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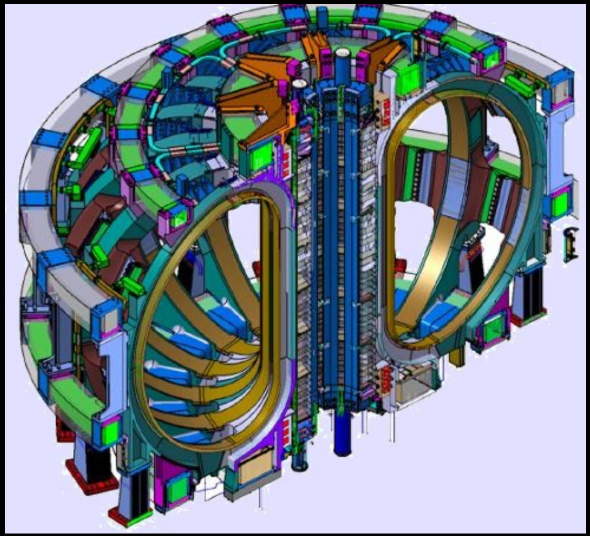
Thermal Challenges for Superconductors in Big Science

M. Dhallé, A. Nijhuis, H. ten Kate, M. ter Brake

Thema-bijeenkomst "Thermal Challenges", Mikrocentrum Veldhoven, 15 Mei 2019

Superconductors = key *enabling* technology for Big Science



Magneto-hydrodynamics (fusion):

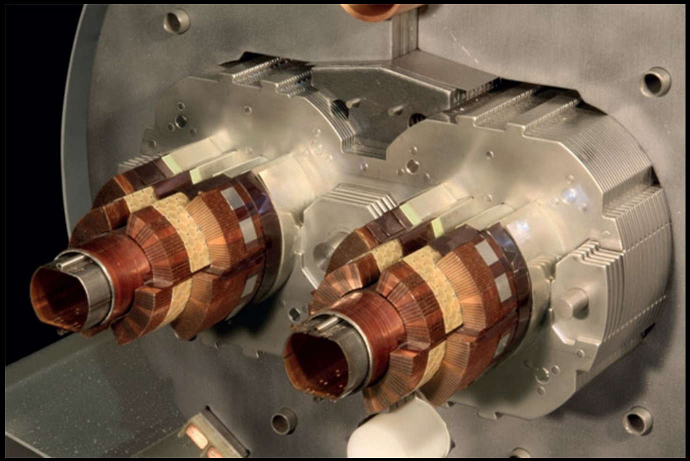
$$J \times B + \nabla P = 0$$

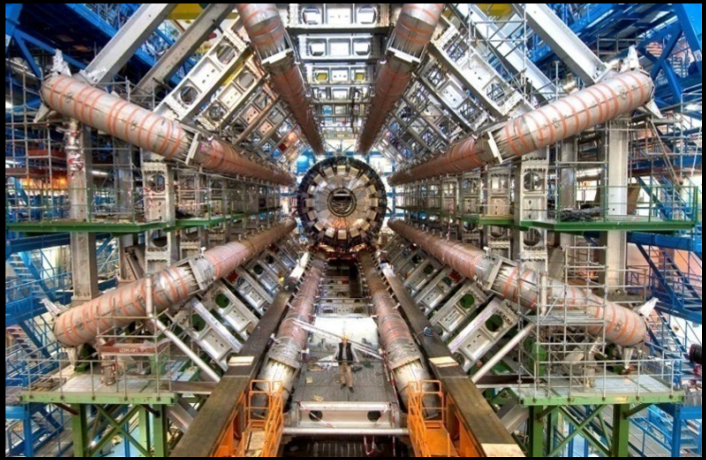
Circular beams (high-energy physics):

$$BR = 3.336\, p$$

Higher *B* $\rightarrow$

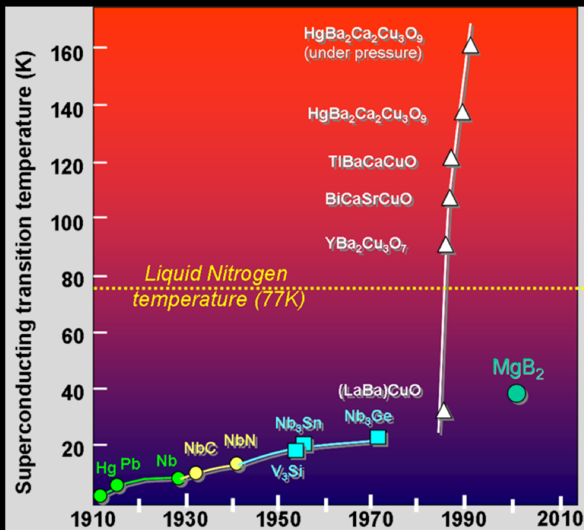
more <u>compact</u> machines

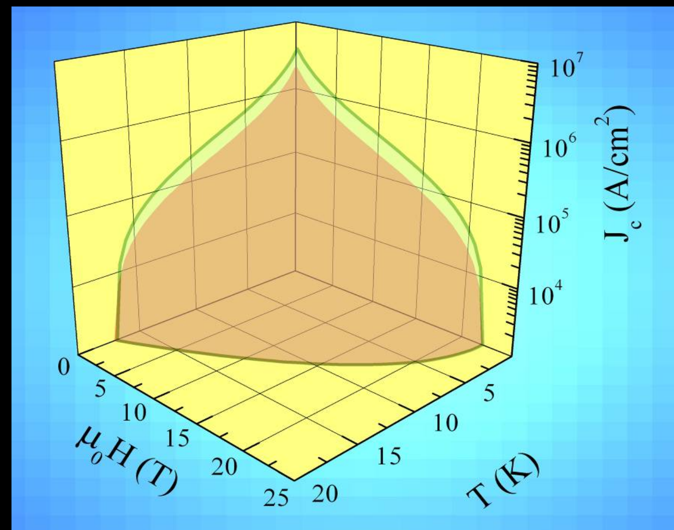




Thermal challenges for superconductors

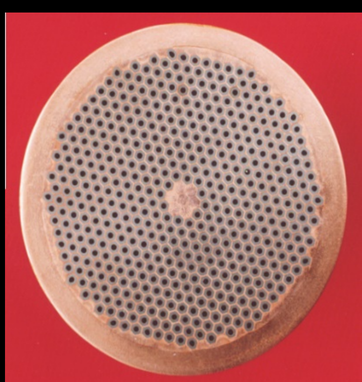
Safeguard (cryogenic) operational temperature

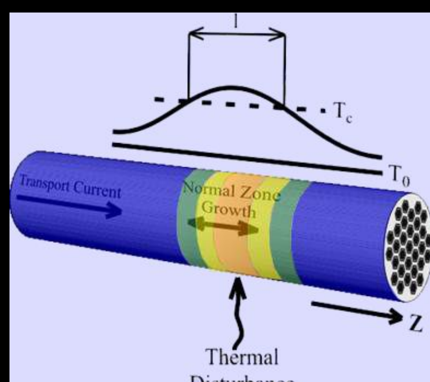


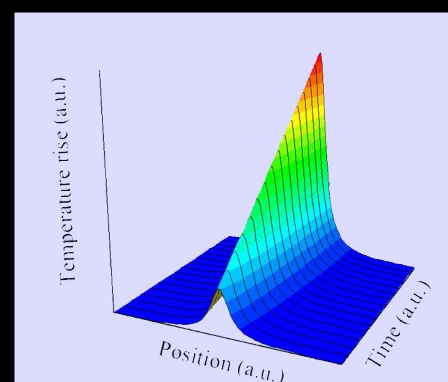


Against

- Cryostat loss
- Feedthrough loss
- AC loss (dynamic)
- Radiation loss
- …





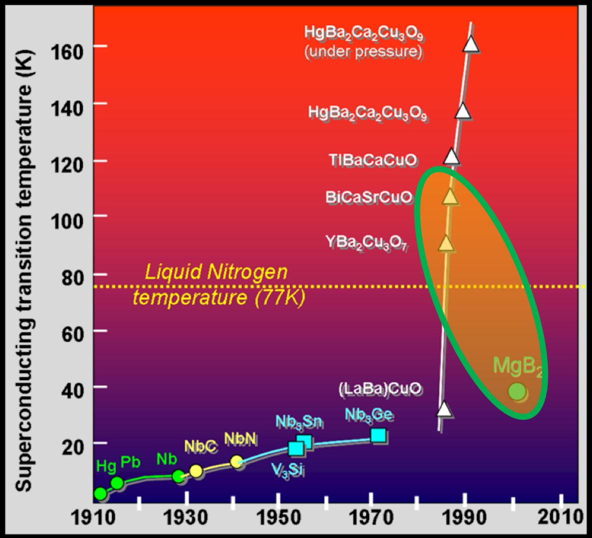


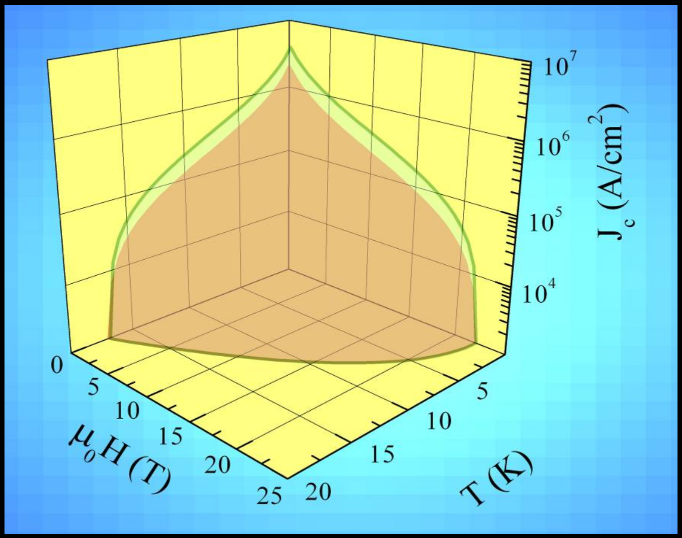
Issues

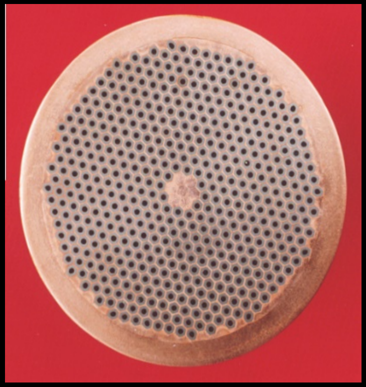
- Stability (*J,B*)
- 'Quench'
  detection / protection

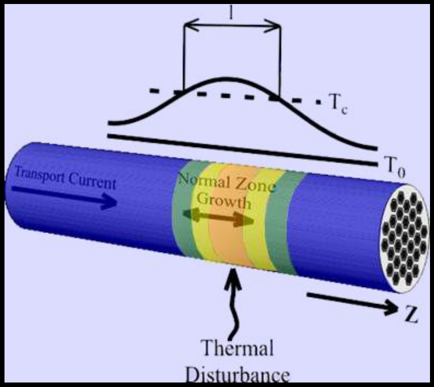
Thermal challenges for superconductors

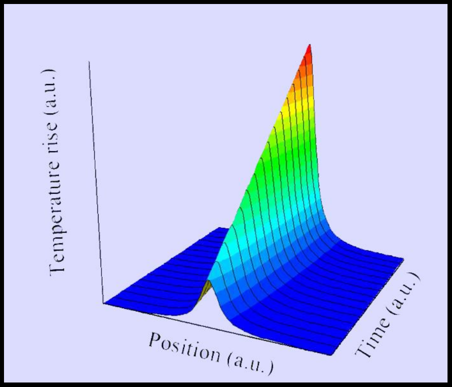
Safeguard (cryogenic) operational temperature











High-Temperature Superconductors (HTS) rapidly maturing

Higher *T*
and/or higher *B*

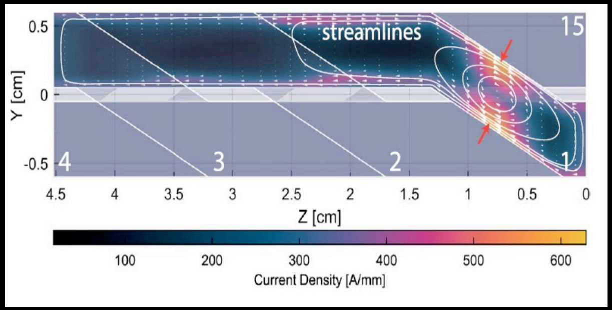
- Further size reduction
- Increased stability

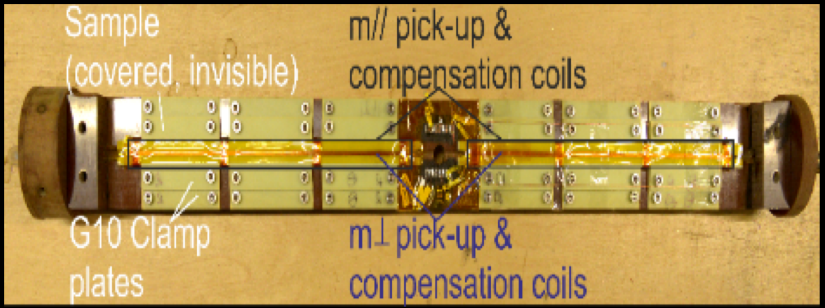
but ...

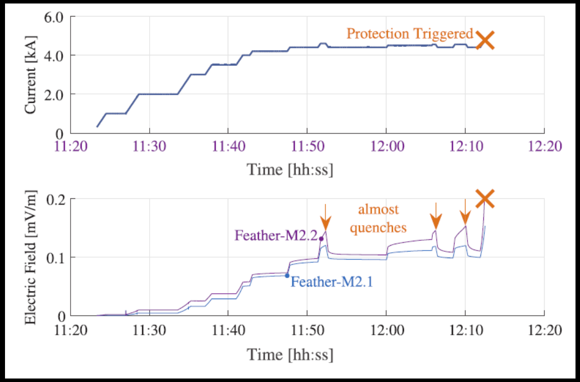
- Harder quench detection
- Increased AC loss
- Increased cost

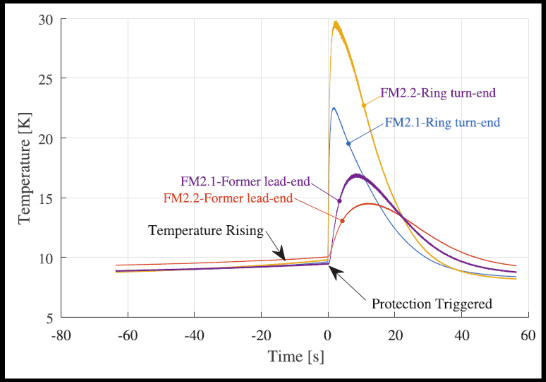
HTS magnets for HEP *(1)*

20T – class dipole insert (ReBCO Roebel cable)





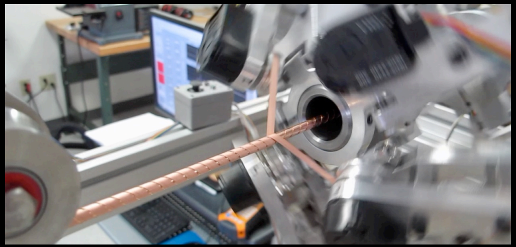


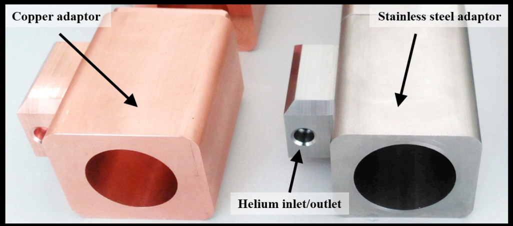


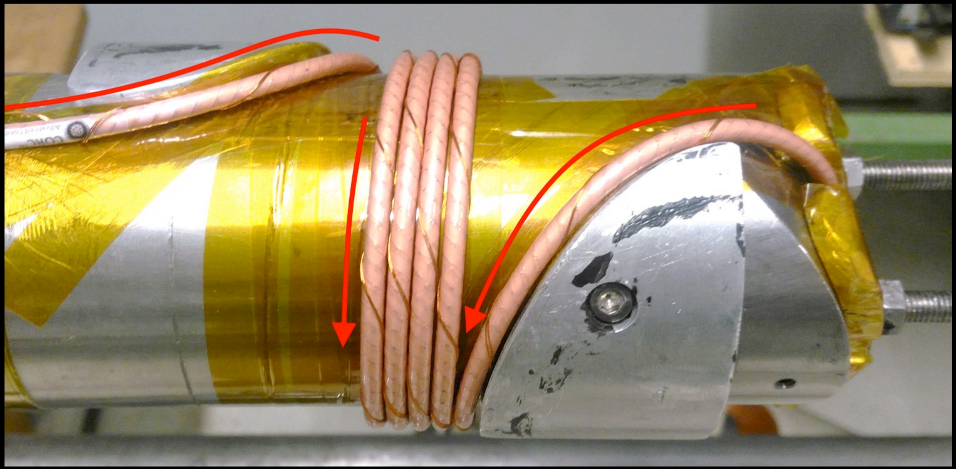
EuCARD-2 FCC EuroCirCol

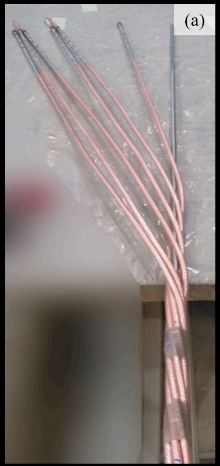
HTS magnets for HEP (2)

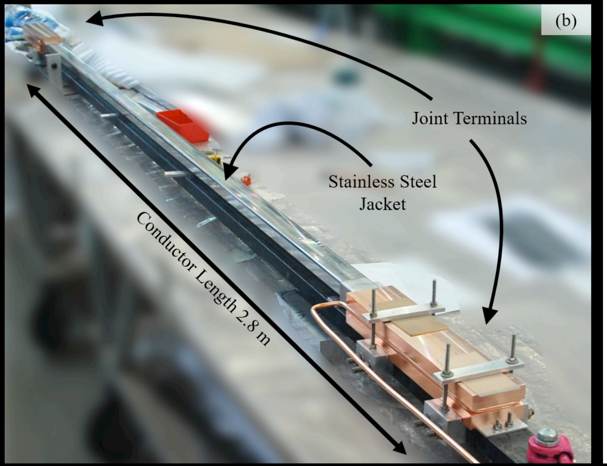
HTS detector-grade solenoid (ReBCO CorC CICC)

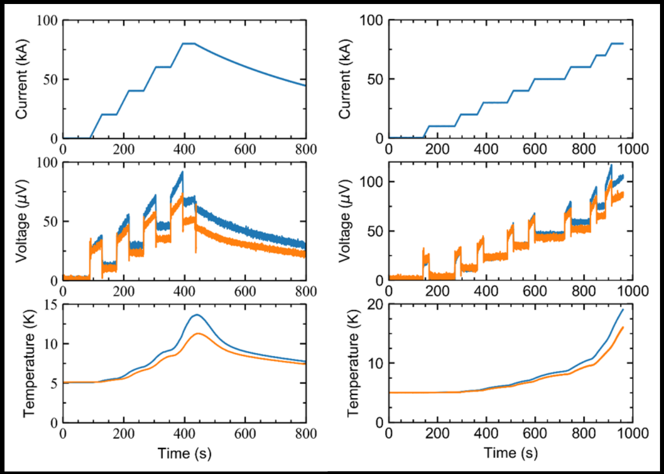








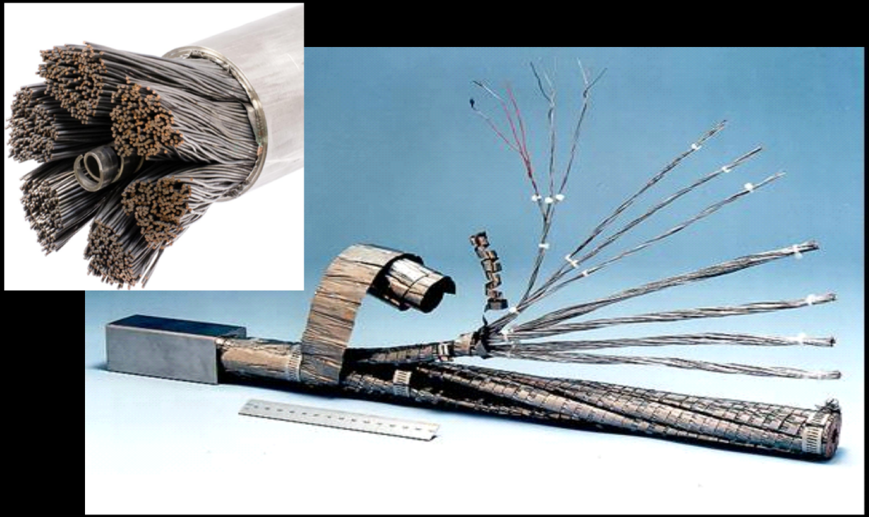


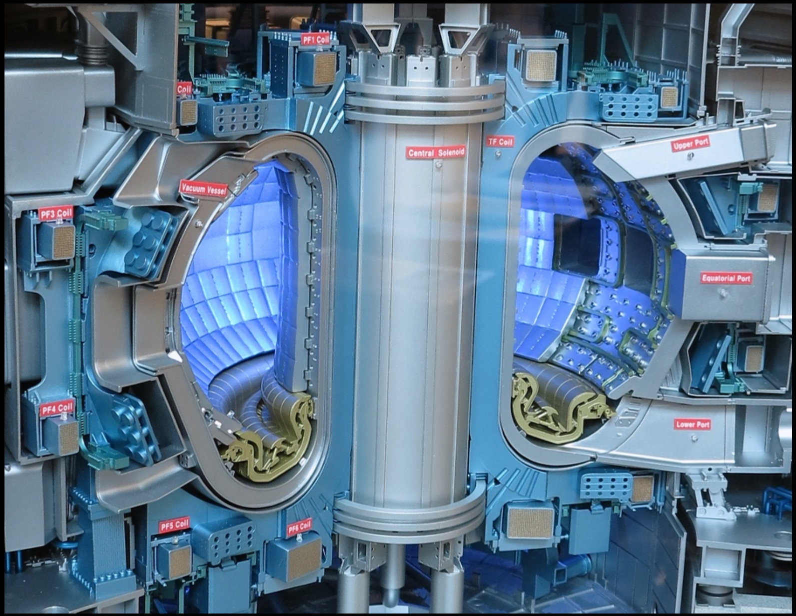


Heating of superconductors in ITER Coils

Superconductor operation is limited by:

- ✓ temperature
- ✓ magnetic field
- ✓ current
- ✓ mechanical stress (TF & CS)



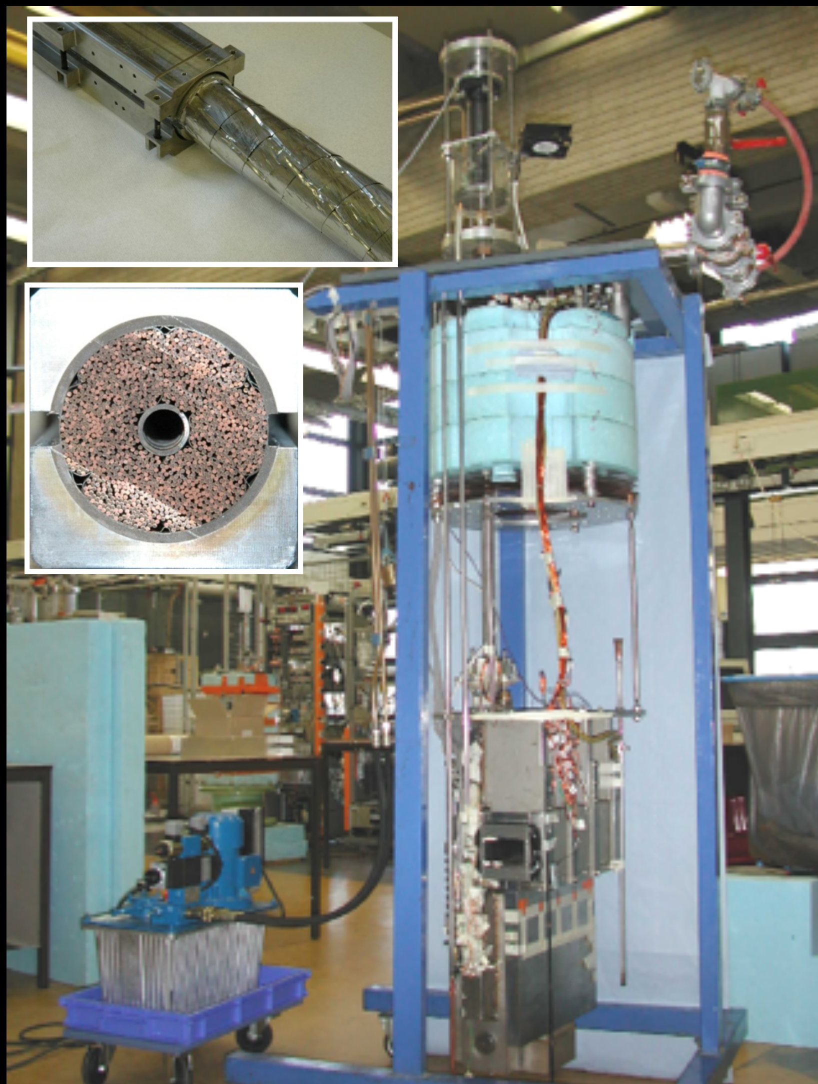


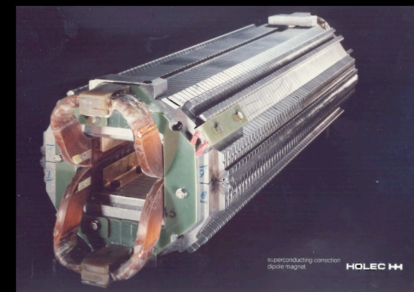
Plasma Operating Scenario determines temperature superconductors:

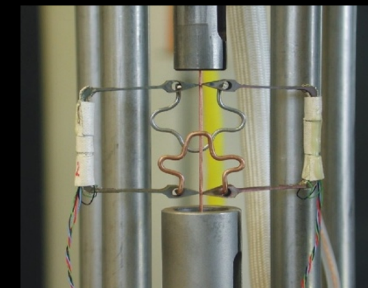
- ✓ nuclear heating
- ✓ structure eddy currents
- ✓ superconductor AC losses

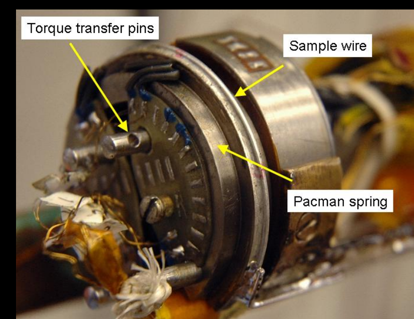
Unique detailed numerical multi-physics **ITER Superconductor Model JackPot AC-DC** developed at University of Twente, best equipped to predict the operational temperature margin for all ITER coils during any Plasma Operating Scenario.

Unique experiments ▶ precise model inputs







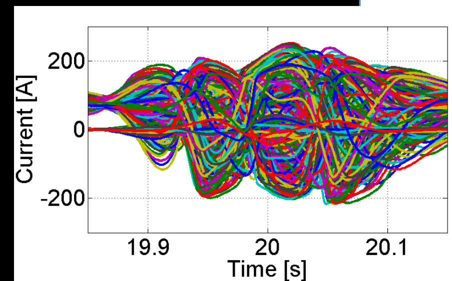


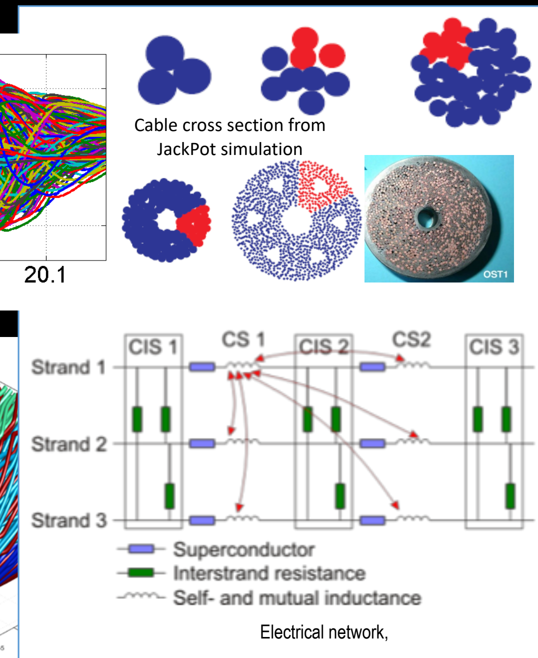
Unique experiments on ITER Superconductors at University of Twente (ITER Reference Lab), determining electromagnetic, thermal and mechanical properties required for performance prediction under Plasma Scenario coil operation.

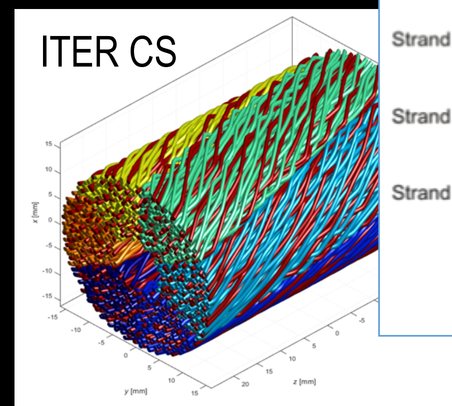
JackPot AC-DC ITER cable/joint model

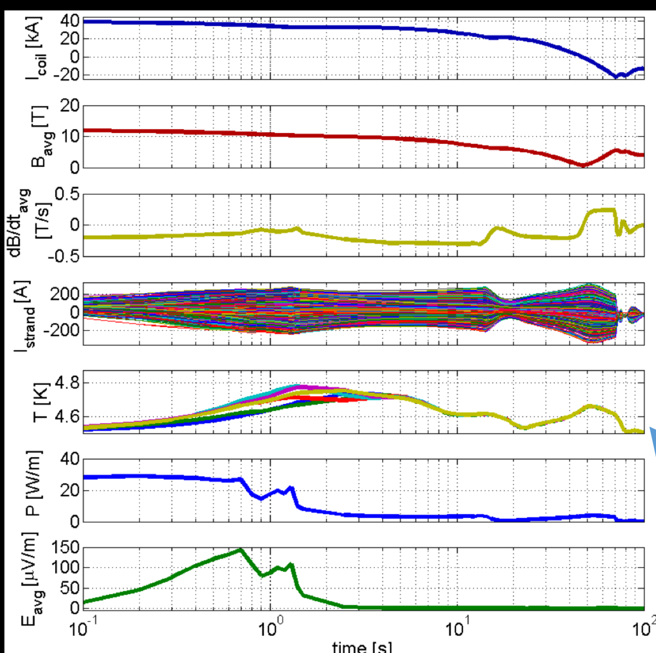
Cable model accurately describing ***all* (>1000)** strand trajectories;
including compaction steps

- ✓ Interstrand contact resistance distribution
- ✓ Strand's self/mutual inductances
- ✓ Coupling with self- & coil background field
- ✓ Strand's scaling law $I_c(B,T,\varepsilon)$ and $V(I)$







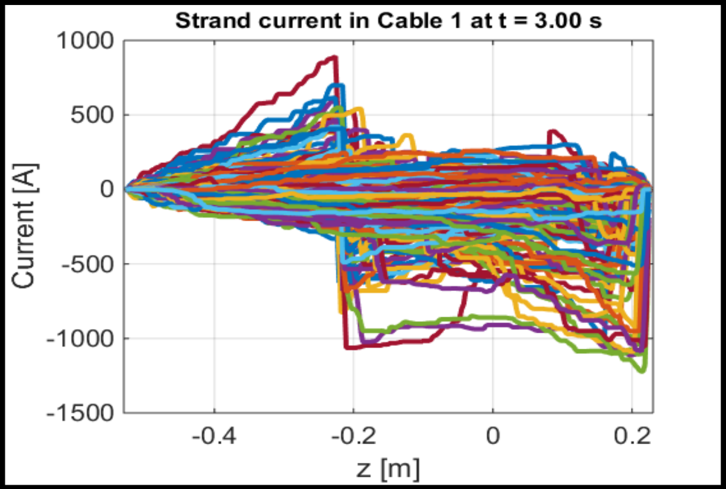


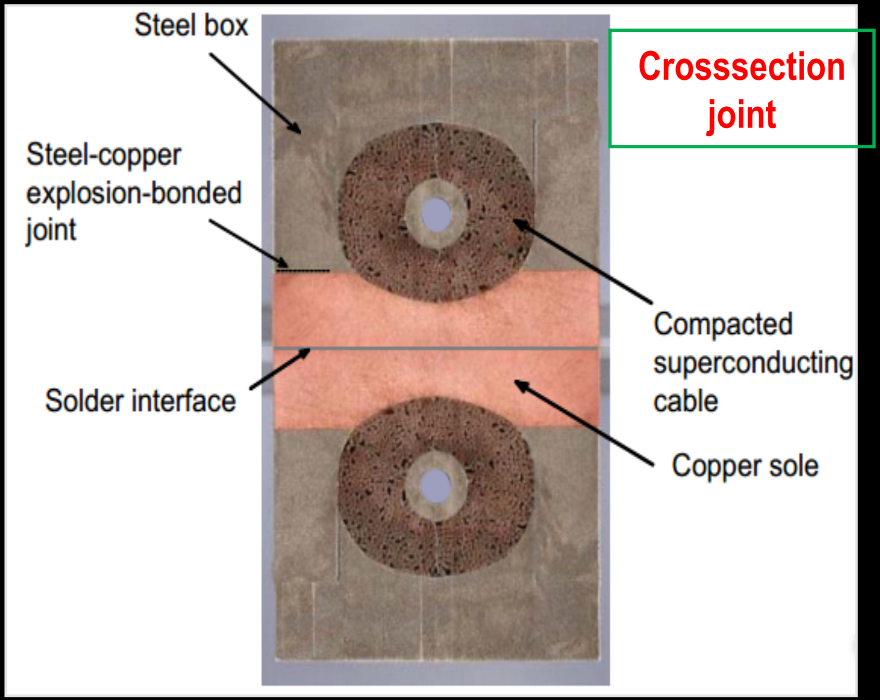
Model output:
Simulation for ITER CS
15 MA Plasma Scenario:
Highest temperature in turns at inner radius of CSU2 and CSL2 modules.

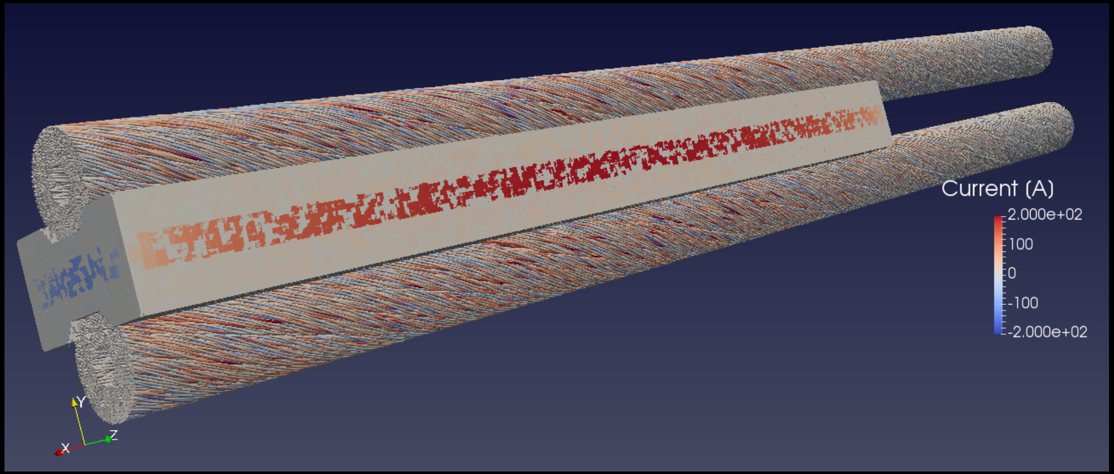
For **faster** and more precise Plasma Scenario operation computations, ***collaboration needed with TUE PS computations.***

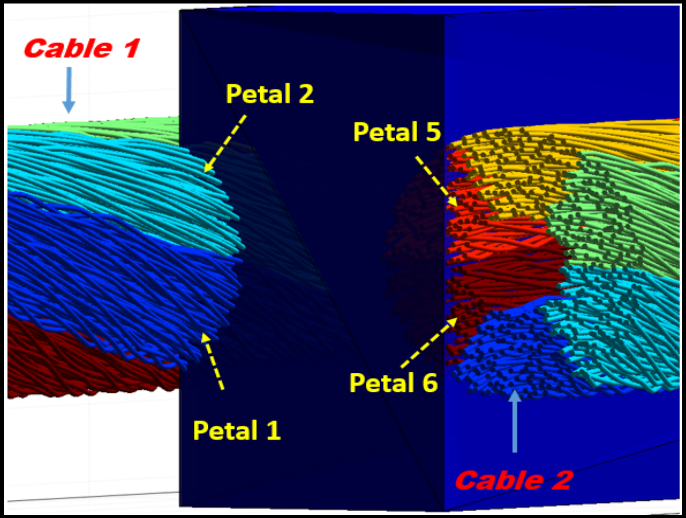
ITER – JackPot analysis of PF Joints- MPM

Stability of ITER Coil Joints during 15 MA Plasma Scenario by electromagnetic and thermal computations at detailed SC wire level.



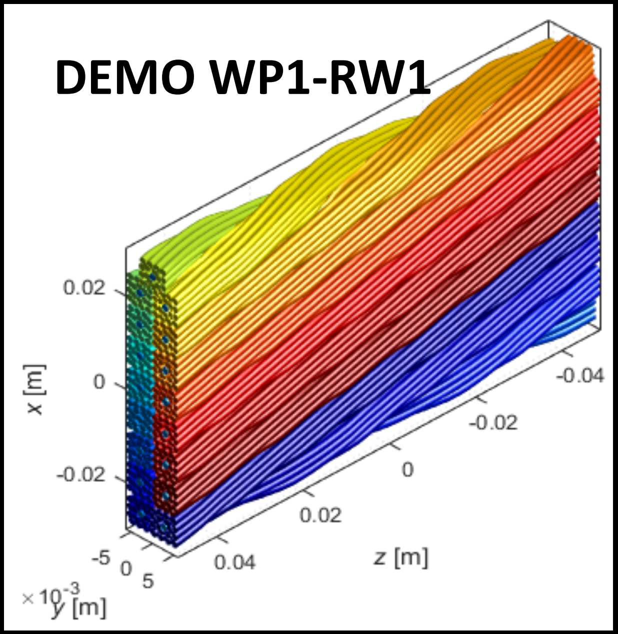


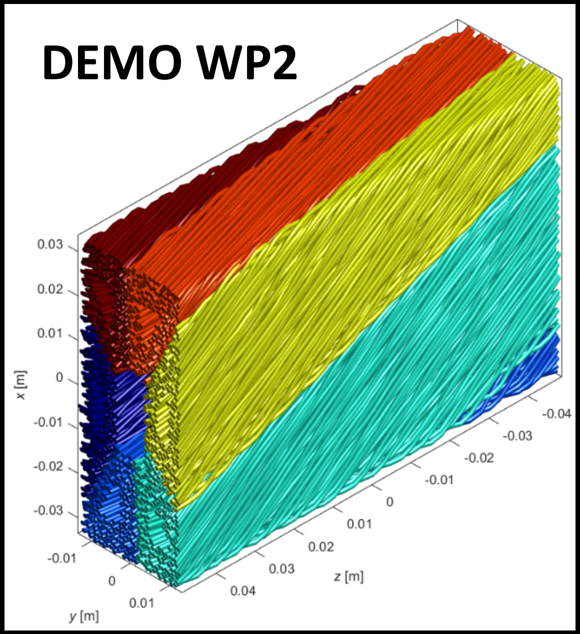


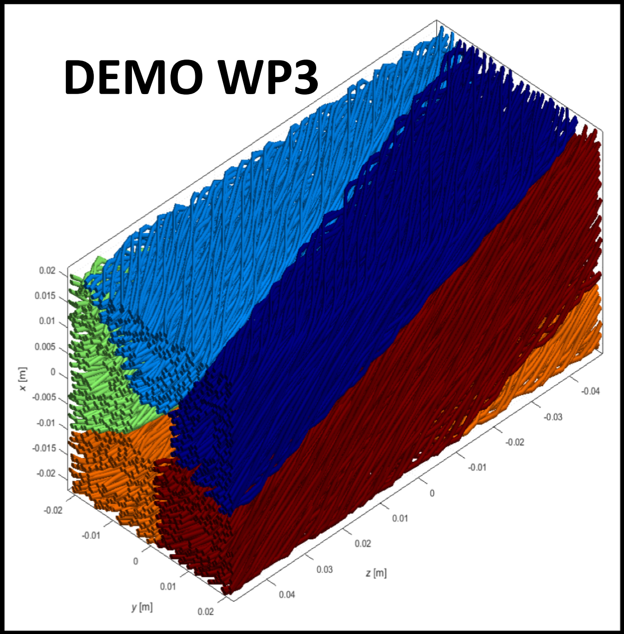


Modeling EUROfusion DEMO TF conductors

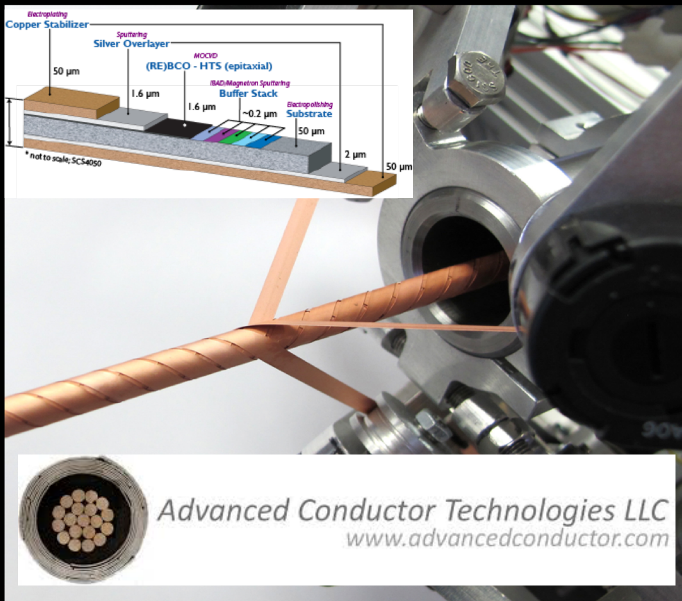
Cable model accurately describing *all* (>1000) strand trajectories in CICC for analysis of the current distribution, Minimum Quench Energy, and Power dissipation during DEMO operation scenario.



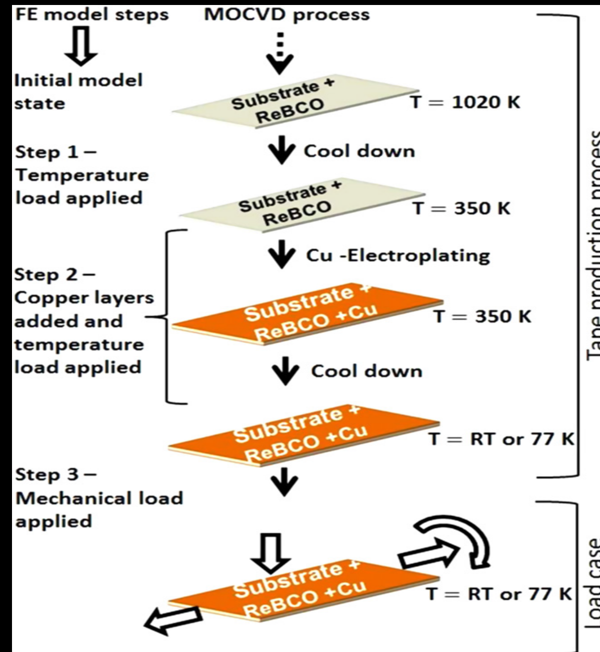


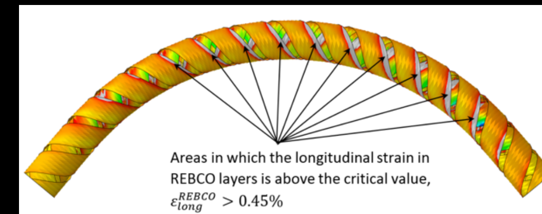


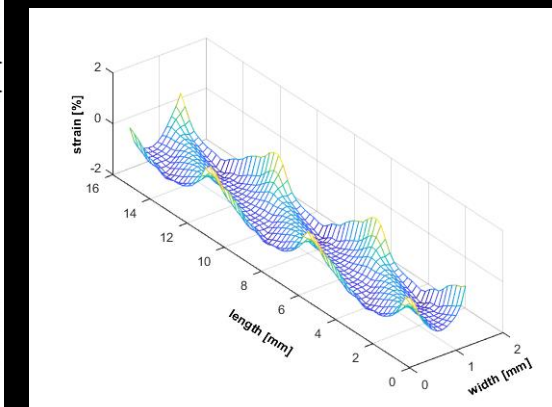
Design optimization of DEMO HTS cables

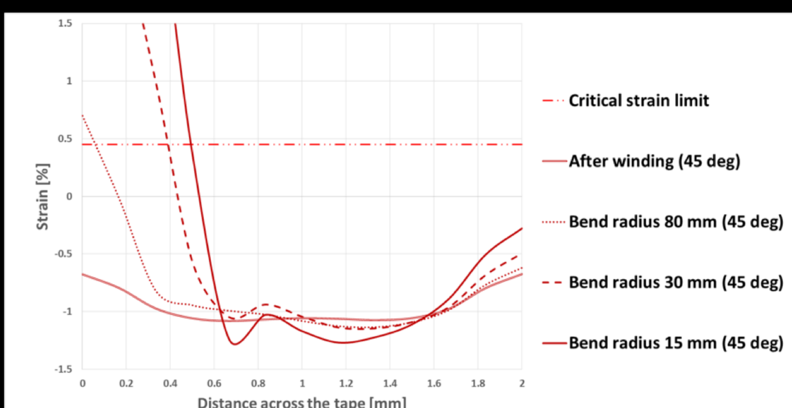


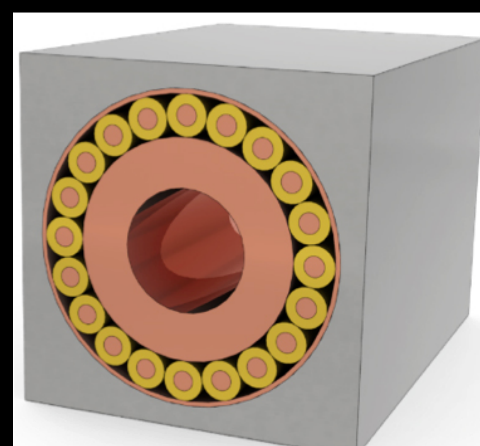
Cable-On-Round-Core

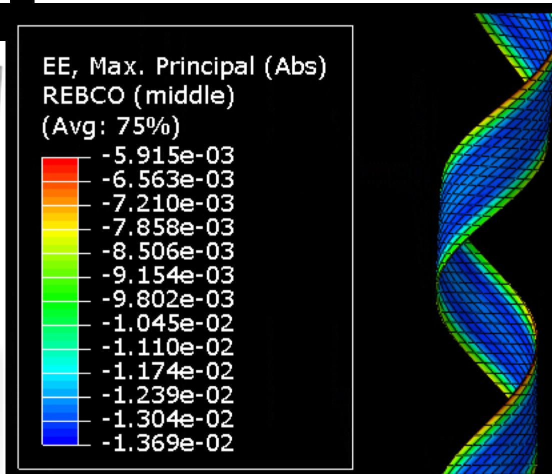






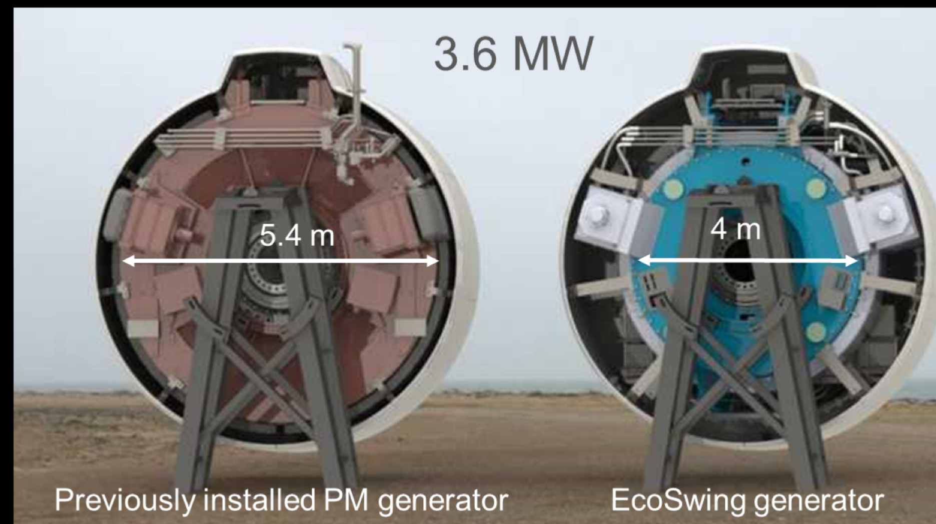


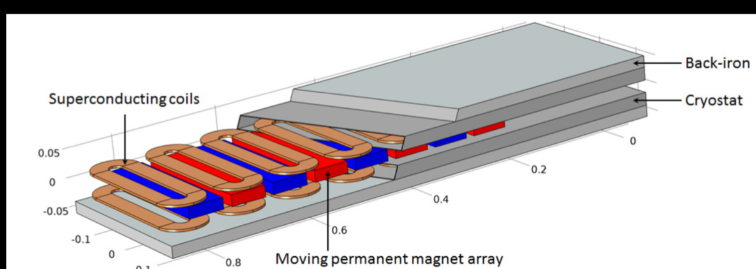


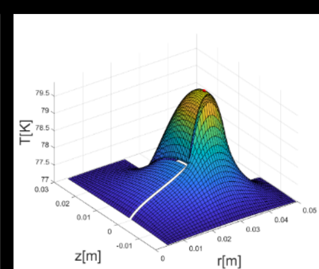


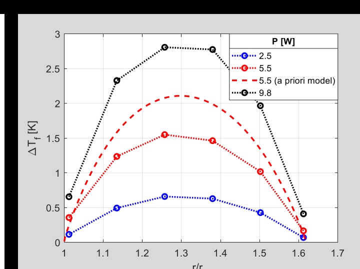
Spin-out projects

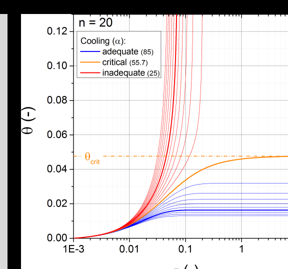
Renewable energy (EcoSwing), cyclic economy (SMDS), enhanced performance (HSLM) , …











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