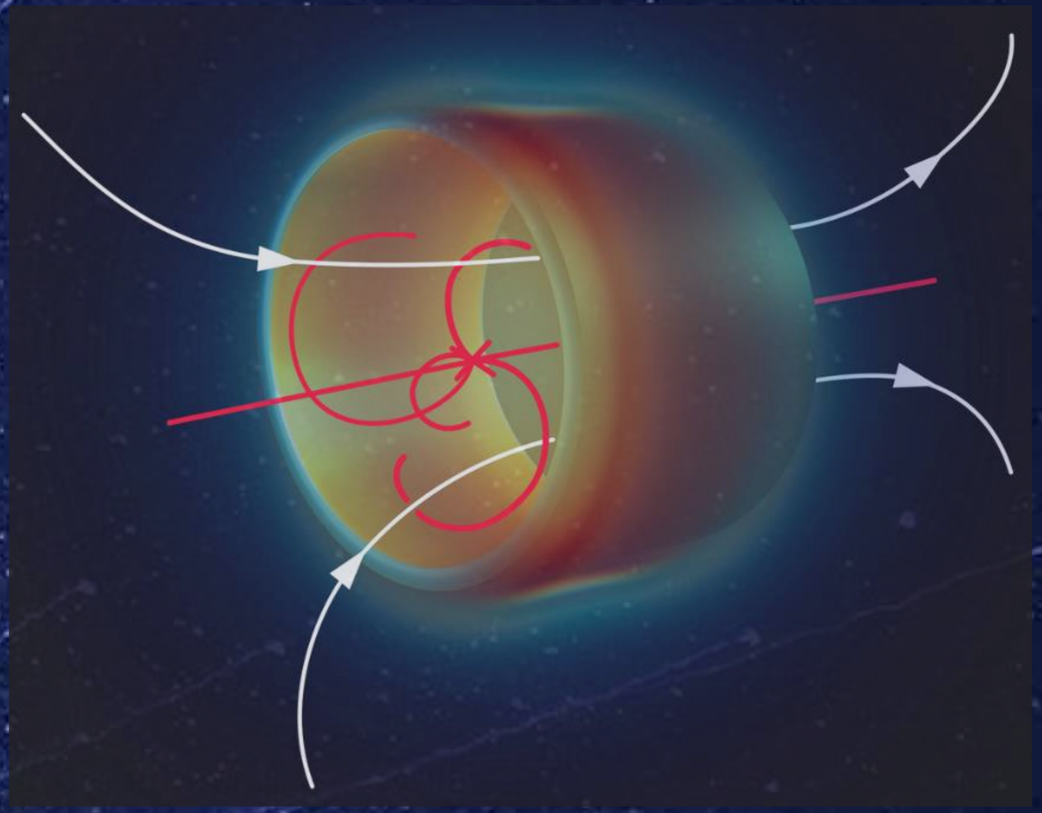
**Nikkie Deelen,** Alexey Dudarev, Benoit Curé, Matthias Mentink



# DETECTOR MAGNETS FOR FCC-EE

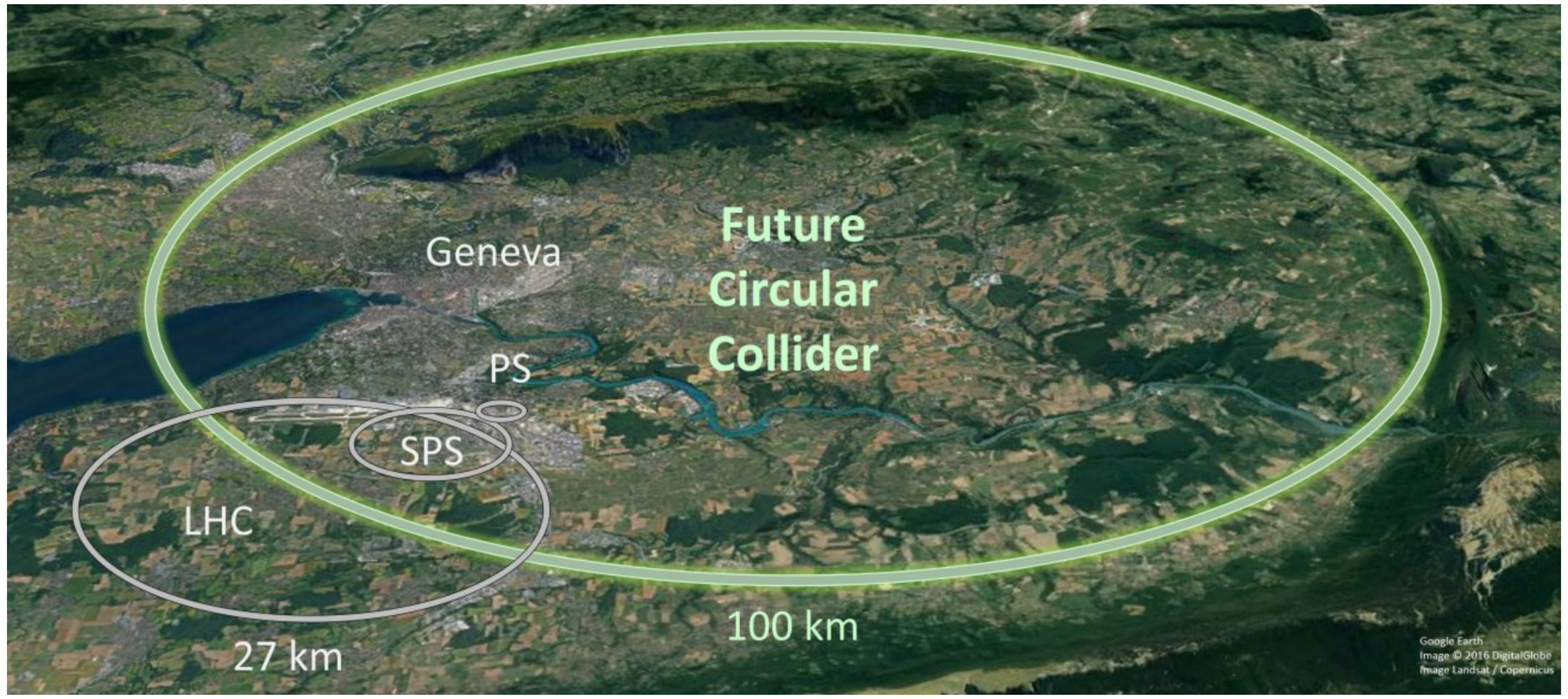
Superconducting solenoids for the IDEA and CLD Detector concepts

# CONTENT OF THIS TALK

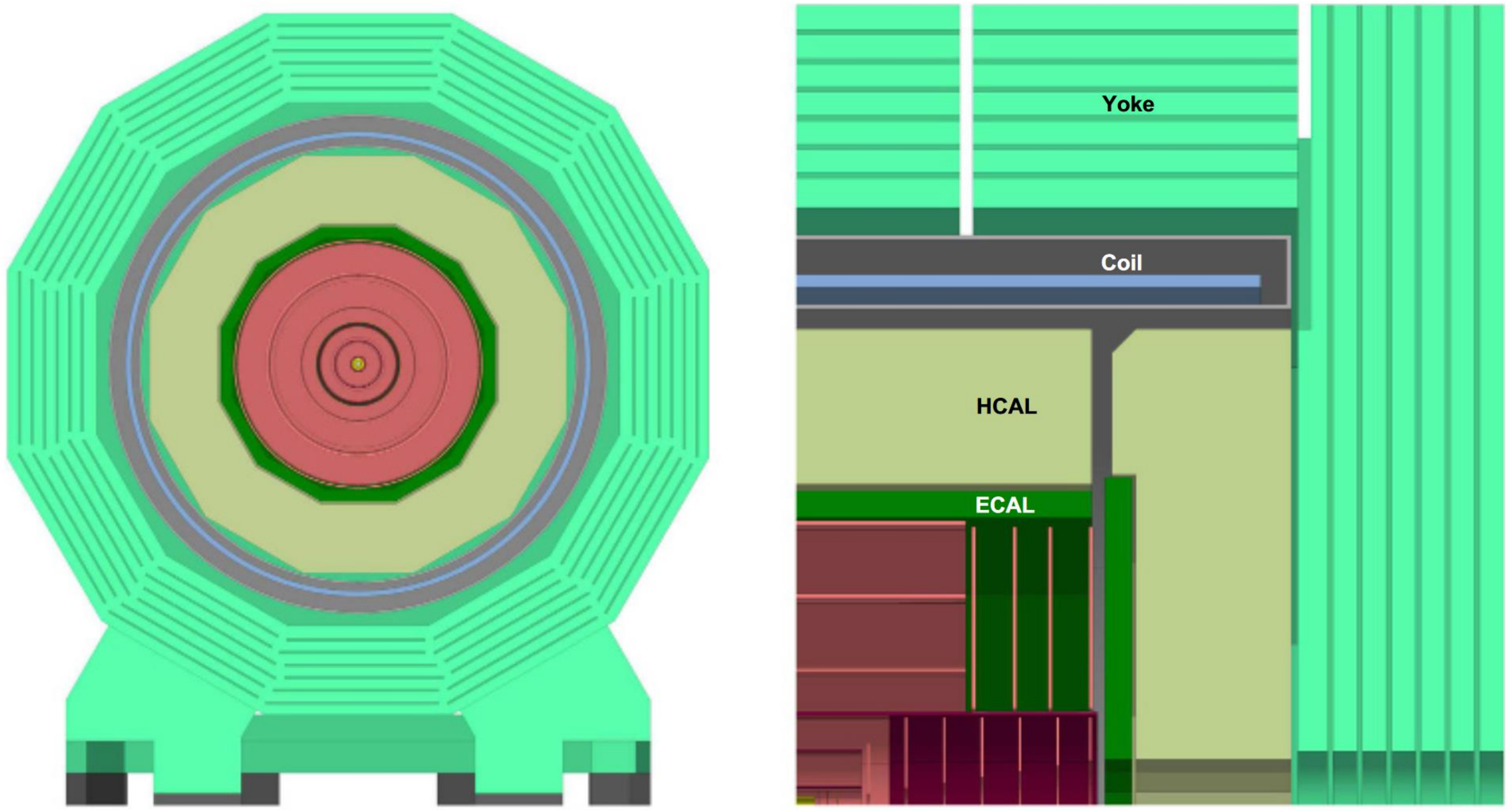
- Introduction: FCC-ee Detector magnets
- The CLIC-Like Detector (CLD) superconducting solenoid
- The International Detector for Electron-positron Accelerators (IDEA) superconducting solenoid
- 3D Quench studies on the IDEA superconducting solenoid
- Summary

# 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**



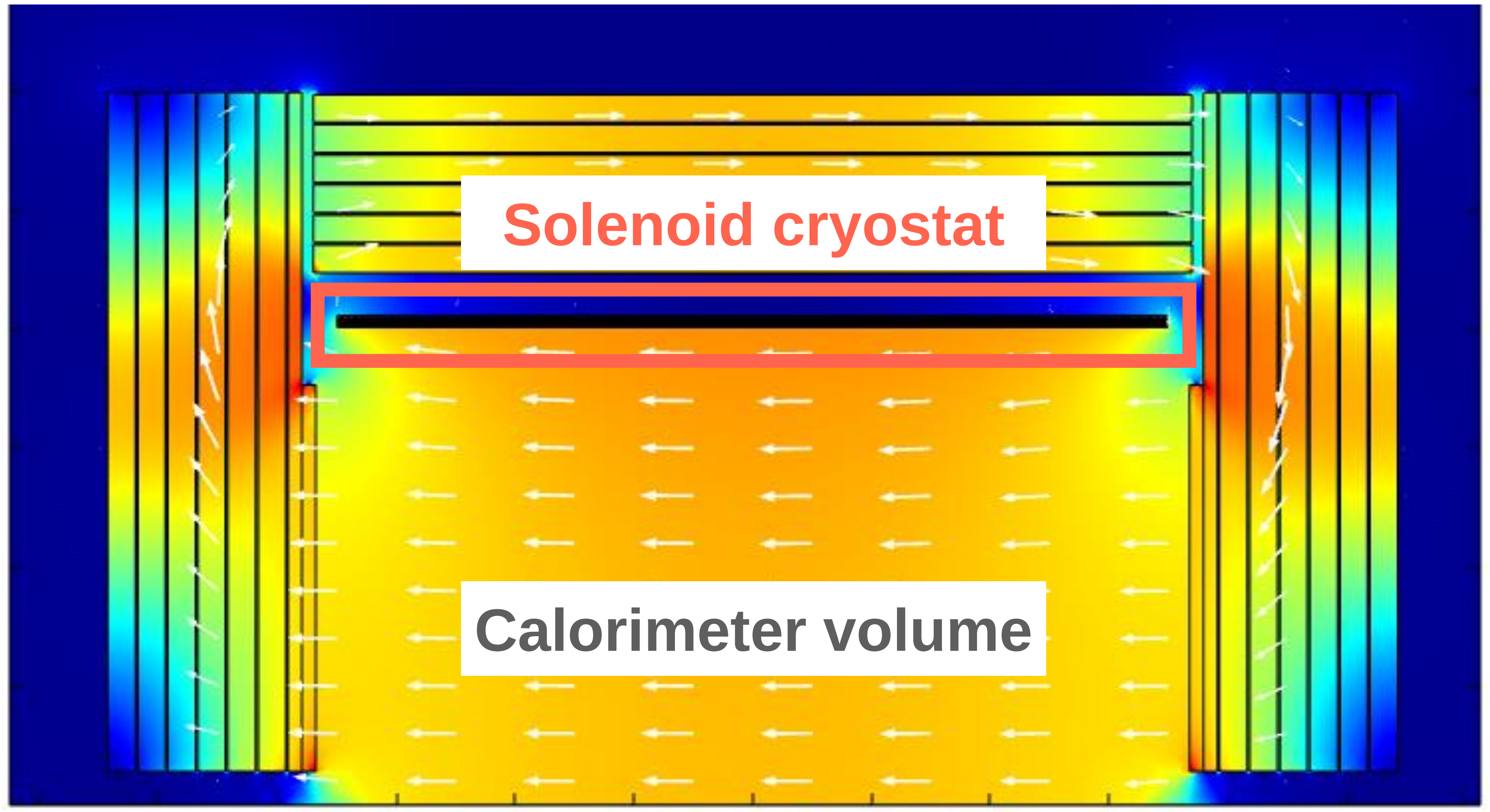

- Two detector designs are being studied for FCC-ee
- **International Detector for Electron-positron Accelerators** (IDEA) / **CLIC-Like Detector** (CLD [14])
- Both have superconducting solenoid with **$B_{center}$ of 2 T**
- IDEA solenoid **inside,** CLD solenoid **outside** calorimeters

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

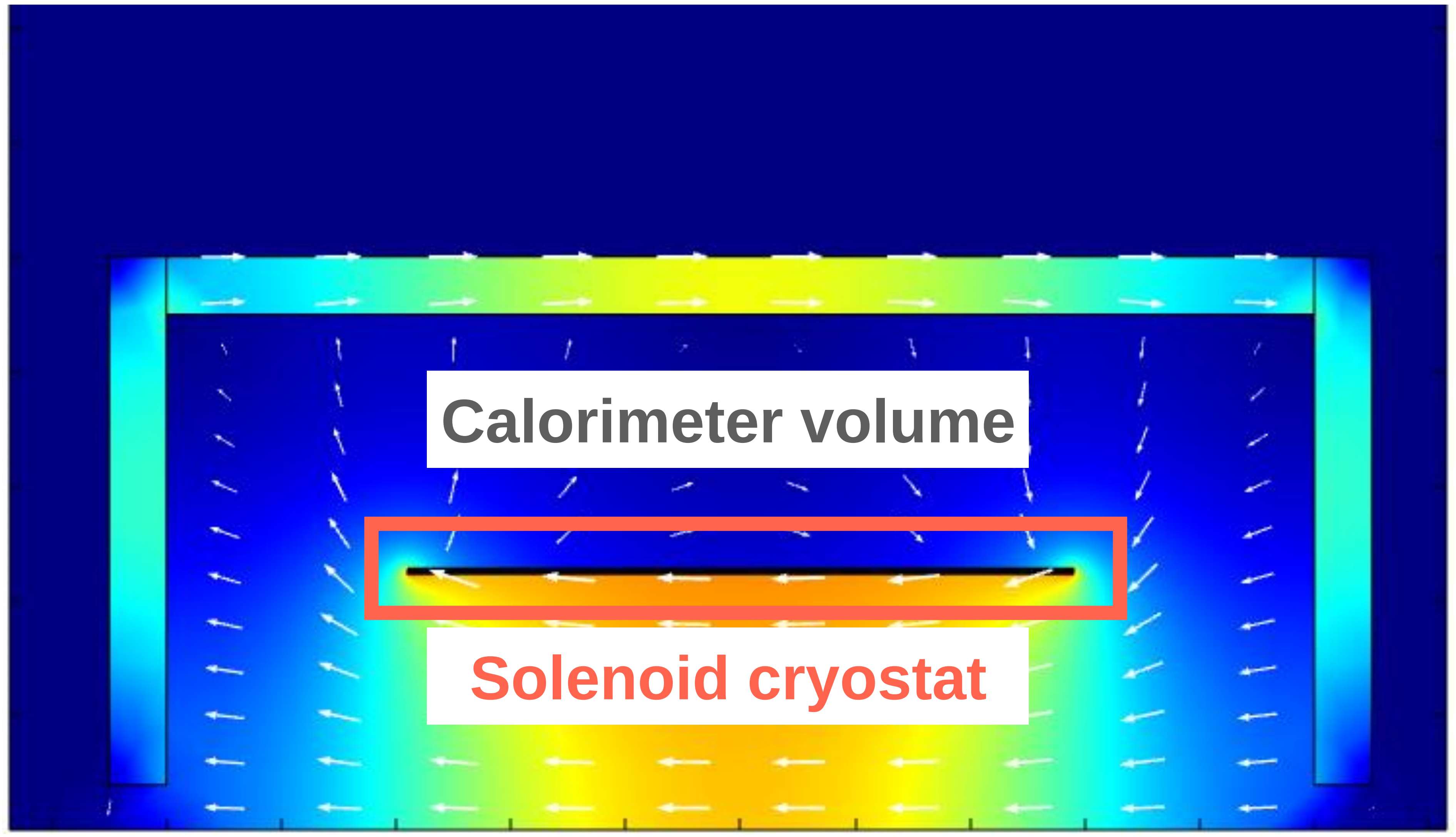
# Two Detector magnets

- 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

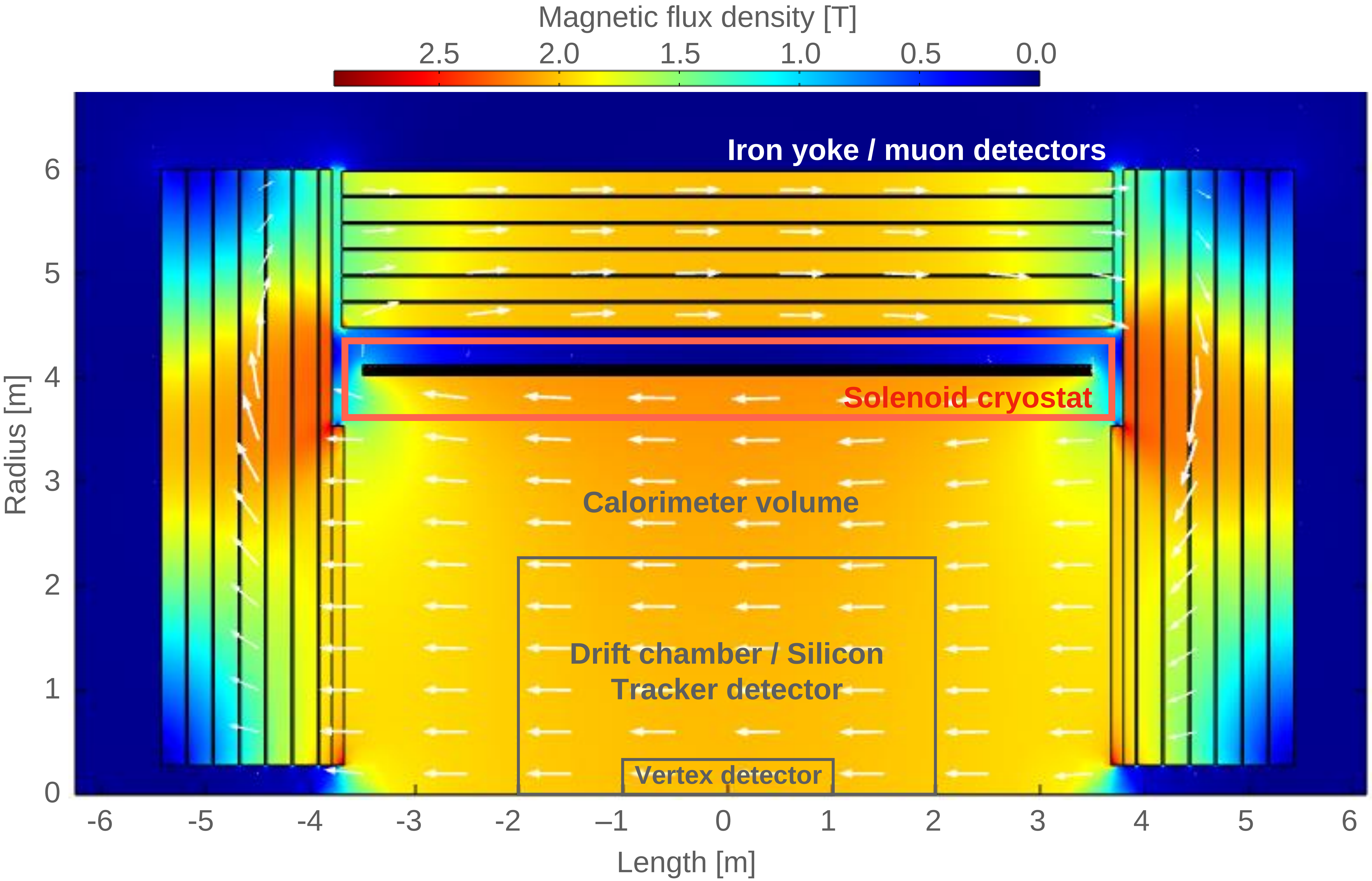



International Detector for Electron-positron Accelerators



# The design of the **CLD** Detector Magnet

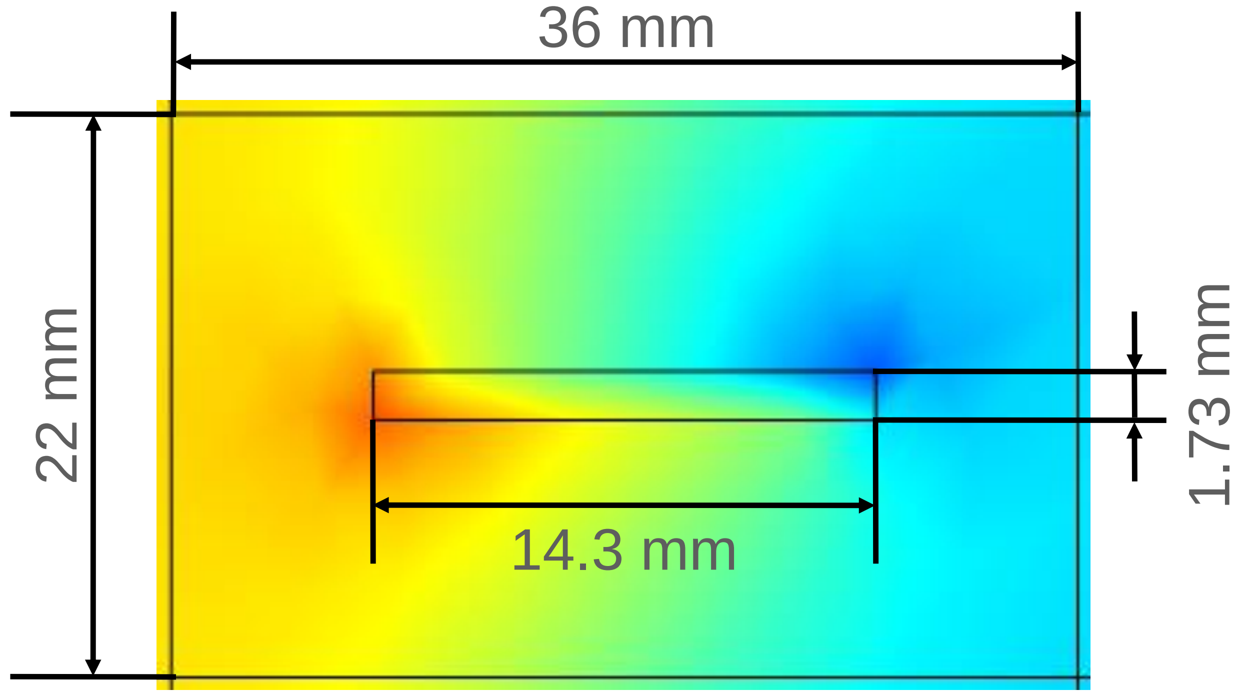
# CLD Detector design




**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]**

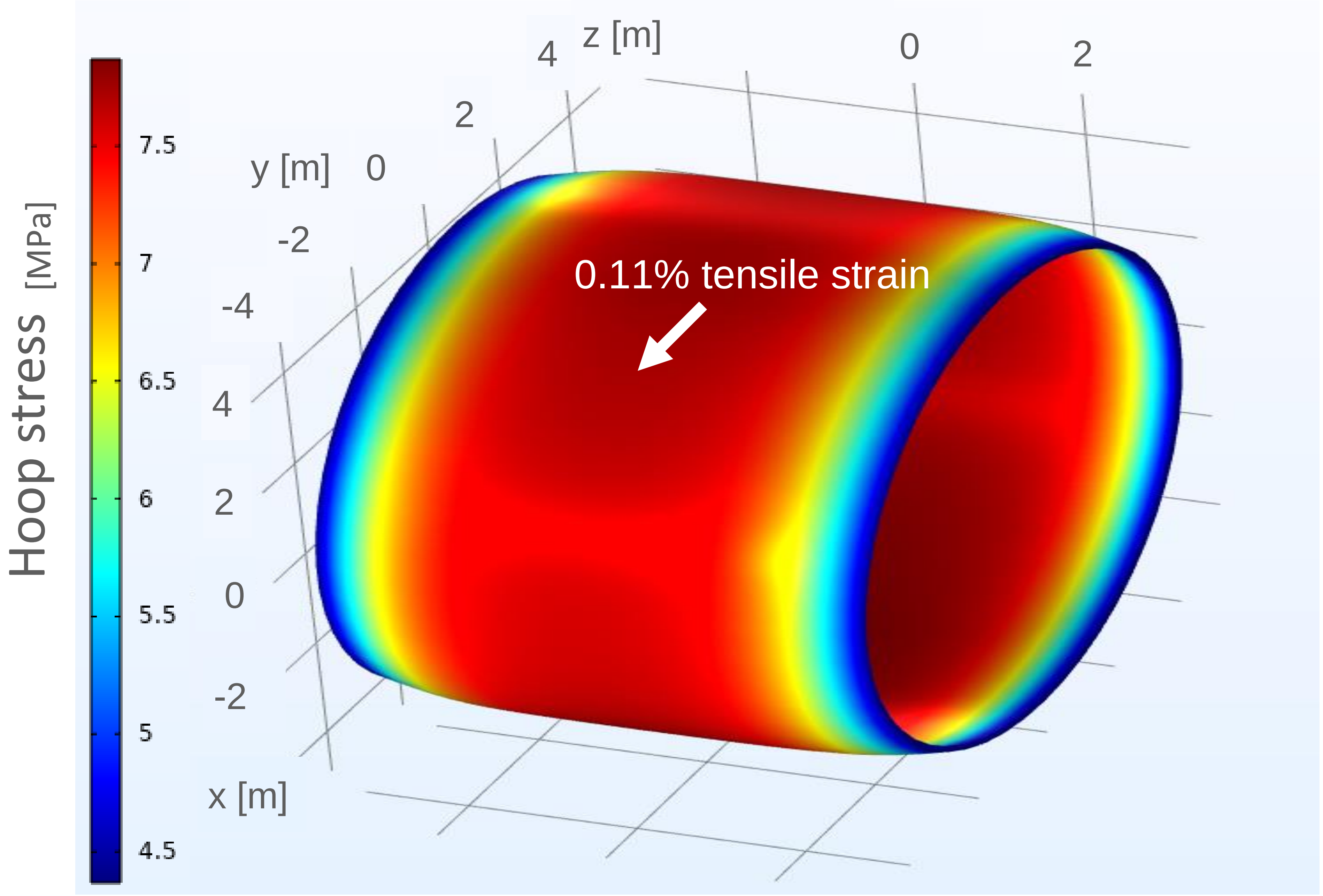


# Mechanical support for the CLD magnet

- 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

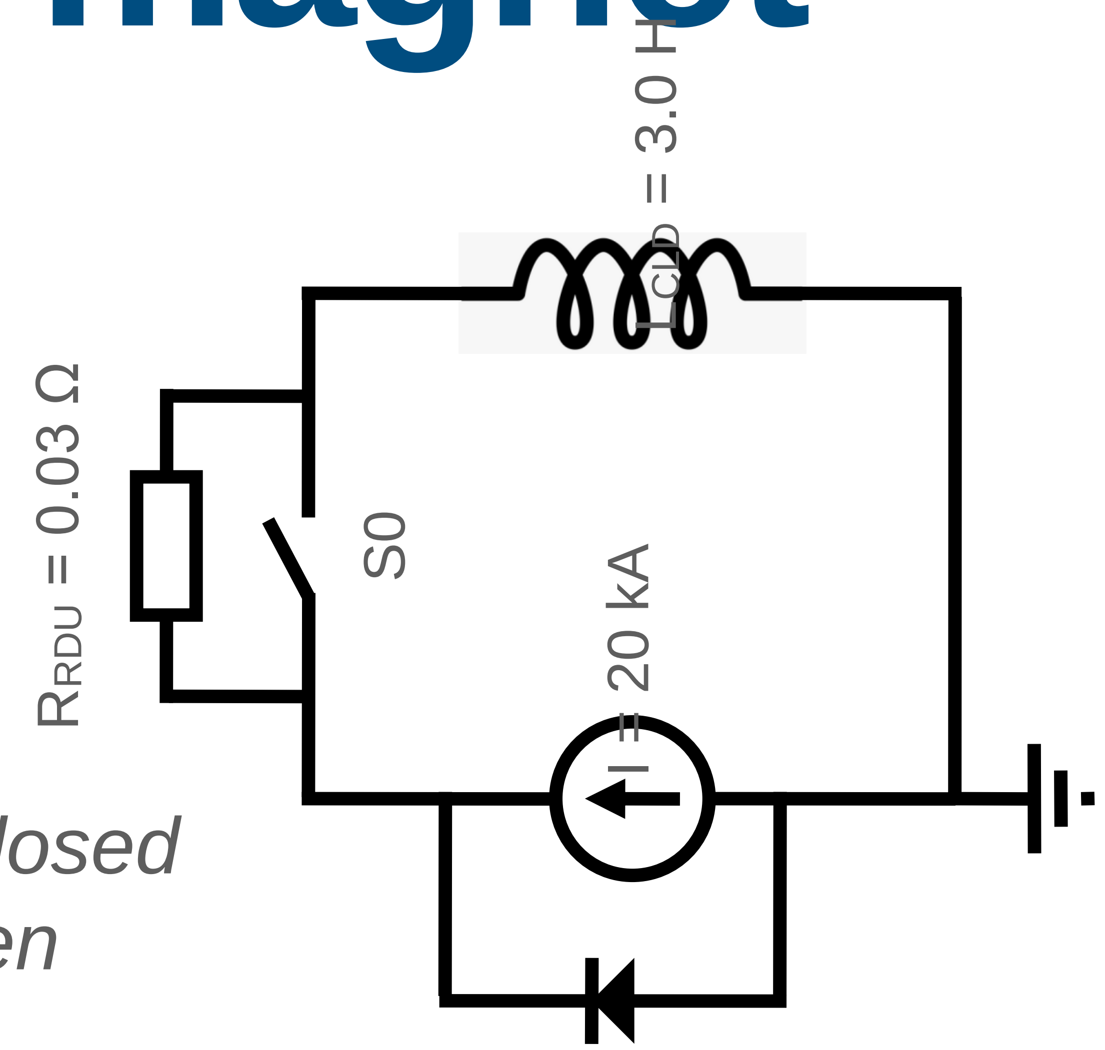



| | Conductor | Support | |
|---|---|---|---|
| Parameter | Value | Value | Unit |
| Material | Ni-doped aluminium | Aluminium 5083 | |
| Yield strength | 147 (with NbTi) [3] | < 209 @ 4.2 K [13] | MPa |
| Young's modulus | $75 \times 10^3$ | $81 \times 10^3$ | MPa |

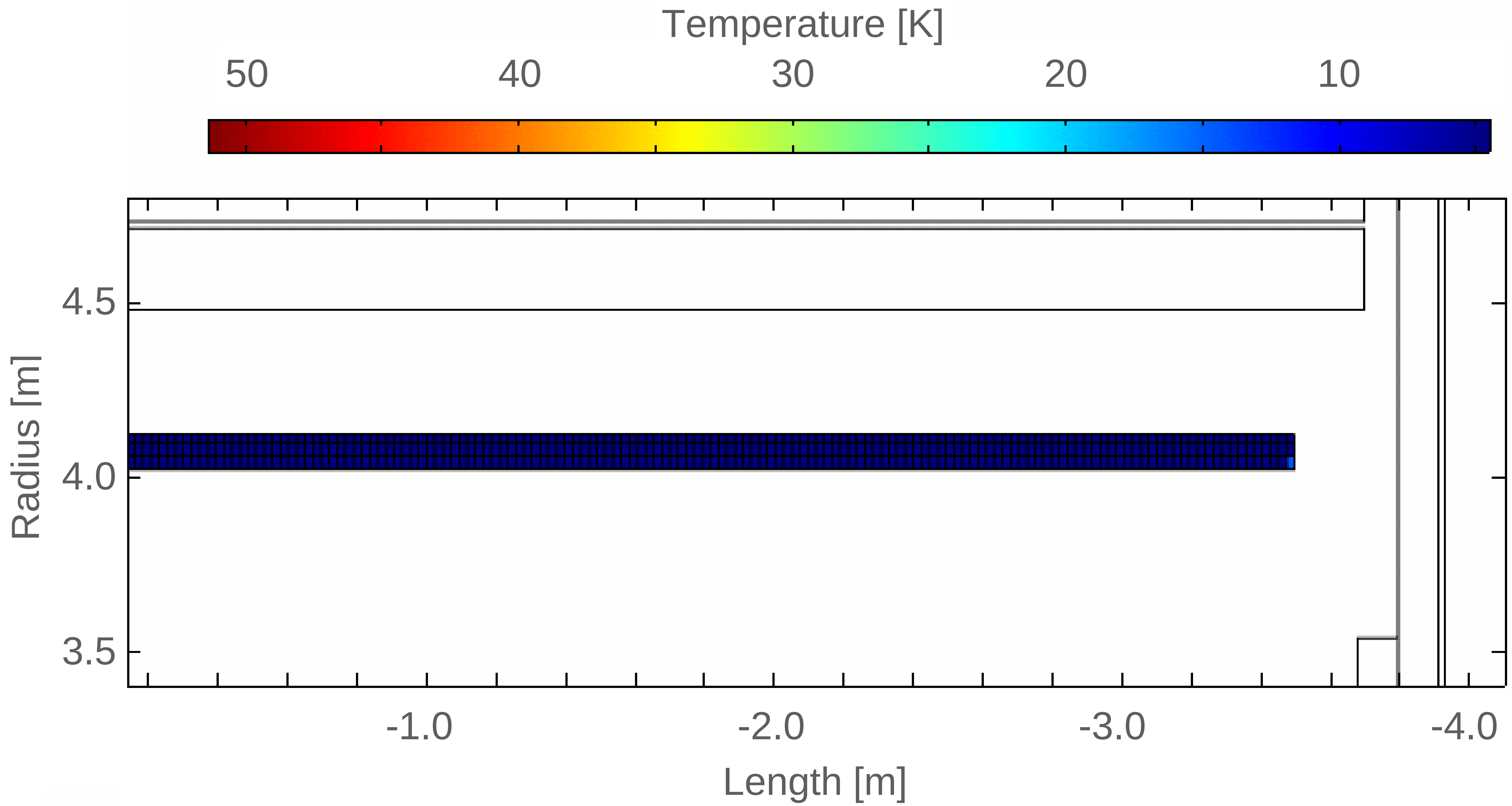
- Peak von Mises stress: **75 MPa**
- Peak tensile strain: **0.11 %**
- Peak shear stress: **0.24 MPa**
- Alternative solution: pure aluminium stabiliser with welded on aluminium-alloy reinforcements (CMS [12])

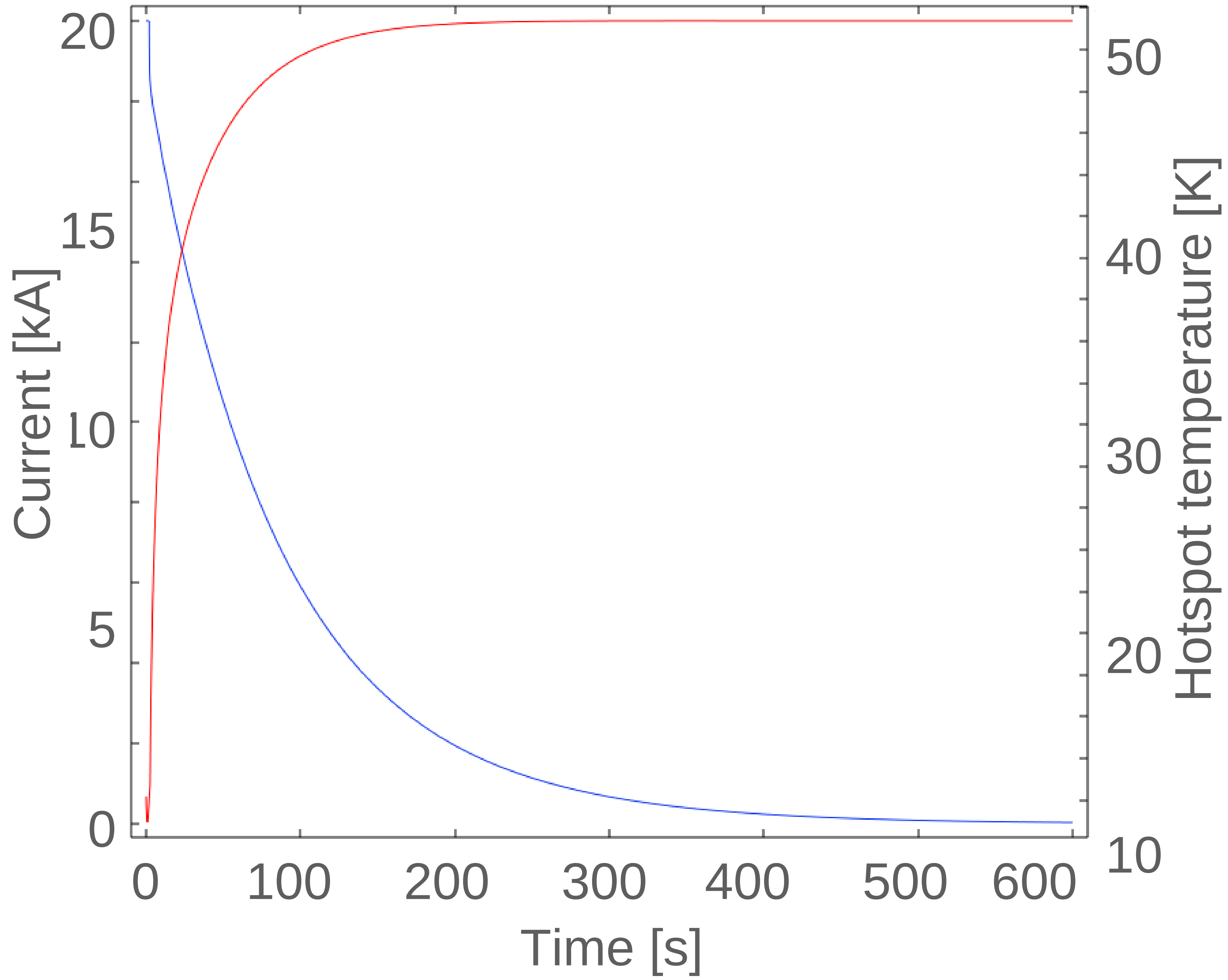
# 3D Quench simulations of the CLD magnet

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



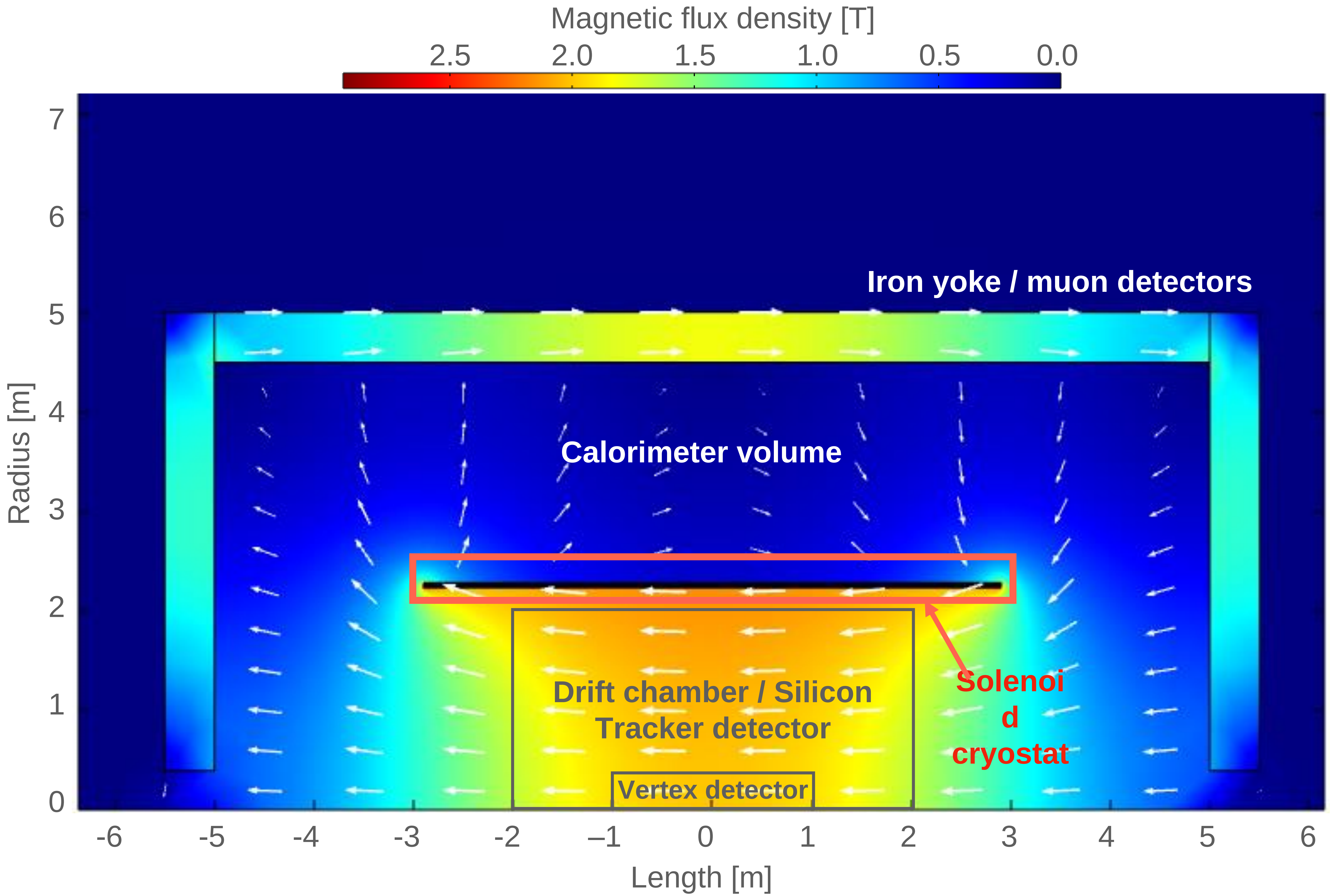

*Before quench: S0 = closed*
*After quench: S0 = open*



# The design of the **IDEA** Detector Magnet

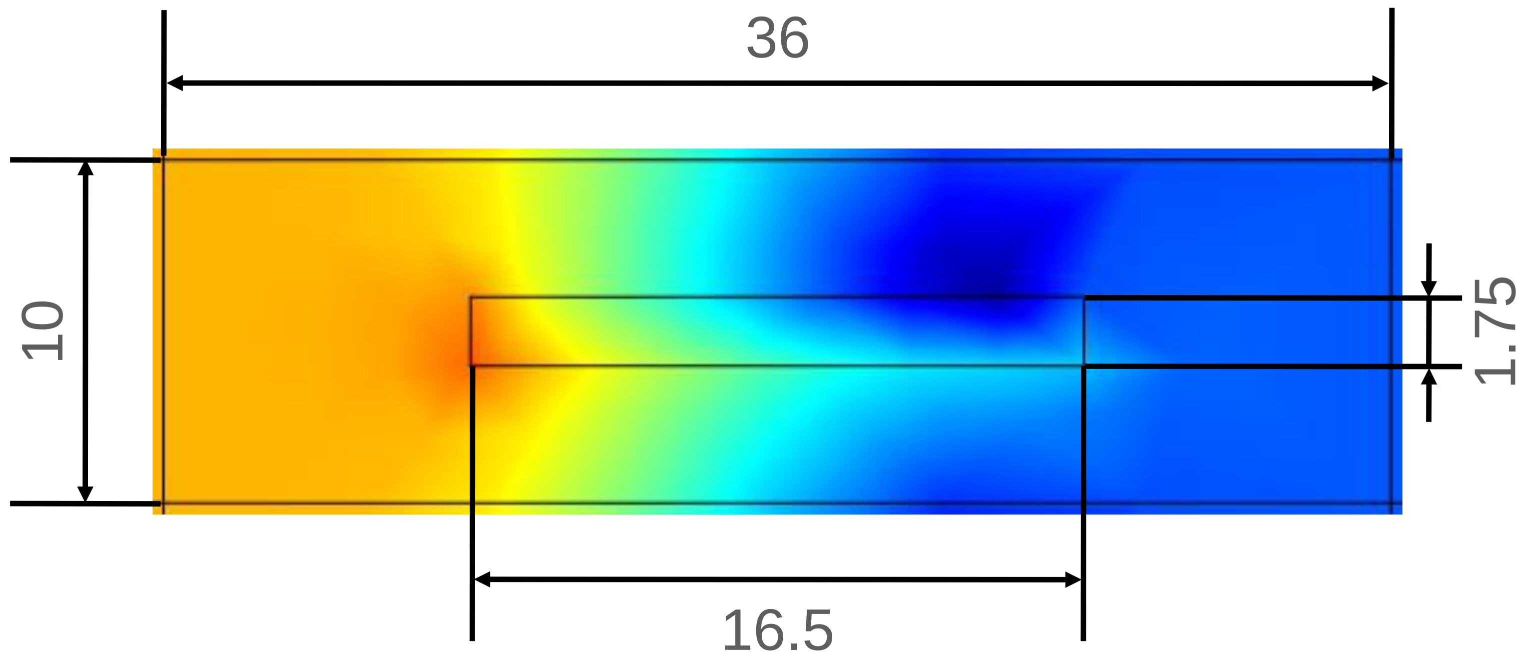
# IDEA Detector design




**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

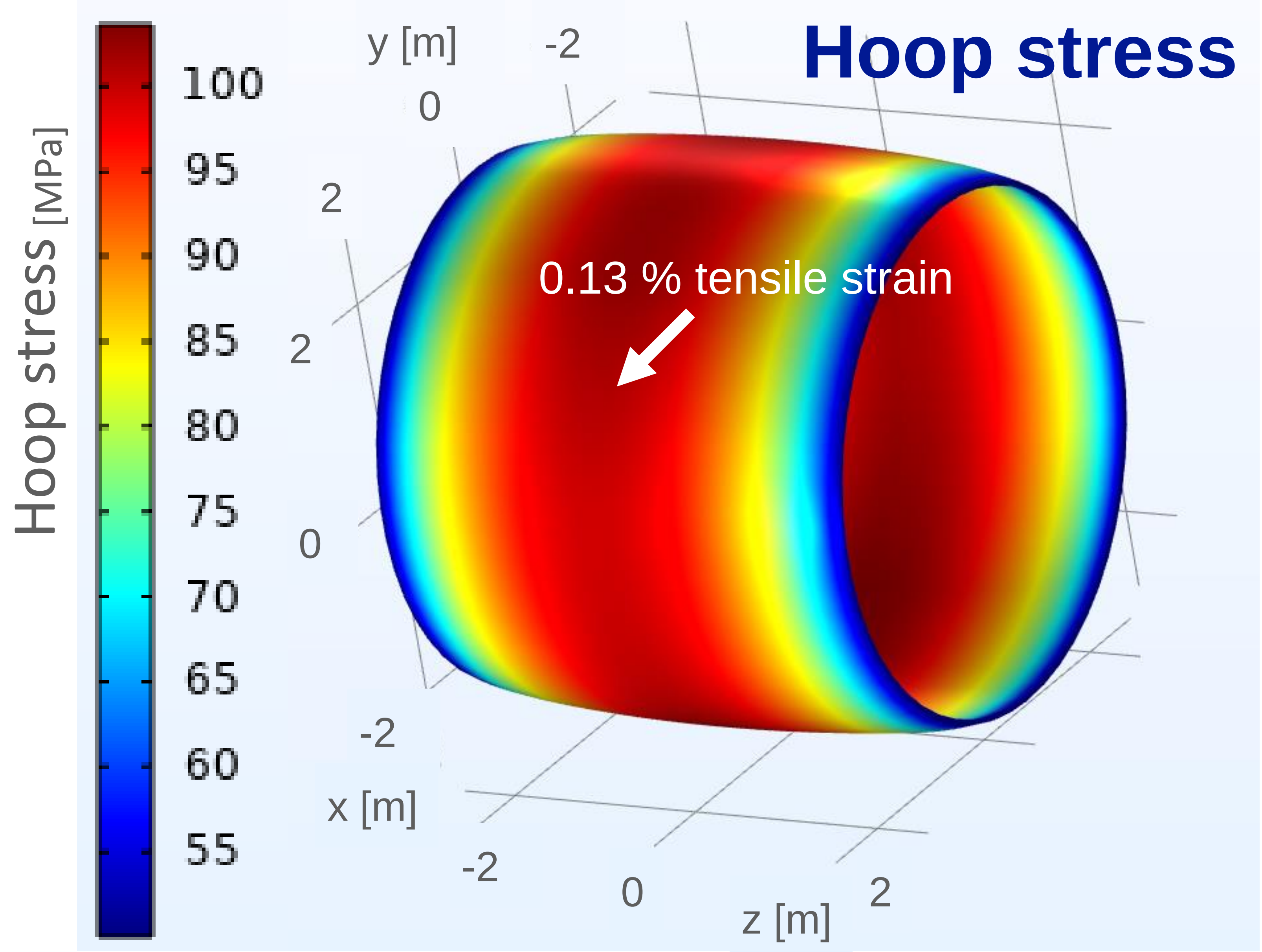
- Support cylinder with thickness of 12 mm
- Support cylinder material: aluminium 5083

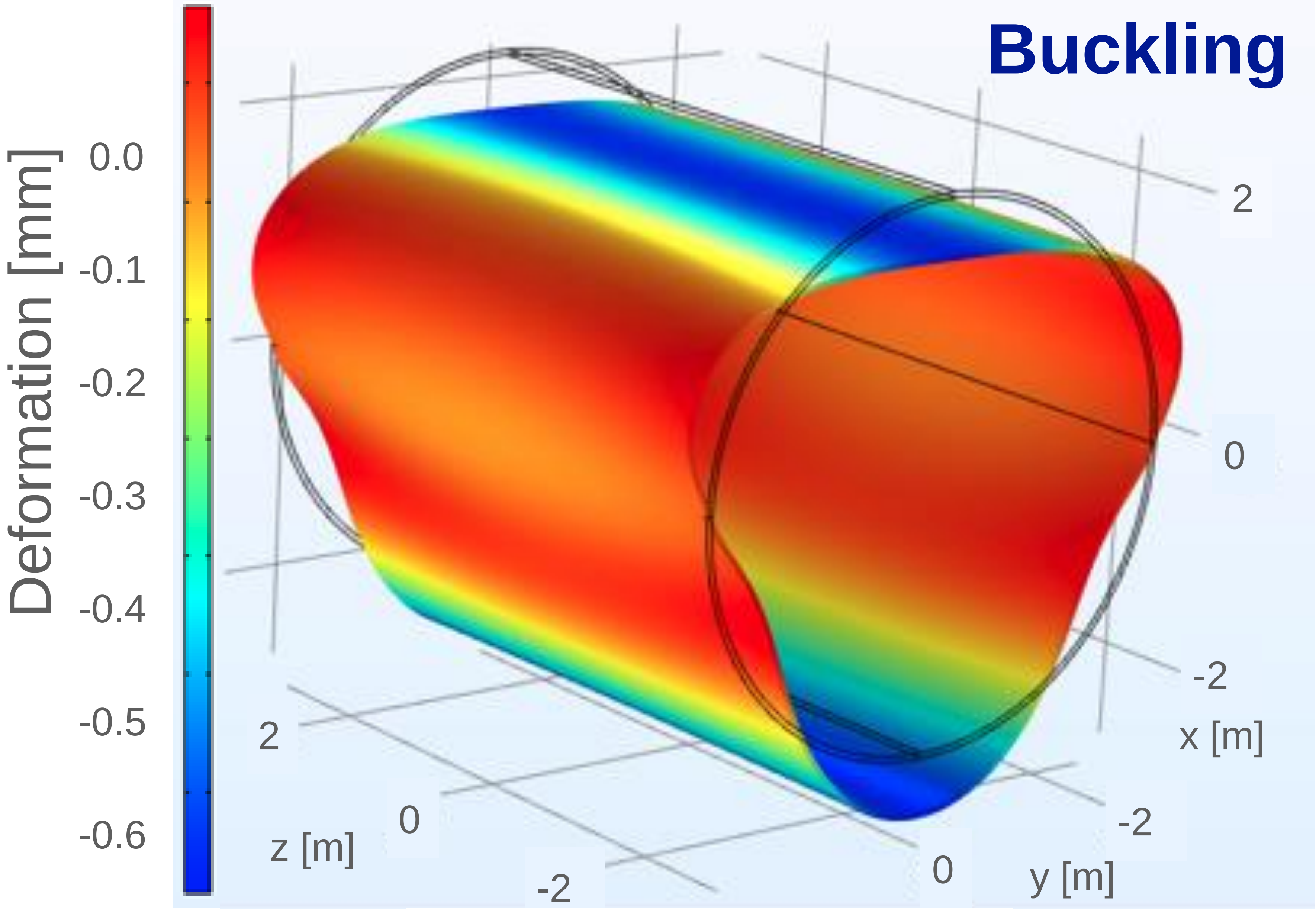
**Transparency of the cold mass: 0.76 $X_0$**

**Energy density: ~14 kJ/kg [2]**

- First mechanical analysis is promising

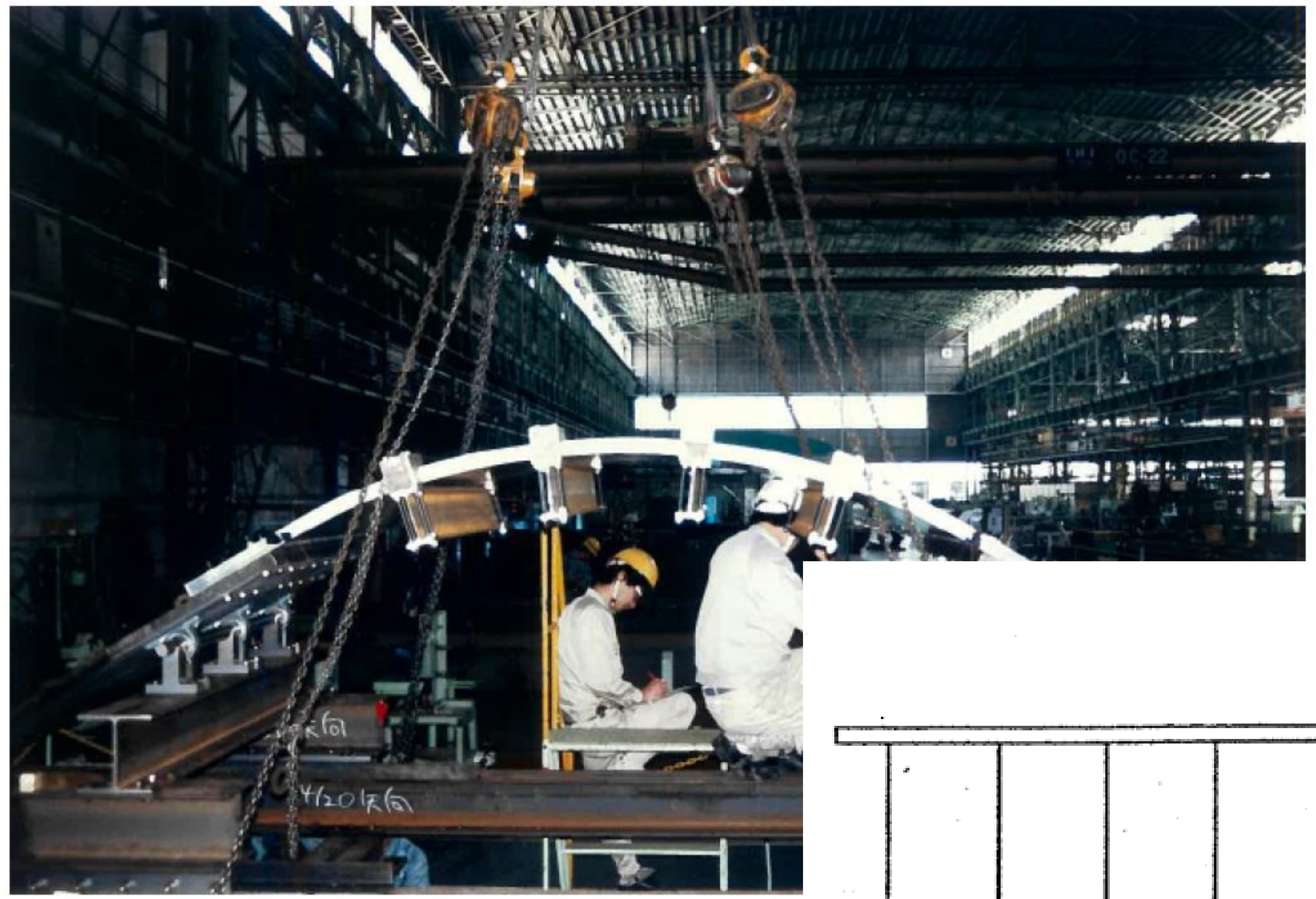
| | Conductor | Support | |
|---|---|---|---|
| Parameter | Value | Value | Unit |
| Material | Ni-doped aluminium | Aluminium 5083 | |
| Yield strength | 147 (with NbTi) [3] | 209 @ 4.2 K [13] | MPa |
| Young's modulus | 75 x $10^3$ | 81 x $10^3$ | MPa |




- 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]

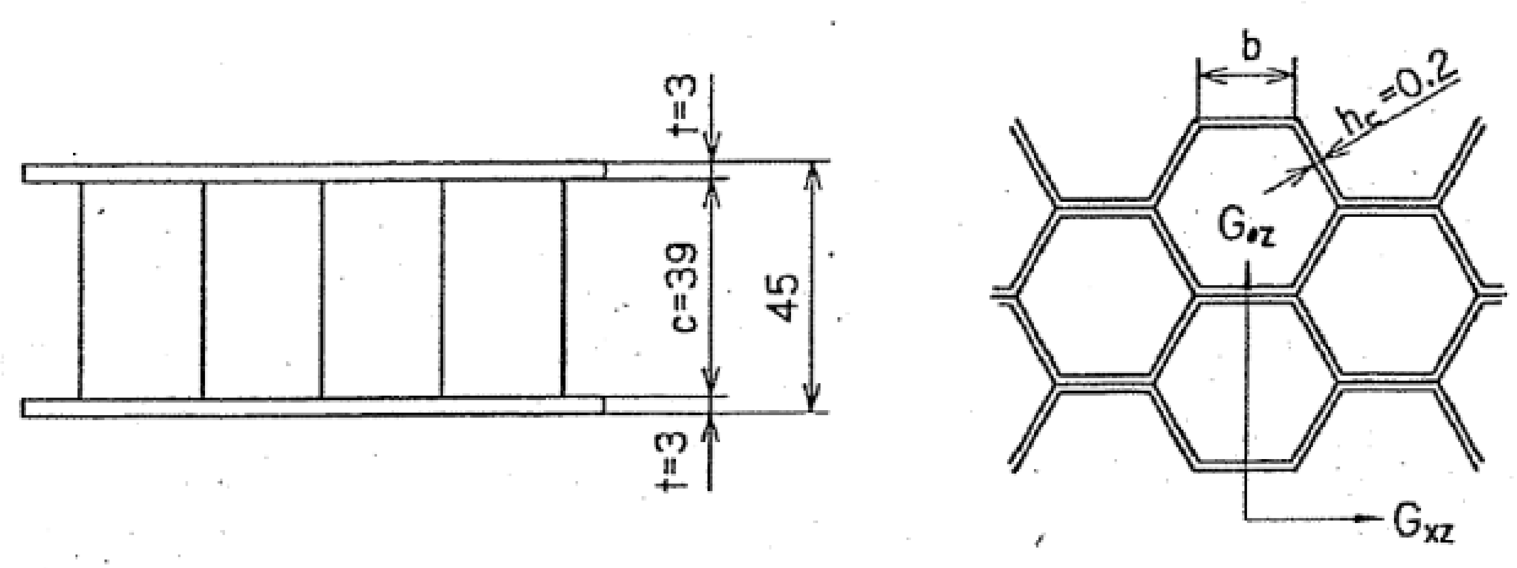
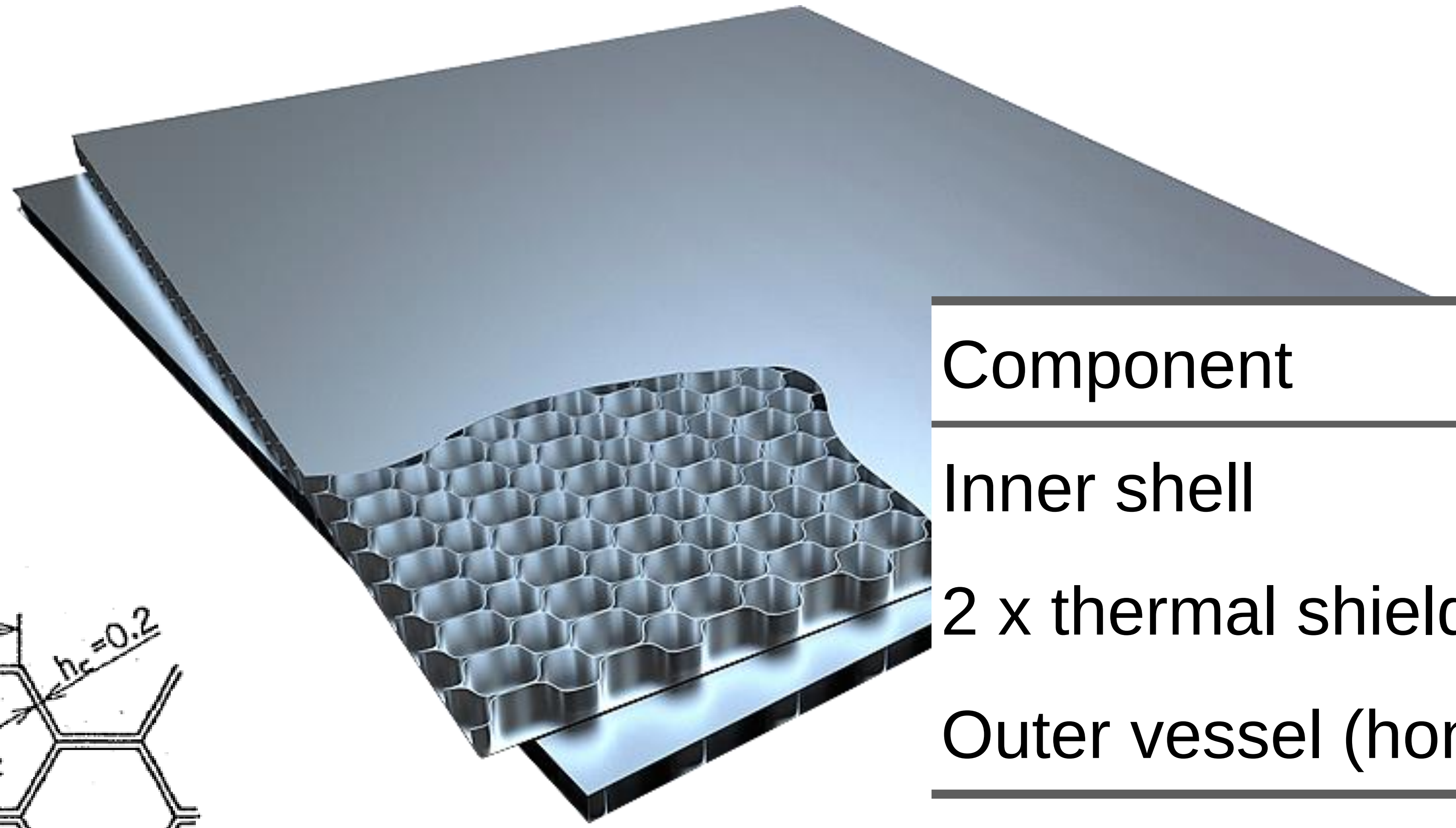
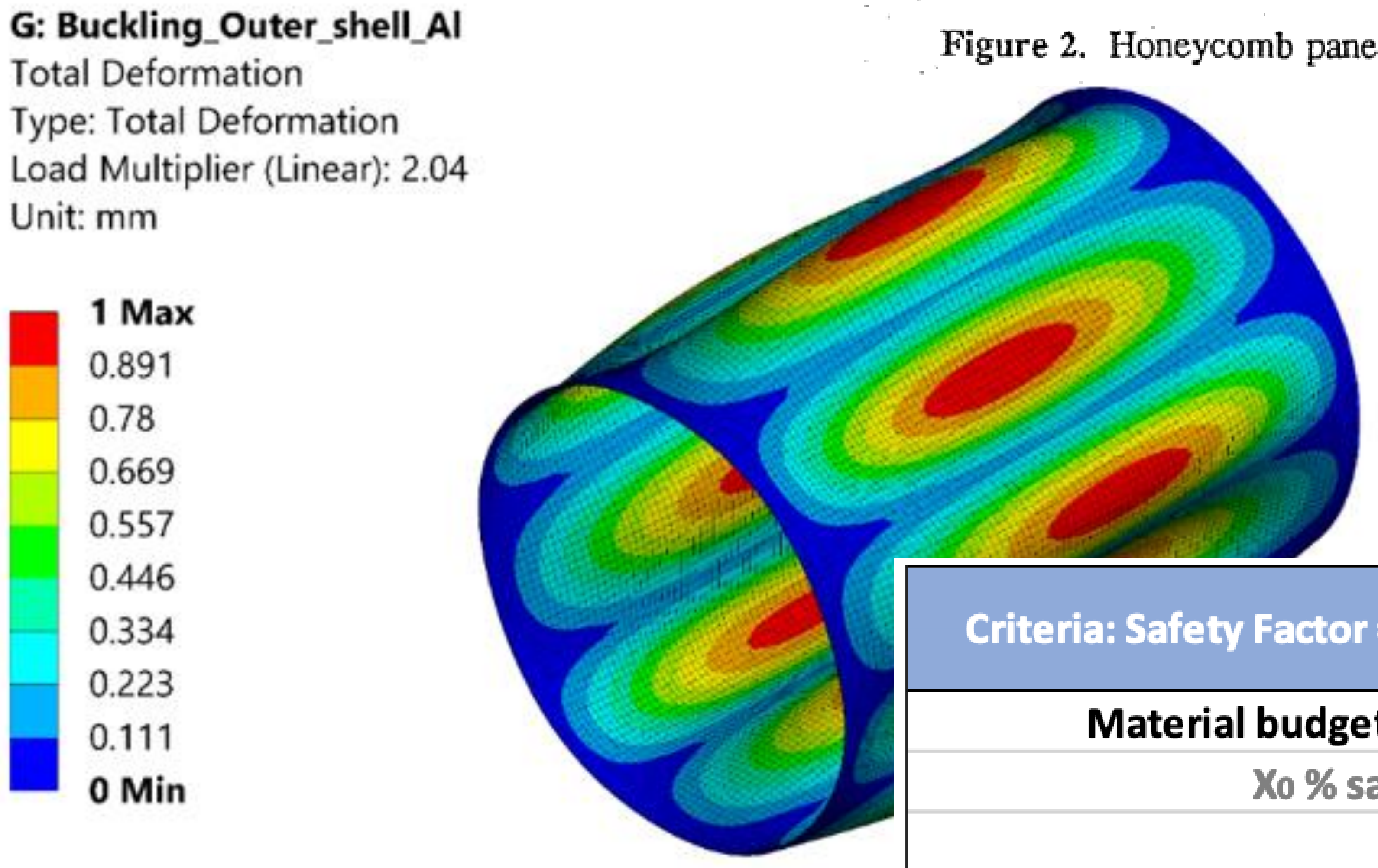



Figure 2. Honeycomb panel configuration in the preliminary design.



| 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% |

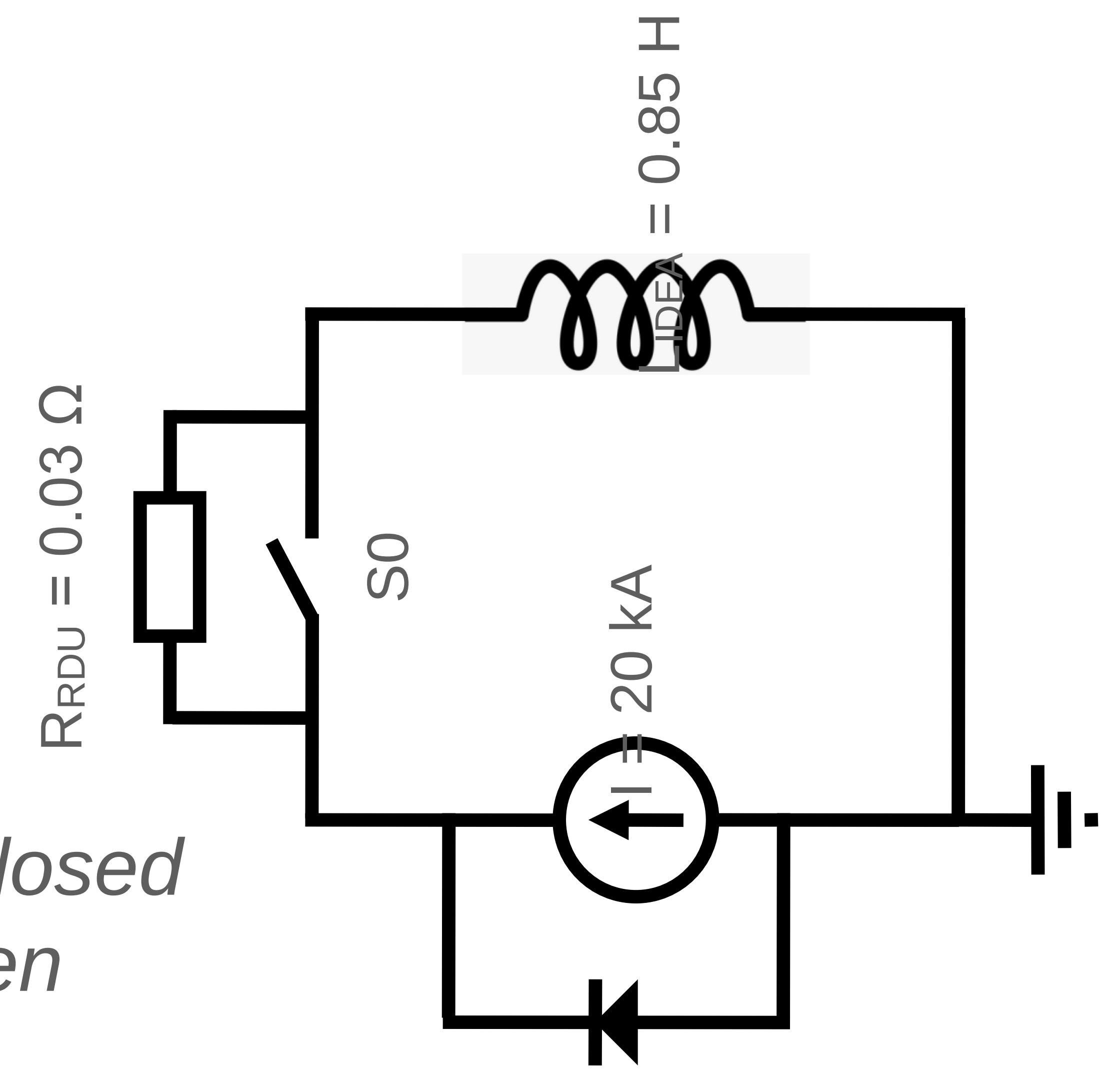
## For vacuum vessel:

- 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

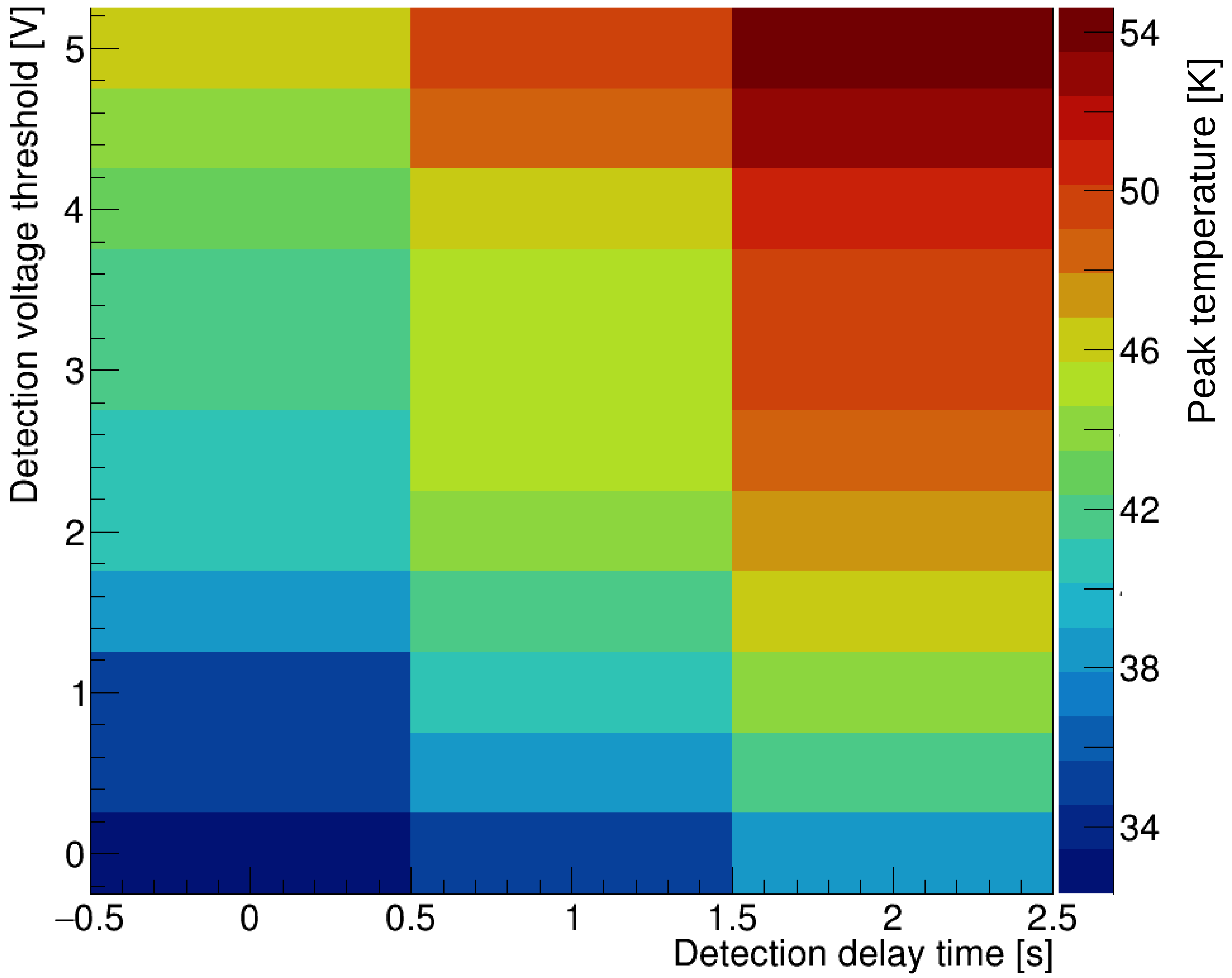
## Quench detection




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

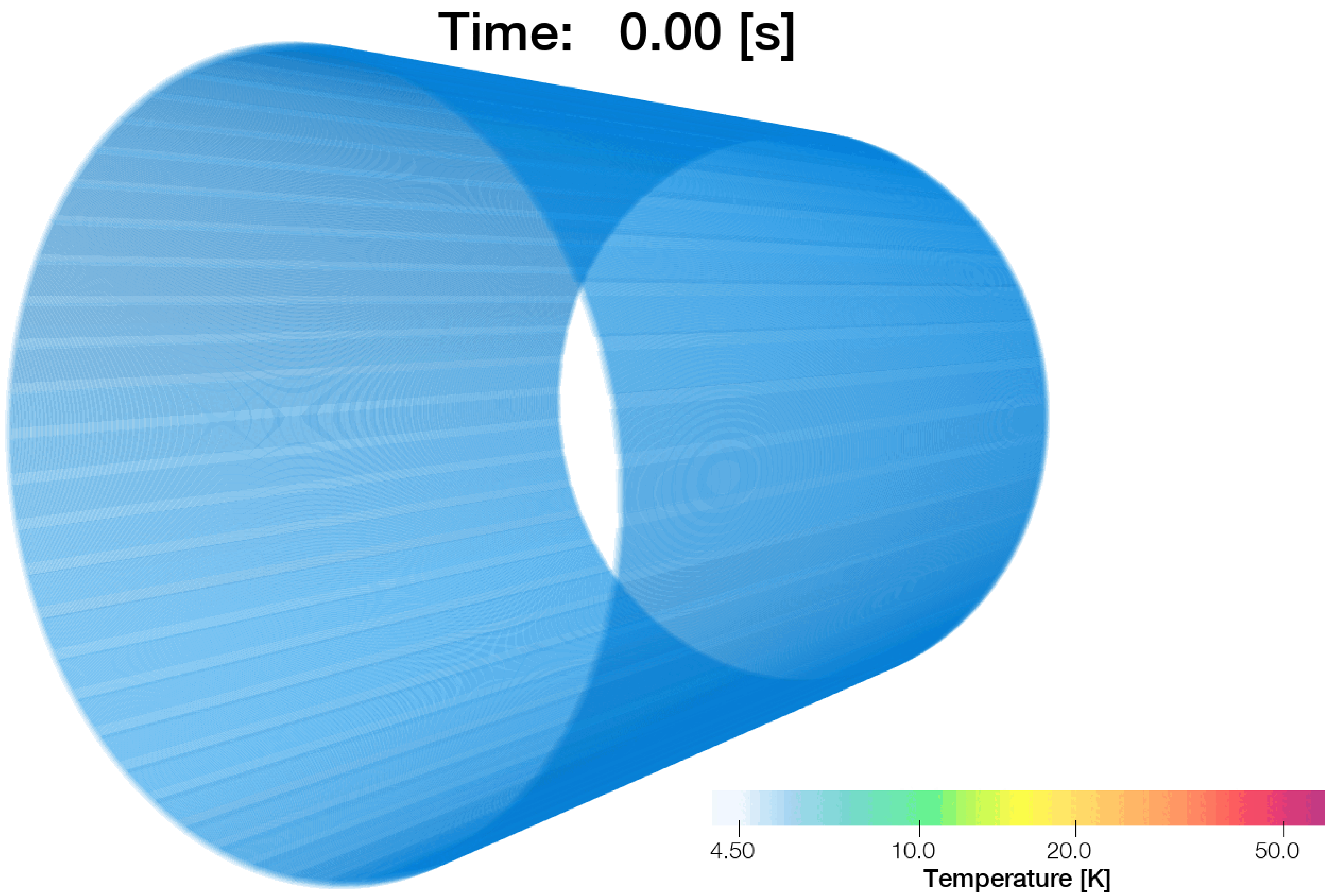
- 3D thermo-electrical network software called **Raccoon2** based on the work described in [9]
- Validated with data measured at the ATLAS Central Solenoid [10]
- **First detection: scan voltage threshold vs. delay**
- Experience with the ATLAS CS (delay 1.2s)

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

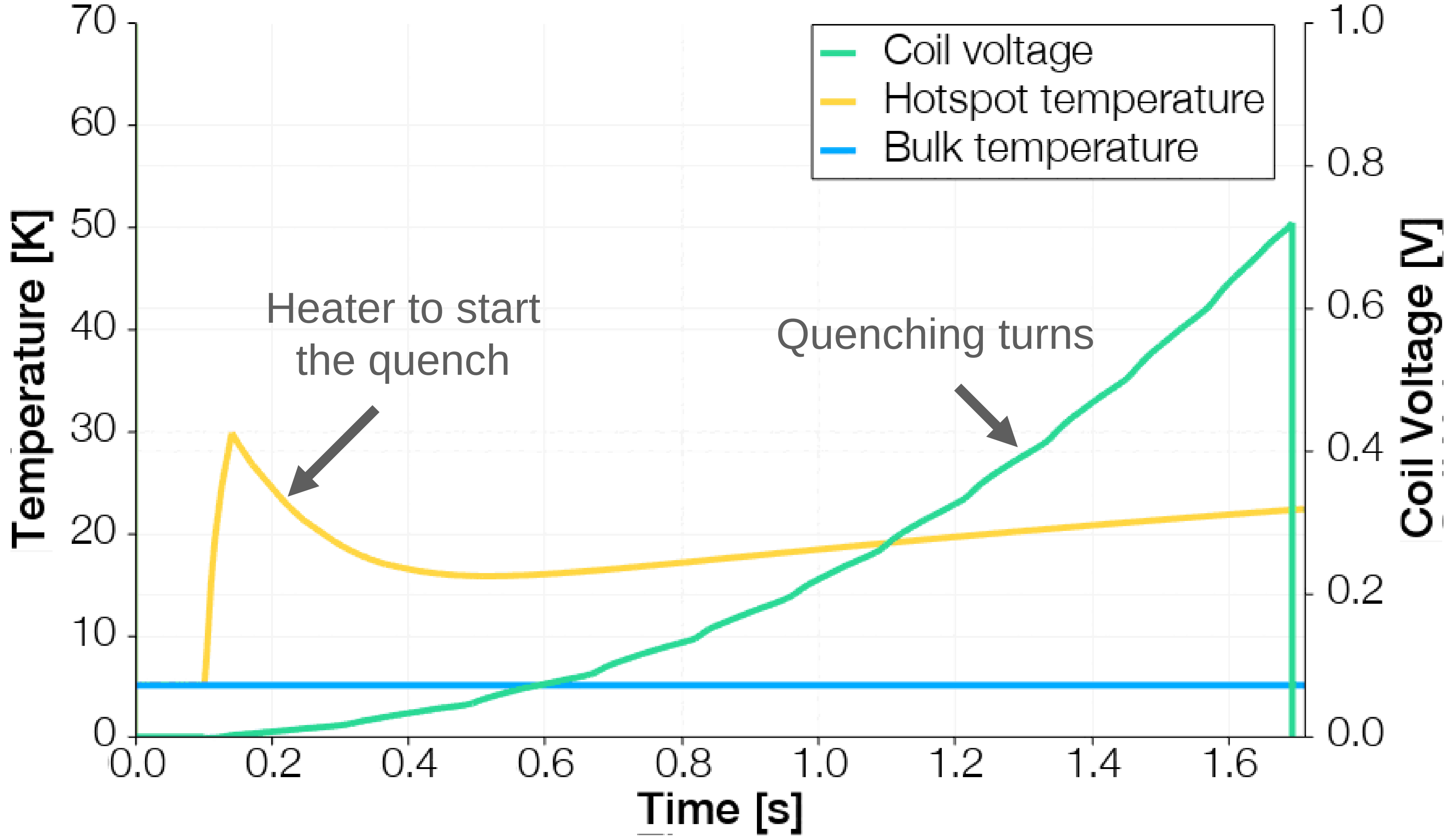


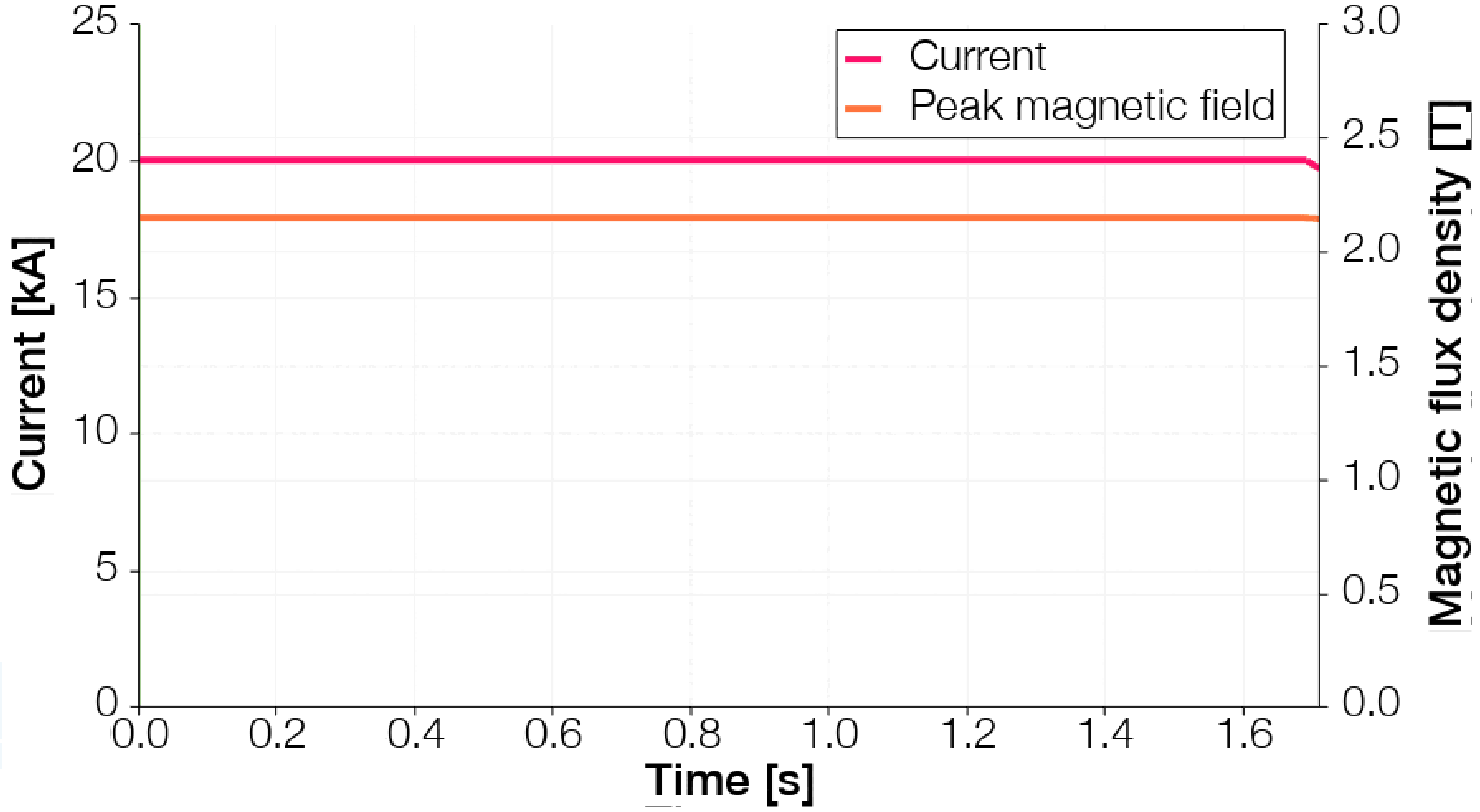
# 3D Quench simulations IDEA: RDU + QP strips

## Initiating the quench



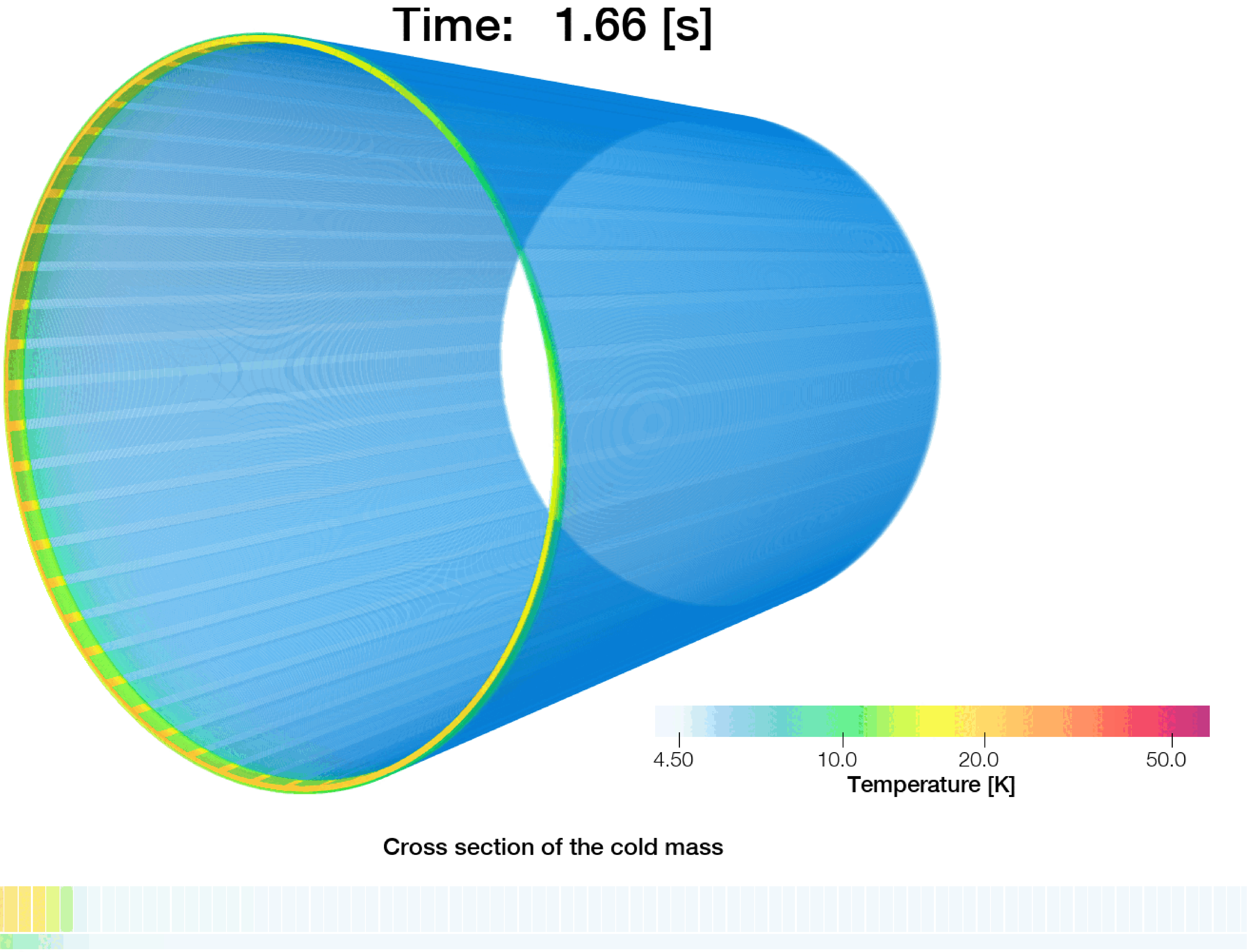

Cross section of the cold mass



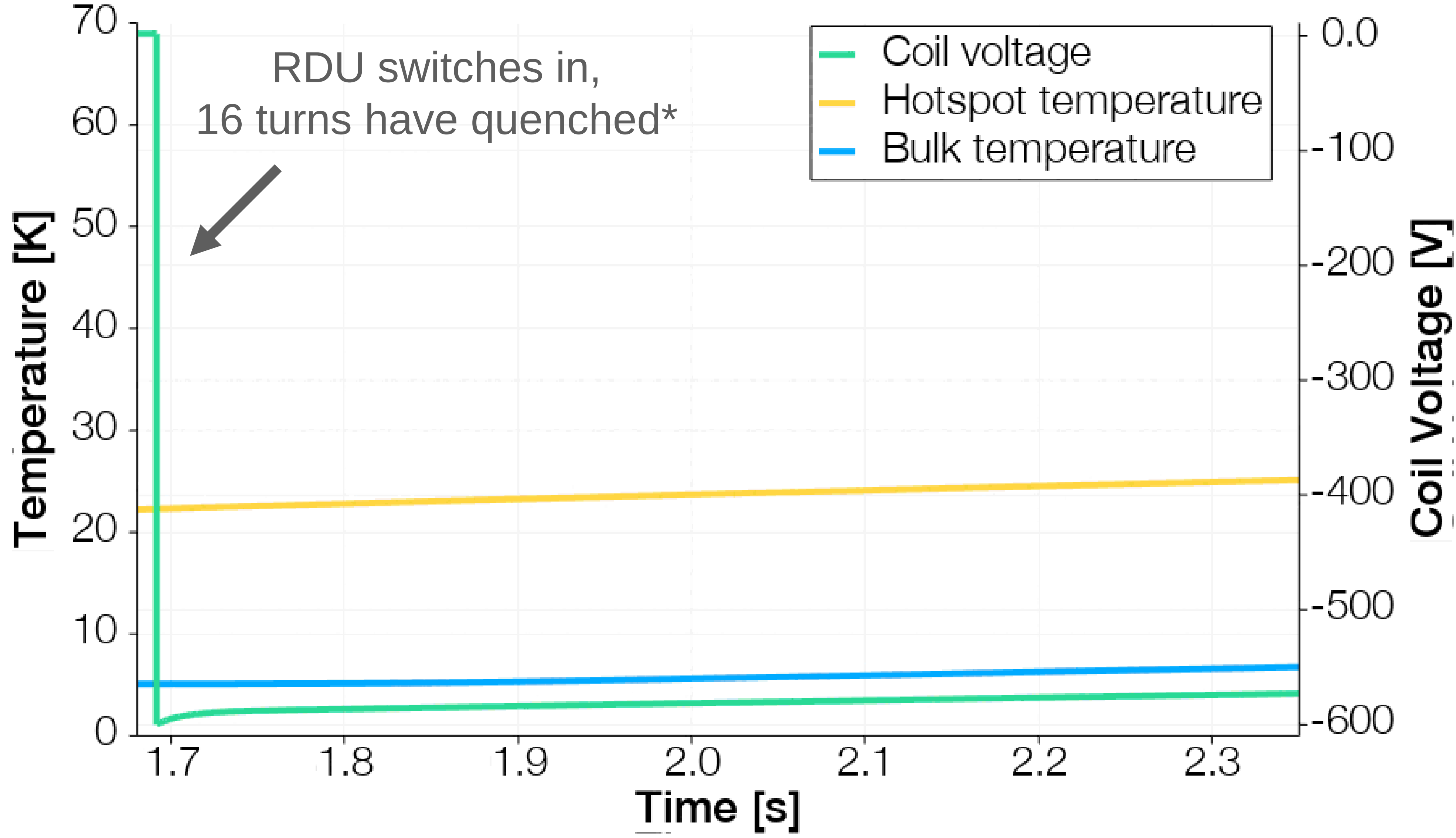



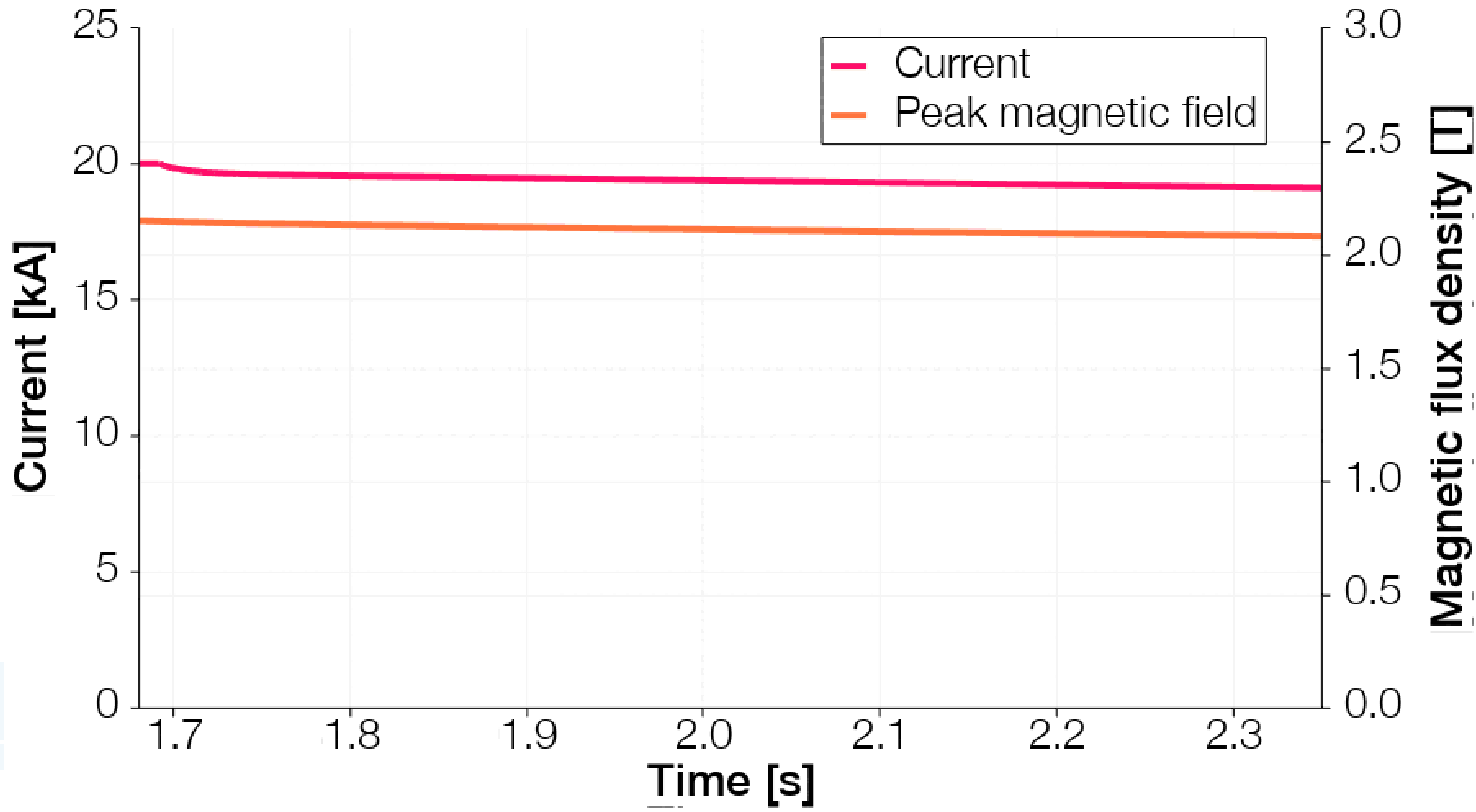
# 3D Quench simulations IDEA: RDU + QP strips

## Switching in the extraction resistor




Cross section of the cold mass

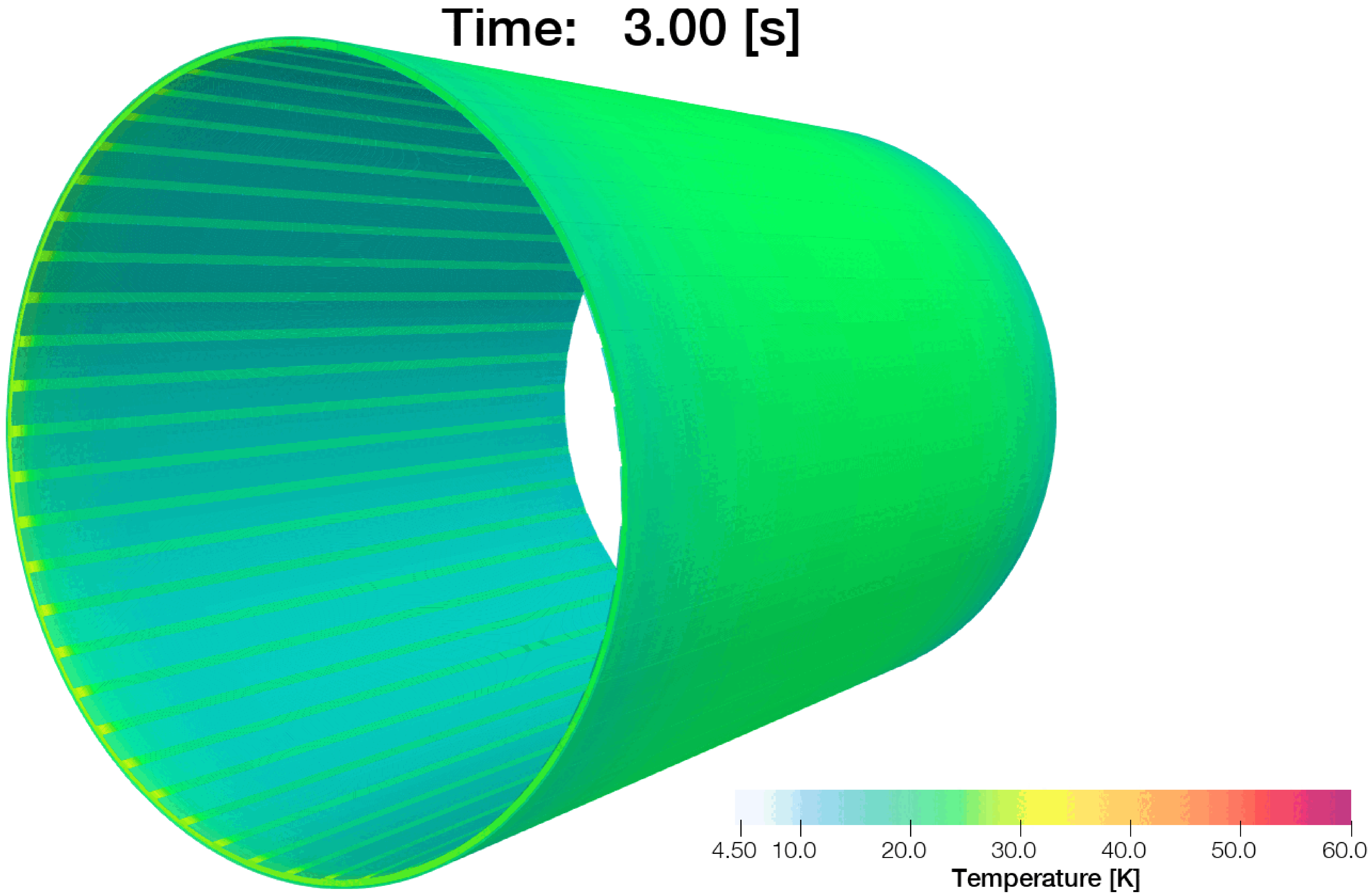


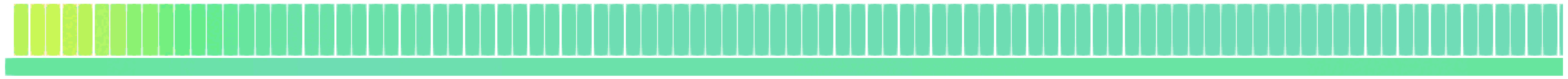

* With QP strips 16 turns quench before RDU, without strips 11 turns quench before RDU

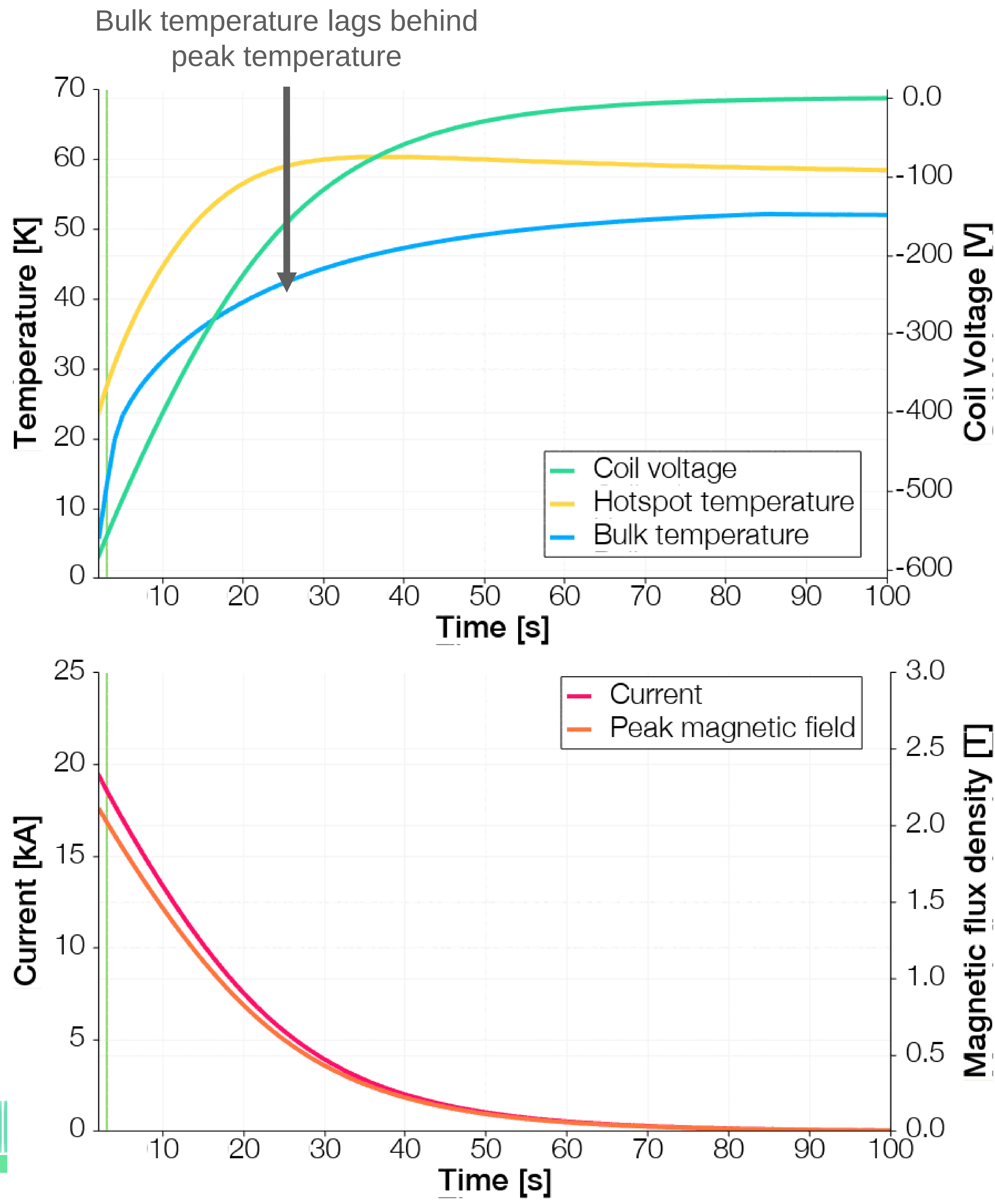
# 3D Quench simulations IDEA: RDU + QP strips

## Extracting the energy from the magnet




Cross section of the cold mass





# 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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