

# Protection design and modelling at Tampere University (TAU)

Tiina Salmi

with contributions from: D. Liu, D. Sotnikov, M. Lyly, H. Milanchian, M. Haajari, S. Bakrani Balani,  
D. Wu, P. Lammintausta, ...

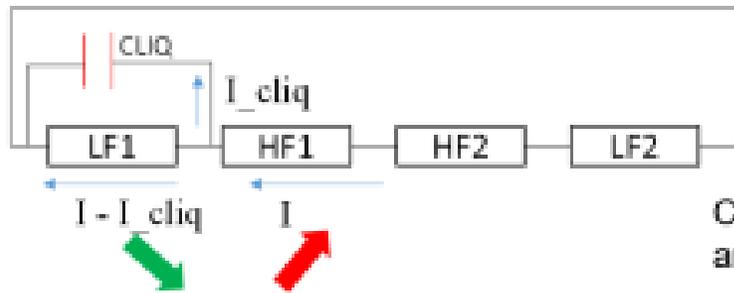
# Current status of superconducting magnet research at TAU

- **PI:** Academy Research Fellow Tiina Salmi
- **Team:** 1 PhD student, 1 postdoc, 1 part-time postdoc, 2-3 researchers/research assistants
- **Projects:**
  - Academy reserach fellow project for Nb<sub>3</sub>Sn magnet quench protection (2020-2026),
  - Academy project for HTS magnet modeling, (2019-2023)
  - Business Finland co-innovation project for HTS magnet design, manufacture and test (2020-2023)

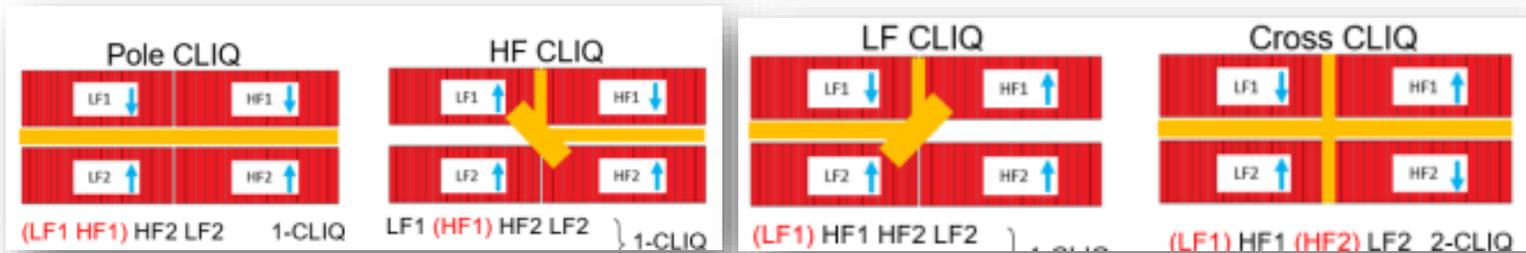
# Nb<sub>3</sub>Sn accelerator magnet quench protection

- Academy of Finland funding for high-field magnet quench protection
- Up to now: Analysis of the CEA magnet R2D2 with CLIQ or heaters

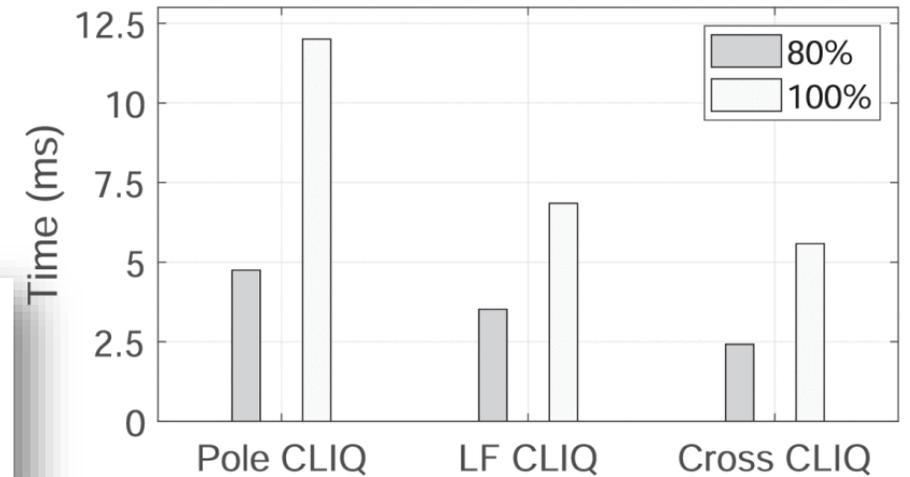
## 1. Analyzing different CLIQ connection options and optimizing the parameters (D. Liu, now at LUT)



Connection of magnet blocks and current direction definition



Time to quench 80% and 100% the magnet with the optimized CLIQ C and V at  $I_{nom}$  (14588 A).

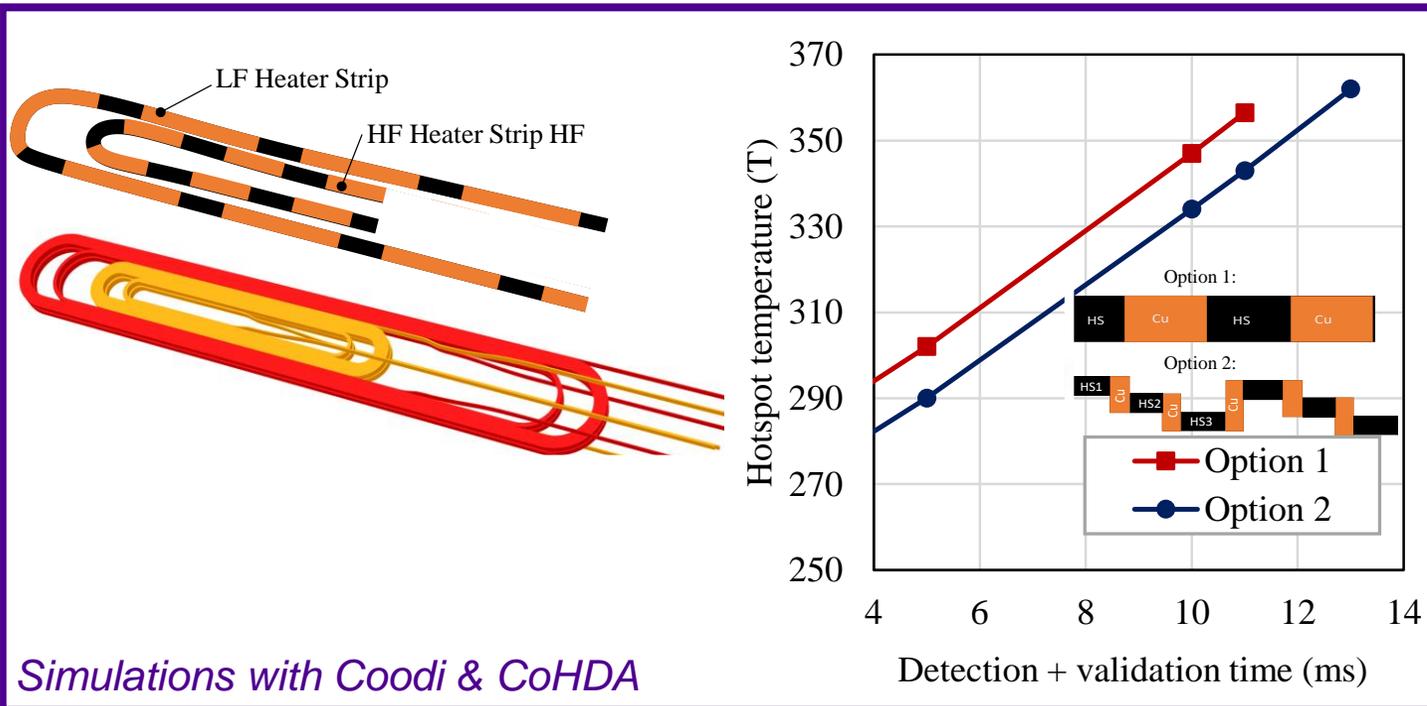


Simulations with CERN STEAM-LEDET

# Nb<sub>3</sub>Sn accelerator magnet quench protection

- Academy of Finland funding for high-field magnet quench protection
- Up to now: Analysis of the CEA magnet R2D2 R2D2

## 2. Analyzing different heater layout options, and optimizing the parameters (T. Salmi)



## 3. Improving modeling tools (S. Bakrani Balani, T. Salmi)

Numerical simulation of quench propagation in cable pre-heated with heater



Excel spread-sheet tool to guide heater design

General parameters		Unit	Value
Heater strip thickness	m	2.54E-05	
HFU voltage	V	900	
Stainless steel resistivity @4.5 K	Ohm-m	5.00E-07	

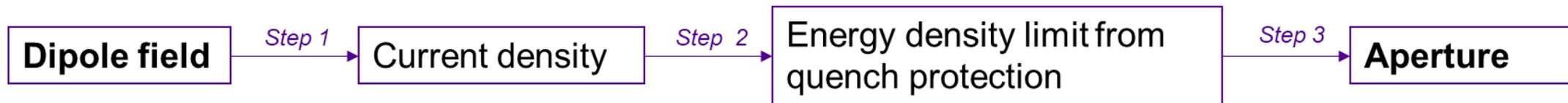
  

Strip name	Strip width (mm)	Strip length (m)	HS length (m)	HS period (m)	R strip (Ohm)	R_marg, strip (Ohm)	R_marg, circ. (Ohm)	se
R2D2 LF+HF straight cu-plated, 900 V	35	2	0.05	0.1	0.56	0.5	1	
R2D2 HF straight cu-plated, 900 V	35	1.2	0.05	0.06	0.56	0.5	1	
R2D2 LF straight cu-plated, 900 V	33	2.7	0.05	0.12	0.67	0.5	1	
R2D2 LF+HF comparable to long magnets, 900 V	30	2	0.05	0.2	0.26	0.5	1	

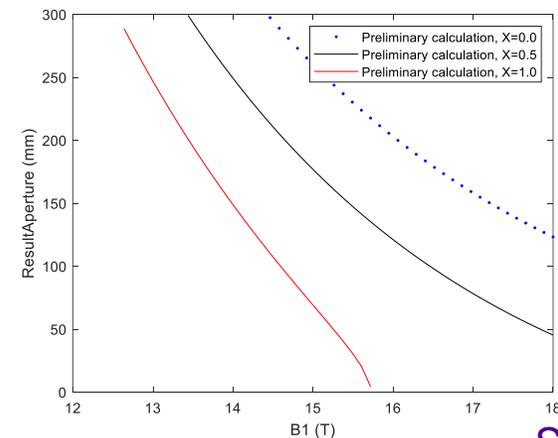
# Small contribution to the muon collider accelerator magnet protection

- Contributing to the accelerator magnet parameter feasibility mapping with the INFN team

*Analytical mapping of feasible parameters based on limits from quench protection (T. Salmi)*



*Example calculation about magnetic field aperture vs. dipole field based on analytic expressions  
 – Updated calculation to be presented at the Muon collider Magnets WG meeting 27.4.2023*

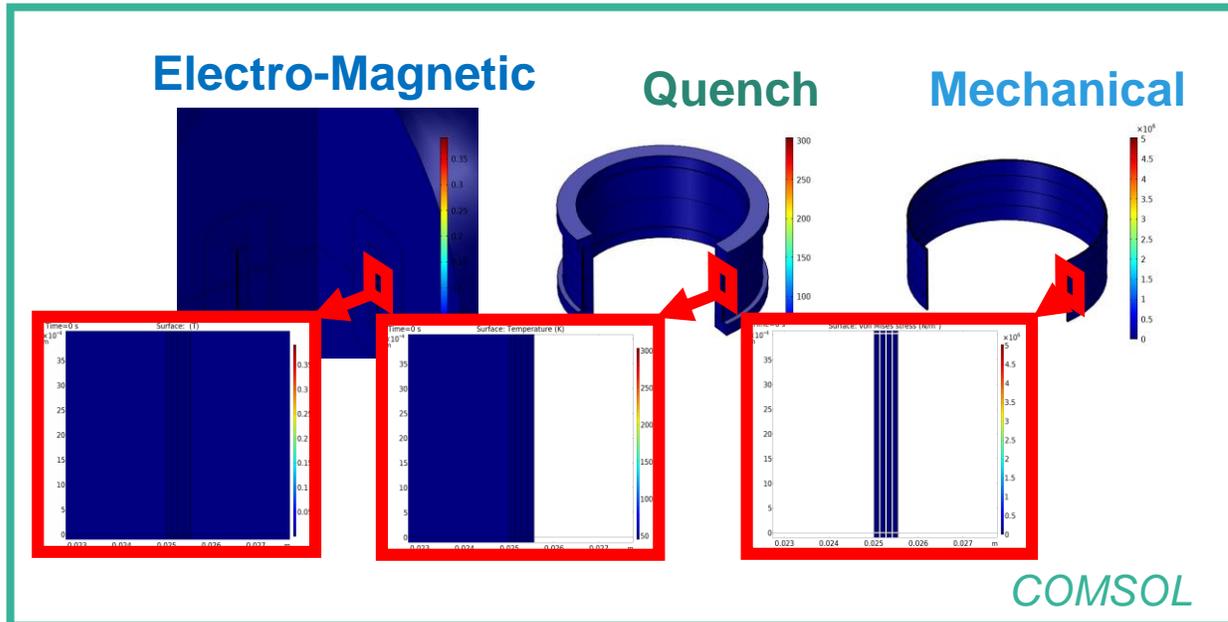


*Simulations with MATLAB*

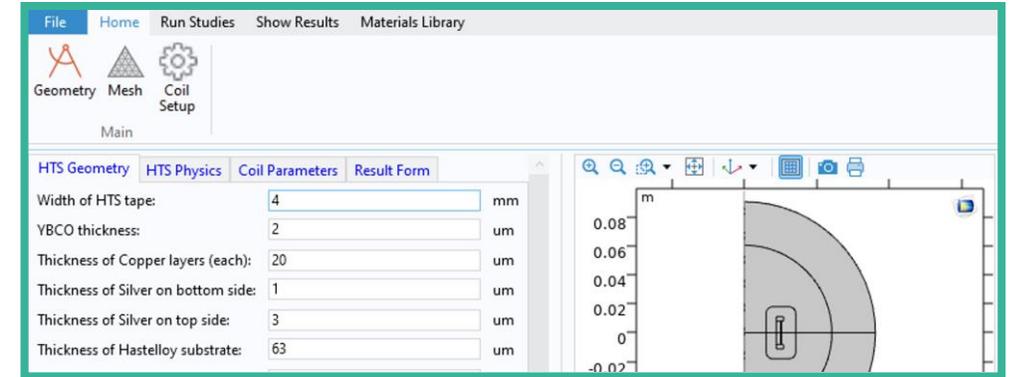
# HTS magnet modeling

- Several simulation models for quench, electromagnetics, and mechanics (COMSOL, Sparselizard, Matlab, Fortran90,... + AI explorations
- Currently being applied to a single-tape solenoid demo

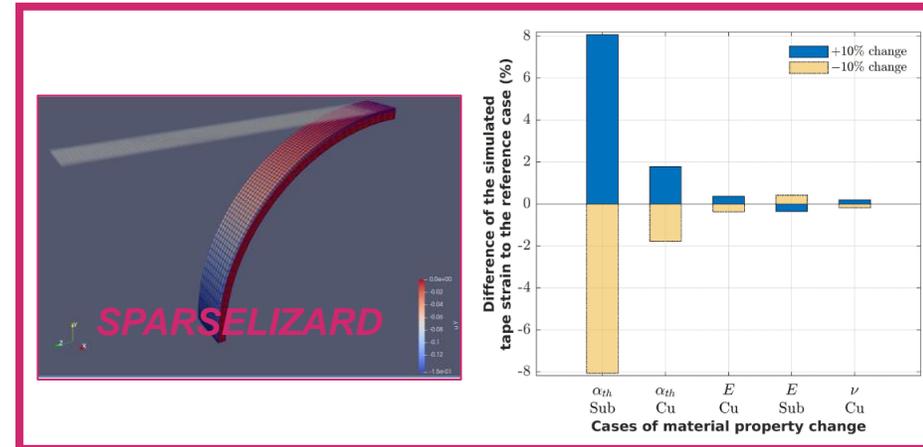
## 1. Example of coupled multiphysics simulation for HTS solenoid (Dmitry Sotnikov (now at PSI))



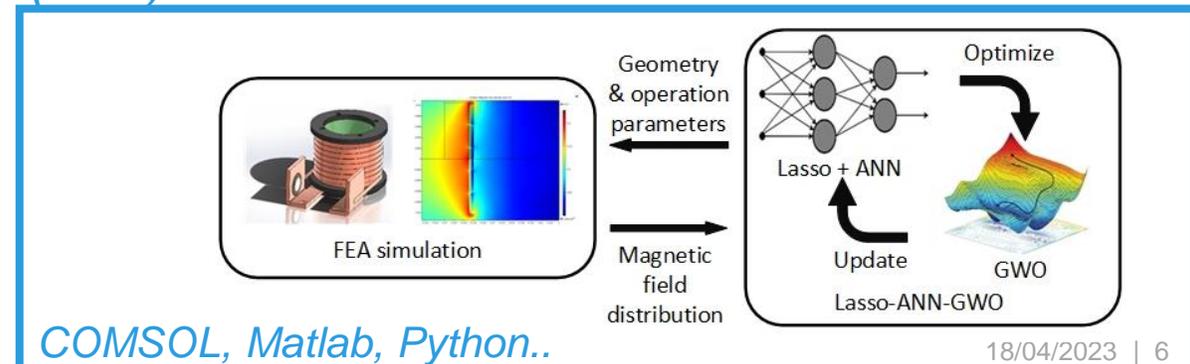
## 2. Application for user-interface of the COMSOL model (M. Haajari, D. Sotnikov)



## 3. HTS tape stress and strain during cool-down, loading, quench, etc. (H. Milanchian)



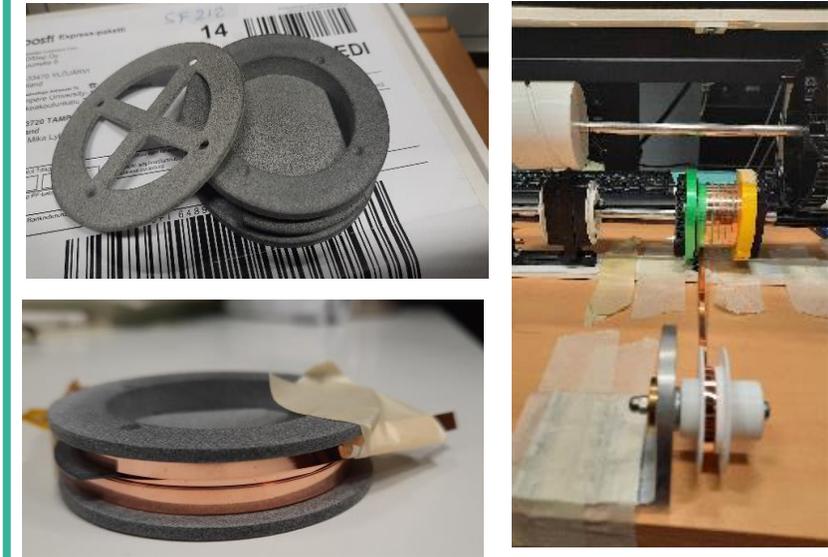
## 4. Surrogate model based optimization, case study of solenoid field (D. Wu)



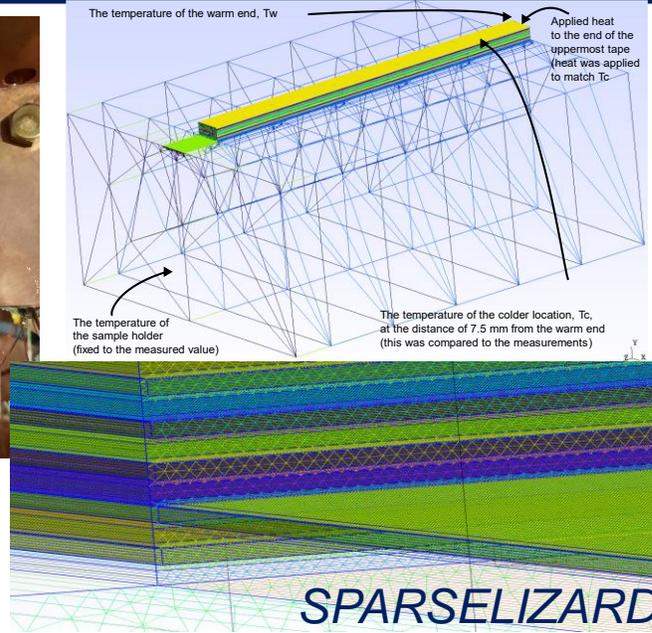
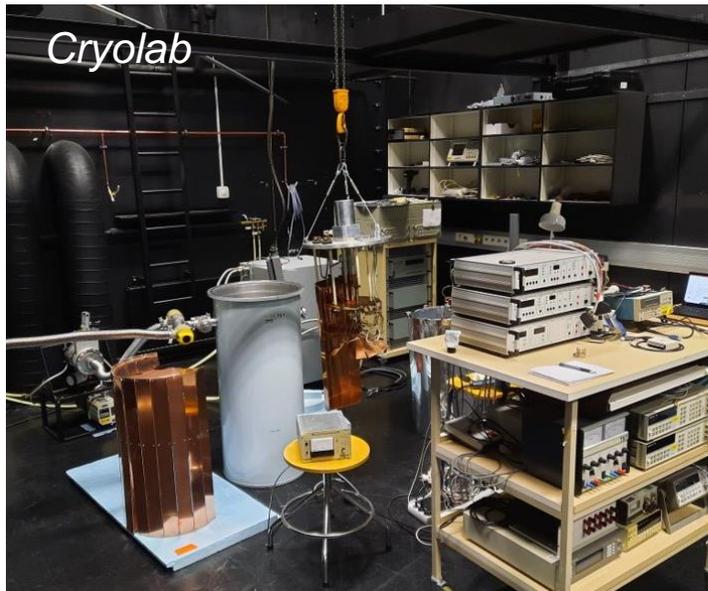
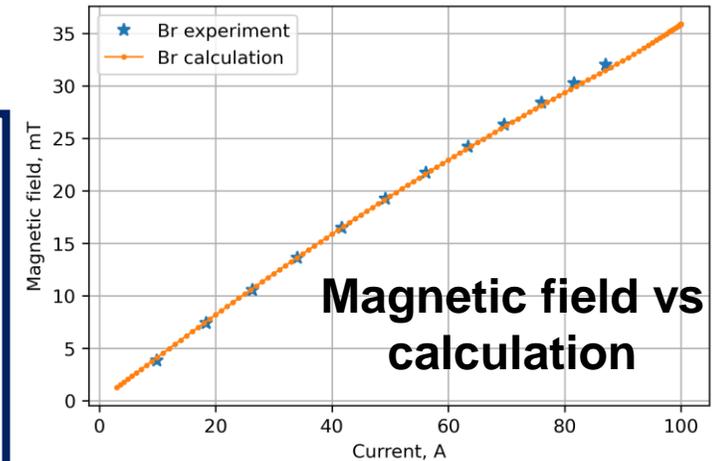
COMSOL, Matlab, Python..

# HTS magnet experimental

- TAU Cryolab re-started and upgraded 2021-2023
- First mini demo solenoids wound and tested in LN2
- Small sample measurements (resistivity, thermal cond.) in Cryocooler (down to 12 K)
  - HTS tapes, 3D-printed metals
- Experiments with AE, etc...



*Thermal cond. measurement of HTS tape stacks and simulation (M. Lyly, P. Lammintausta)*



# Recent publications

## N3Sn magnet quench protection

- D. Liu *et al.*, "CLIQ Protection Design for the Graded Nb3Sn Research Racetrack Dipole Demonstrator (R2D2)," *IEEE TAS*, 2023, 4701105, doi: 10.1109/TASC.2023.3247983.
- T. Salmi *et al.*, "Quench Protection of Nb3Sn High Field Magnets Using Heaters, a Strategy Applied to the Graded Racetrack Dipole R2D2," *IEEE TAS* 2023, doi: 10.1109/TASC.2023.3251280.

## HTS tape and magnet simulation

- H. Milanchian *et al.*, "HTS Tape Mechanical Behavior Sensitivity on Material Properties and Thickness of Material Layers," *IEEE TAS* 2023, doi: 10.1109/TASC.2023.3251293.
- J. Ruuskanen *et al.*, "Modeling Eddy Current Losses in HTS Tapes Using Multiharmonic Method," *IEEE TAS* 2023, doi: 10.1109/TASC.2023.3242619.

## With AI explorations:

- D. Sotnikov, *et al.*, "Prediction of 2G HTS Tape Quench Behavior by Random Forest Model Trained on 2-D FEM Simulations," *IEEE TAS*, 2023, doi: 10.1109/TASC.2023.3262212.
- M. Yazdani-Asrami *et al.*, "Roadmap on artificial intelligence and big data techniques for superconductivity", *SUST*, 2023, doi: 10.1088/1361-6668/acbb34
- D. Wu *et al.* A novel constrained multiobjective optimization algorithm based on dimension selection using AI, *Journal of Mechanical Design*, 2023

## Other:

- D. Liu, T. Salmi and J. Lin, "Potential Performance of Fully Superconducting Generators for Large Direct-Drive Wind Turbines," *IEEE TAS*, 2023, doi: 10.1109/TASC.2023.3255826.

# Strengths and interests in HFM

- Nb<sub>3</sub>Sn accelerator magnet protection, especially with quench heaters
- Accumulating HTS magnet modeling and analysis skills
- Philosophy is towards sharable tools, e.g., "spreadsheet tool" for HTS magnets analysis, open-source model for HTS tape mechanical analysis, etc...
- Currently no larger-scale application development at TAU, would be happy to direct activity to bring contribution to bigger international projects and to HFM
- Would be extremely valuable to arrange exchange periods to the TAU team-members abroad to learn and contribute (e.g., multiphysics modeling and analysis, magnet technology and testing)