CERN

Integration of QLASA with STEAM

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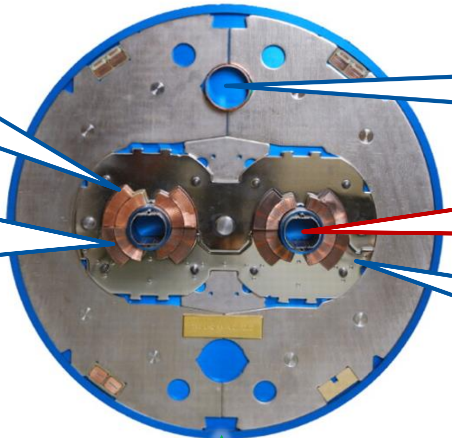
1. Introduction
2. QLASA
3. Application

What is the Challenge?

Electro-dynamics
- Inductive coupling
- Saturation
- Coupling currents
- Magnetization

Thermo-dynamics
- Coupling losses
- Magnetization losses
- Joule heating
- Heat transfer
- Quench propagation



Fluid dynamics
- Superfluid Helium
- Phase transition

Material properties
- Extreme non-linearity within few Kelvin

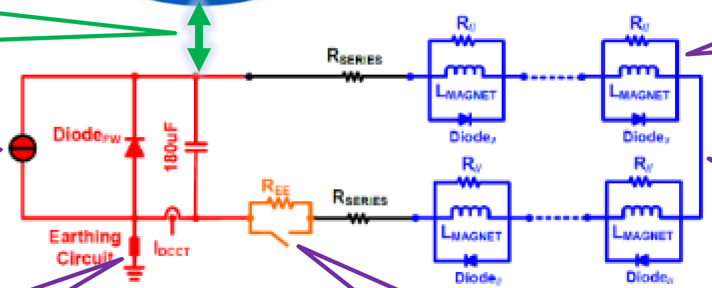
Mechanics
- Lorentz forces
- Thermal strain

mm → km

μs → 100 s

Coupling
- Information exchange
- Stability of solution
- Performance

Converter
- Controller
- Output filter & ringing



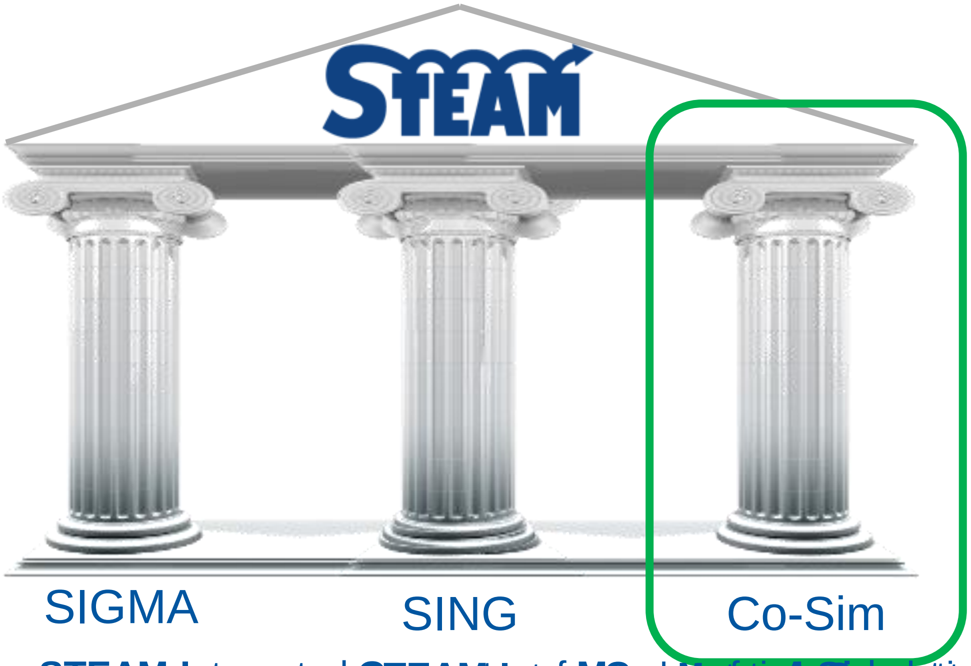
Quench detection and protection
- Fast voltage detection
- CLIQ
- Quench heaters

Circuit
- Large number of magnets and components, including diodes, thyristors, capacitors,
- Properties as f(T, **B**)

Earthing circuit
- Fuse

EE system
- Arcing
- EM waves

STEAM, Simulation of Transients Effects in Accelerator Magnets



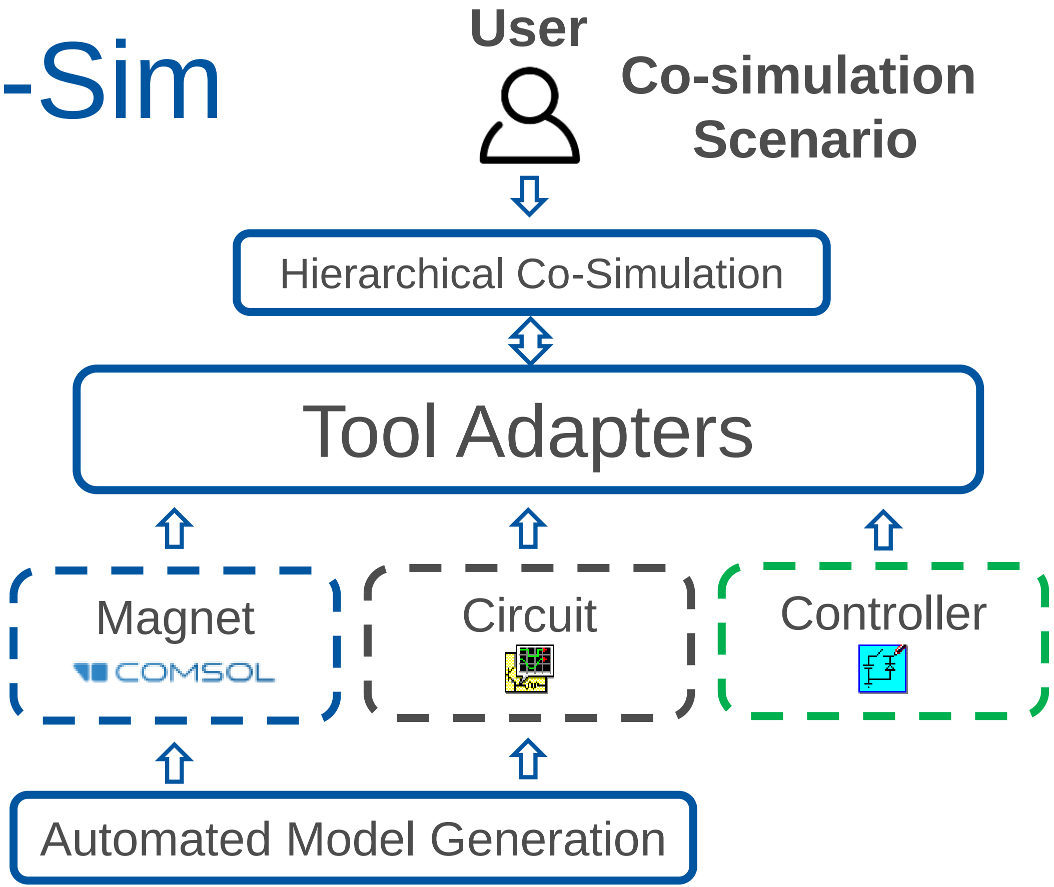
- Multi-physics, multi-scale, multi-rate
- Solid simulation framework, for the life-time of the LHC and beyond
  - Fulfills accelerator-specific need
  - Maintainability
- Coupling of existing optimized simulation tools
- Consistent physics formulation and automatic model generation

STEAM Co-Sim

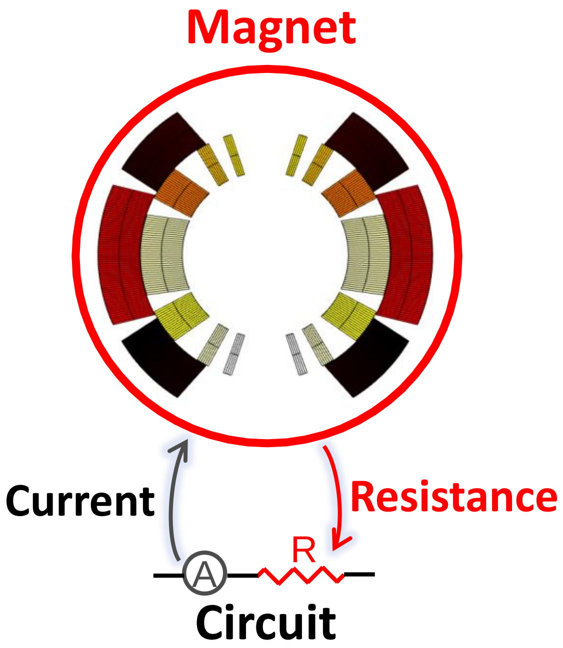
Co-simulation platform

LTSpice
PSpice
LEDET
COMSOL
QLASA

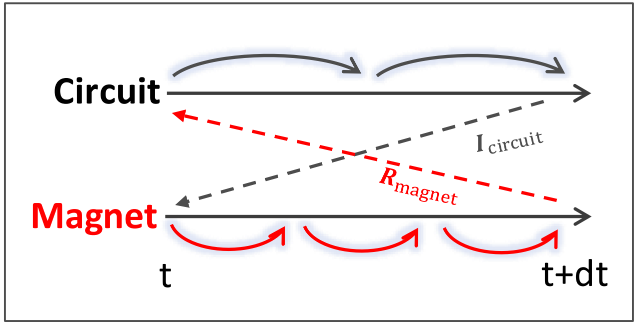
Legend:
Released
In the pipeline



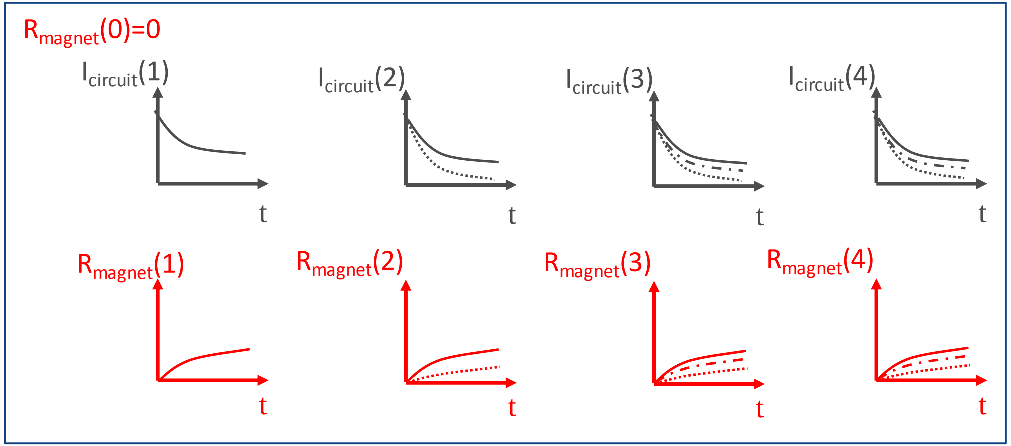
Field/Circuit coupling



Waveform relaxation



Iteration until convergence is reached



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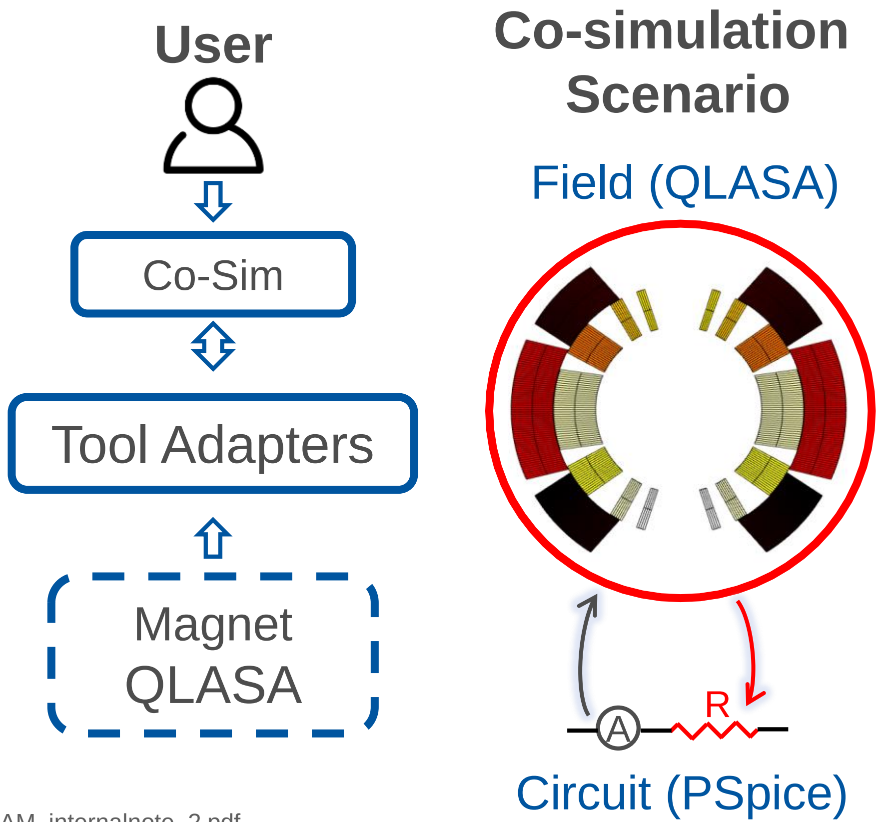
QLASA

- 3D Analytic Quench Propagation
- Solenoid-based modelling
  - Adjustments needed for other magnets
- Time-dependent
  - Temperature
  - Heat capacity
  - Current
  - Superconducting properties
  - Magnetic field
- Current driven mode
  - Power controller deactivated



Collaboration with (Vittorio Marinozzi) INFN

Details of QLASA implementation: https://edms.cern.ch/ui/file/1976188/1/QLASAinSTEAM_internalnote_2.pdf

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Applications

- Test campaign, STEAM Co-Sim
- Hollow Electron Lens
- Toroidal Superconducting Coil

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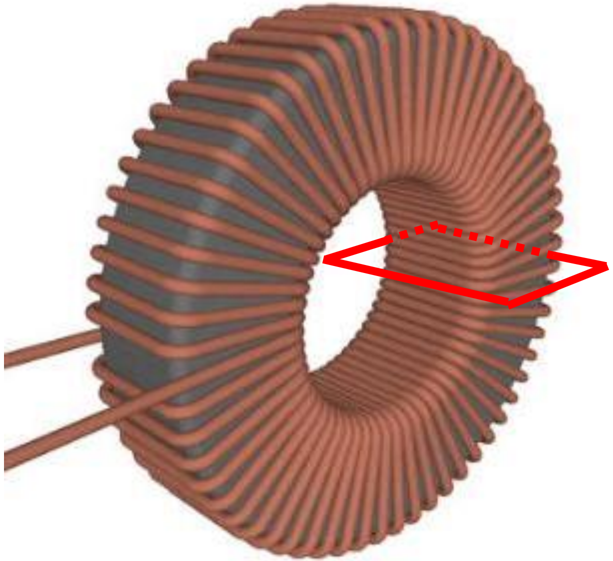
R&D of a Toroidal Superconducting Coil



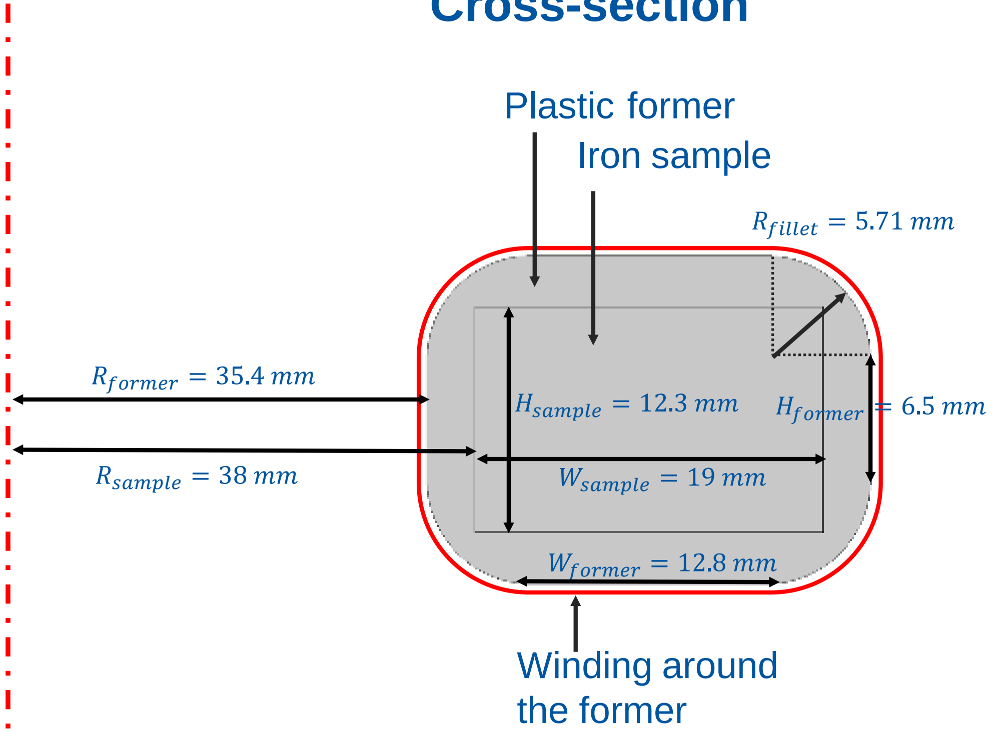
Note, this is not the actual coil, just an example

- High magnetic field (4 T)
  - Characterization of iron for 11 T magnet (permeability)
- Simulations
  - Quench protection studies
  - Assess operational currents (40 A, 80 A and 150 A)

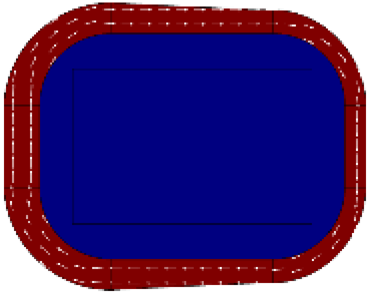
Coil Geometry

- Torus-shaped sample of iron
- 3D-printed plastic layer encapsulates the sample
- Copper pickup coil wounded around the torus
- Four layers of single strand Nb-Ti round wire
  - The layers have 540, 536, 532 and 530 windings
- Each layer is insulated with kapton

Cross-section



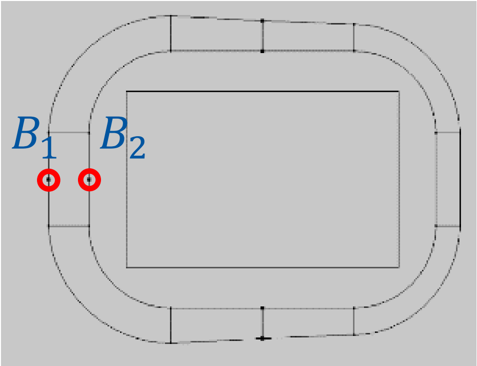
COMSOL Model – Fieldmap Extraction

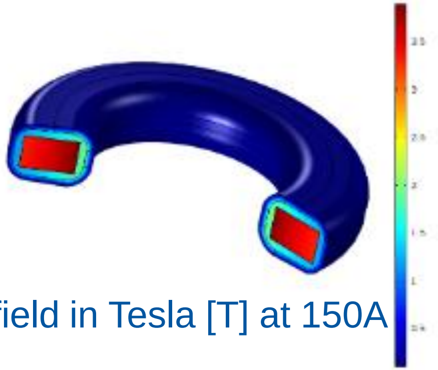


Cross section with current density

$$U = \frac{1}{2} L I^2$$

$$U = \frac{1}{2} \iiint \vec{H} \vec{B} dV$$





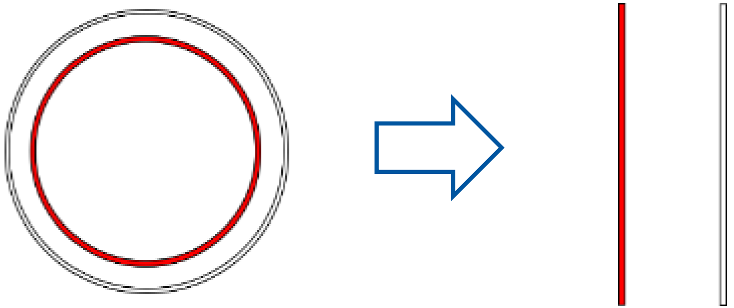
B-field in Tesla [T] at 150A

Current	L	B_1	B_2	Energy
40 A	0.04592 H	0.0040 T	0.5733 T	36.7 J
80 A	0.02971 H	0.0080 T	1.1466 T	95.1 J
150 A	0.02213 H	0.0149 T	2.1500 T	249 J
150 A no iron	0.01346 H	0.0149 T	2.1500 T	151 J

Toroidal to Solenoidal Coil

Geometric Transformations

1. Winding volume
2. Cross-section
3. Solenoid length

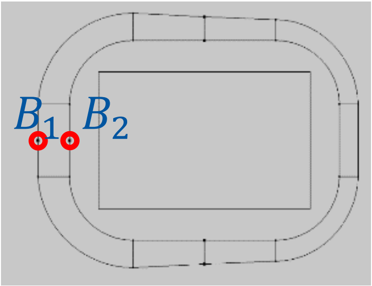


Toroidal shape

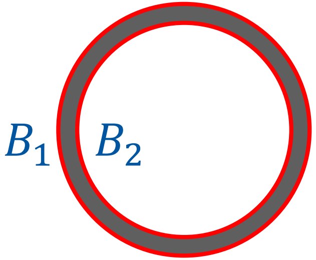
Solenoidal shape

Magnetic field assumptions

Coil cross sections



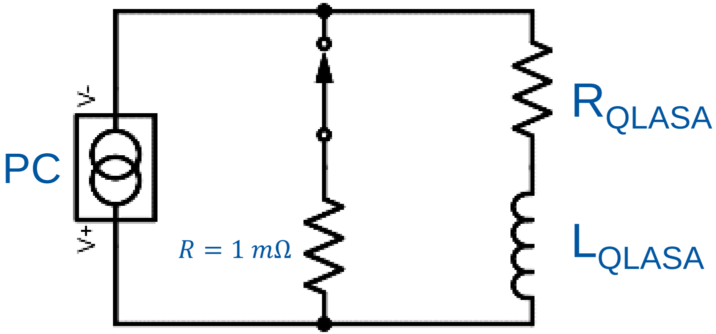
B-field in toroidal shape



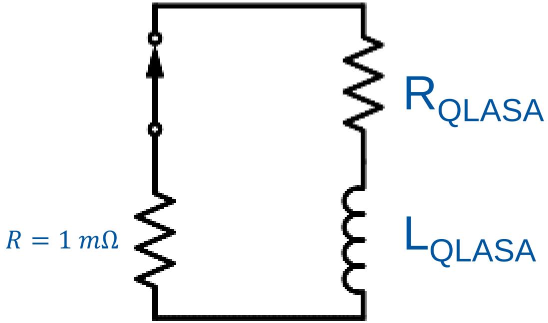
PSpice circuit

- Power converter
  - Current source
- Threshold voltage (1 V)
  - PC switched off
  - Crowbar closed

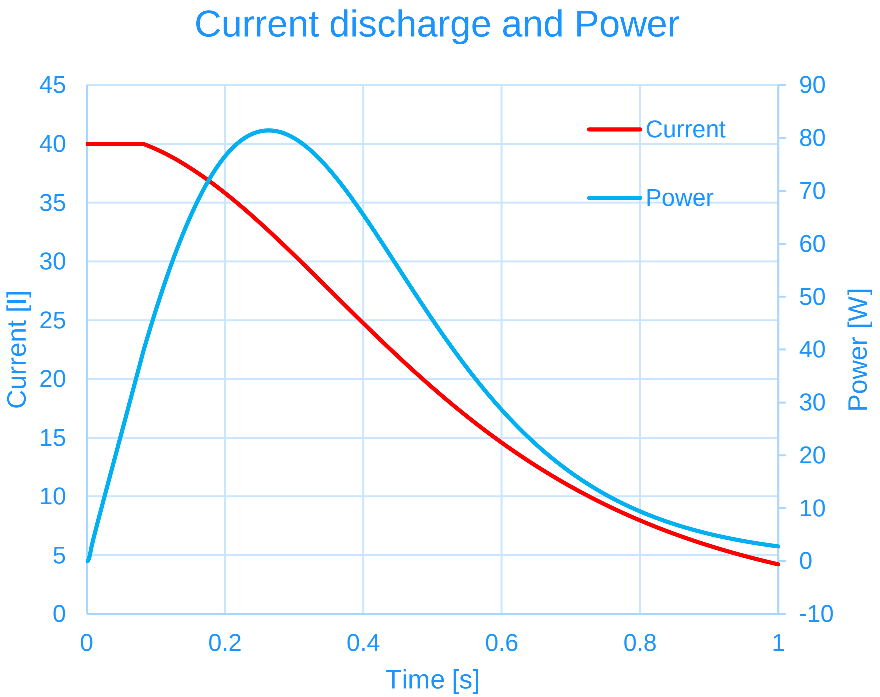
Before quench

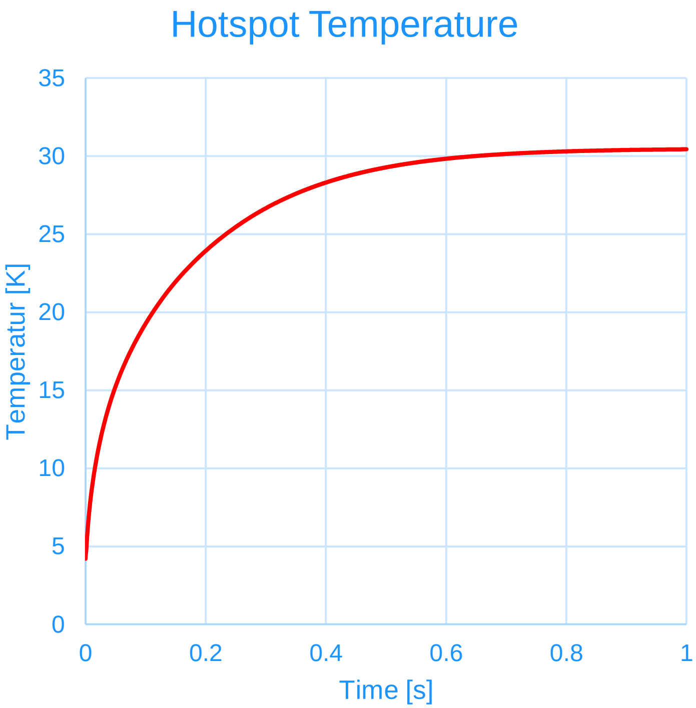


After quench

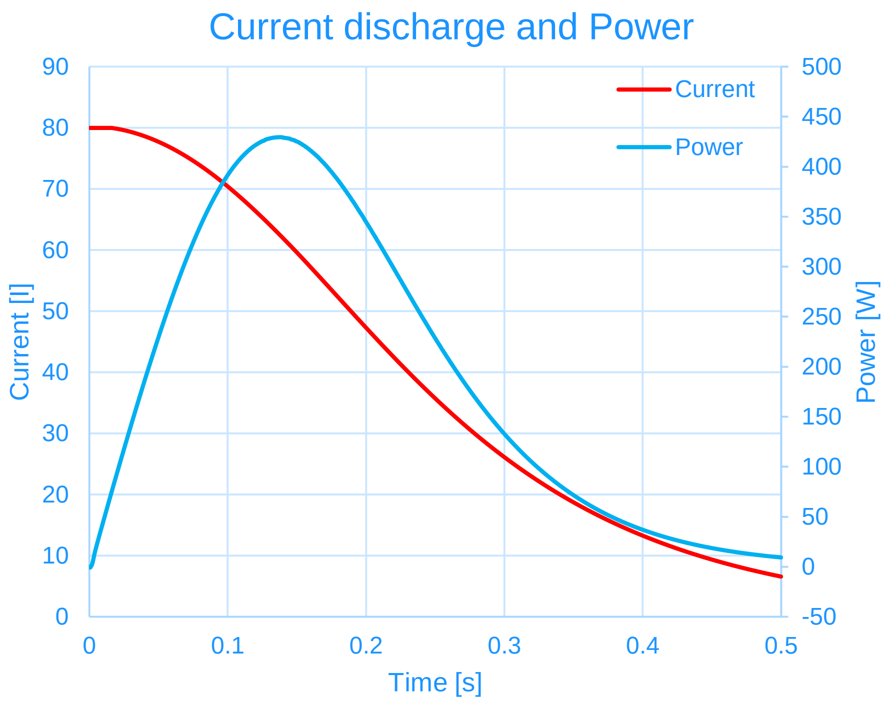


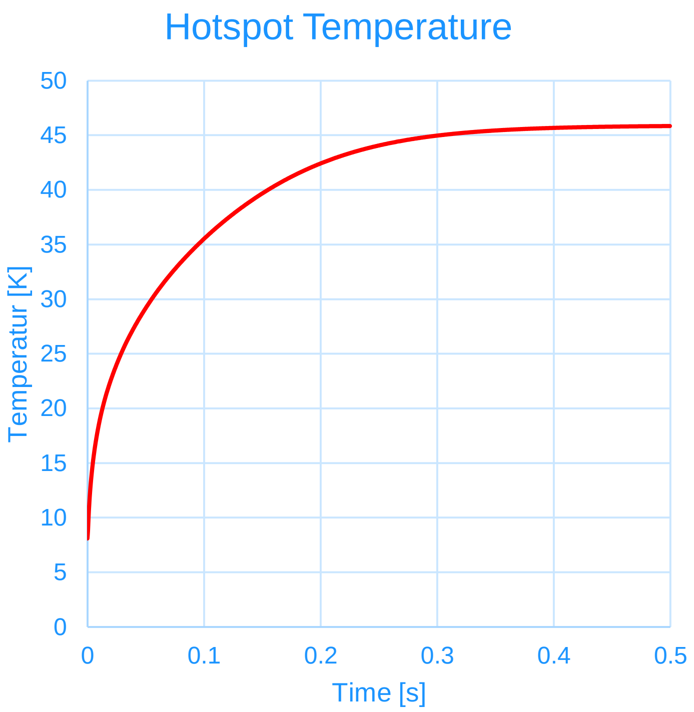
Field/circuit coupling results @ 40 A



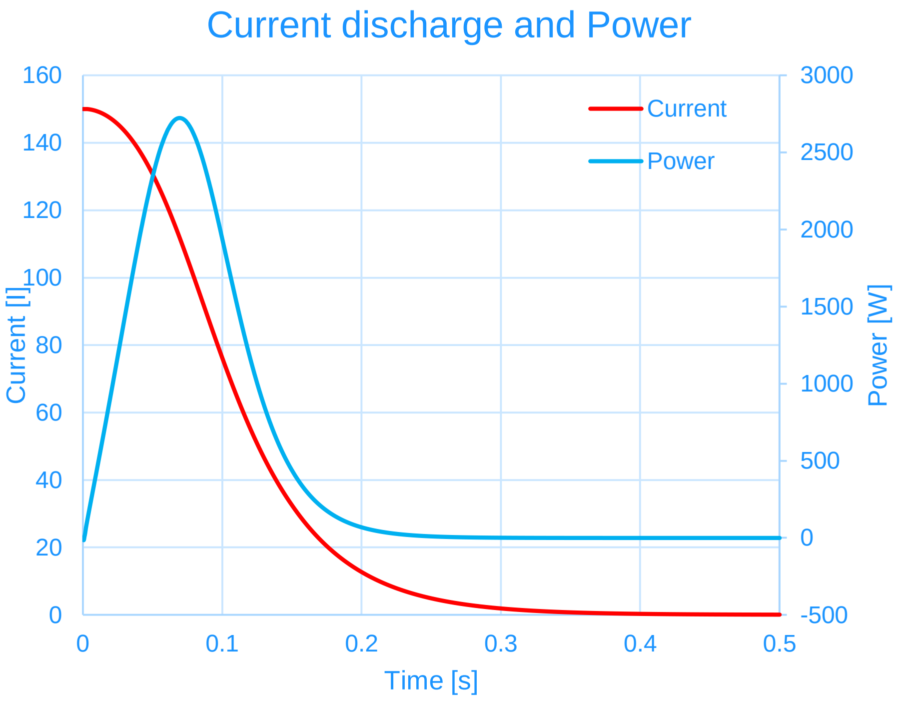


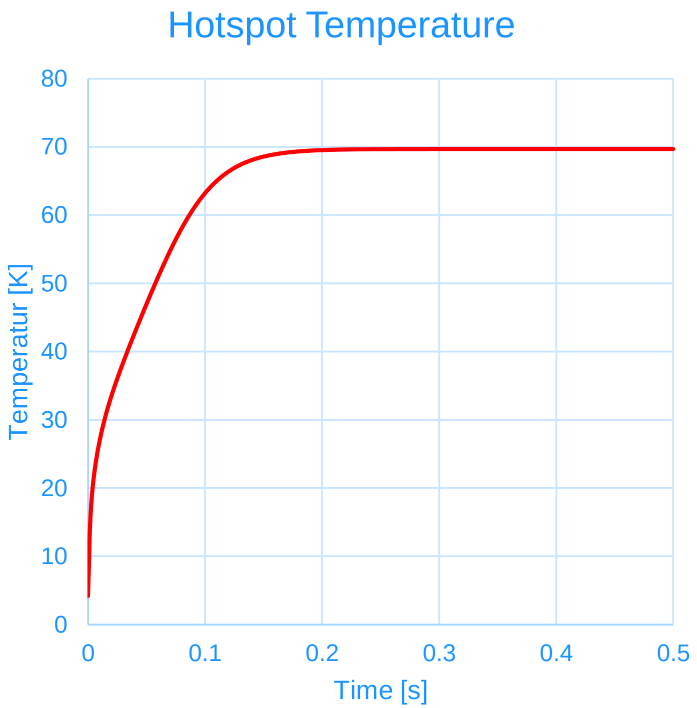
Field/circuit coupling results @ 80 A



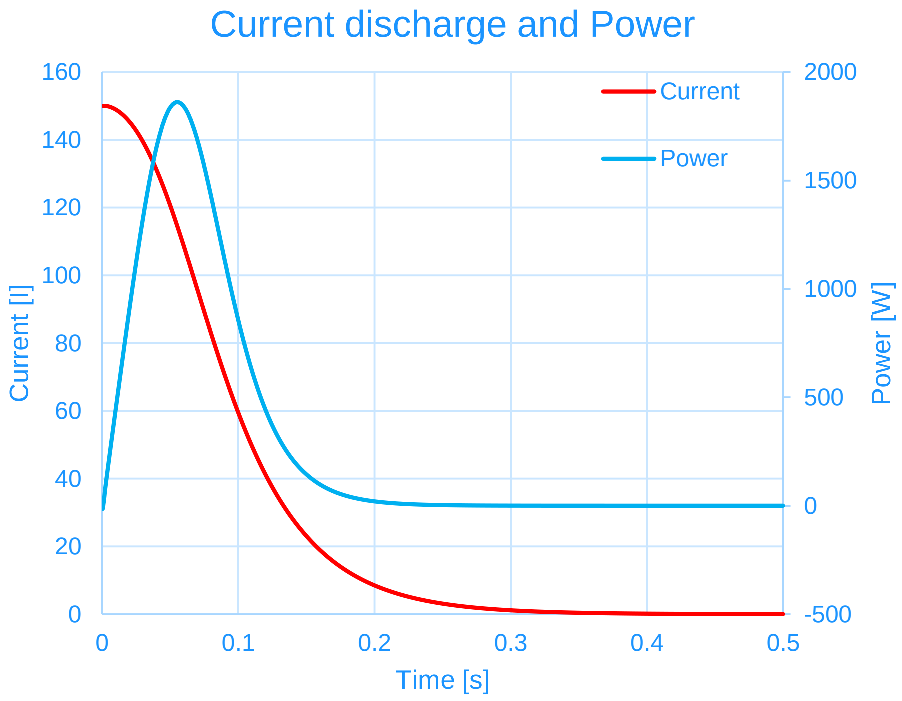


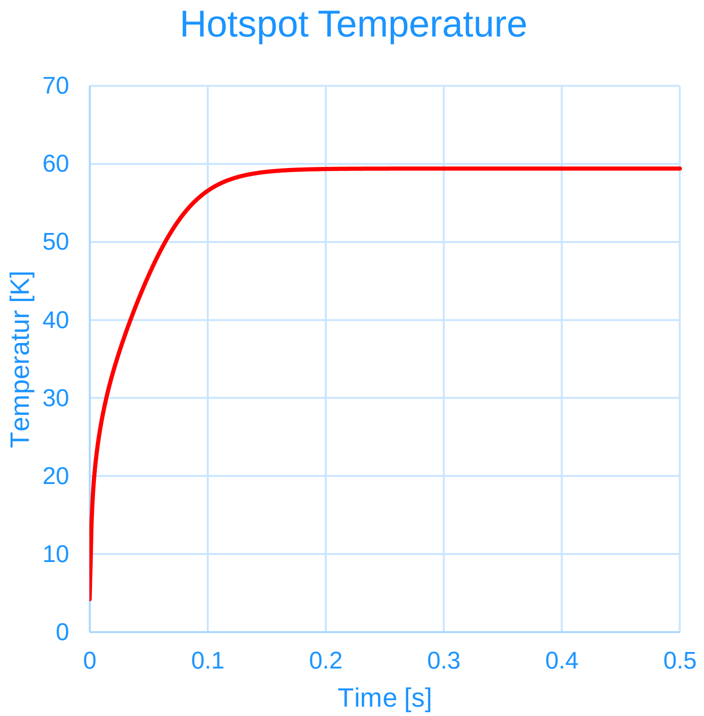
Field/circuit coupling results @ 150 A





Field/circuit coupling results @ 150 A (without Iron)





Conclusion

- STEAM Co-Sim
  - QLASA successfully integrated
  - Allows more advance circuit coupling
- Toroidal Superconducting Magnet
  - The magnet is self-protected in the given configurations for all currents, 40 A, 80 A and 150 A
  - The ramp rate of the current should not induce a voltage in the coil higher than the threshold voltage of the power controller.

Questions?