Sigma model generator status

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On behalf of the STEAM team

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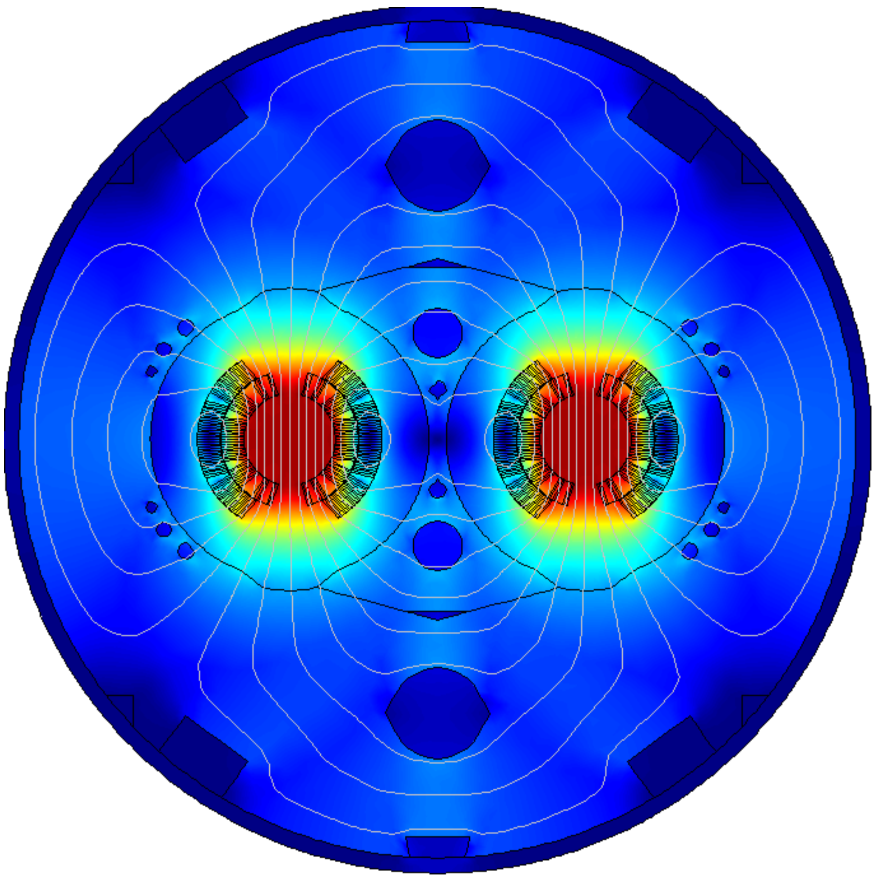
What is SIGMA?



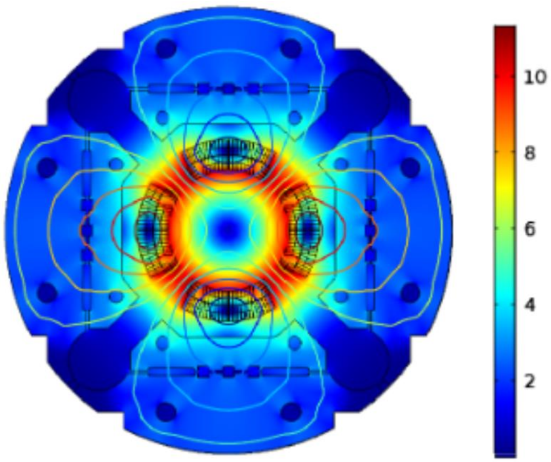
- SIGMA: STEAM Integrated Generator of Magnets for Accelerators

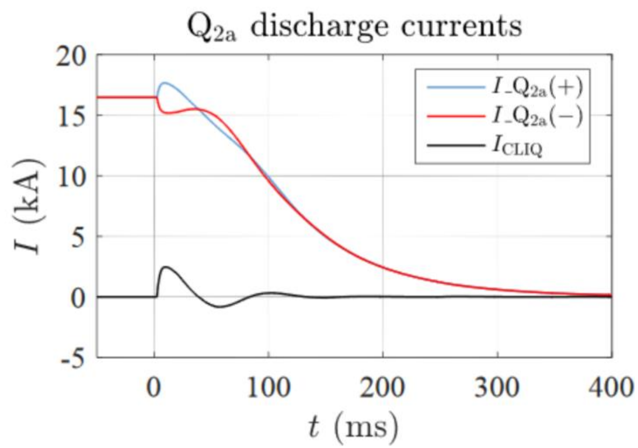
- Accelerator magnets have complex geometries, complex physics, complex component-specific non-linear properties

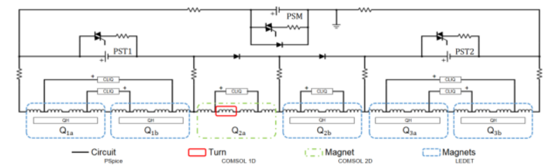
- Therefore, a tool is needed that can:
  - Generate a 2D FEM model with correct geometry, non-linear properties, physics, etcetera
  - Can translate from one simulation tool (Roxie) to another simulation tool
  - Can support multiple simulation tools, such as FEM-based tools (Comsol, Ansys, GetDP?), and other tools (LEDET, QLASA, …)

- Original development mainly driven by Lorenzo and Marco

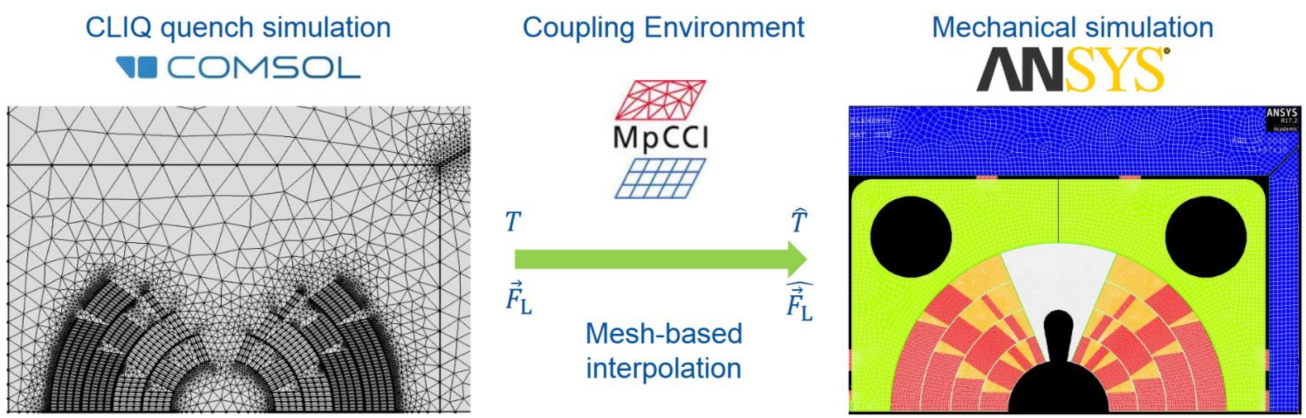
Examples of previous uses







L. Bortot et al., “STEAM: A Hierarchical Co-Simulation Framework for Superconducting Accelerator Magnet Circuits”, presented at Magnet Technology Conference 25, (2017)

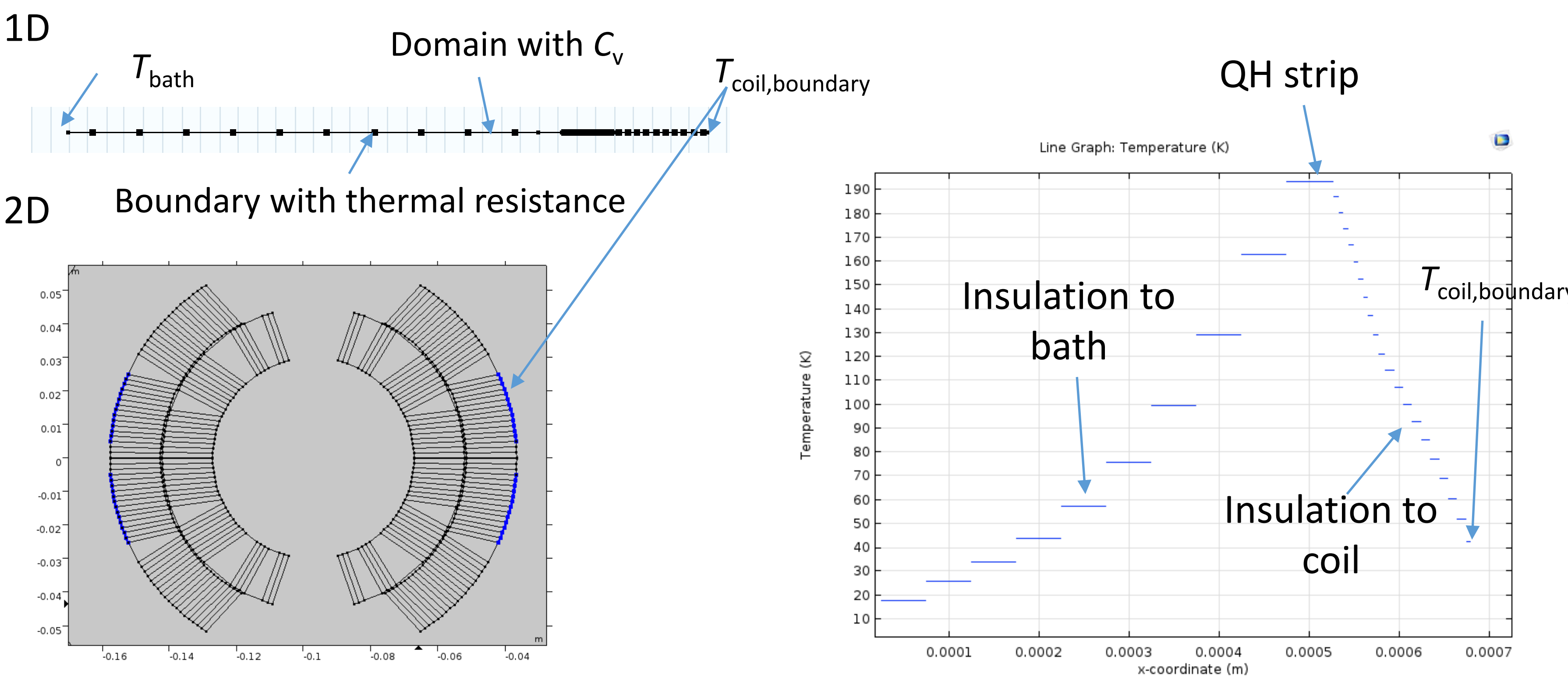


M. Prioli et al., “Analysis of Mechanical Stress during Quench”, presented at FCC week 2018

(Foreseen) developments

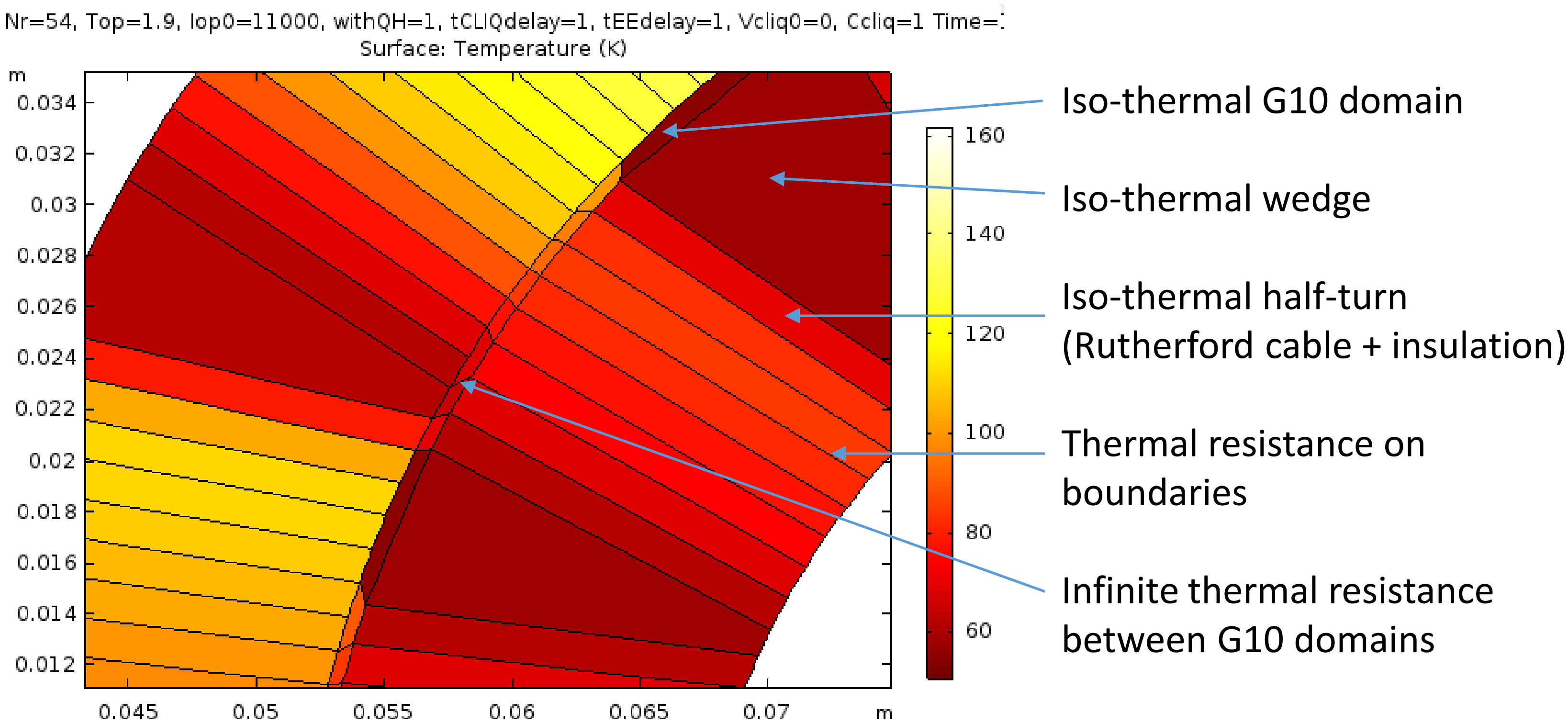
- Roxie-to-SIGMA translator (Soufiane / Michal)
  - Iron BH curves, coil geometry, conductor properties
- Validation study for Ansys quench model (Lucas Brouwer (LBNL) / Edvard)
- Sigma-to-LEDET translator (Emmanuele)
- Comsol model development
  - Automatic CLIQ circuit implementation in Comsol model + test cases (Edvard / Marco)
  - Implementation of quench heaters
  - Thermal links
  - Model optimization for faster runtime and stability
  - Physics review
  - Comparison against experimental measurements

Quench heaters in COMSOL



- Original intended approach: Use of the COMSOL “general layer” feature to introduce Quench heaters (Lorenzo)
- But: Various bugs were found in the COMSOL general layer implementation, so that this concept is very difficult to implement
- Therefore, an alternative: Coupling of 1D quench heater component to 2D coil component
  - 1D component “sees” average temperature of the 2D coil boundary
  - 2D component receives heat flux at the edge of the 1D component
  - Iso-thermal domains with heat capacity + boundaries with thermal resistance, to avoid negative temperatures (Comsol-specific problem)

Thermal links between inner and outer layers



- In Comsol: Low thermal domain conductivity leads to negative temperatures
- Therefore: Iso-thermal G10 domains, all thermal resistance is on boundaries
- Infinite thermal resistance between G10 interlayer domains, to prevent a thermal short
- Infinite thermal resistances boundaries currently manually implemented, automatic SIGMA implementation is under investigation

Model optimization for faster runtime / Physics check

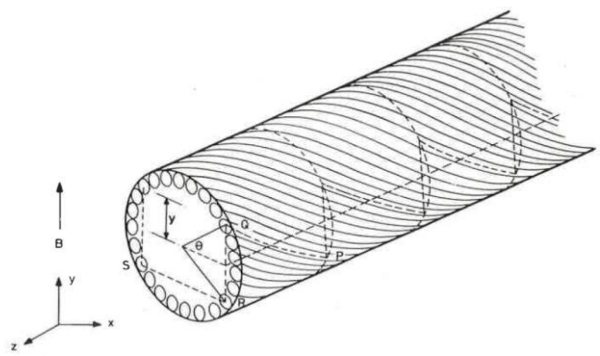


Fig. 8.15. Twisted filamentary composite in changing transverse field showing zig-zag path used to calculate flux linkages.

Source: Wilson – Superconducting magnets

Is this generally applicable?

Inter-filament coupling currents:

$$\tau_{IFCC} = \frac{\mu_0}{2}\left(\frac{l_{tp}}{2\pi}\right)^2 \frac{1}{\rho_{eff}}$$

$$M_{IFCC,x} = \frac{-2\tau_{IFCC}}{\mu_0}\left(\frac{\delta B_x}{\delta t}\right)$$

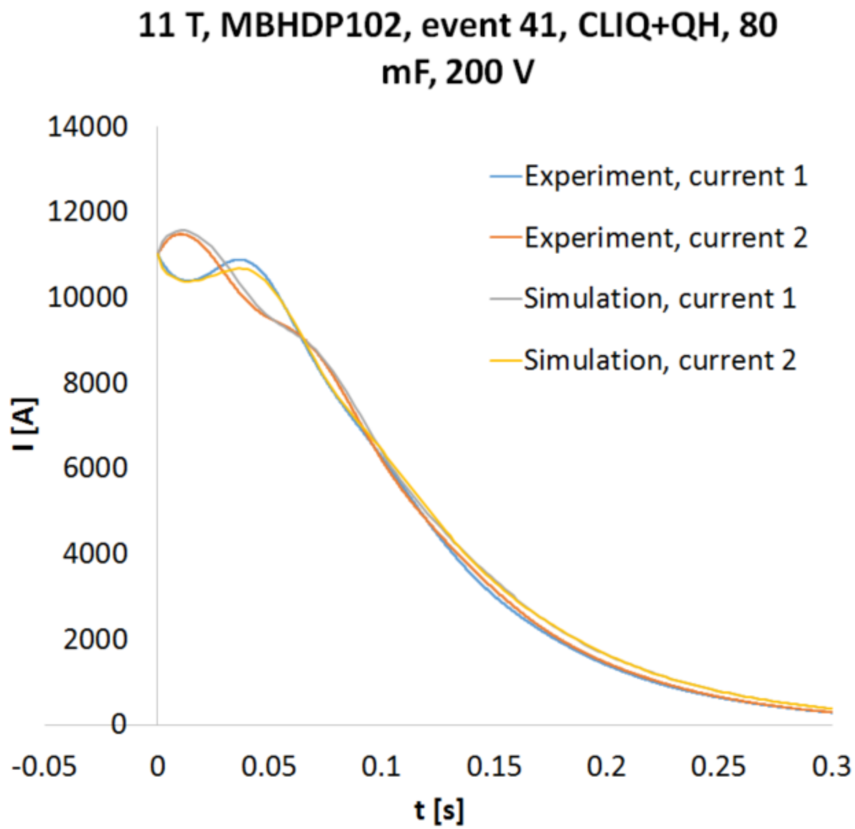
$$M_{IFCC,y} = \frac{-2\tau_{IFCC}}{\mu_0}\left(\frac{\delta B_y}{\delta t}\right)$$

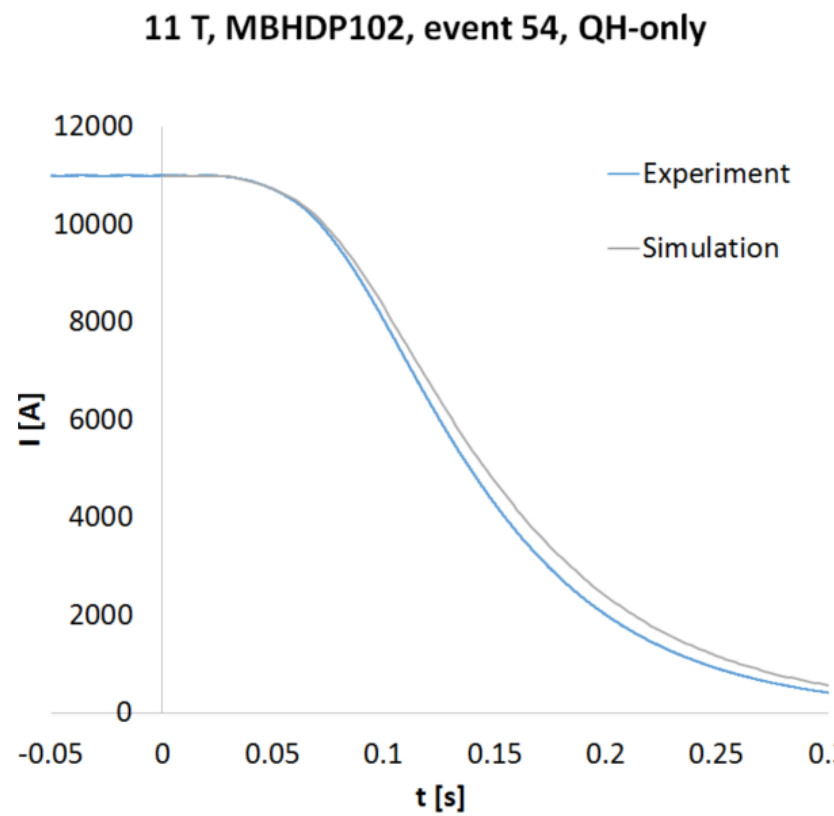
$$Q_{IFCC} = -\left(M_{IFCC,x}\left(\frac{\delta B_x}{\delta t}\right) + M_{IFCC,y}\left(\frac{\delta B_y}{\delta t}\right)\right)$$

In strands, while super-conducting

- Model optimization:
  - Solver tweaks + minimal use of operators (average, minimum, maximum) for enhanced performance (initially, 10x reduced computation time)
  - Enhanced solver stability by numerically suppressing high-frequency components
  - Typical runtime for fine-meshed full double-aperture magnet with thermal exchange between layers, quench heaters, copper wedges, and CLIQ, but without ISCC: 20-40 mins
- Physics review:
  - Inter-filament coupling currents, derived for single strand that sees external field. Is this generally applicable (with other strands in close proximity)?
  - Documentation of Comsol model with revised equations, to be reviewed by STEAM team

Comparison against experimental measurements





- Ongoing effort
- Preliminary results are encouraging

Summary

- STEAM Integrated Generator of Magnets for Accelerators: Tool for generating magnet models

- (Foreseen) developments:
  - Roxie-to-SIGMA translator
  - SIGMA-to-LEDET translator
  - Ansys quench model
  - Comsol model
    - Automatic generation of CLIQ circuit
    - Addition of Quench Heaters
    - Various tweaks for enhanced performance
    - Review of physics
    - Validation versus experimental results
    - Comsol has clear limitations, but through work-arounds, desired features and performance seem attainable