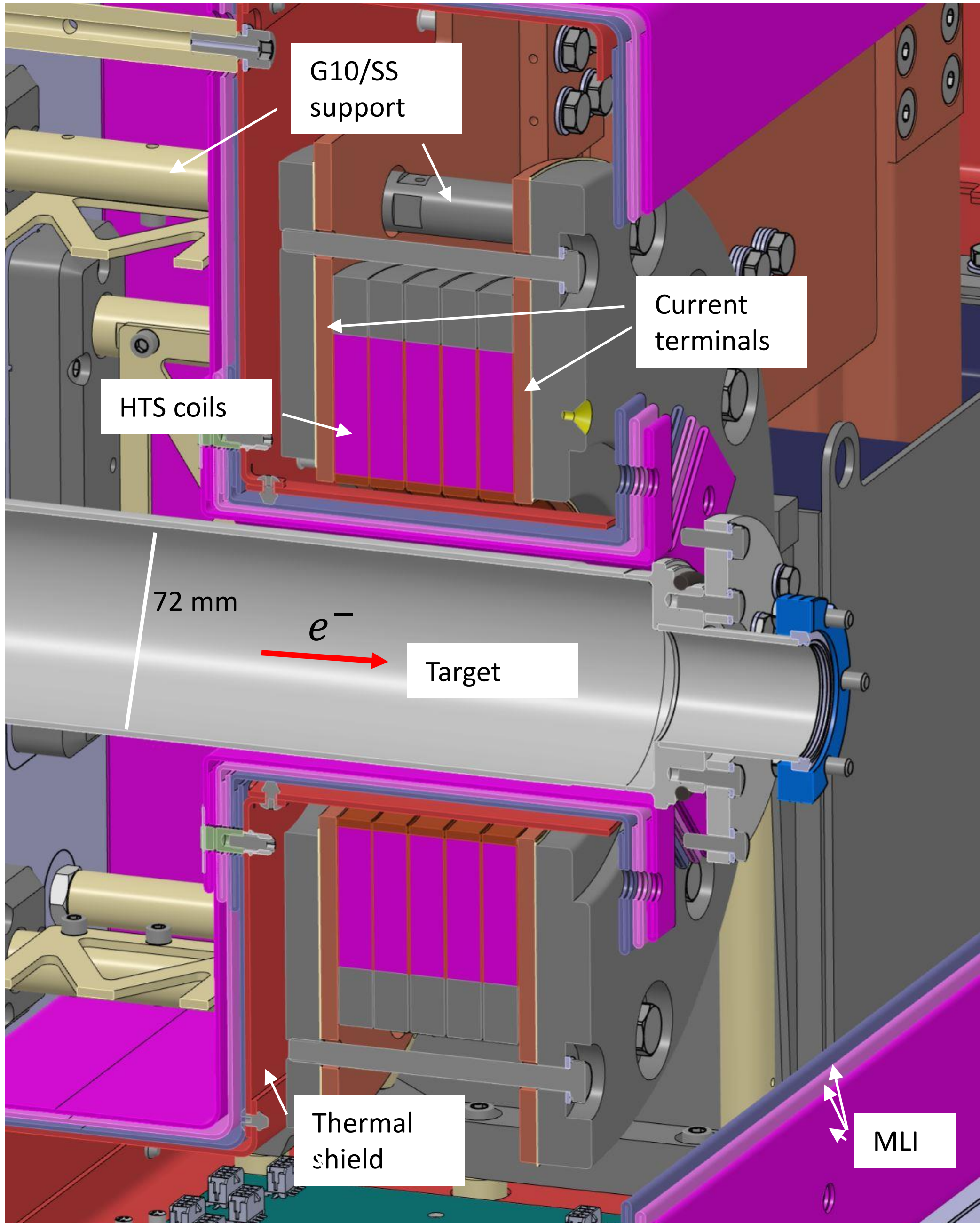
P^3 will demonstrate high yield,
but not radiation robustness

P3 (unshielded)	**FCC-ee (2 cm Tungsten)**
18 kGy/year	23 MGy/year
10^{-8} DPA/year	$2 \cdot 10^{-4}$ DPA/year

B. Humann, doi:10.18429/JACoW-IPAC2022-THPOTK048

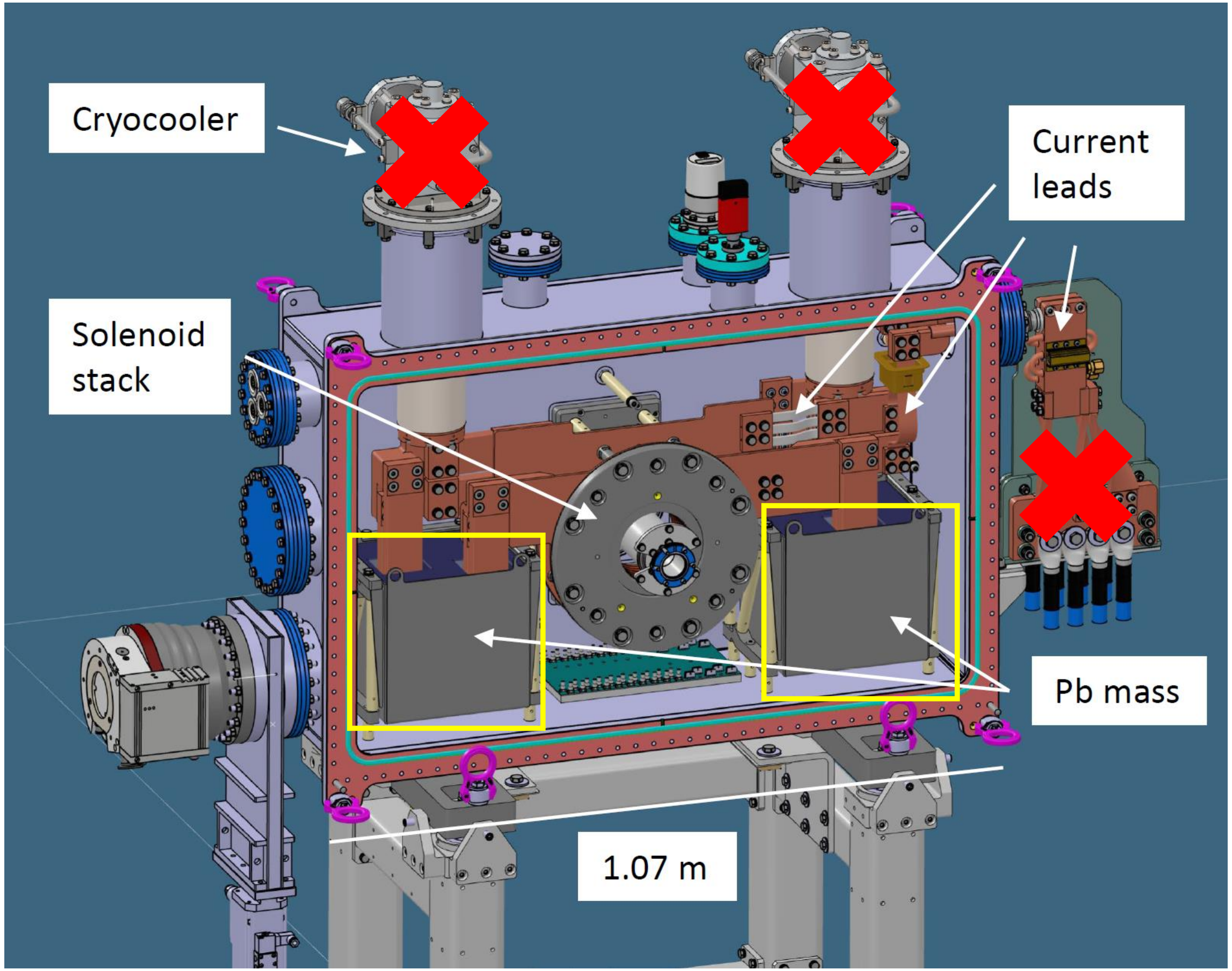
Conduction-cooled system
15 T bore, 20 T conductor @ 1.2 kA, 15 K

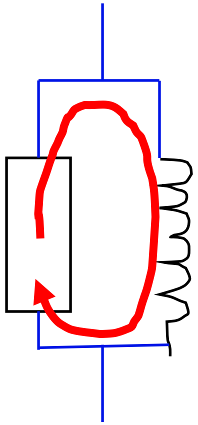




Fault scenario:

Coolers stop

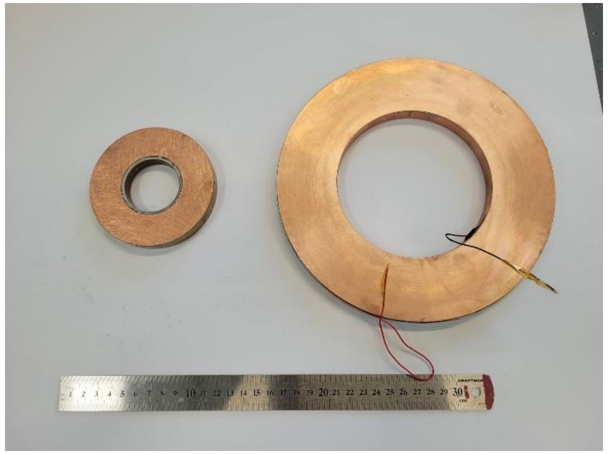




Open circuit

Stored energy gets dissipated in coils+buffers

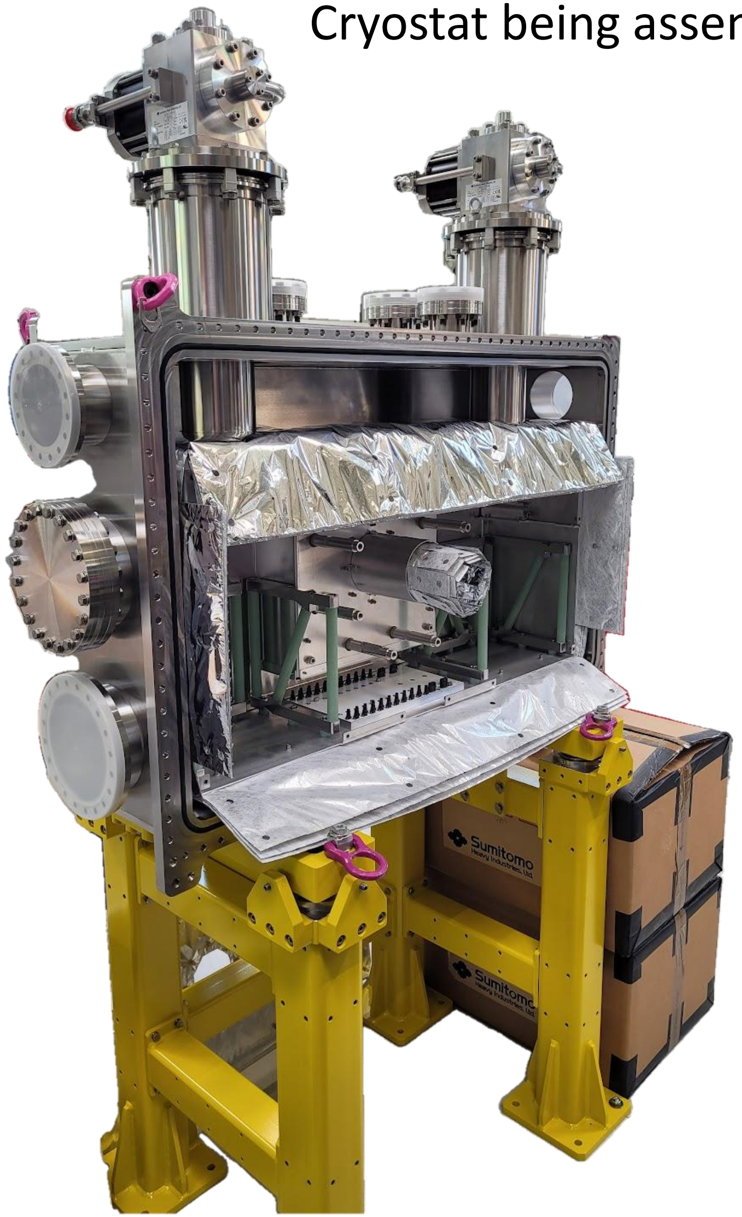
Magnet under construction



Coils being manufactured

Lead buffer casting

Cryostat being assembled



Conclusions

Several no-insulation HTS magnet projects ongoing at PSI

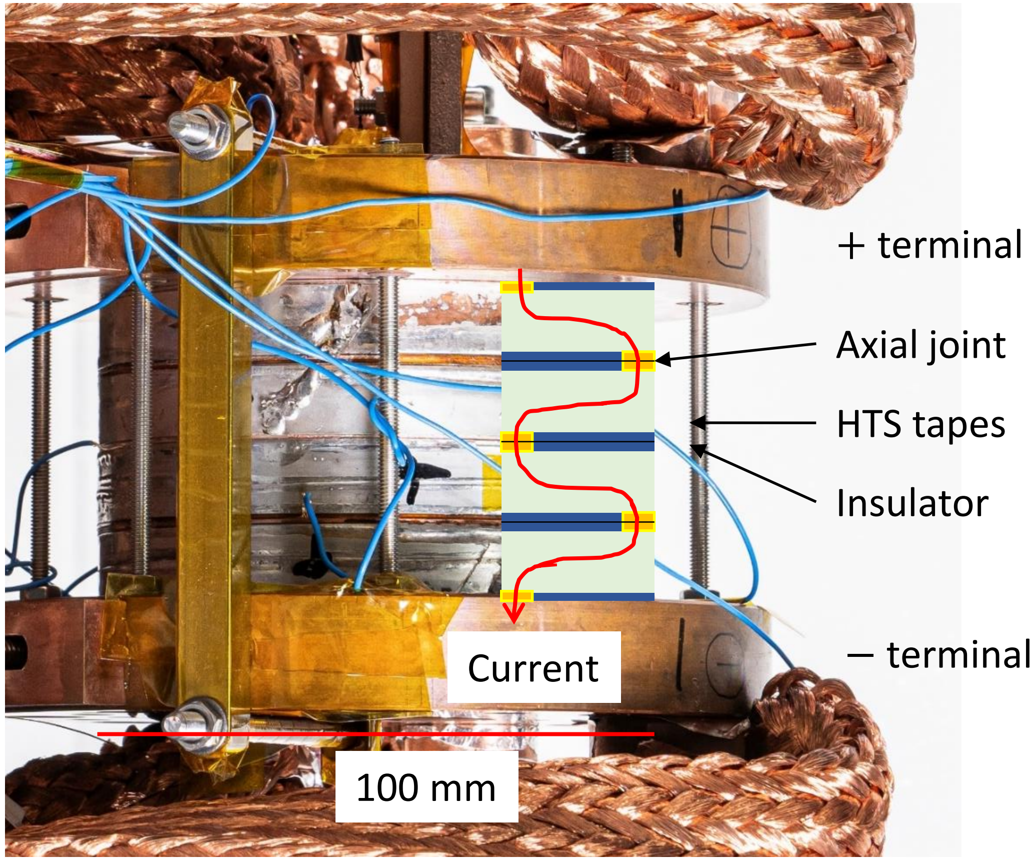
- 18 T split solenoid
- RIXS manipulator compact solenoid
- Positron capture solenoid

Leaning on experience gained via 18 T solenoid

No-insulation HTS magnets ideally suited for

- DC applications
- Loose magnetic field quality requirements
- Compact solutions

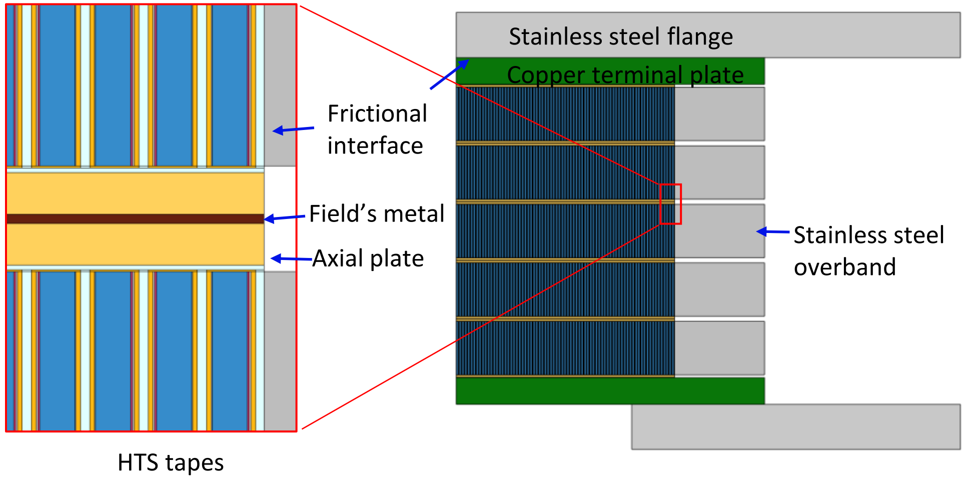
NI HTS Technology Solenoid



Single-layer solder-impregnated pancakes modular

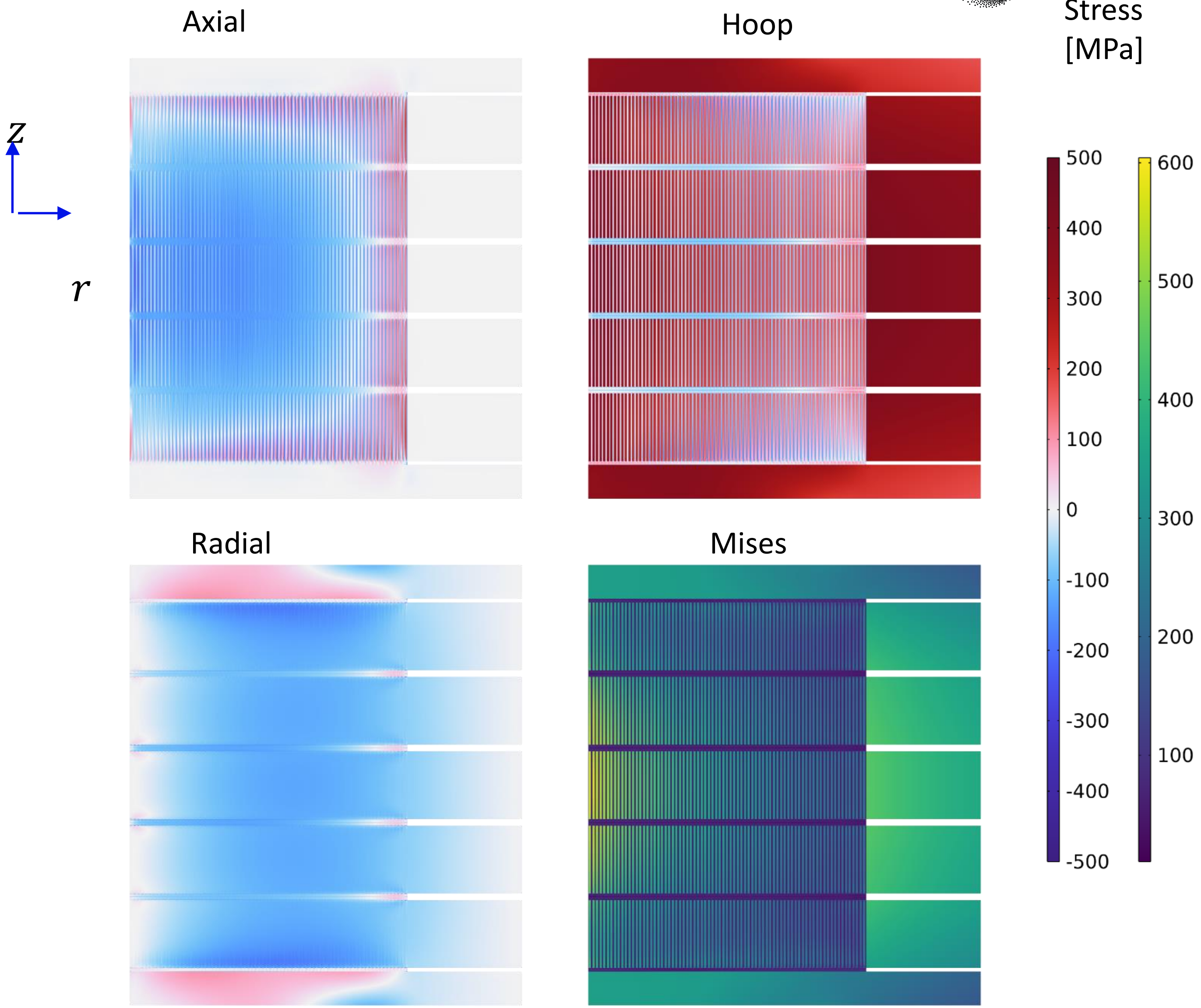
Rapidly develop infrastructure via license agreement with Tokamak Energy

Mechanical



Tape structure explicitly modeled to capture
-differential thermal contraction
-plasticity

Max	radial stress	2	MPa
Min	axial stress	-155	MPa
Max	hoop stress (substrate)	450	MPa

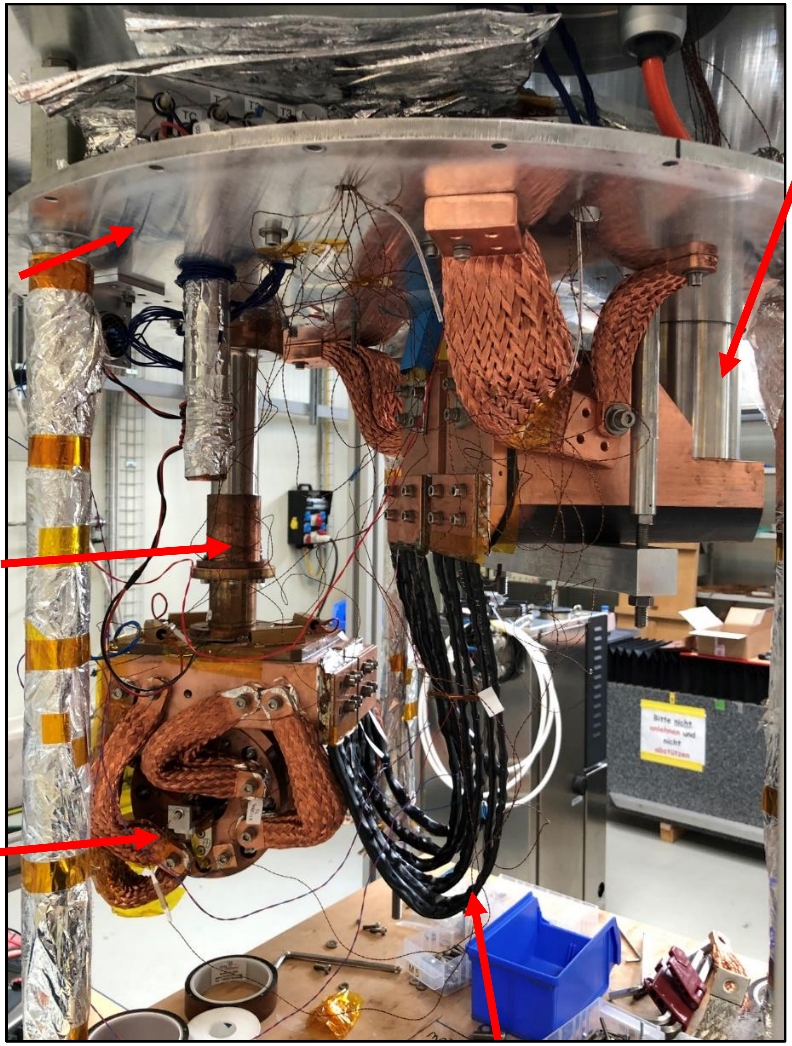


Cryogen-free test stand

radiation shield top plate

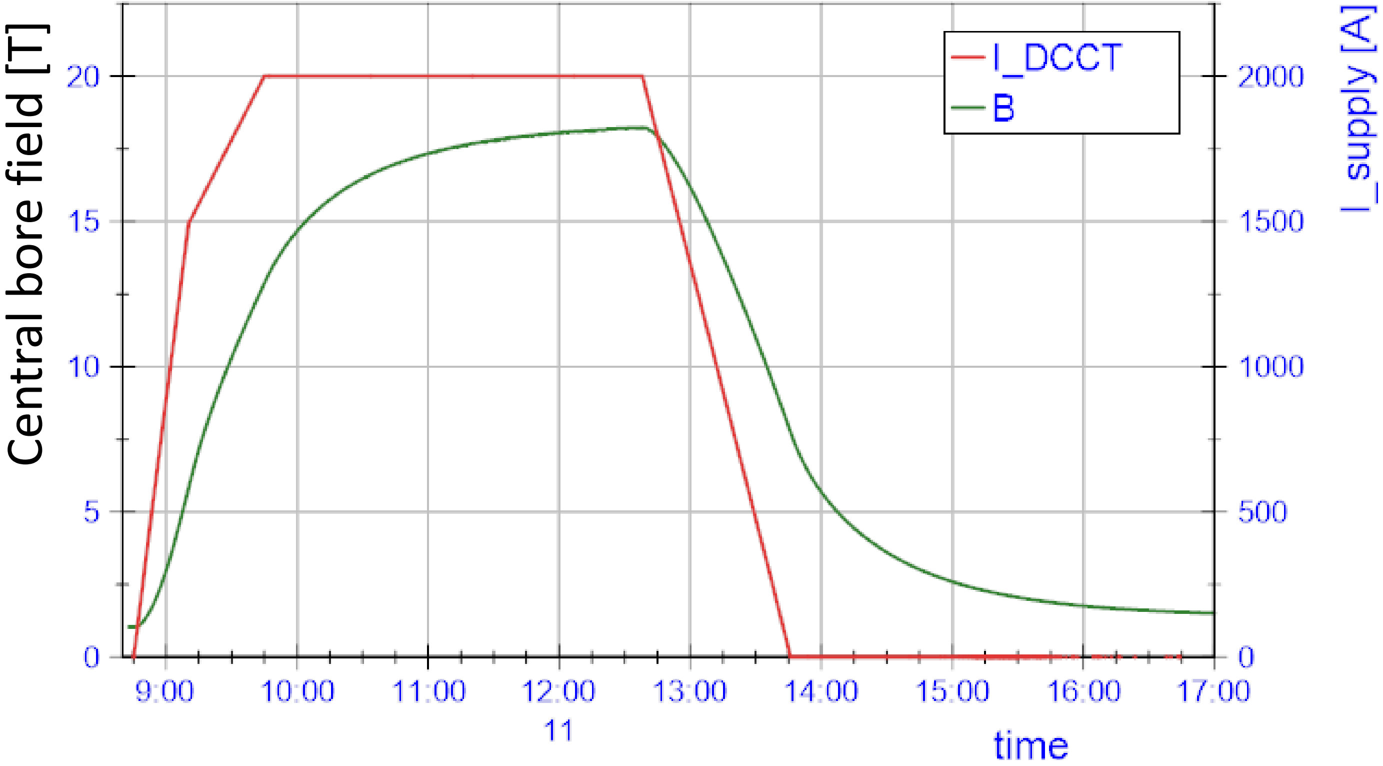
1st cryocooler
4 K coldhead

stack of 4 NI HTS coils with connectors



HTS leads

2nd cryocooler



18 T by 4 stack at 2 kA, 12 K

Electromagnet/thermal simulation

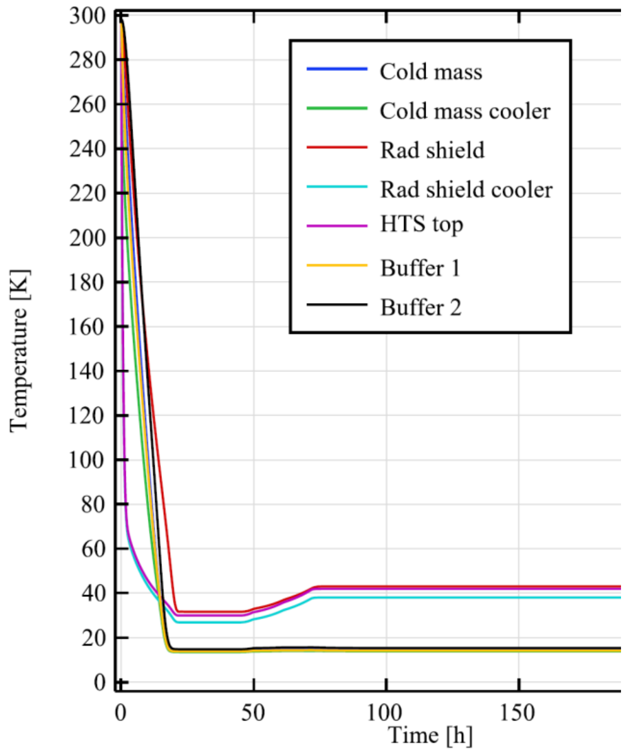
2D axisymmetric H-formulation,

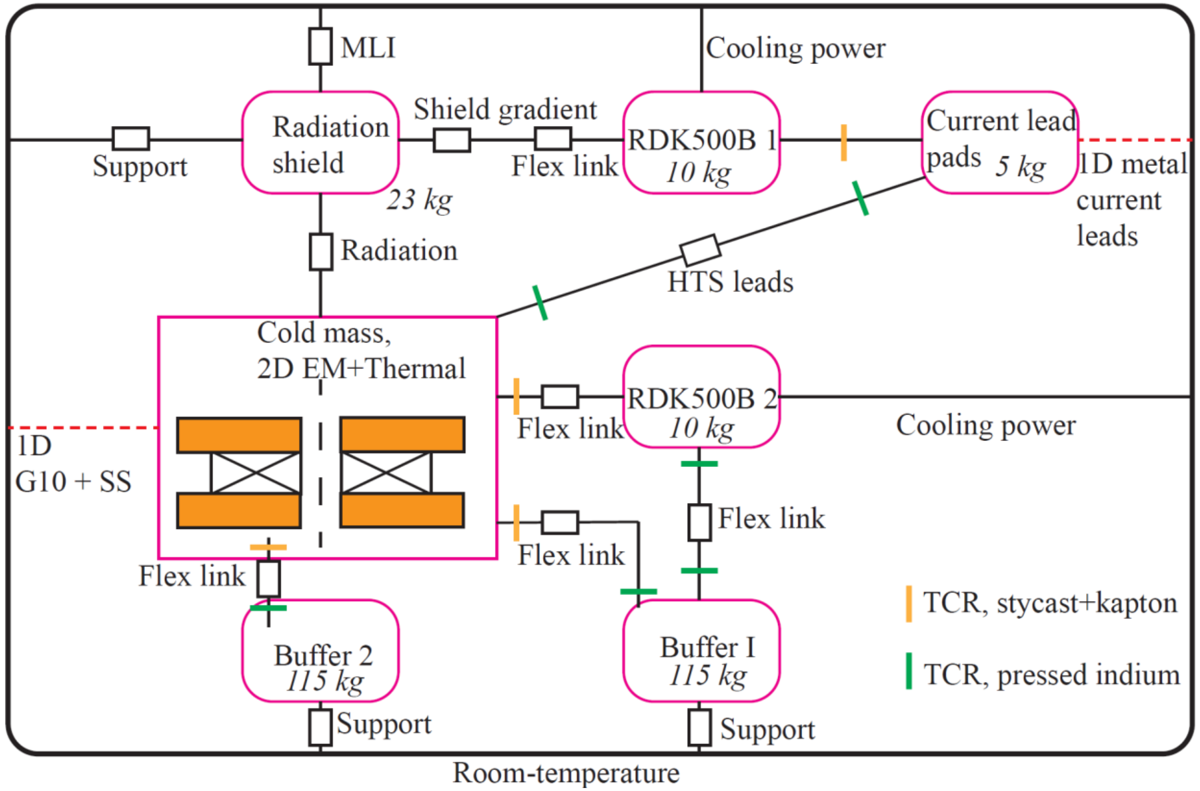
- homogenized winding pack,
- Anisotropic resistivity matrix with off-diagonal terms to account for the spiral nature of the coils [1]

$$\boldsymbol{\rho}_{\text{coil}} = g\boldsymbol{\rho}' g^{-1} = \begin{bmatrix} \rho_{\text{rr}} & \rho_{\text{r}\phi} & 0 \\ \rho_{\phi r} & \rho_{\phi\phi} & 0 \\ 0 & 0 & \rho_{\text{z}} \end{bmatrix}_{\hat{r},\hat{\phi},\hat{z}}$$

+2D thermal

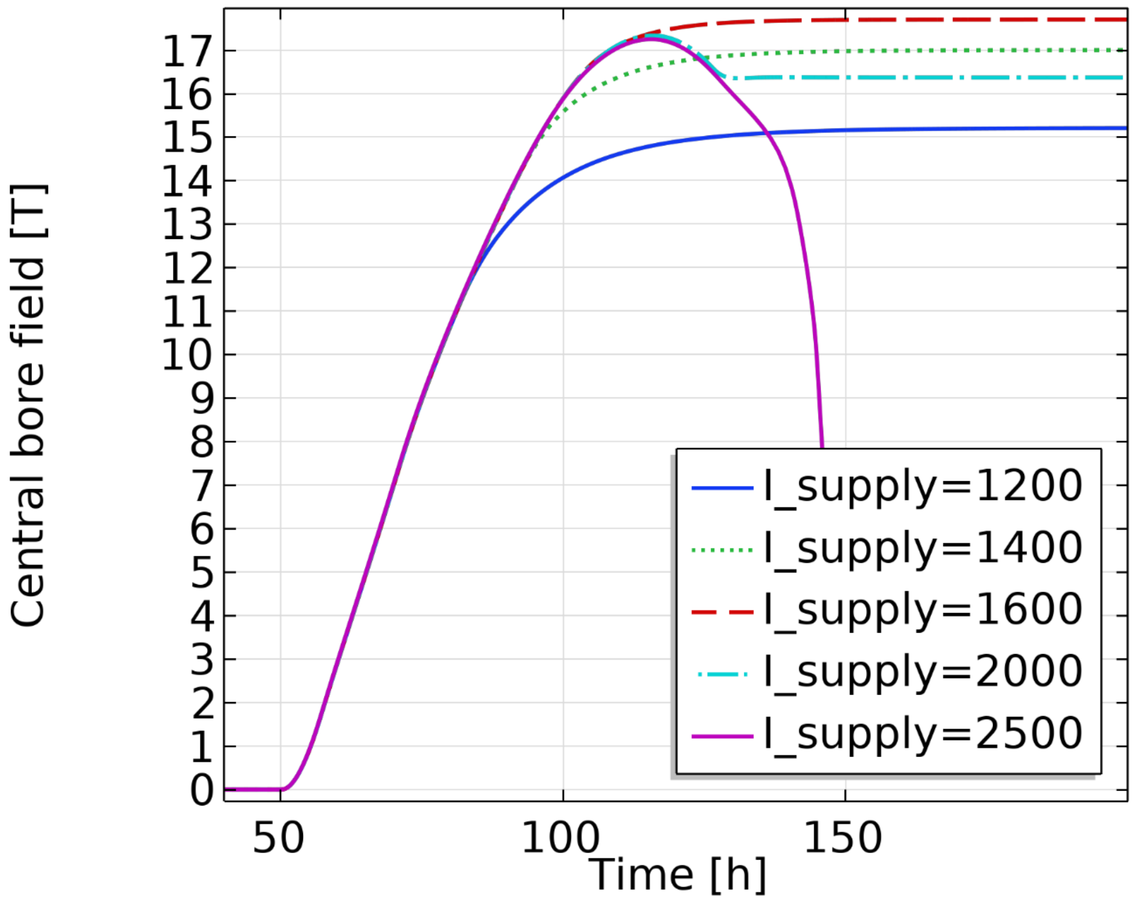
+ Lumped thermal network

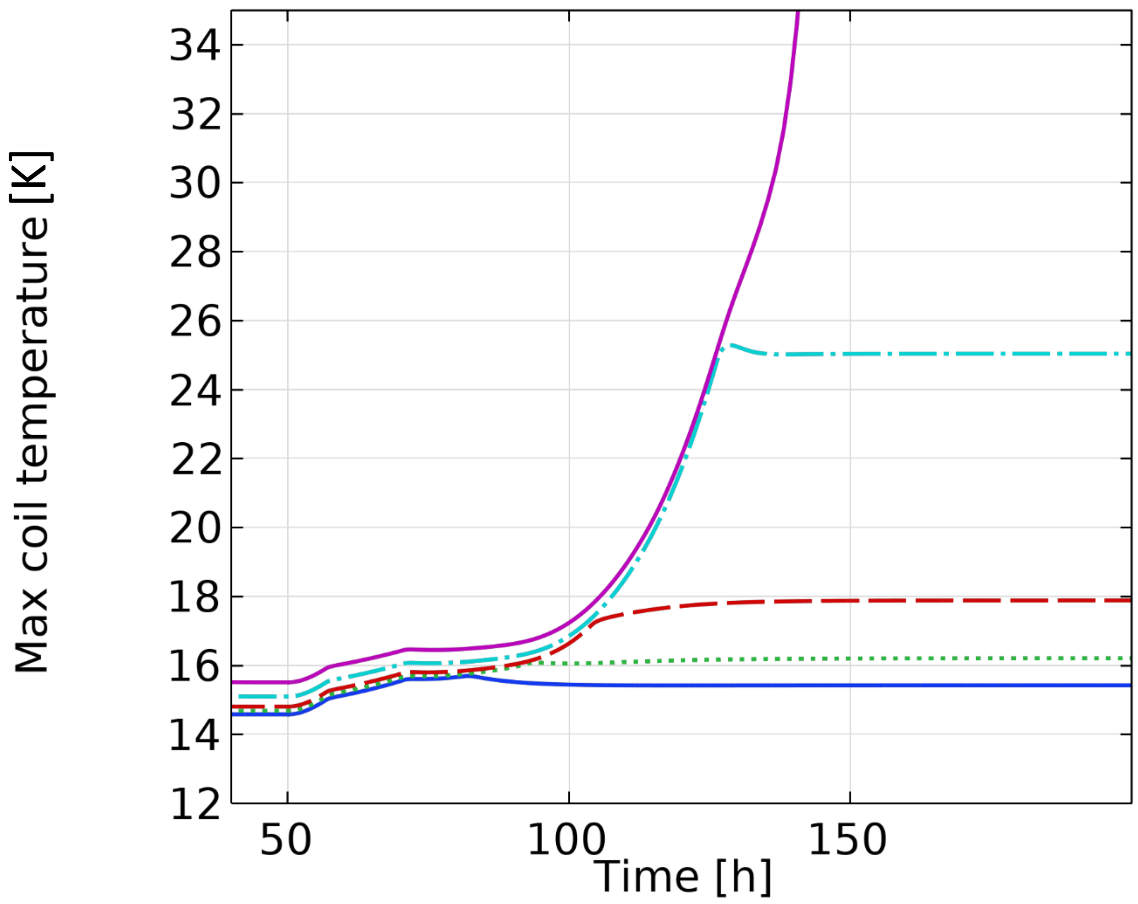




[1] R Mateira, DOI 10.1088/1361-6668/ab9688

Predicted obtainable field strongly depends on thermal aspects



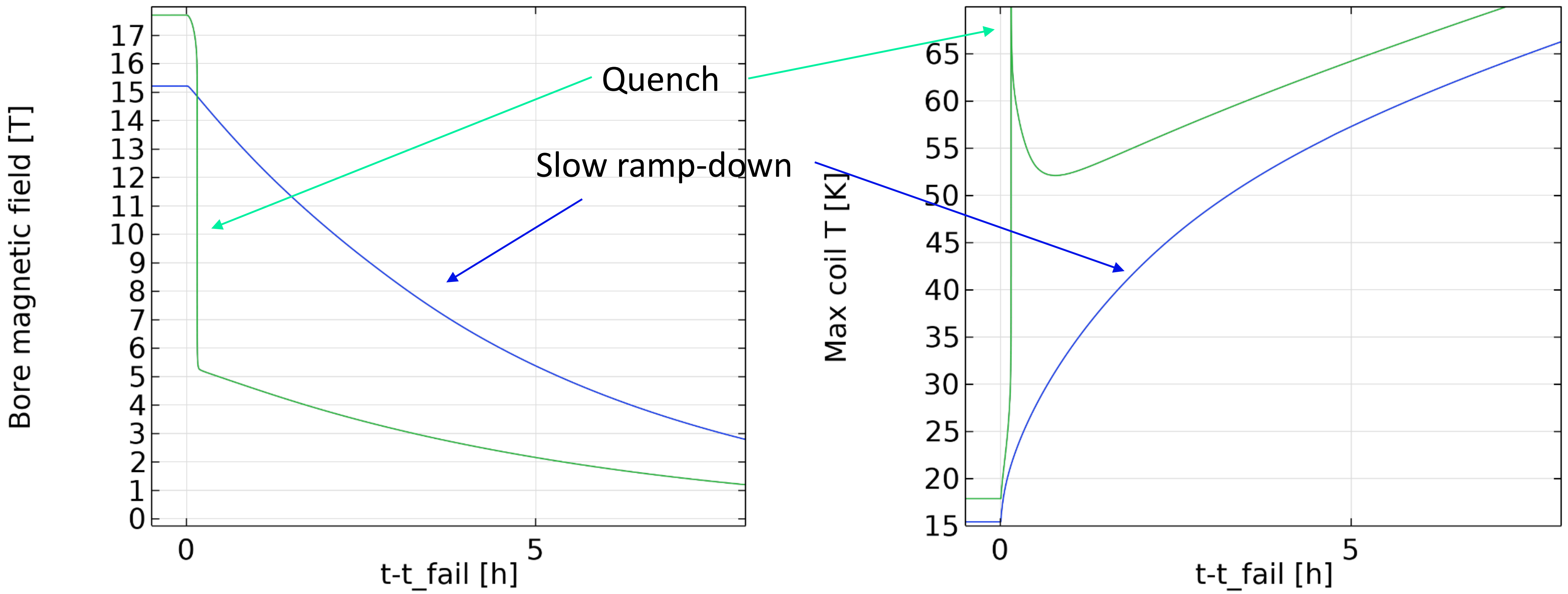


1200 A nominal

17 T reachable*, but magnet at risk of quenching during failure

*Not considering mechanical

Buffer sizing



Buffer size (220kg Pb) chosen by parametric study