FCC 12/09/2022 - SDMW

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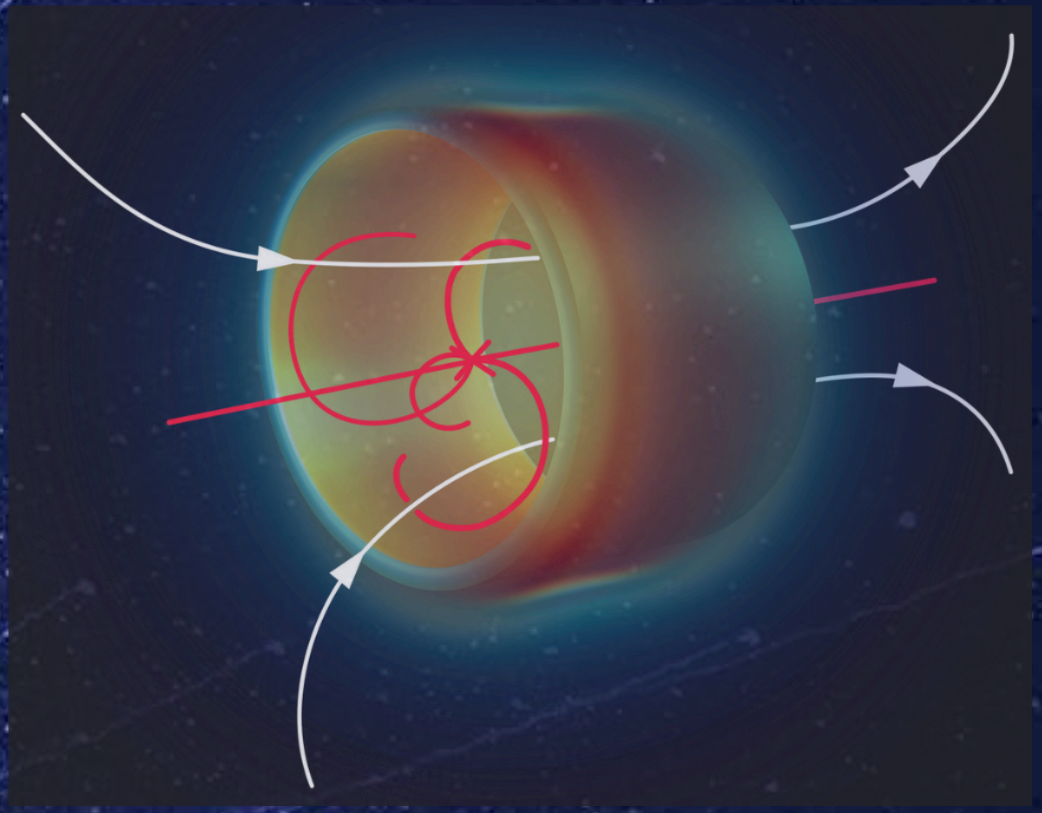


DETECTOR MAGNETS FOR FCC-EE

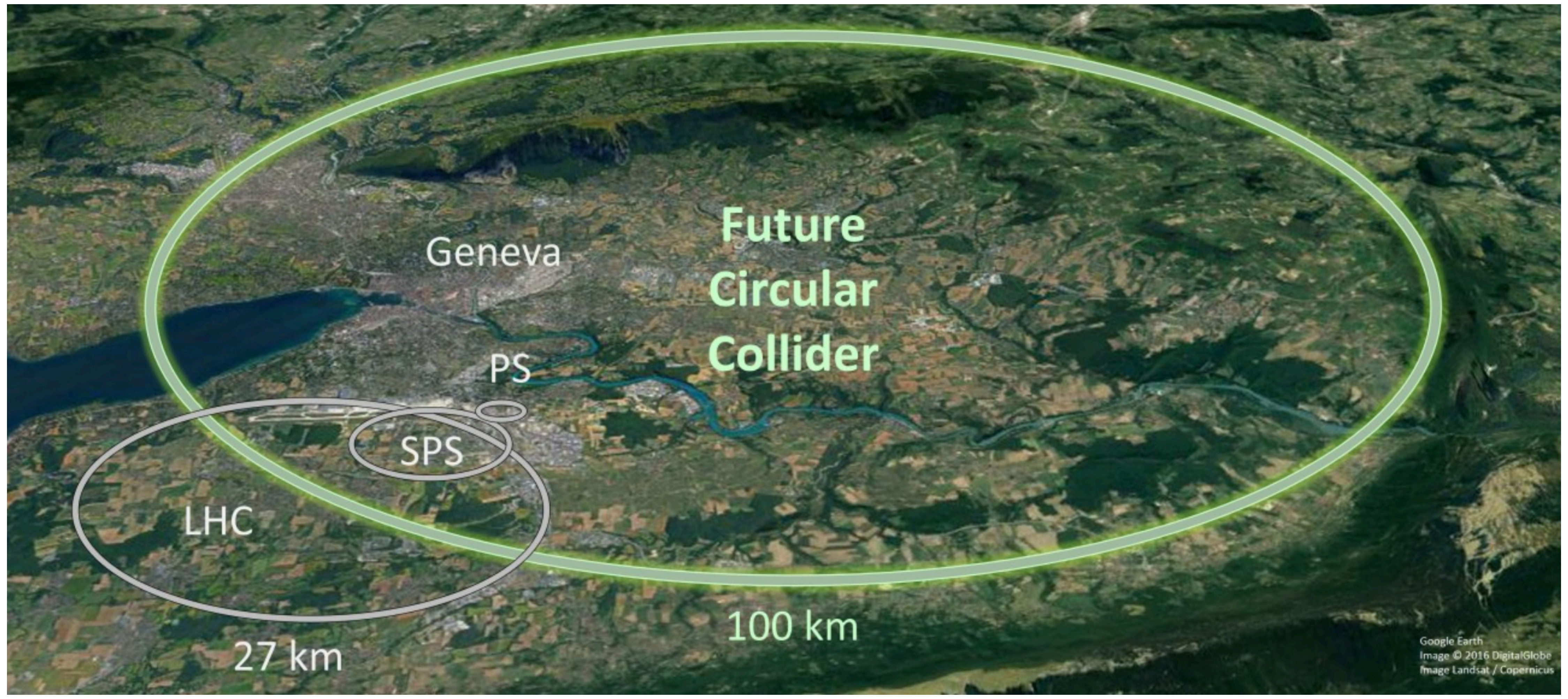
Superconducting solenoids for the IDEA and CLD Detector concepts

CONTENT OF THIS TALK

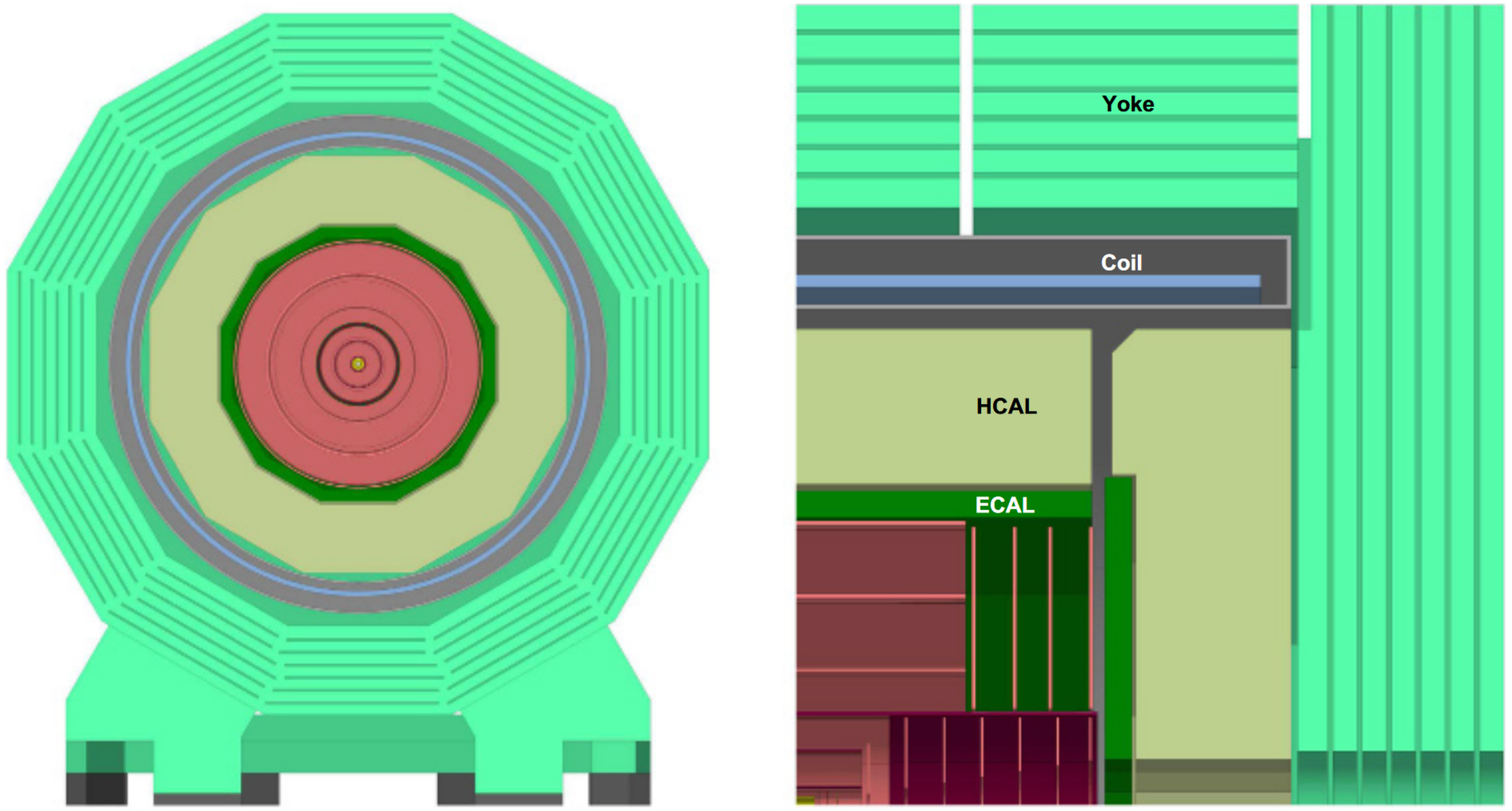
- Introduction: FCC-ee Detector magnets
- The CLIC-Like Detector (CLD) superconducting solenoid
- The International Detector for Electron-positron Accelerators (IDEA) superconducting solenoid
- 3D Quench studies on the IDEA superconducting solenoid
- Summary

Introduction: FCC-ee Detector magnets

- Successor of LHC @ CERN [1]:
  lepton Future Circular Collider
- Tunnel of **~100 km,** centre of mass energy: **88 - 365 GeV**
  - LEP: 27 km, centre of mass energy 91 -209 GeV
- Meant to study **entire electro-weak sector** (W/Z bosons, Higgs, Top quark) in a clean predictable environment
- Designs allows for energy upgrade, tunnel also for **FCC-hh**



CLIC-Like Detector



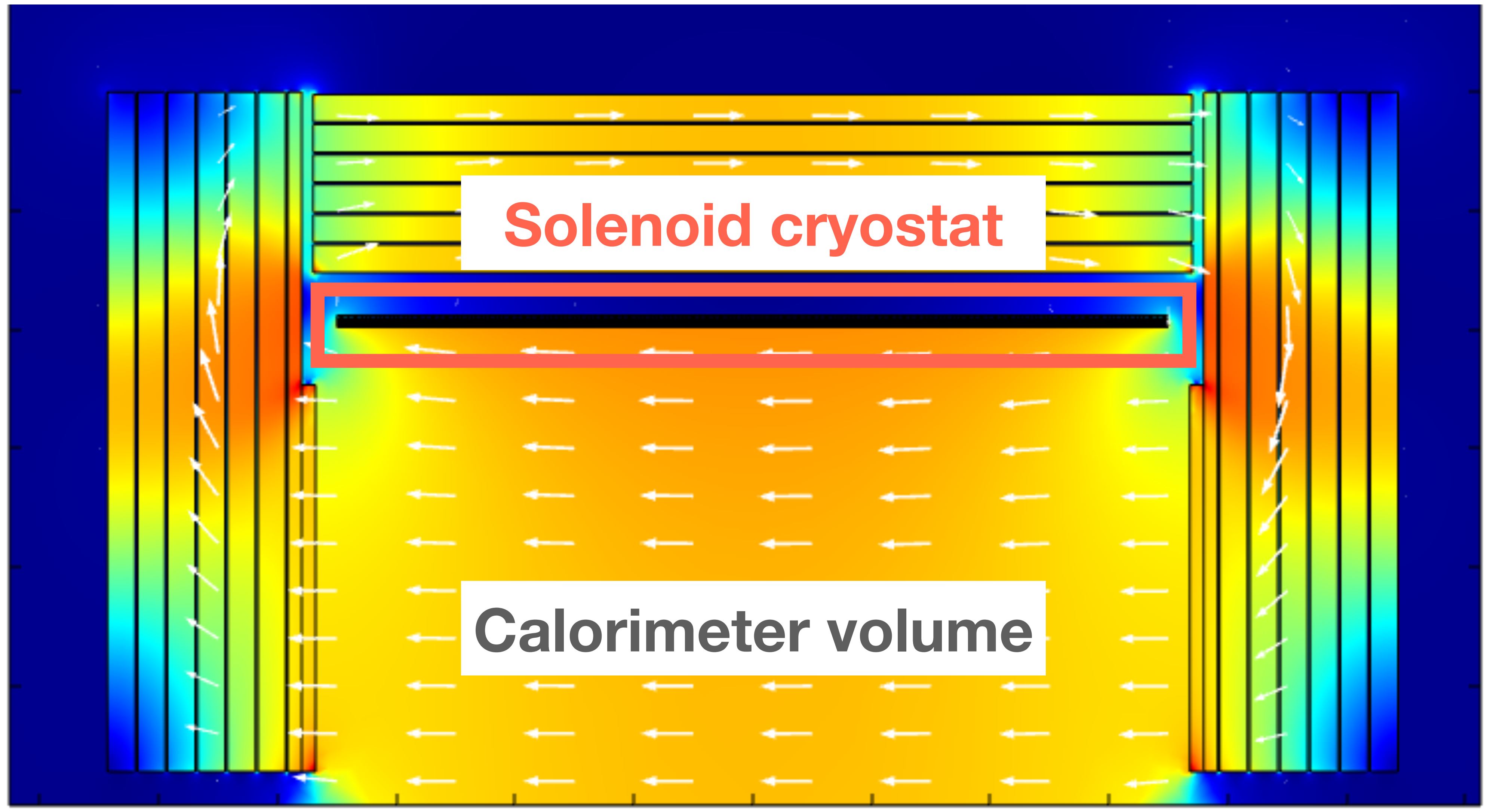
- Two detector designs are being studied for FCC-ee
- **International Detector for Electron-positron Accelerators** (IDEA) / **CLIC-Like Detector** (CLD [14])
- Both have superconducting solenoid with **B_{center} of 2 T**
- IDEA solenoid **inside,** CLD solenoid **outside** calorimeters

This talk: design and quench analysis of FCC-ee magnets

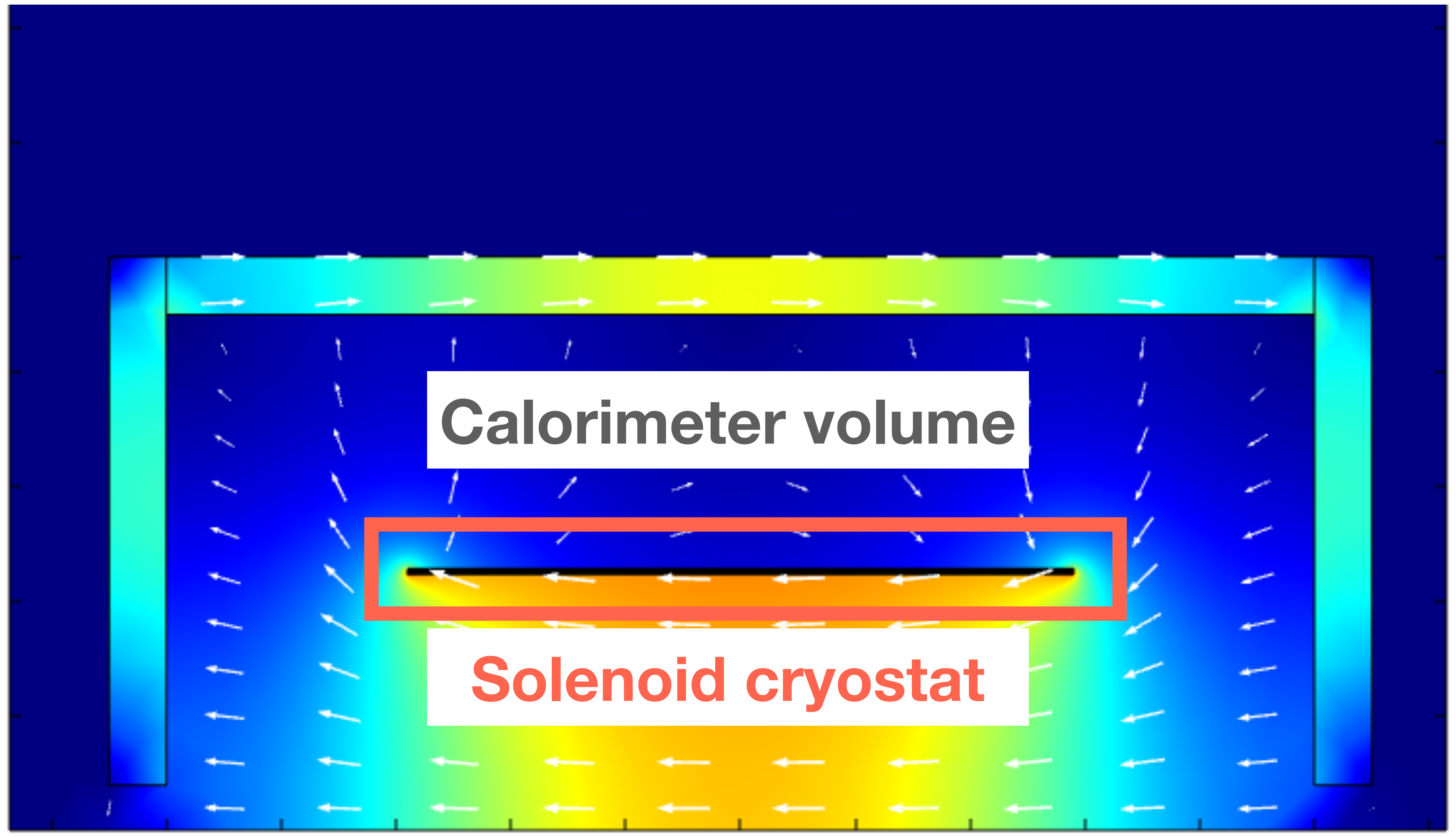
Two Detector magnets

- This talk will cover **two detector magnets**
- CLIC-Like Detector **(CLD)** and International Detector for Electron-positron Accelarators **(IDEA)**
- Both solenoids are based on **aluminium-stabilised NbTi** conductor
- CLD solenoid **outside** calorimeter volume (derived from CLIC design), IDEA **inside** calorimeter volume

CLIC-Like Detector

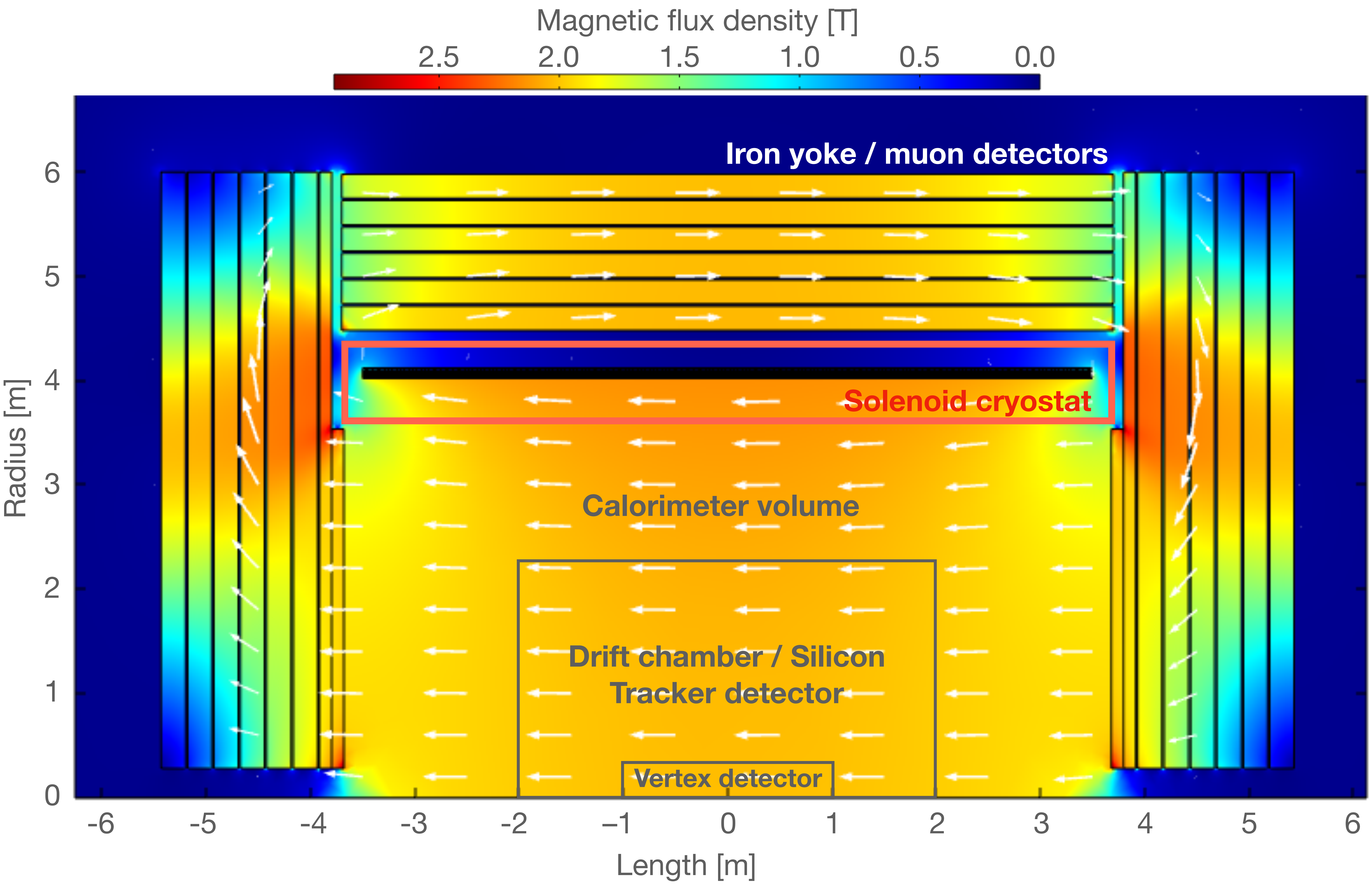


International Detector for Electron-positron Accelerators



The design of the **CLD** Detector Magnet

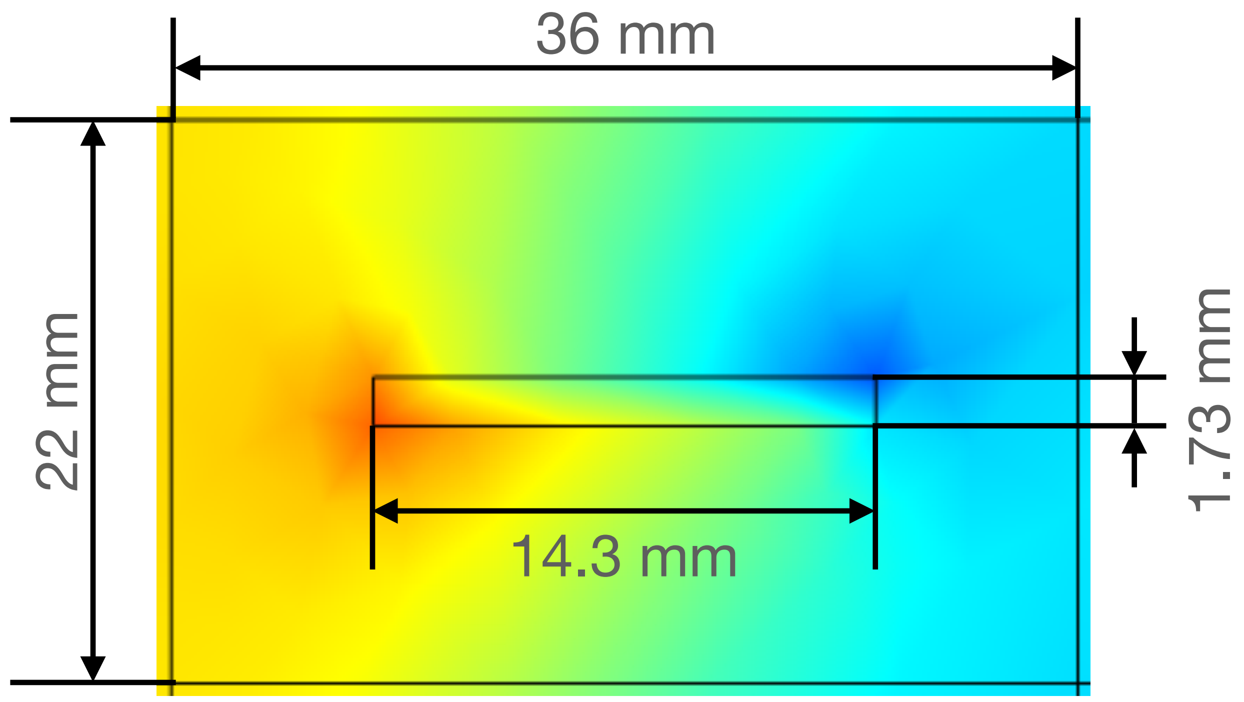
CLD Detector design



Solenoid outside HCal [1,11]

- Free bore diameter: **8.04 m**
- Weight: **9.5 t**
- Central field: **2 T**
  - Operating current: **20 kA**
  - Operating temp.: **4.5 K**
  - Stored energy: **600 MJ**
- Aluminium stabilised **NbTi/Cu** conductor
- Two layers, 300 turns
- Support cylinder of **25 mm**

CMS like [12]

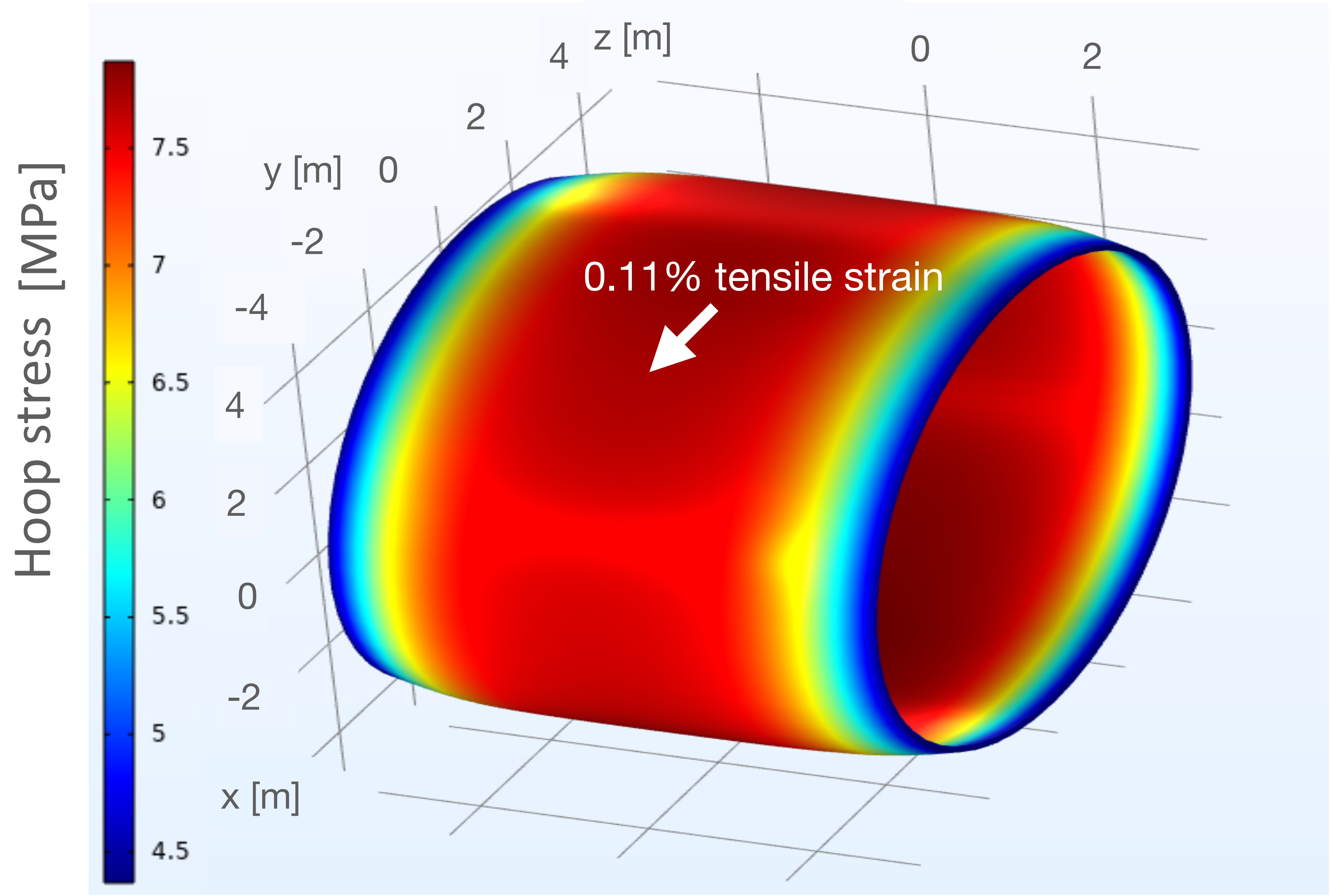


Mechanical support for the CLD magnet

- Support cylinder with thickness of 25 mm
- Support cylinder material: aluminium 5083 series

Energy density: ~12 kJ/kg (like CMS [12])

- First mechanical analysis is promising

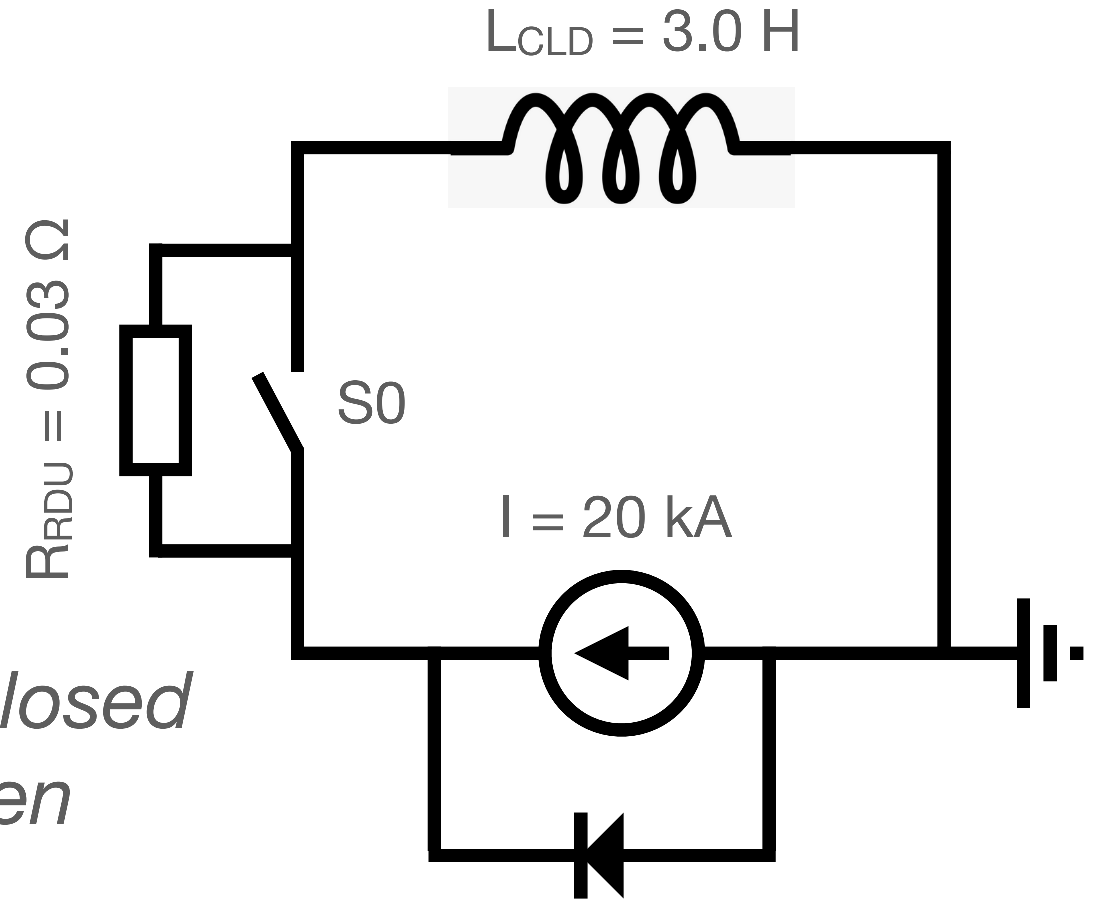


	Conductor	Support	
Parameter	Value	Value	Unit
Material	Ni-doped aluminium	Aluminium 5083	
Yield strength	147 (with NbTi) [3]	< 209 @ 4.2 K [13]	MPa
Young's modulus	75 x 10^3	81 x 10^3	MPa

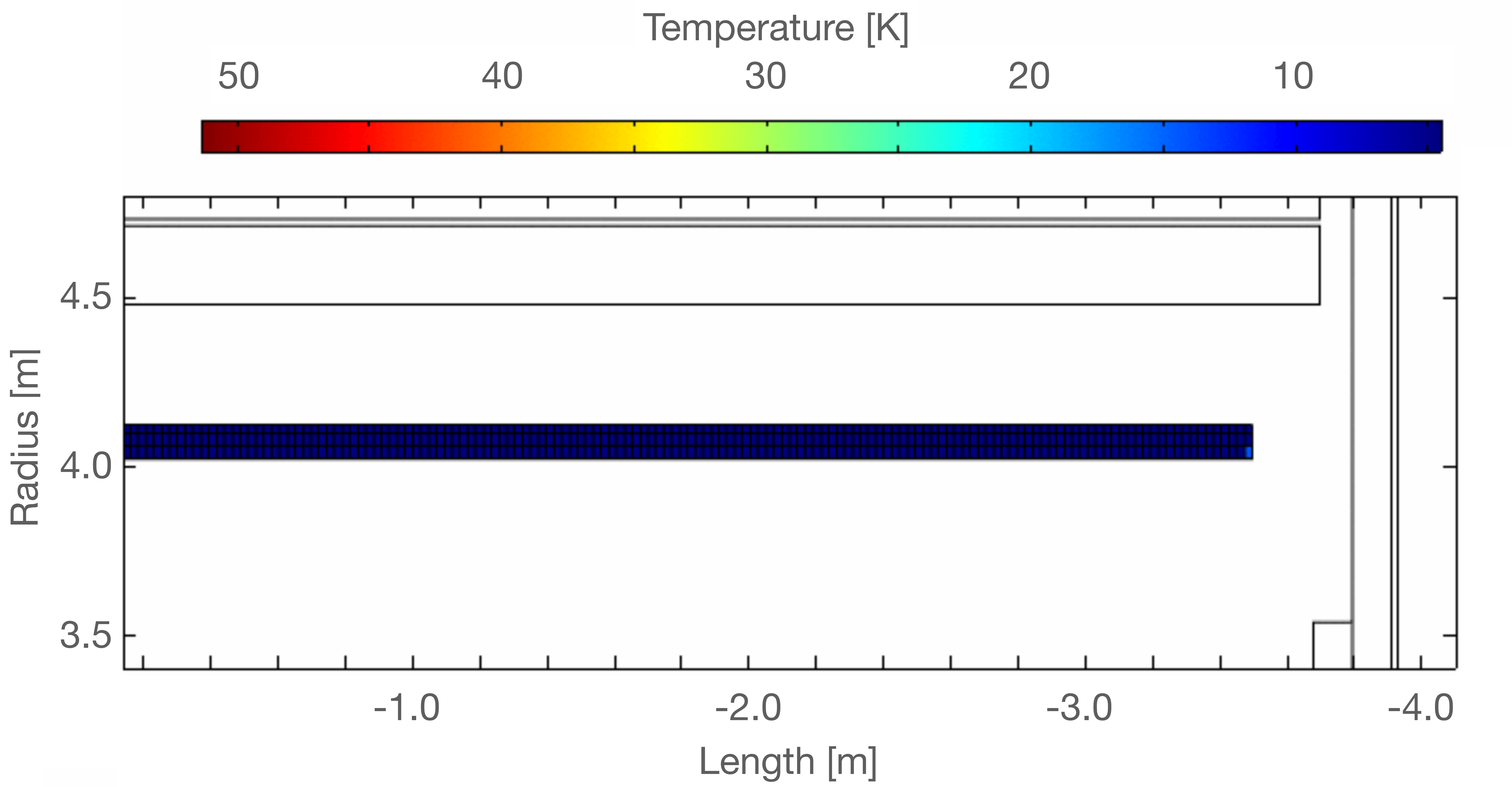
- Peak von Mises stress: **75 MPa**
- Peak tensile strain: **0.11 %**
- Peak shear stress: **0.24 MPa**
- Alternative solution: pure aluminium stabiliser with welded on aluminium-alloy reinforcements (CMS [12])

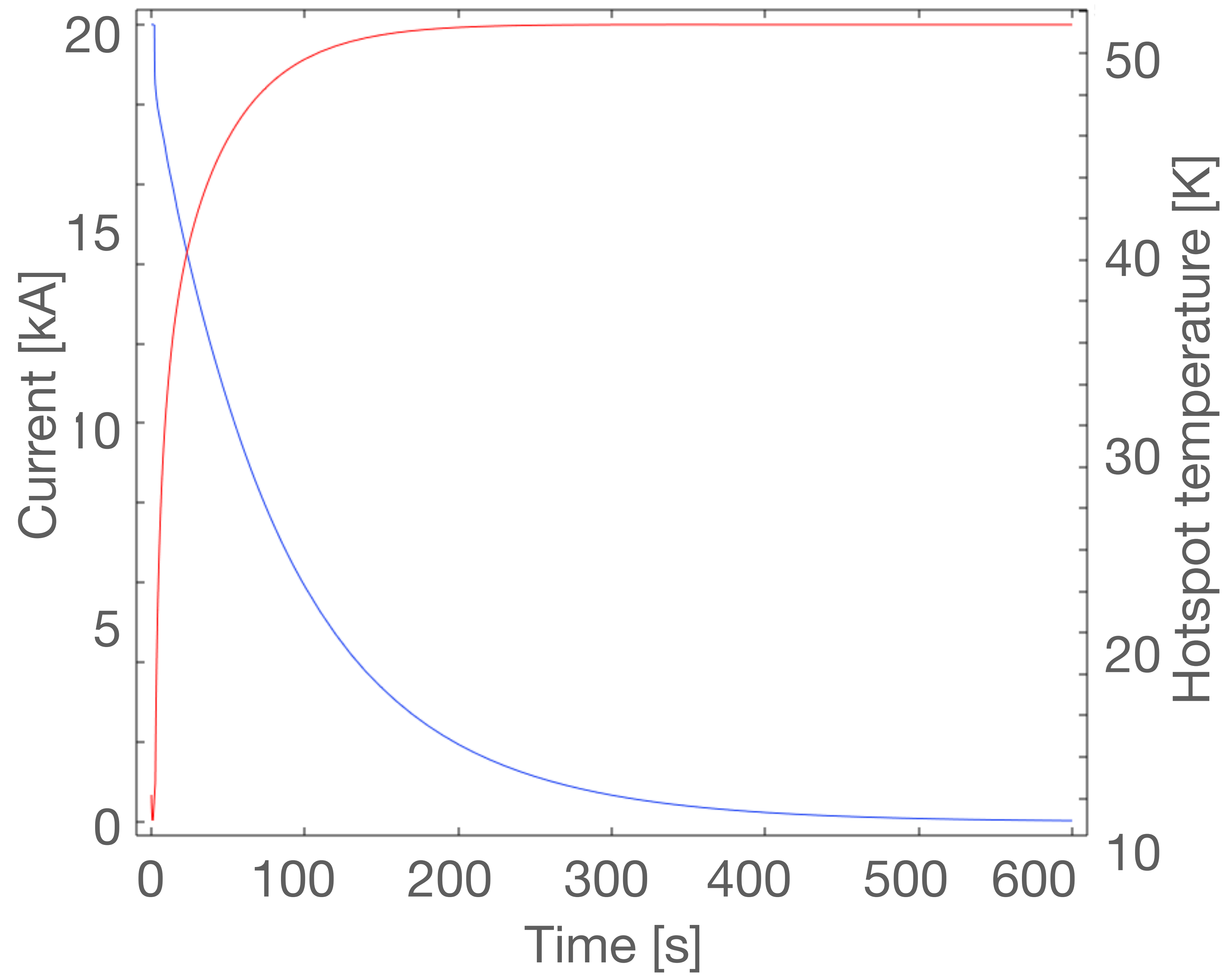
3D Quench simulations of the CLD magnet

- **A 2D quench simulation** was performed
- With an RDU the peak temperature stays **below 60 K**



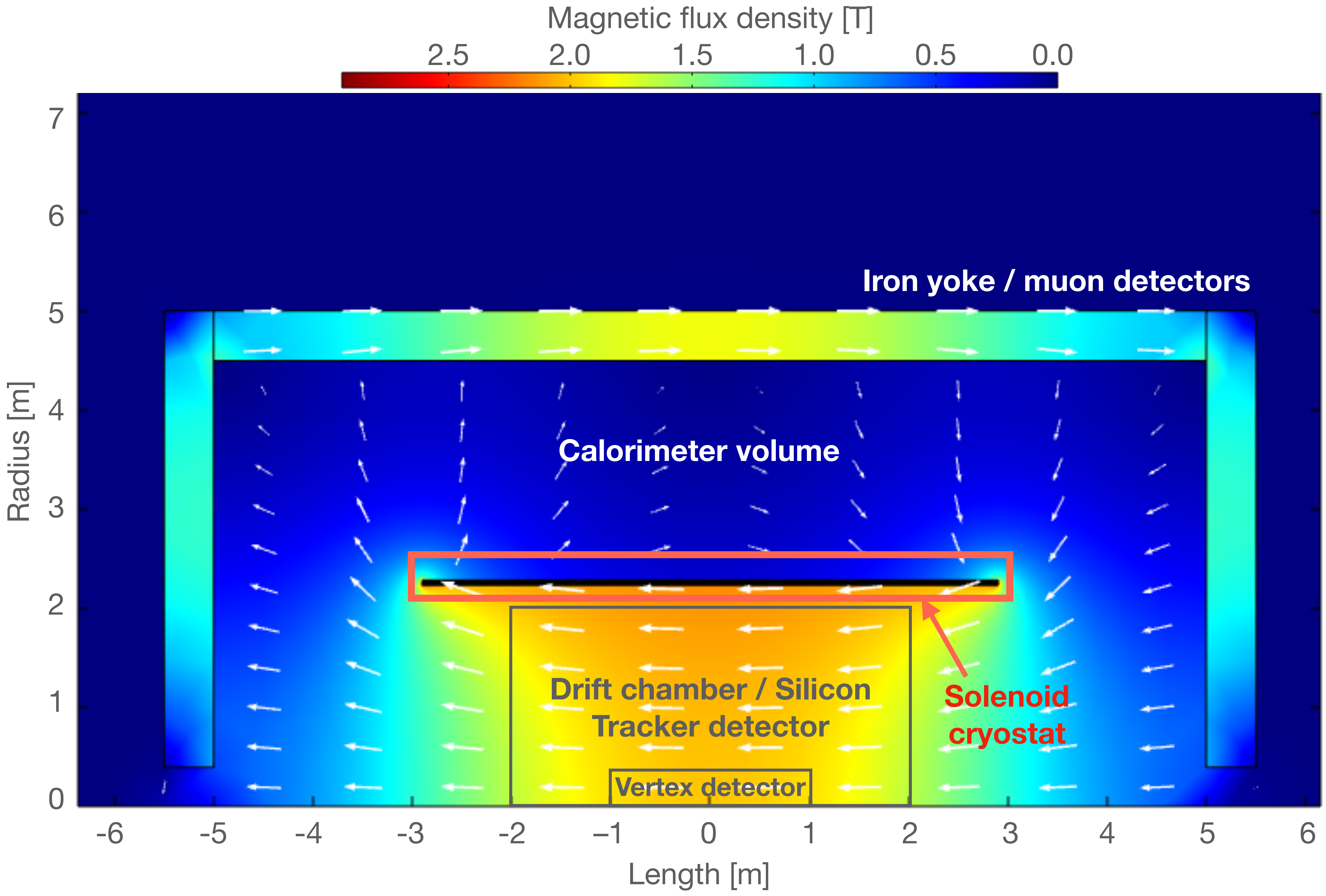
Before quench: S0 = closed
After quench: S0 = open





The design of the **IDEA** Detector Magnet

IDEA Detector design

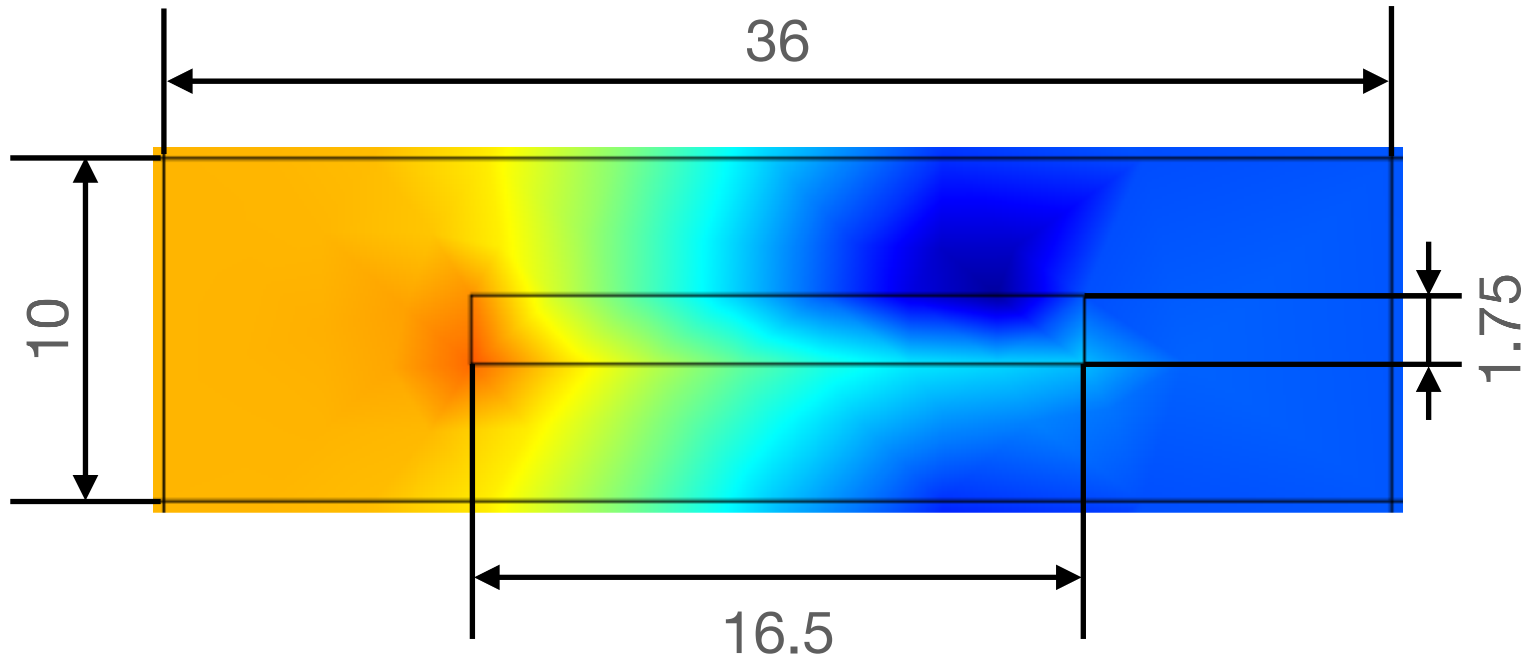


Superconducting solenoid inside calorimeter [1]

- Need transparency: **1 > X_0**
- Free bore diameter: **4 m**
- Weight: **12.5 t**
- Central field: **2 T**
  - Operating current: **20 kA**
  - Operating temp.: **4.5 K**
  - Stored energy: **170 MJ**

- Aluminium stabilised **NbTi/Cu** conductor
- One layer, 530 turns

Trade-off: high stored energy and mechanical stability vs. transparency



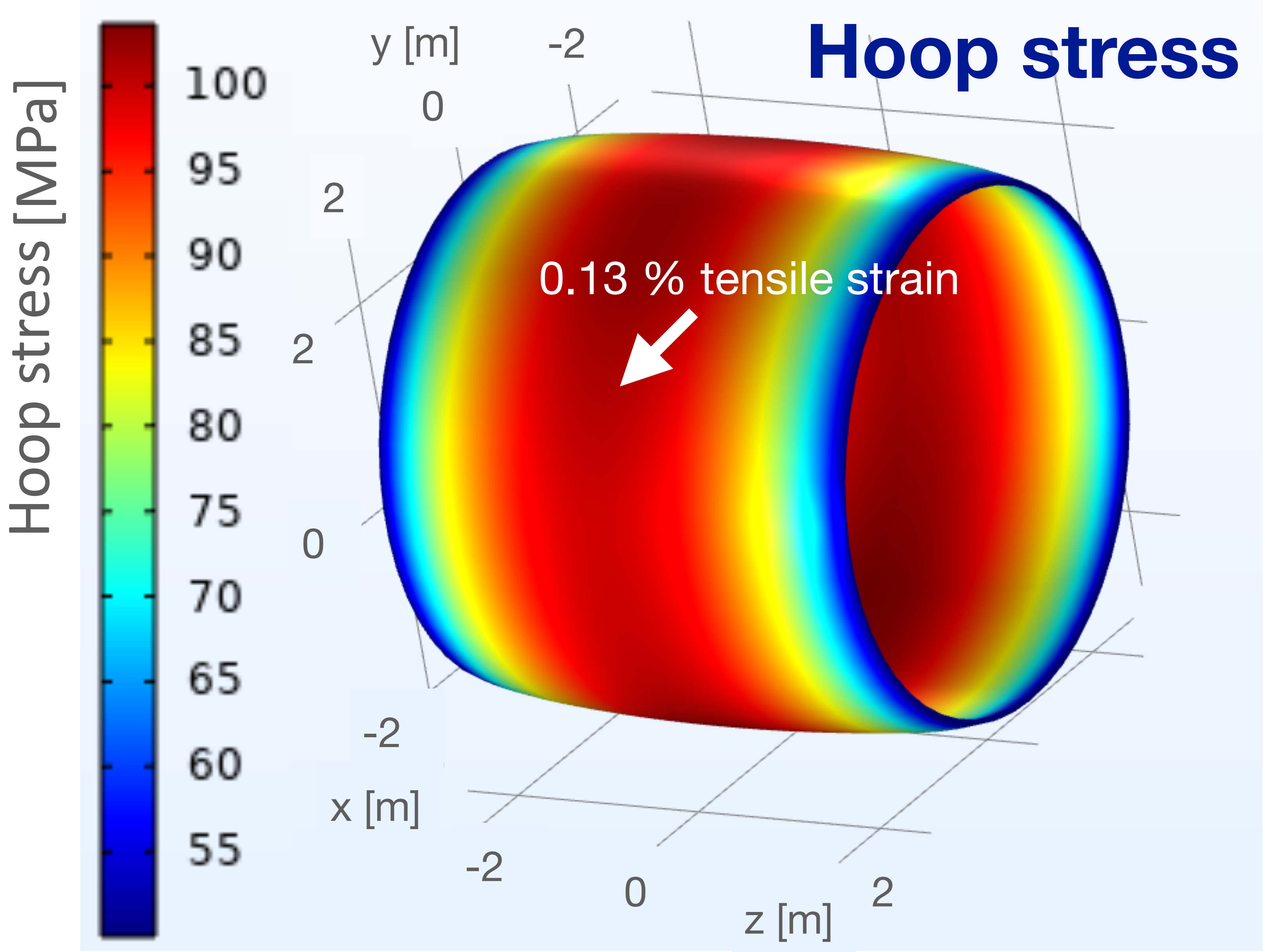
Mechanical support for the IDEA magnet

- Support cylinder with thickness of 12 mm
- Support cylinder material: aluminium 5083

Transparency of the cold mass: 0.76 X_0
Energy density: ~14 kJ/kg [2]

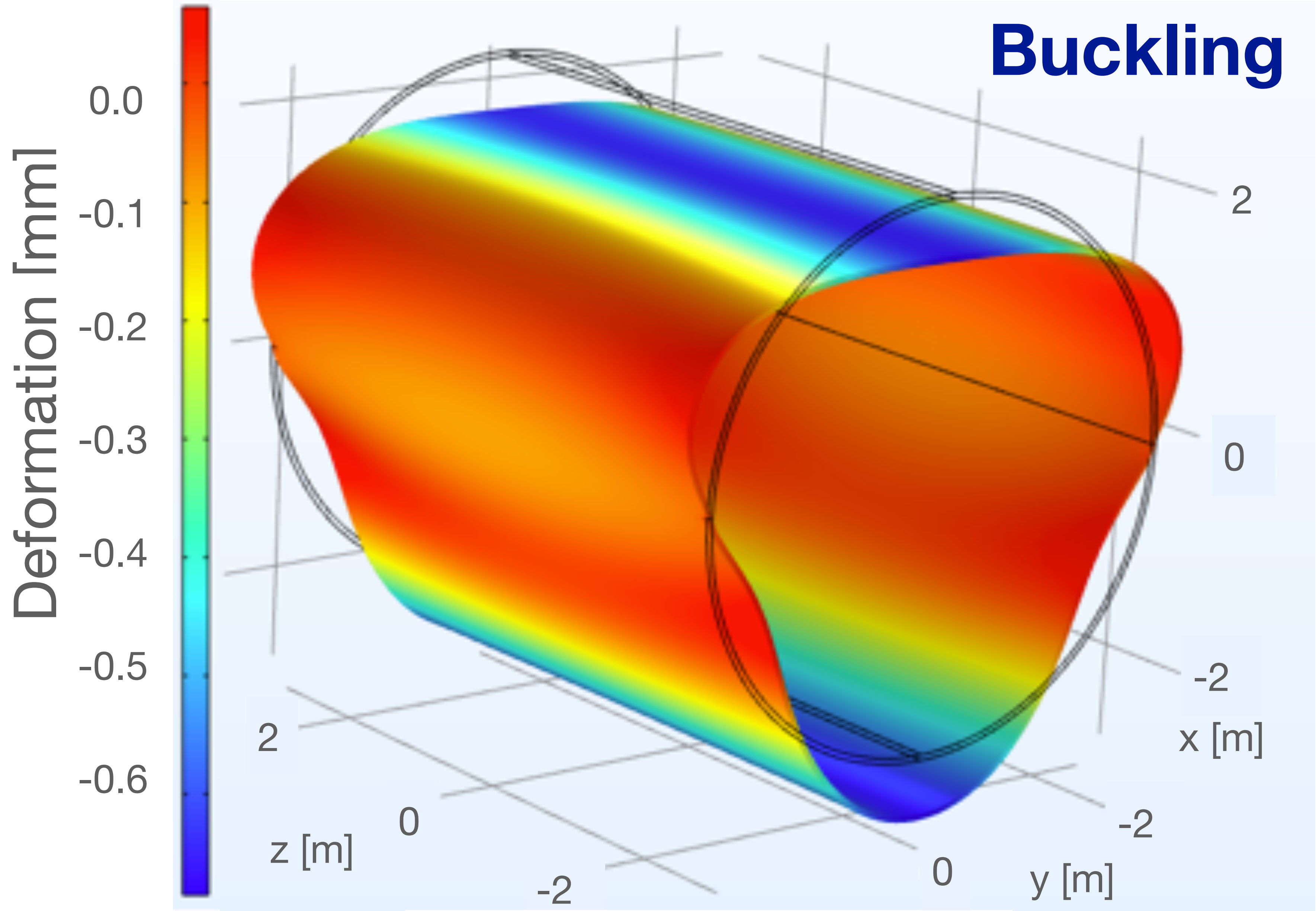
- First mechanical analysis is promising

	Conductor	Support	
Parameter	Value	Value	Unit
Material	Ni-doped aluminium	Aluminium 5083	
Yield strength	147 (with NbTi) [3]	209 @ 4.2 K [13]	MPa
Young's modulus	75 x 10^3	81 x 10^3	MPa



Hoop stress

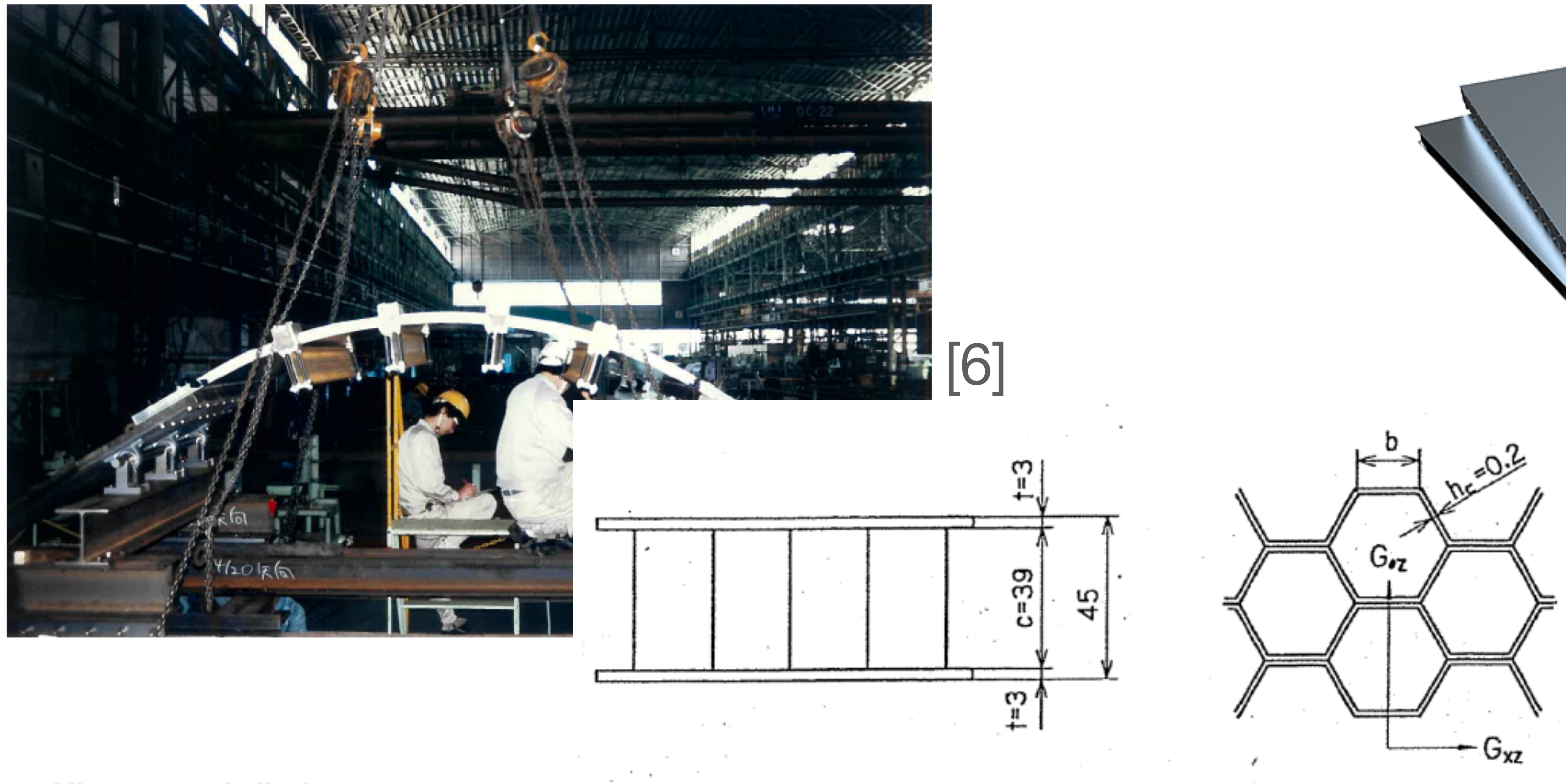
0.13 % tensile strain



Buckling

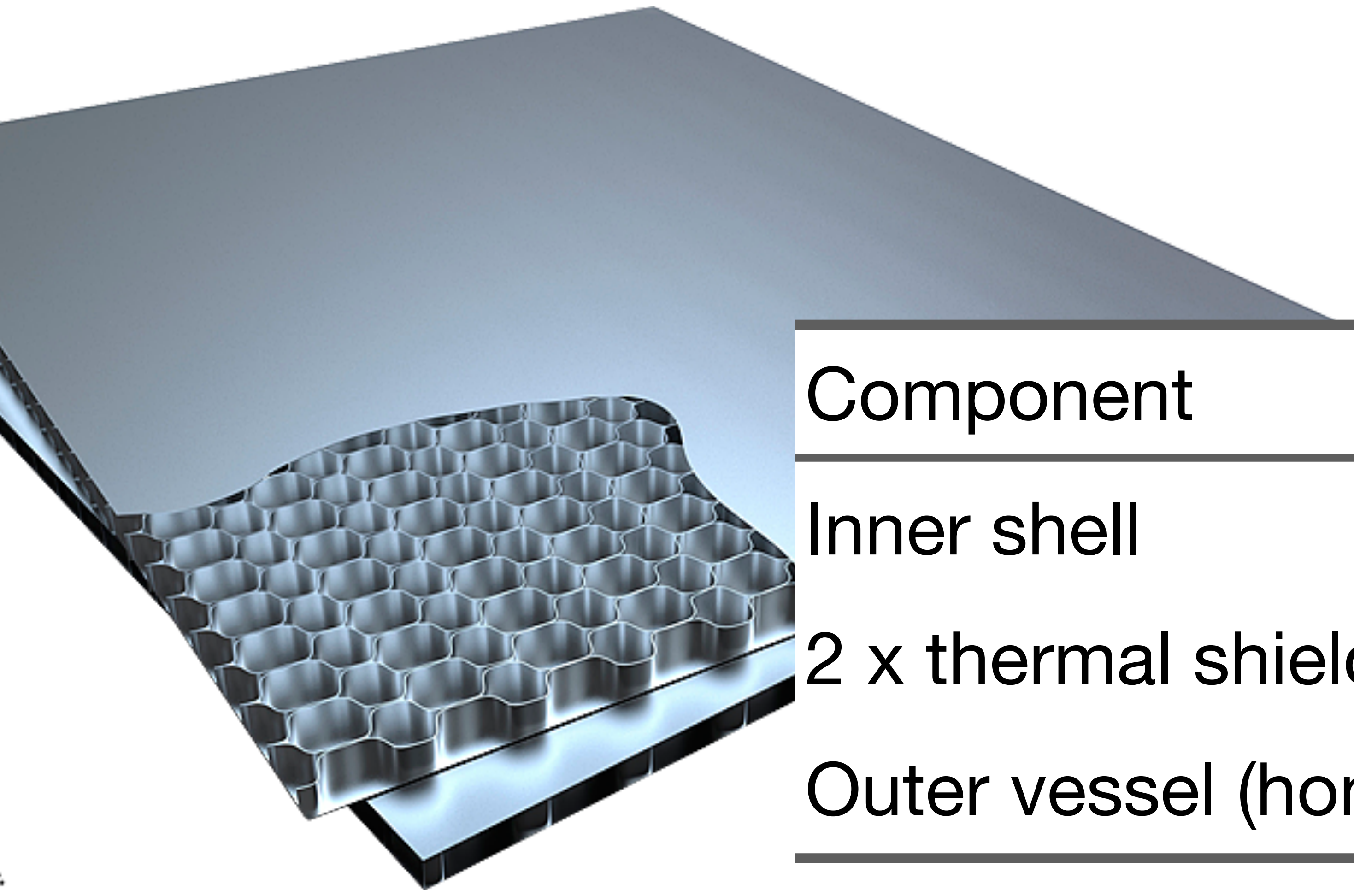
- Peak von Mises stress: **105 MPa**
- Peak tensile strain: **0.13 %**
- Peak shear stress: **0.5 MPa**
- Buckling of coil with simple **(pessimistic)** support, max. deformation: **0.7 mm**

Cryostat for the IDEA magnet



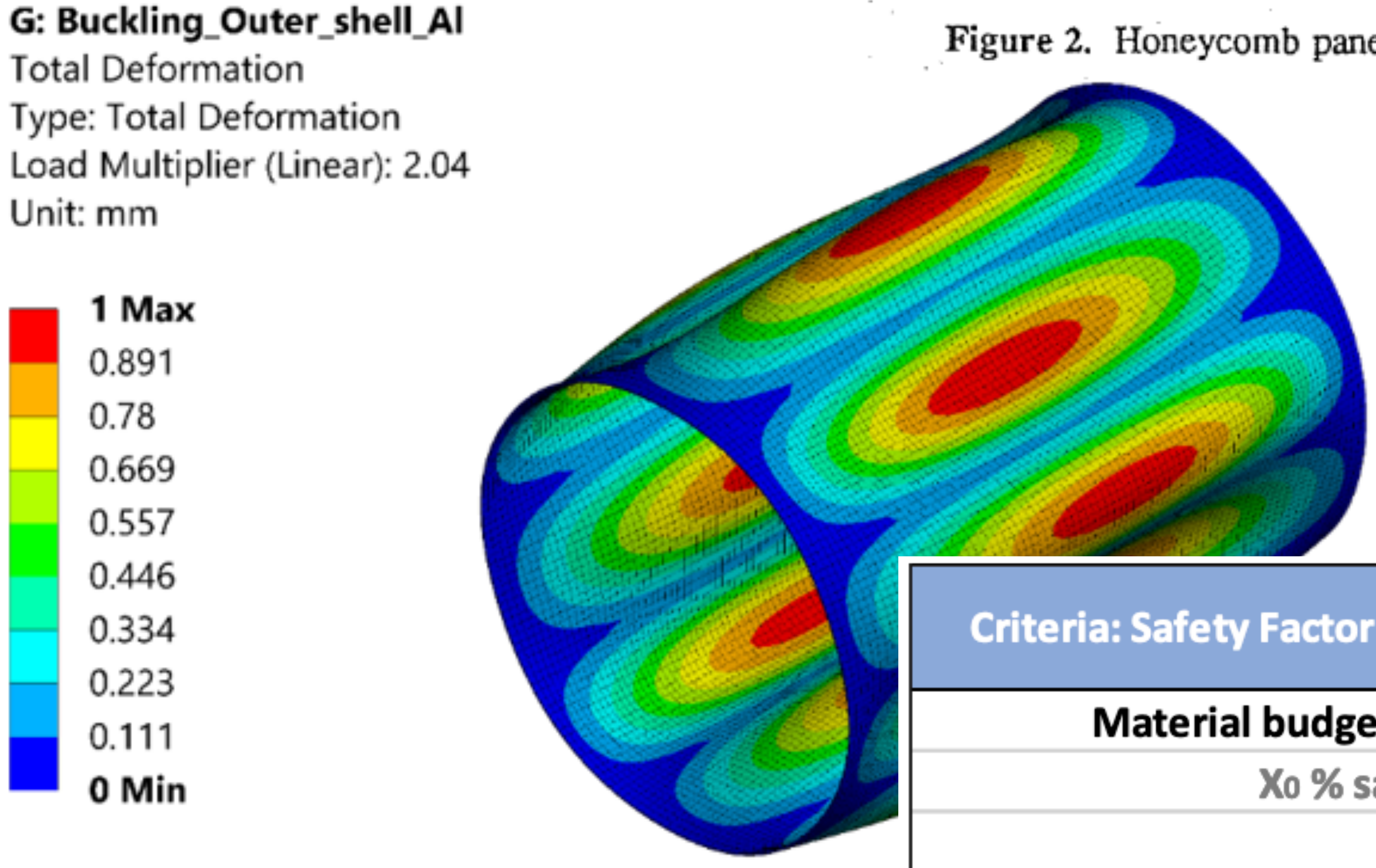
[6]

Figure 2. Honeycomb panel configuration in the preliminary design.



Component	Effective thickness
Inner shell	1.3 mm
2 x thermal shield (50 K)	0.7 mm
Outer vessel (honey-comb)	4.0 mm
Total	6.0 mm

[7]



[8]

Criteria: Safety Factor = 2	Honeycomb Al		Solid shell	
	HM CFRP	Al	HM CFRP	Al
Material budget X/X0	0.017	0.045	0.065	0.24
X0 % savings	-62%	REF	44%	433%
Skin Th. [mm]	1.6	1.7		
Core Th. [mm]	26	40		
Total Th. [mm]	29.2	43.4	16.8	20.9
Thickness % savings	-33.00%	REF	-61%	-52%

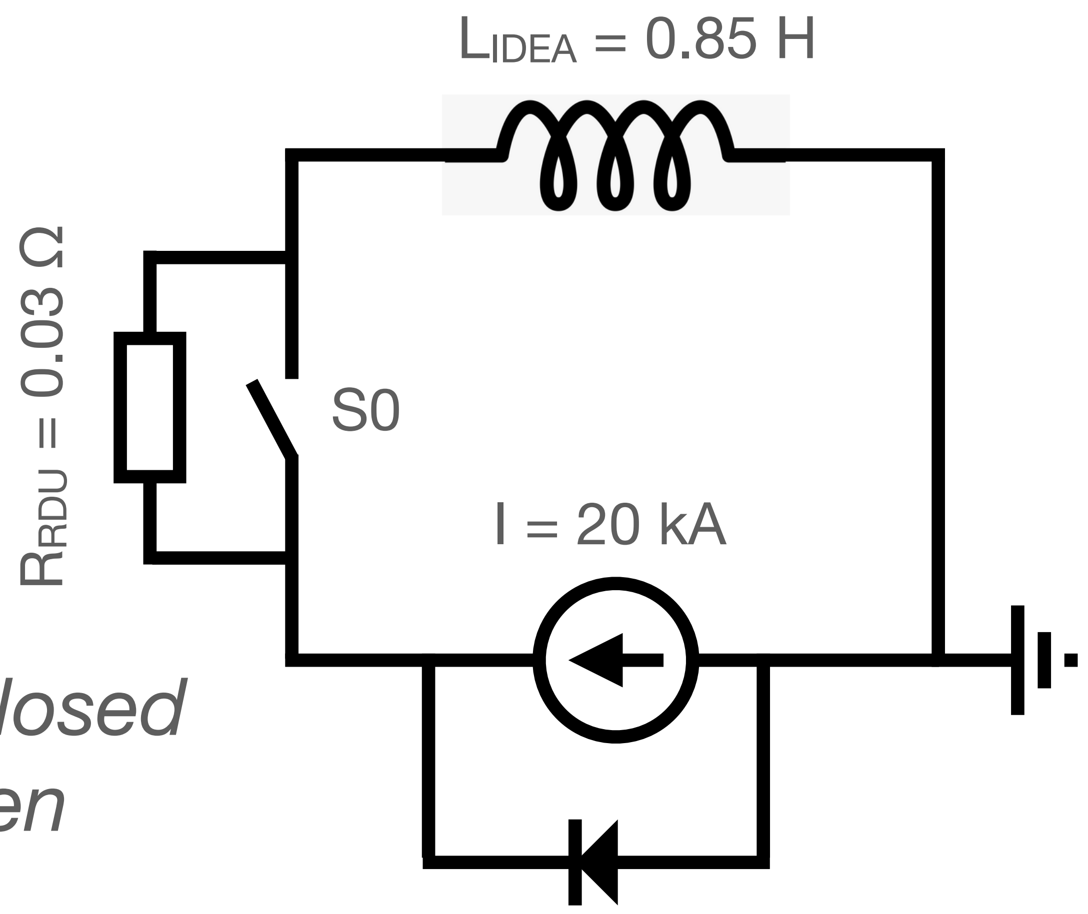
For vacuum vessel:

- Should also be as thin as possible
- Main challenge is on the outside of the solenoid, due to buckling potential
- Previous studies [6, 7]: Al-based honey-comb vessel
- **Ongoing CERN EP R&D WP4 [8]:** C-fibre reinforced plastic vacuum vessels

3D quench simulation of **IDEA** Detector Magnet

3D Quench simulations IDEA magnet

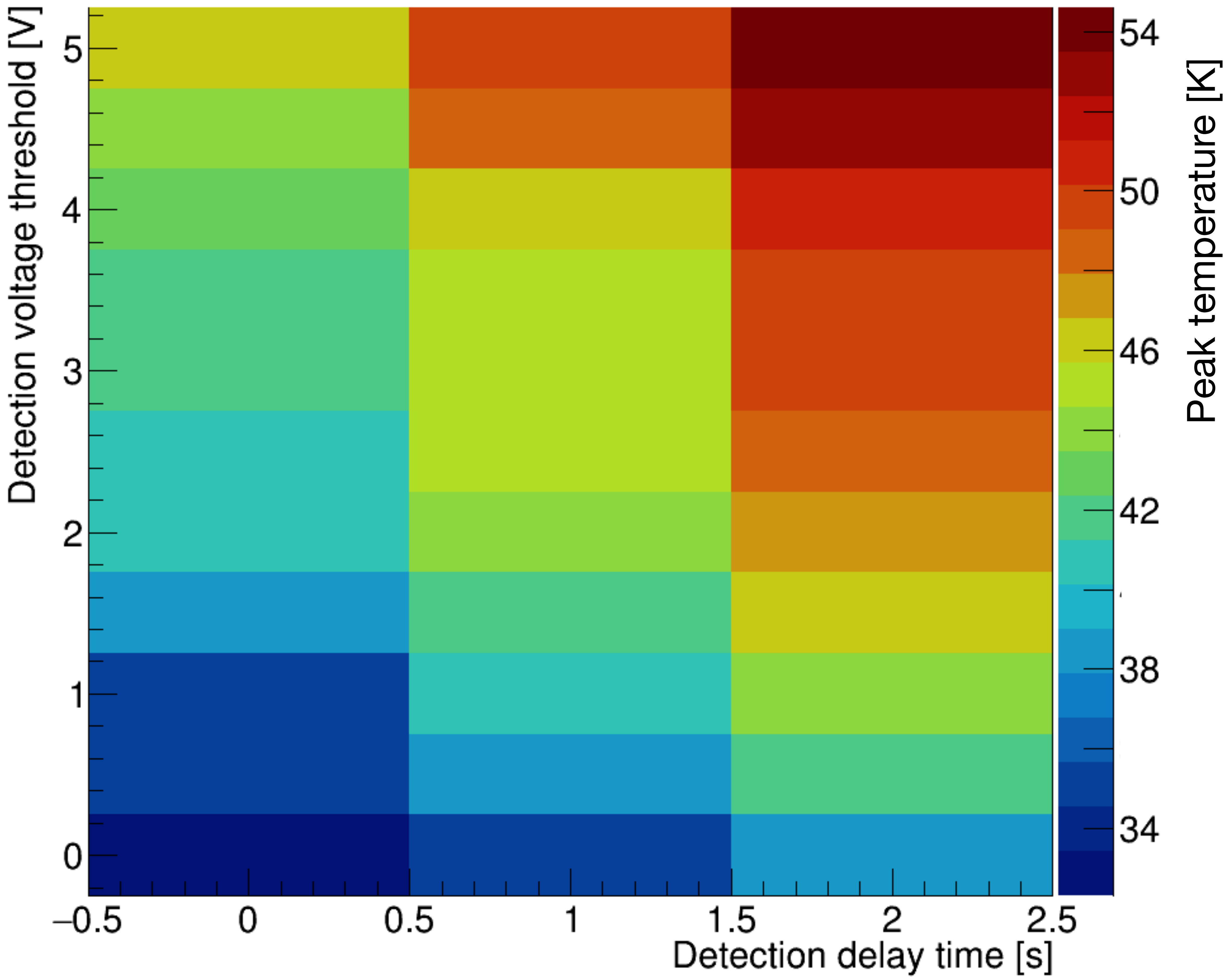
Quench detection



Before quench: S0 = closed
After quench: S0 = open

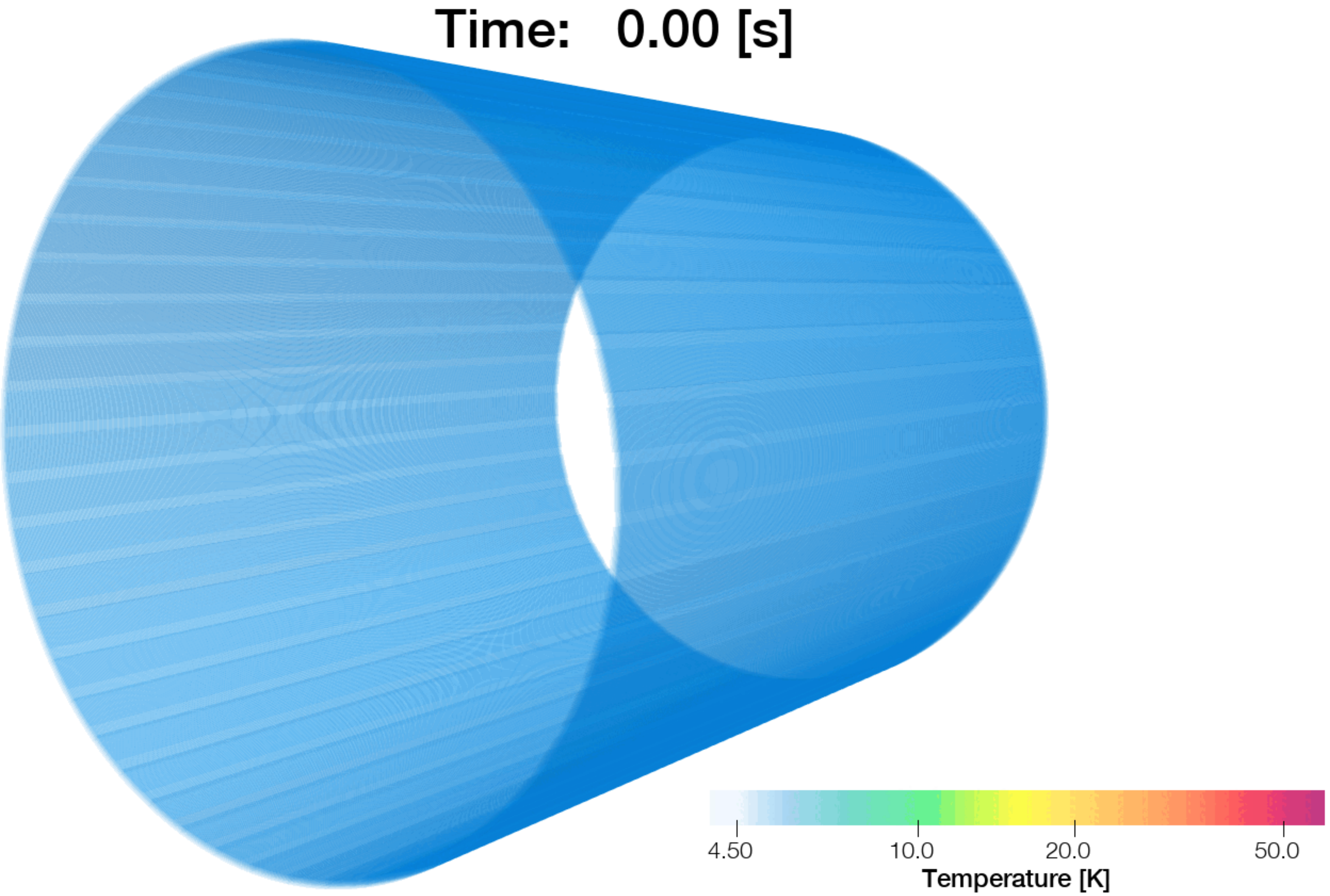
- 3D thermo-electrical network software called **Raccoon2** based on the work described in [9]
- Validated with data measured at the ATLAS Central Solenoid [10]
- **First detection: scan voltage threshold vs. delay**
- Experience with the ATLAS CS (delay 1.2s)

Choice for IDEA: threshold = 0.1V, delay = 1s

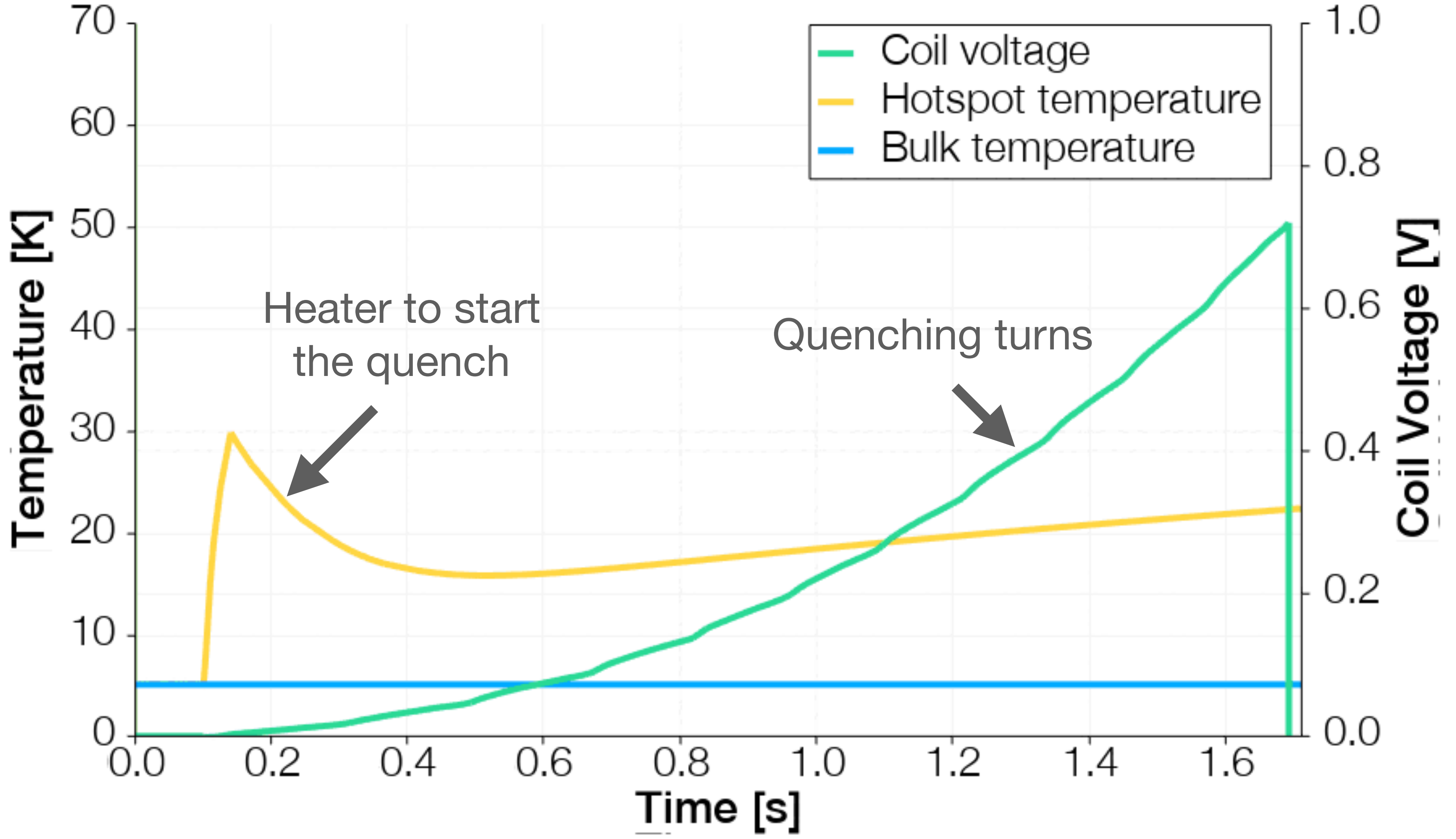


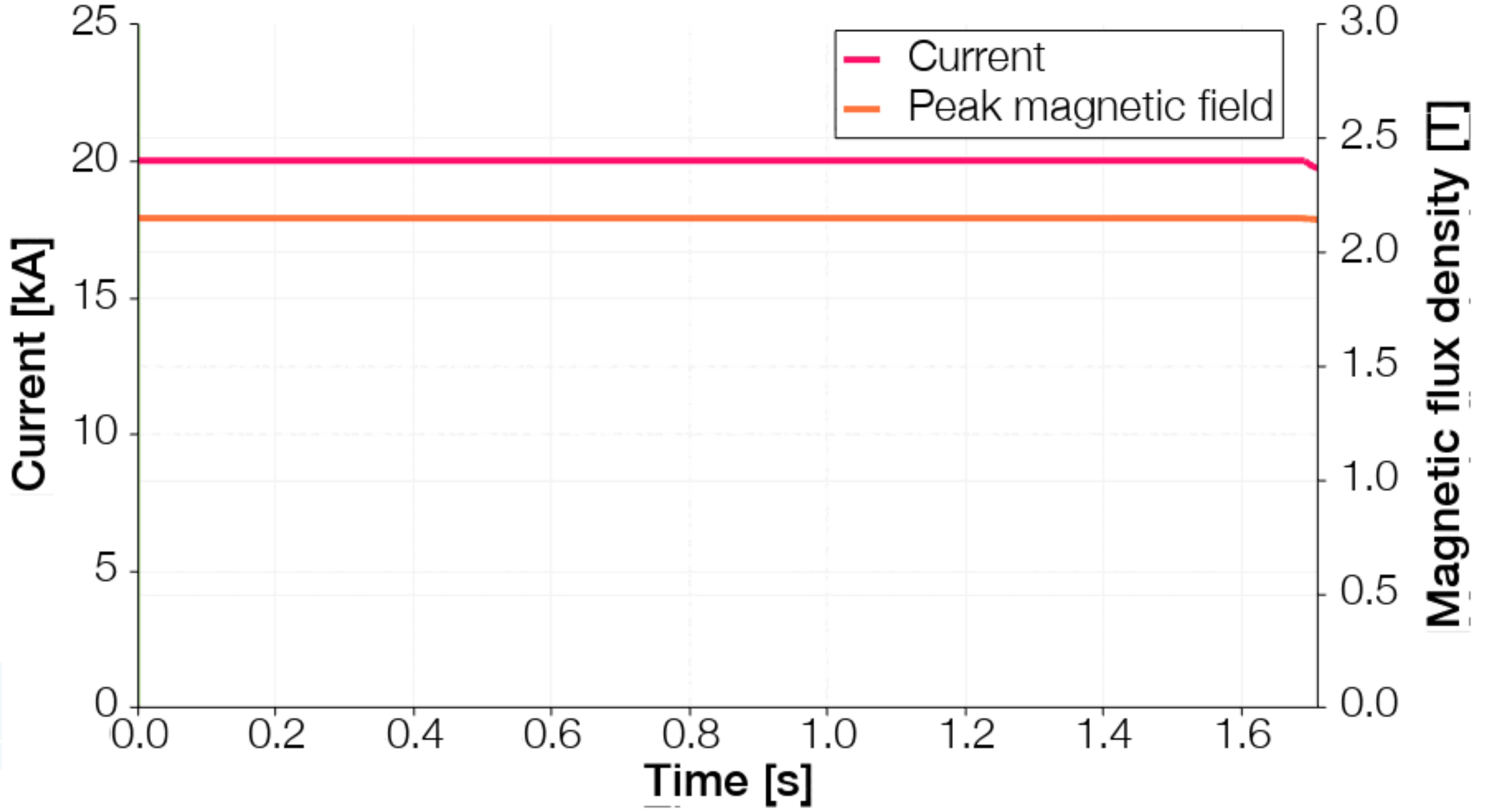
3D Quench simulations IDEA: RDU + QP strips

Initiating the quench



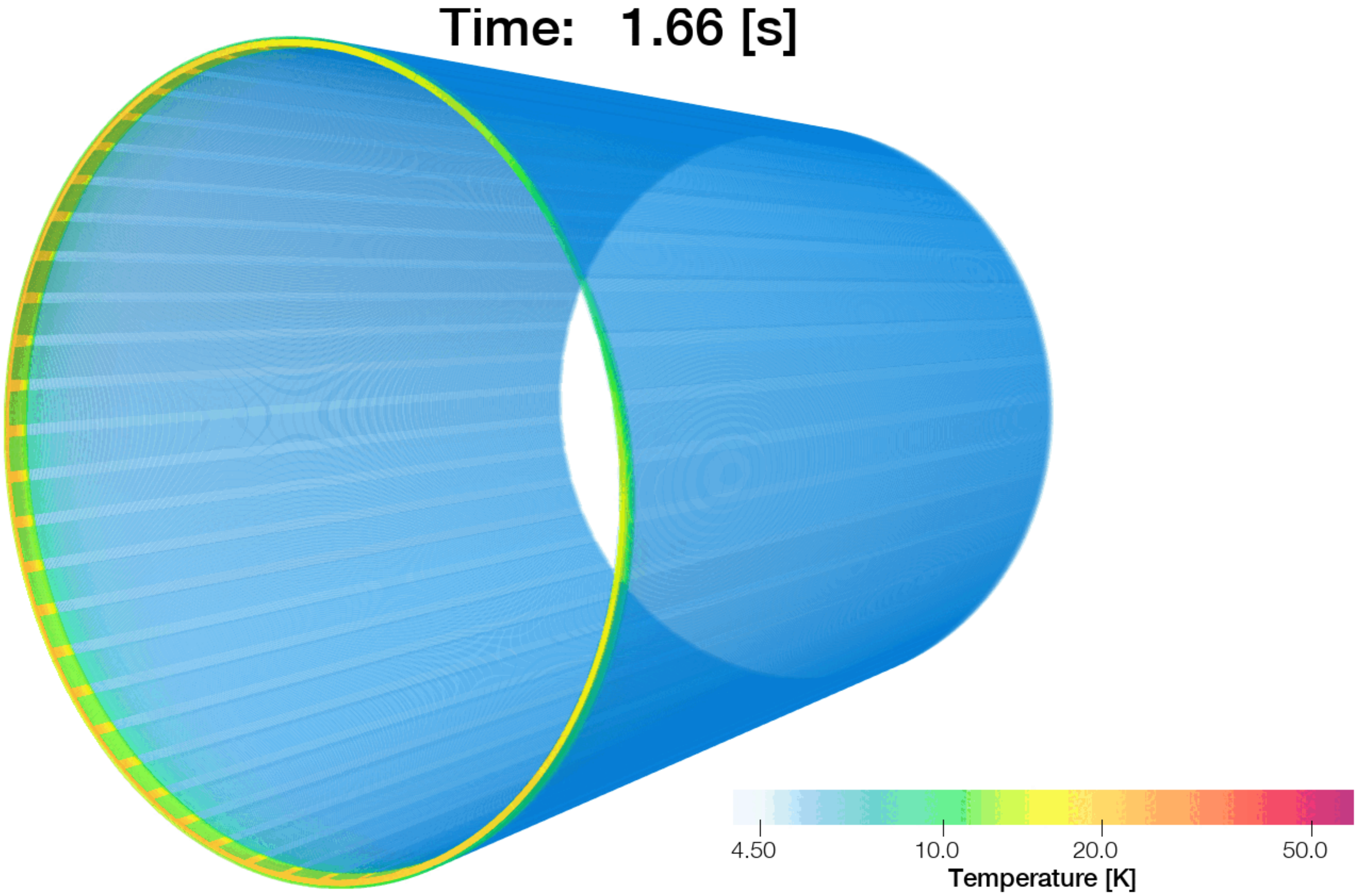
Cross section of the cold mass



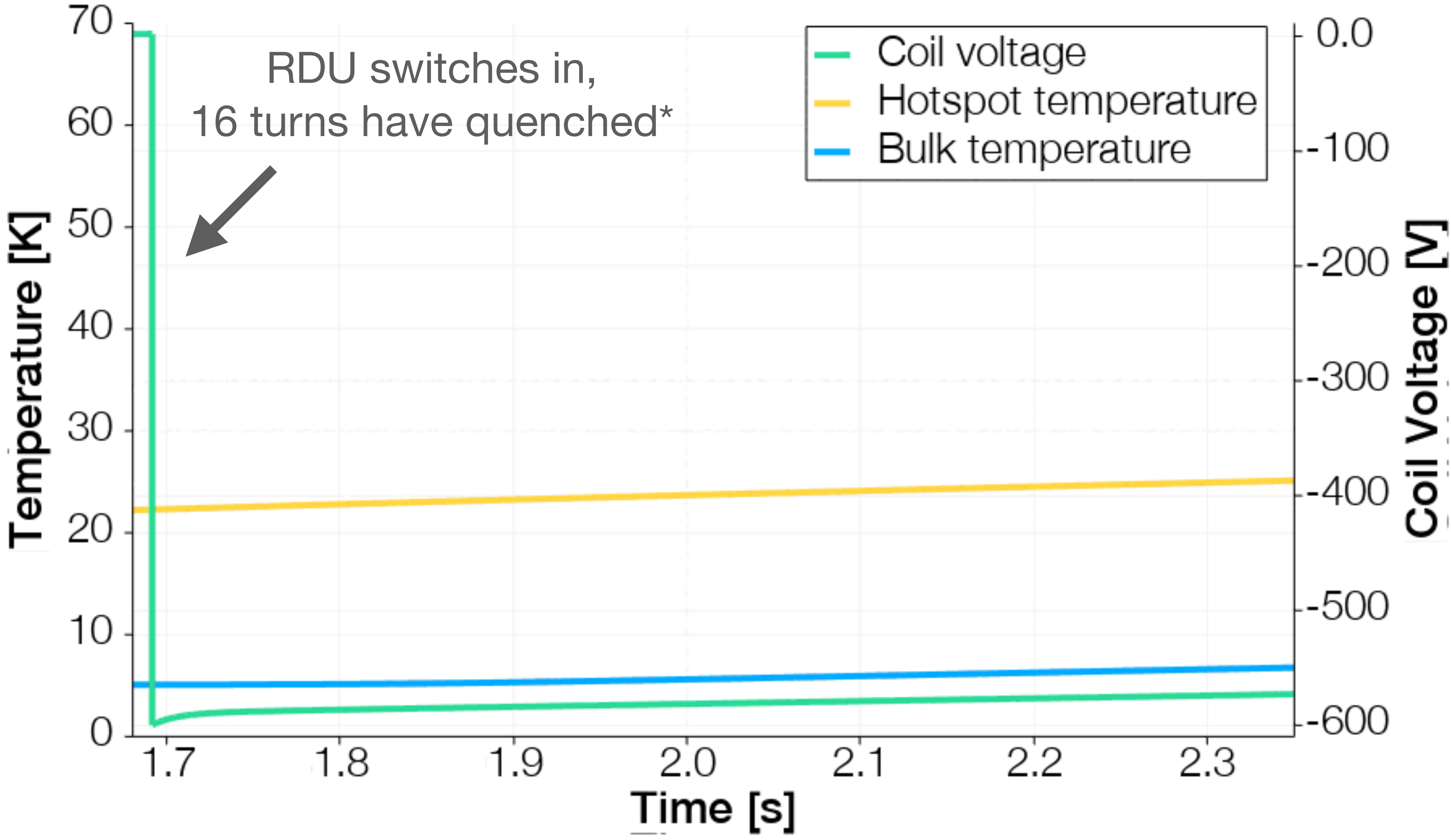


3D Quench simulations IDEA: RDU + QP strips

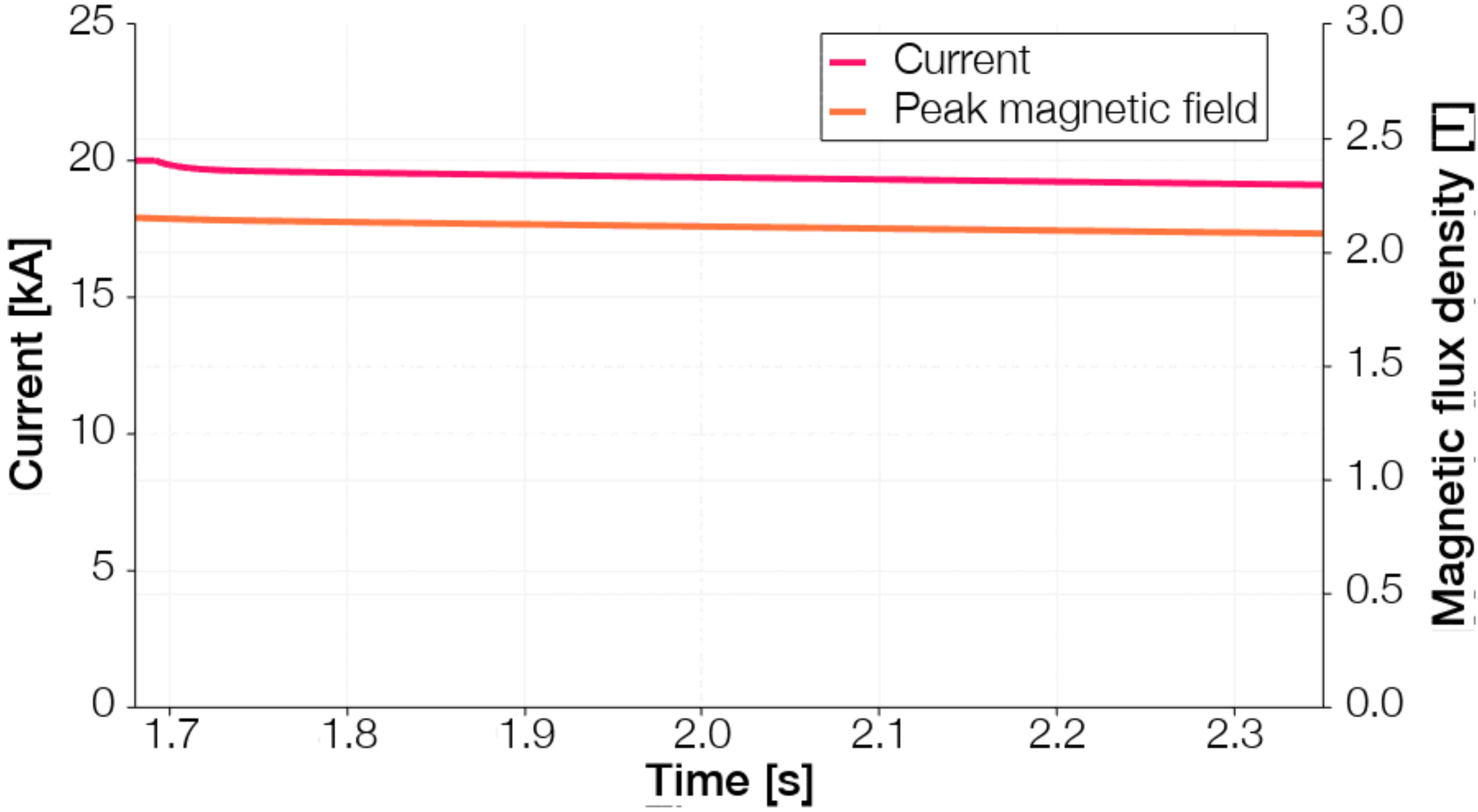
Switching in the extraction resistor



Cross section of the cold mass



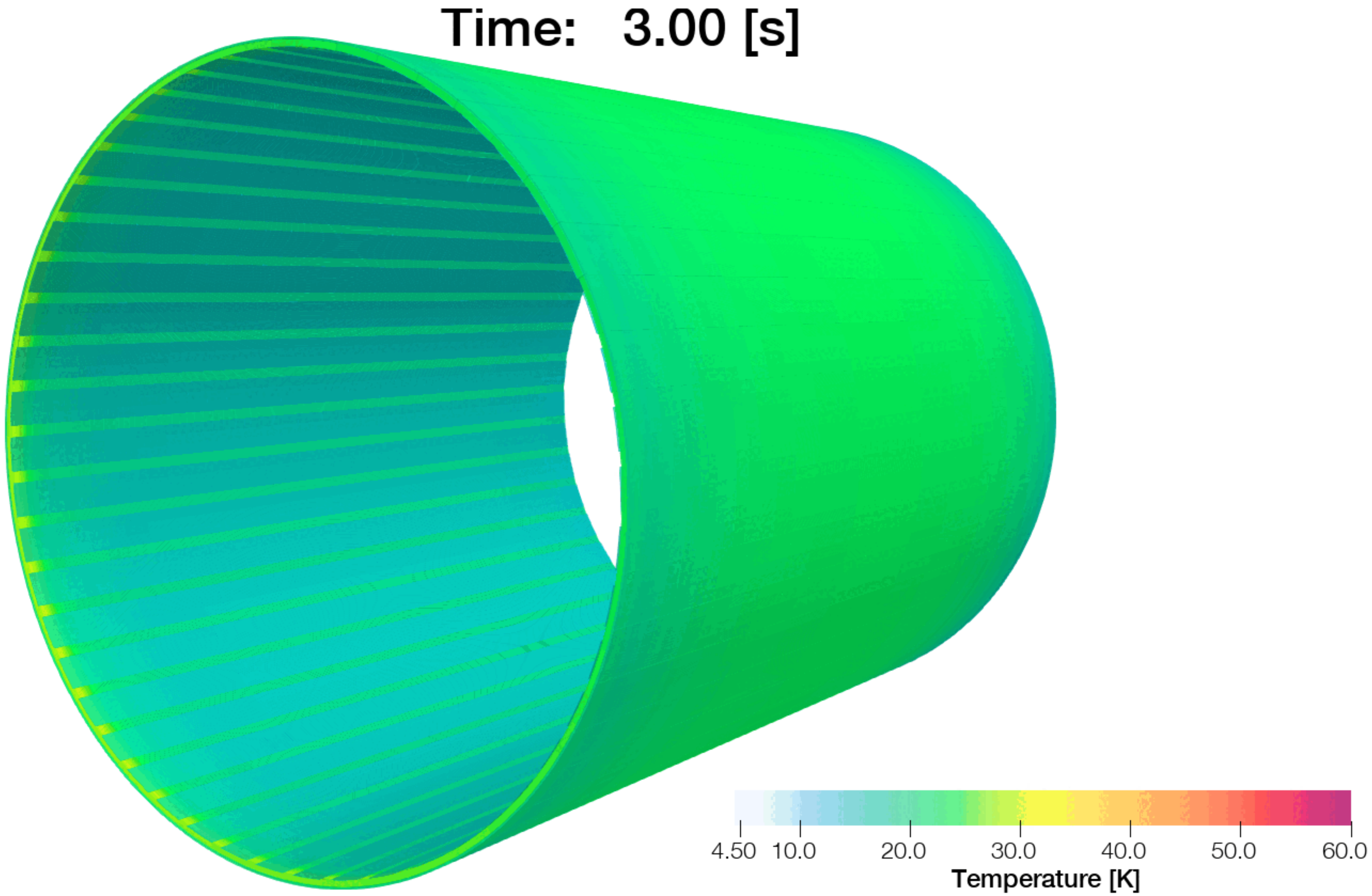
RDU switches in,
16 turns have quenched*



* With QP strips 16 turns quench before RDU, without strips 11 turns quench before RDU

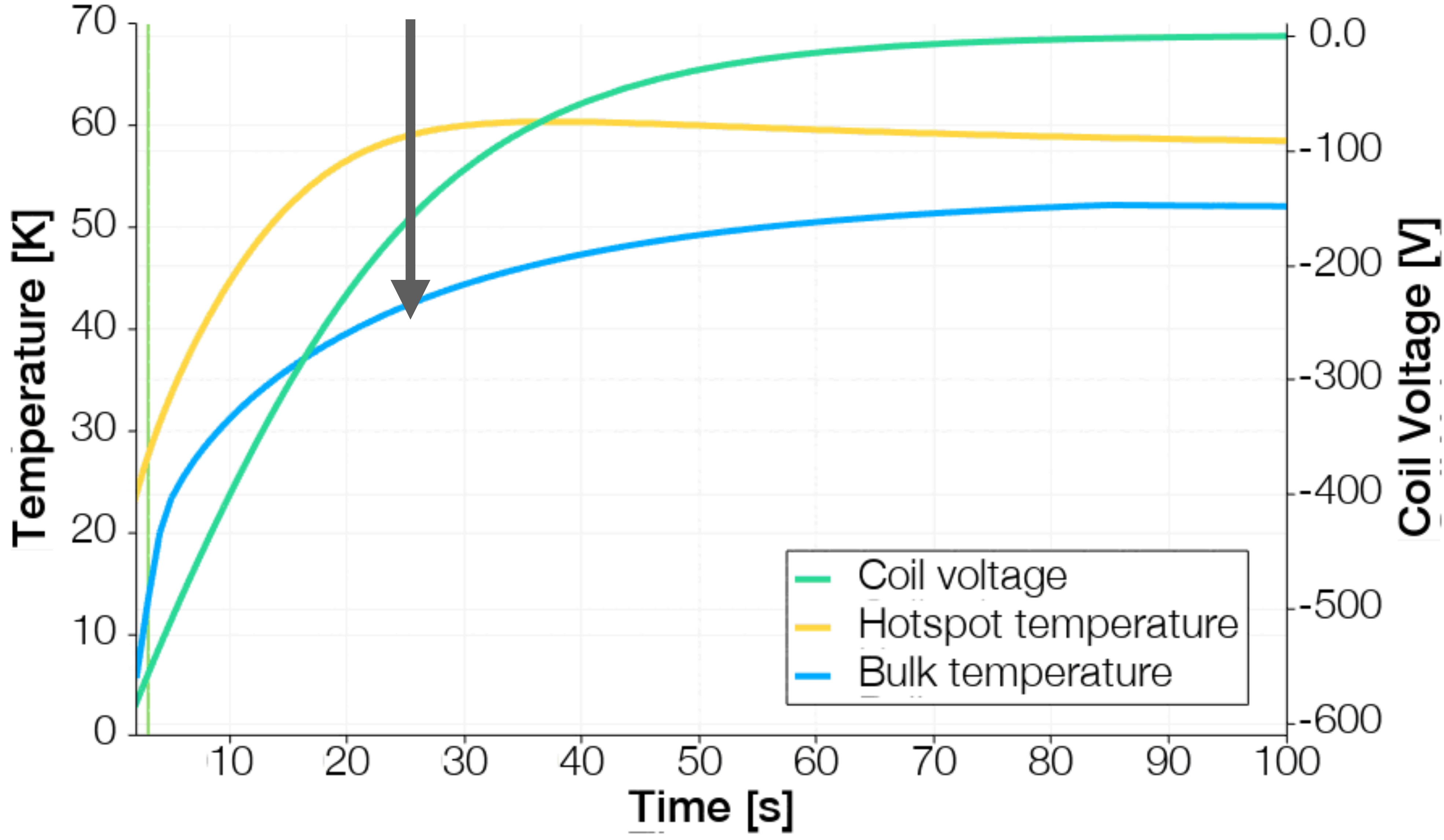
3D Quench simulations IDEA: RDU + QP strips

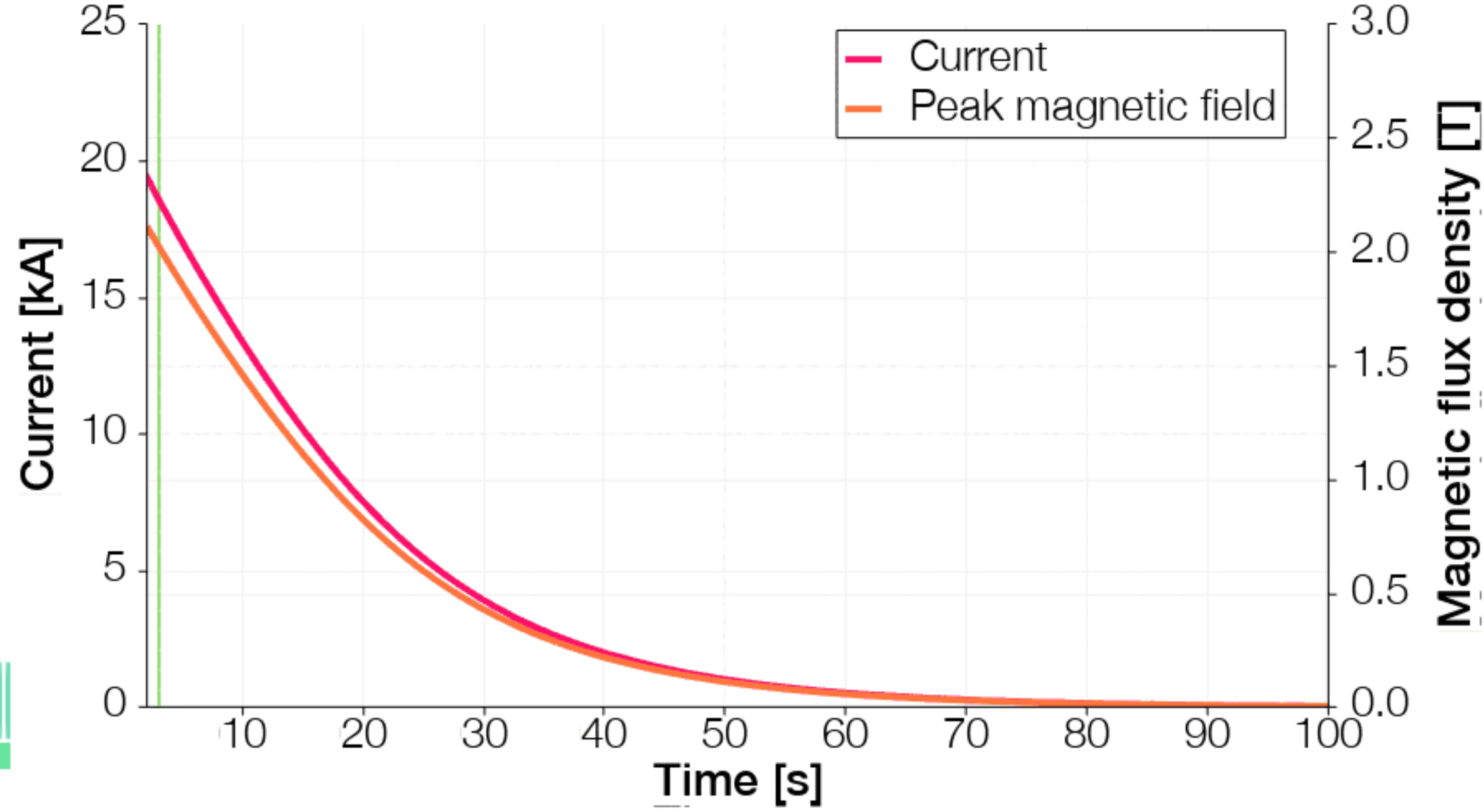
Extracting the energy from the magnet



Cross section of the cold mass

Bulk temperature lags behind peak temperature





Summary

Summary

- **Two detector designs** are being studied for the lepton Future Circular Collider
- Both the **IDEA and the CLD detector concept** include a superconducting solenoid design that would provide a 2 T magnetic field inside the detector
- These studies show **promising results** without immediate show stoppers, though the IDEA design presented is a **very challenging design,** matching the world-record energy density of the Bess Balloon Detector magnet [2]
- Both designs **would require extensive R&D** in the coming years to reach the goals set out in the FCC-ee Conceptual Design Report [1]

Community for Magnets

- **Low-threshold** meeting place, **ONLINE**
- **Inspired by last year's MT conference**

COMET

Community for Magnet Technology

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