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DESIGN AND QUENCH ANALYSIS OF SUPERCONDUCTING SOLENOIDS FOR DETECTORS AT THE FCC-EE

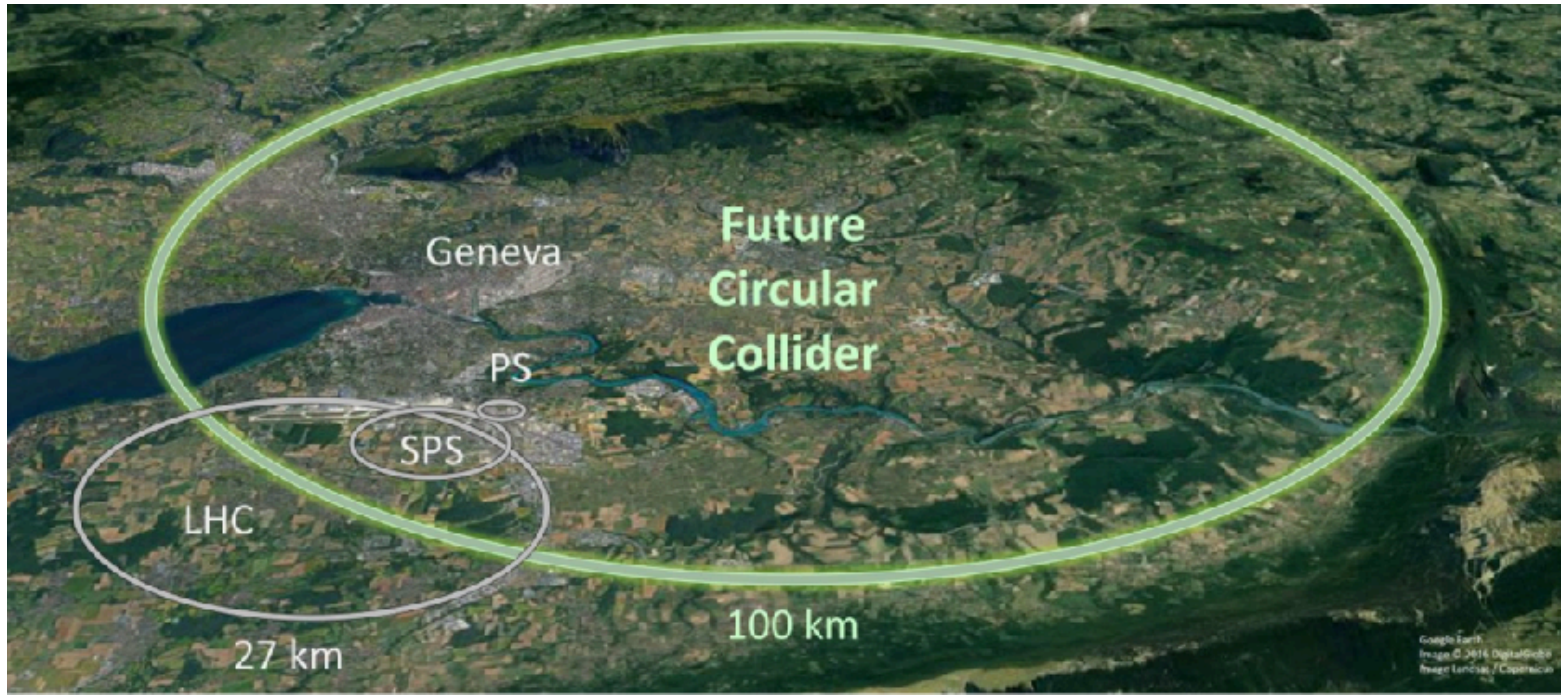
Superconducting solenoids for the IDEA and CLD Detector concepts

CONTENT OF THIS TALK

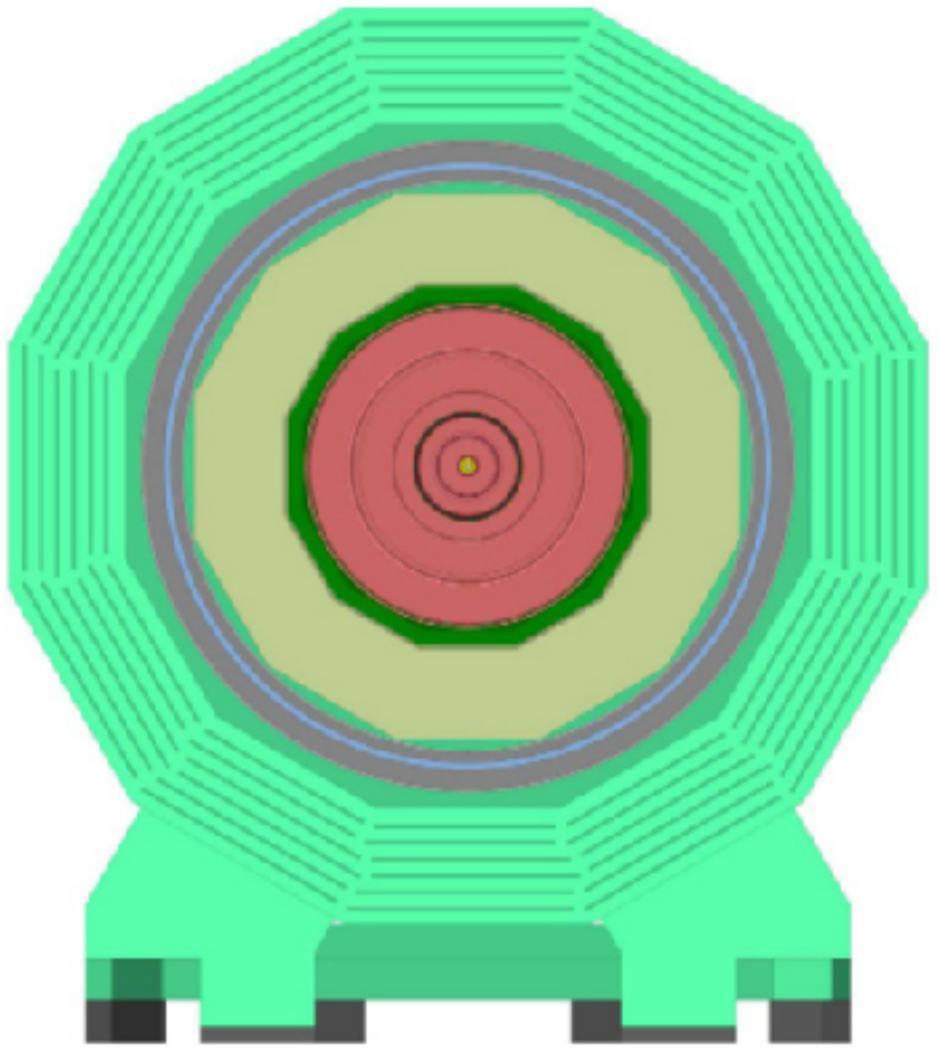
- Introduction: FCC-ee Detector magnets
- The CLIC-Like Detector (CLD) superconducting solenoid
- The International Detector for Electron-positron Accelerators (IDEA) superconducting solenoid
- 3D Quench studies on the IDEA superconducting solenoid
- Summary

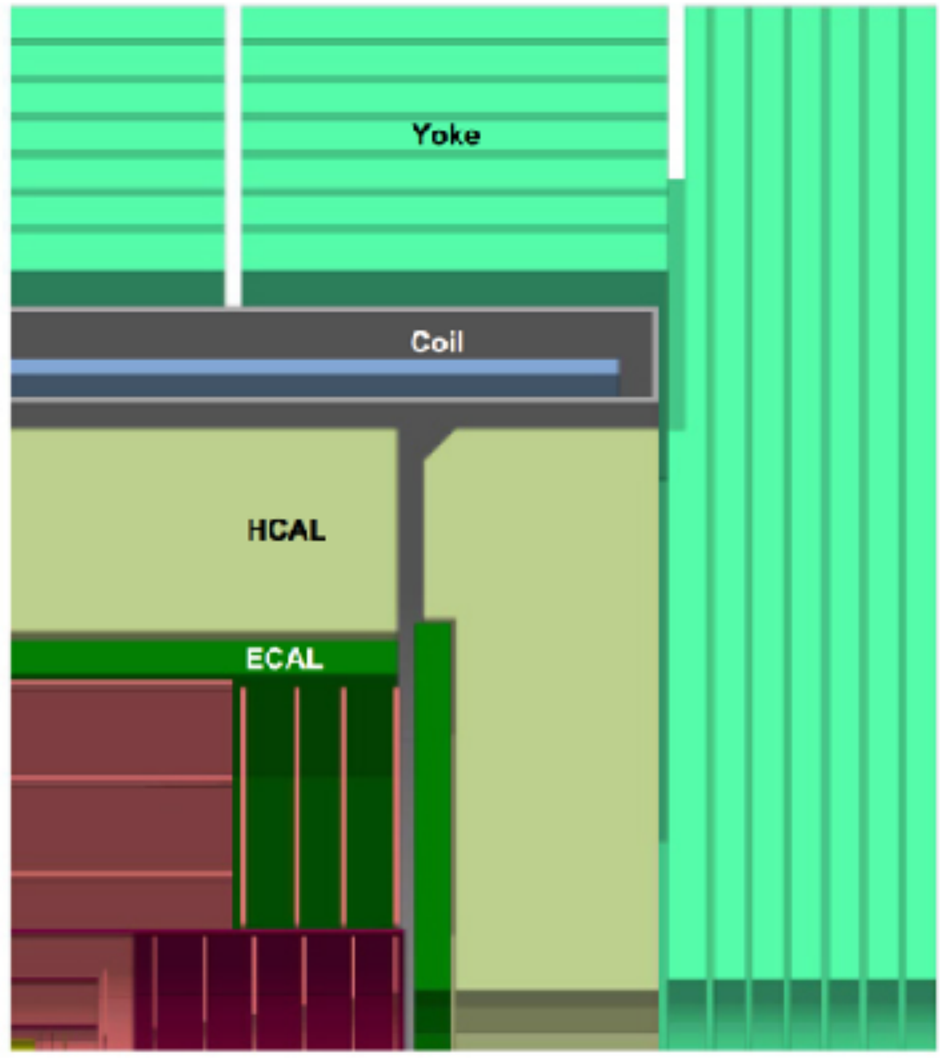
Introduction: FCC-ee Detector magnets

- 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



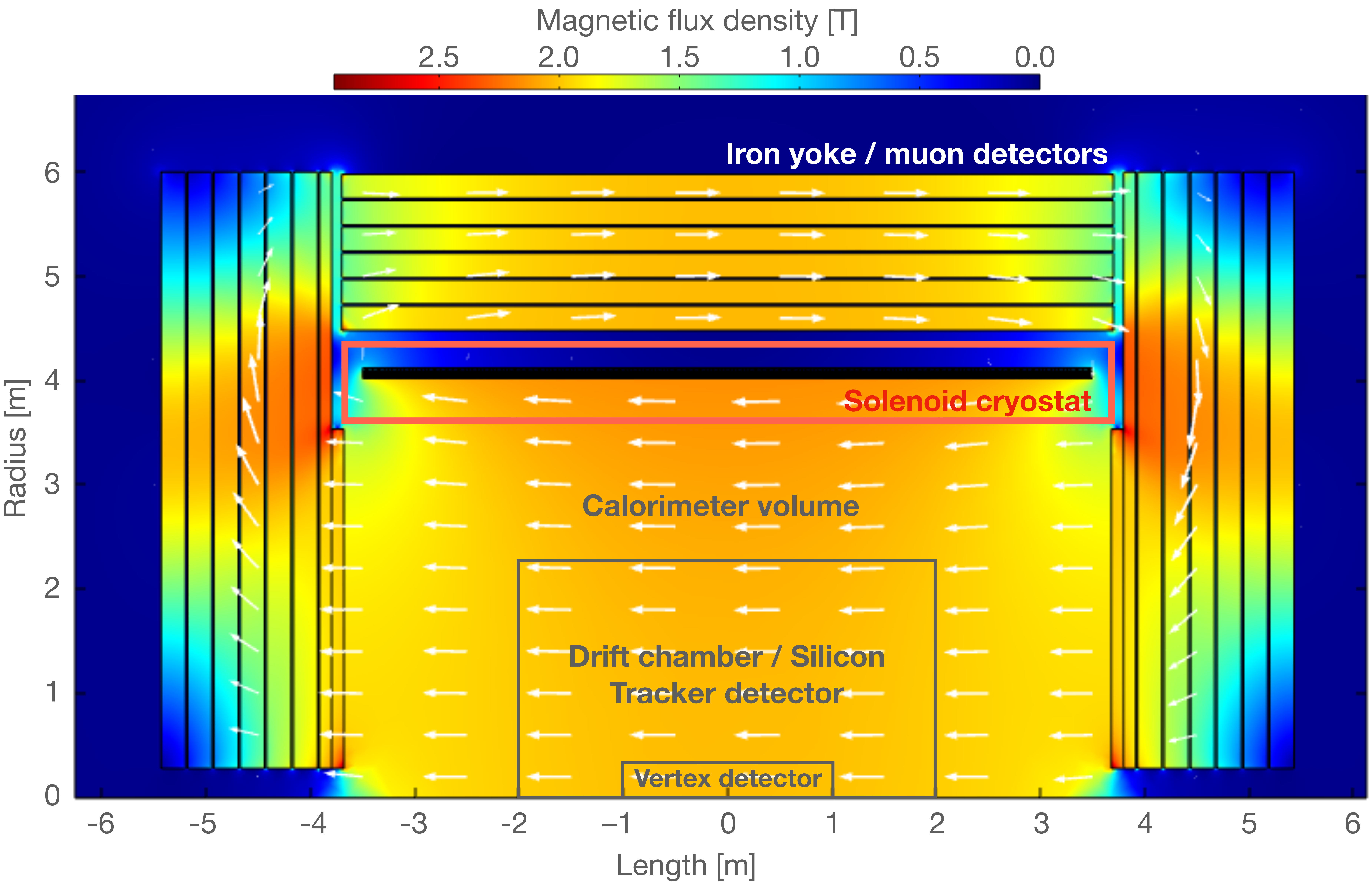


- Two detector designs are being studied for FCC-ee
- **International Detector for Electron-positron Accelerators** (IDEA) and the **CLIC-Like Detector** (CLD)
- Both have superconducting solenoid with $\mathbf{B_{center}}$ **of 2 T**
- IDEA solenoid **inside,** CLD solenoid **outside** calorimeters

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

The design of the **CLD** Detector Magnet

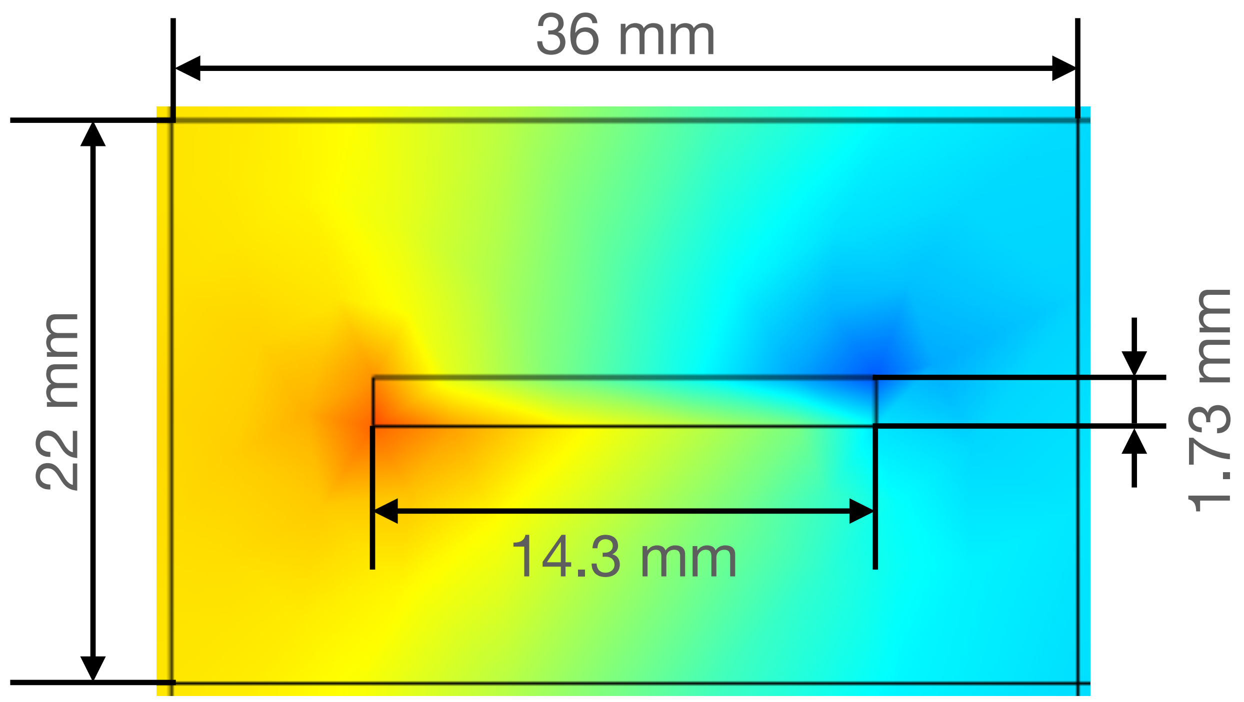
CLD Detector design



Solenoid outside HCal [1,11]

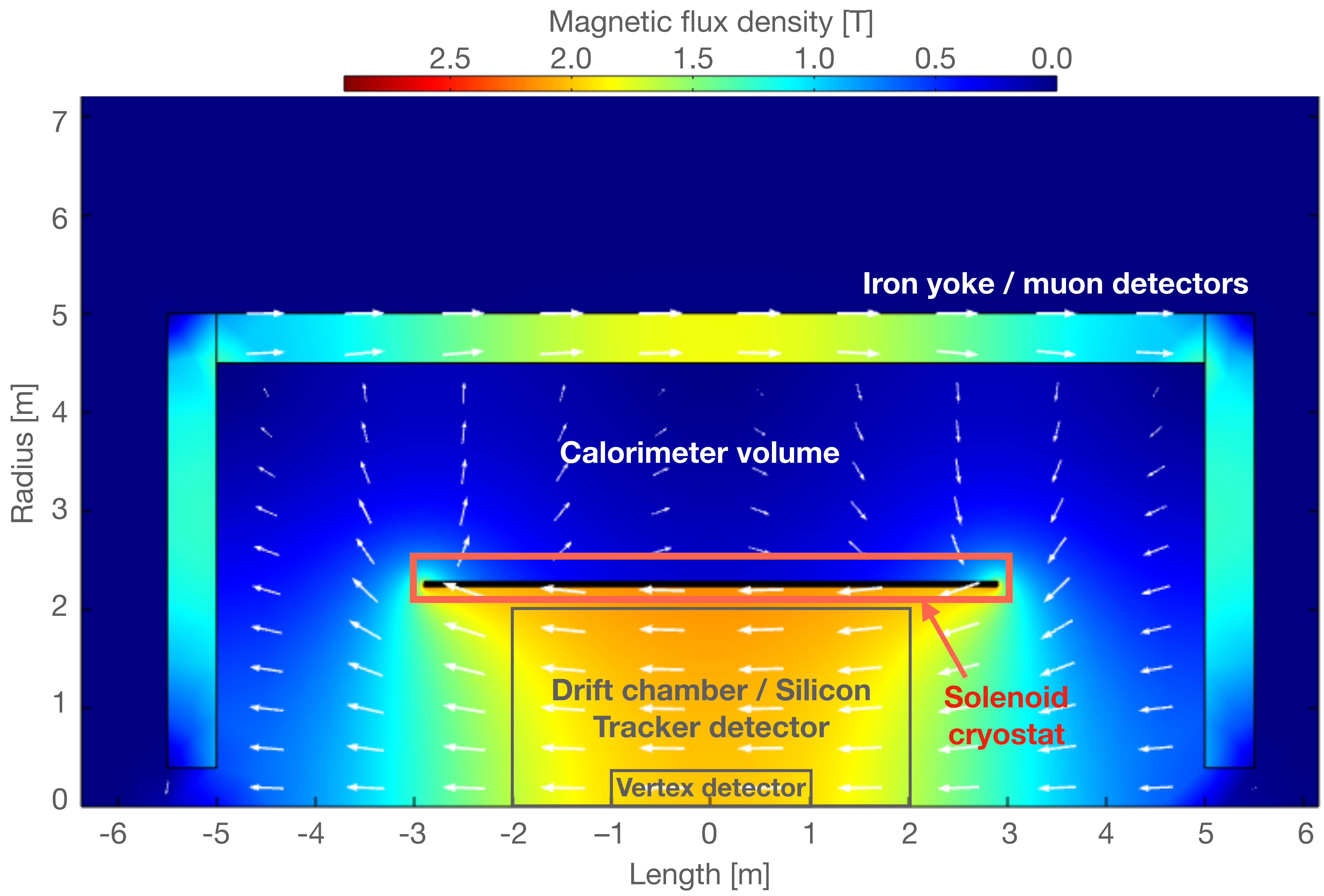
- Free bore diameter: **7.6 m**
- Central field: **2 T**
  - Operating current: **20 kA**
  - Operating temp.: **4.5 K**
  - Stored energy: **600 MJ**
- Aluminium stabilised **NbTi/Cu** conductor
- Two layers, 300 turns
- Support cylinder of **25 mm**

No showstoppers, CMS like [12]



The design of the **IDEA** Detector Magnet

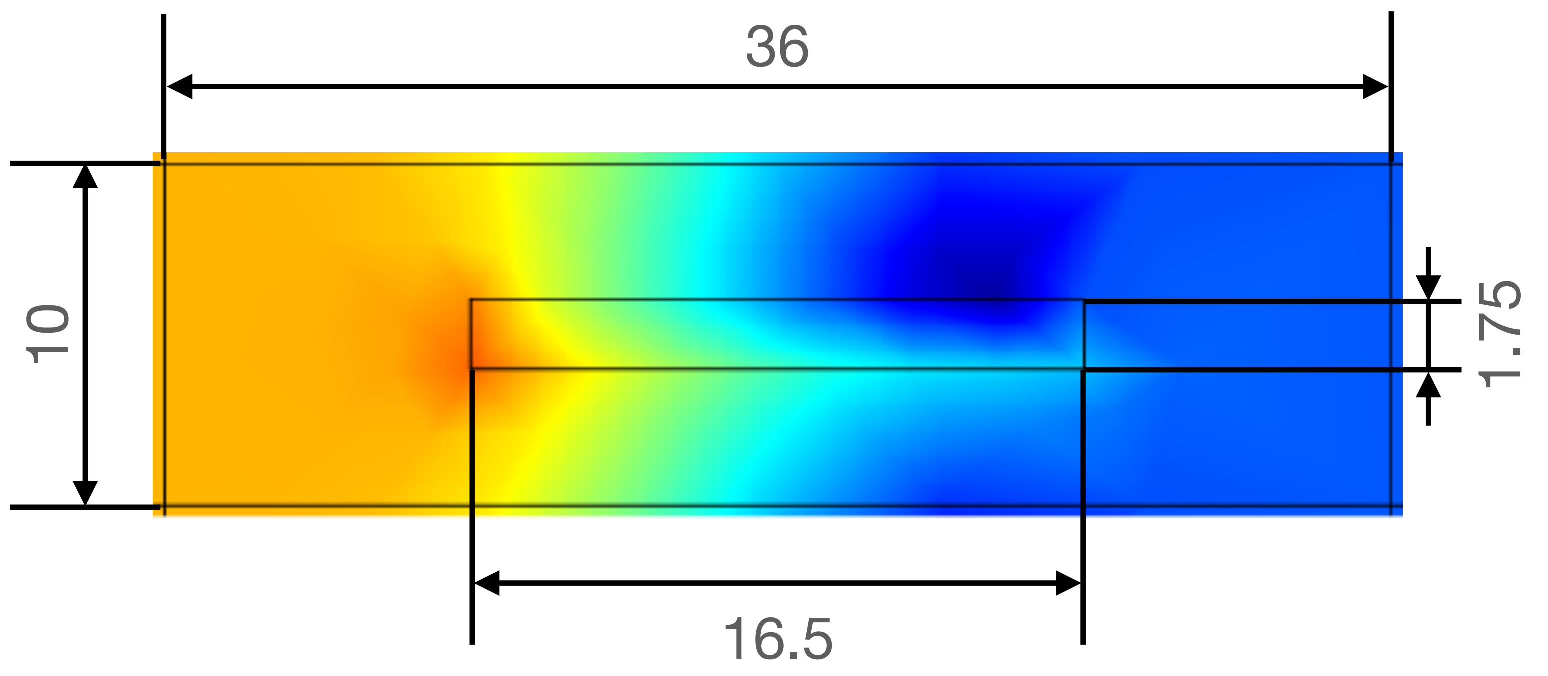
IDEA Detector design



Superconducting solenoid inside calorimeter [1]

- Need transparency: **1 > X_0**
- Free bore diameter: **4 m**
- 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



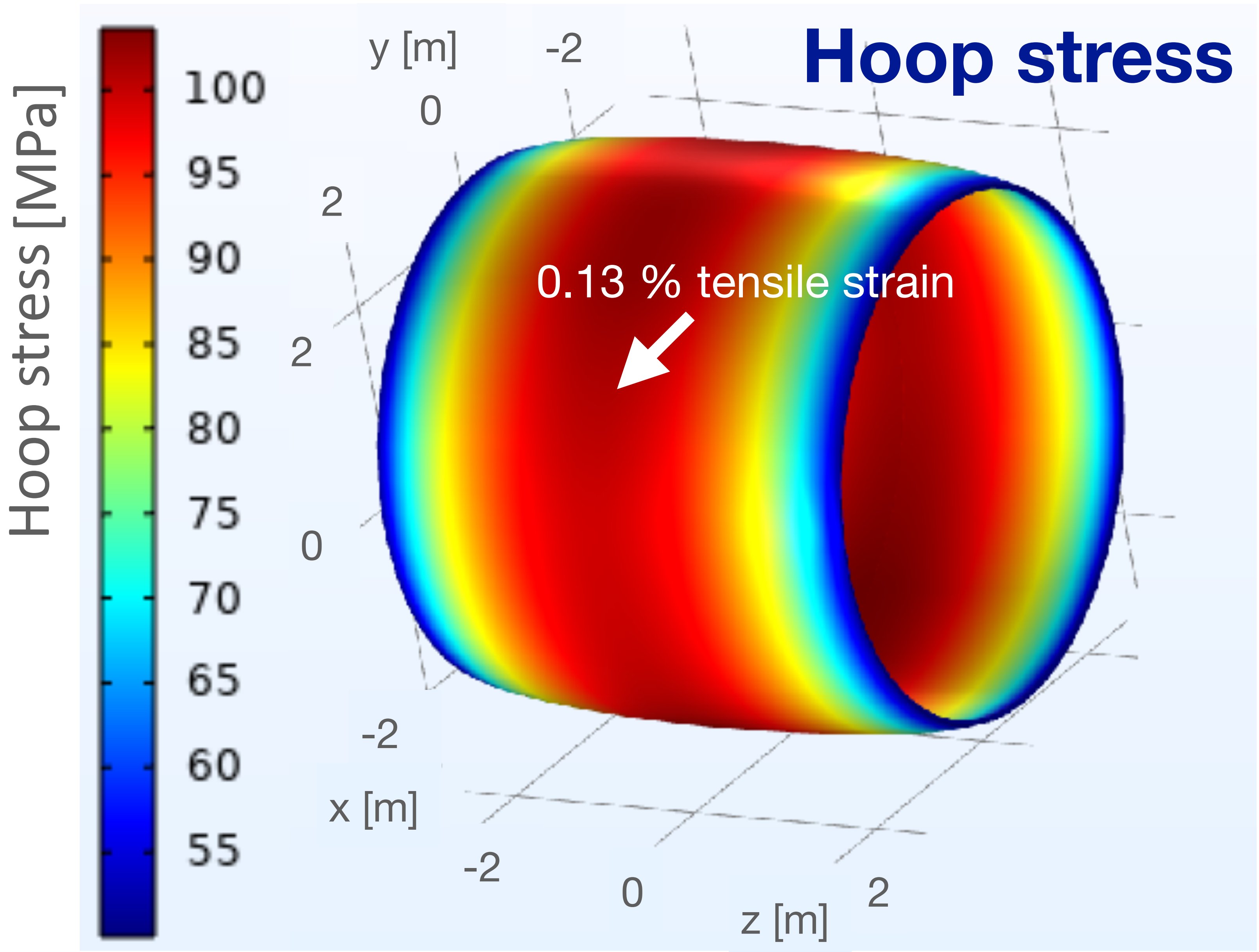
Mechanical support for the IDEA magnet

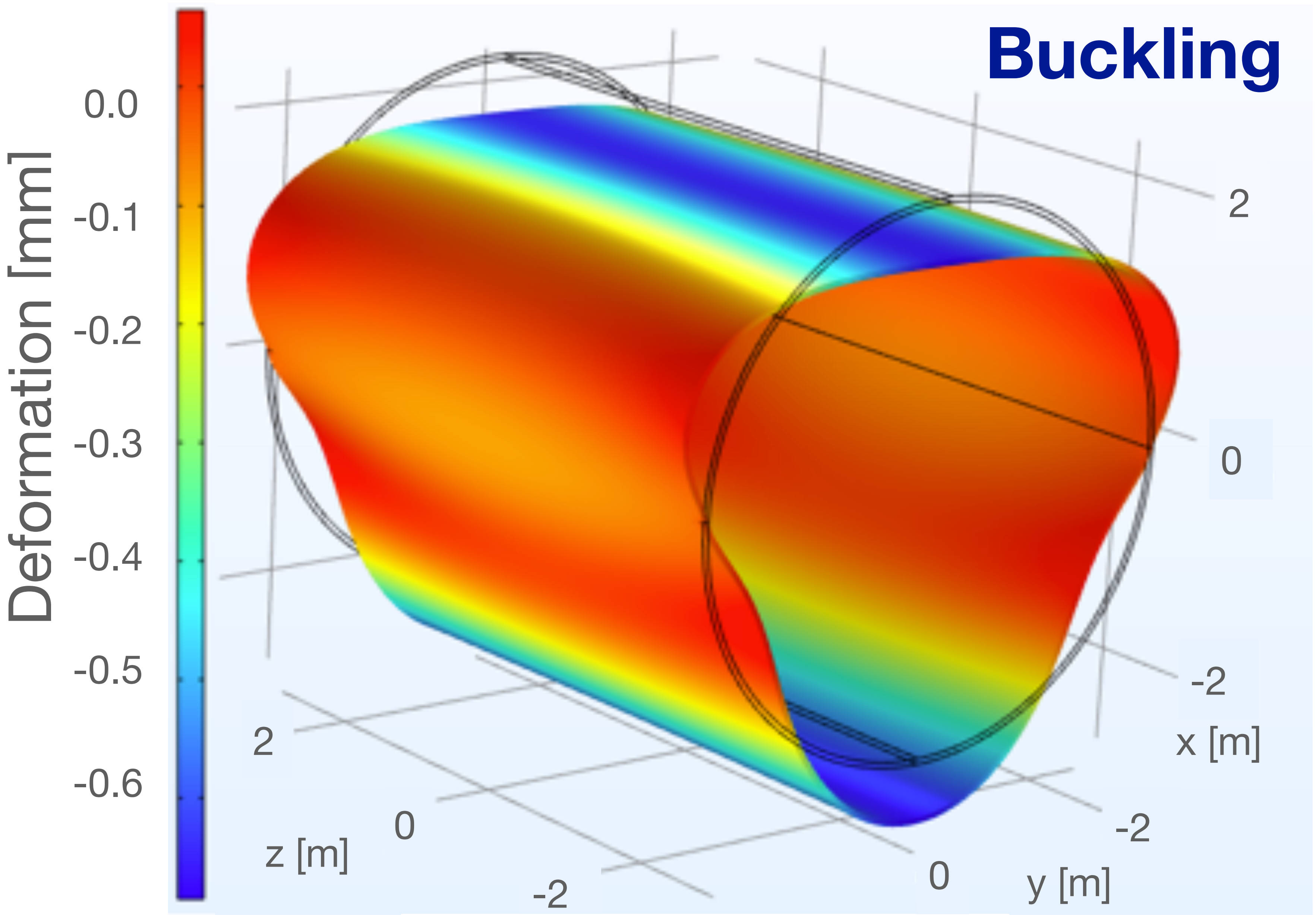
- Support cylinder with thickness of 12 mm
- Support cylinder material: aluminium 6082

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

- First mechanical analysis is promising

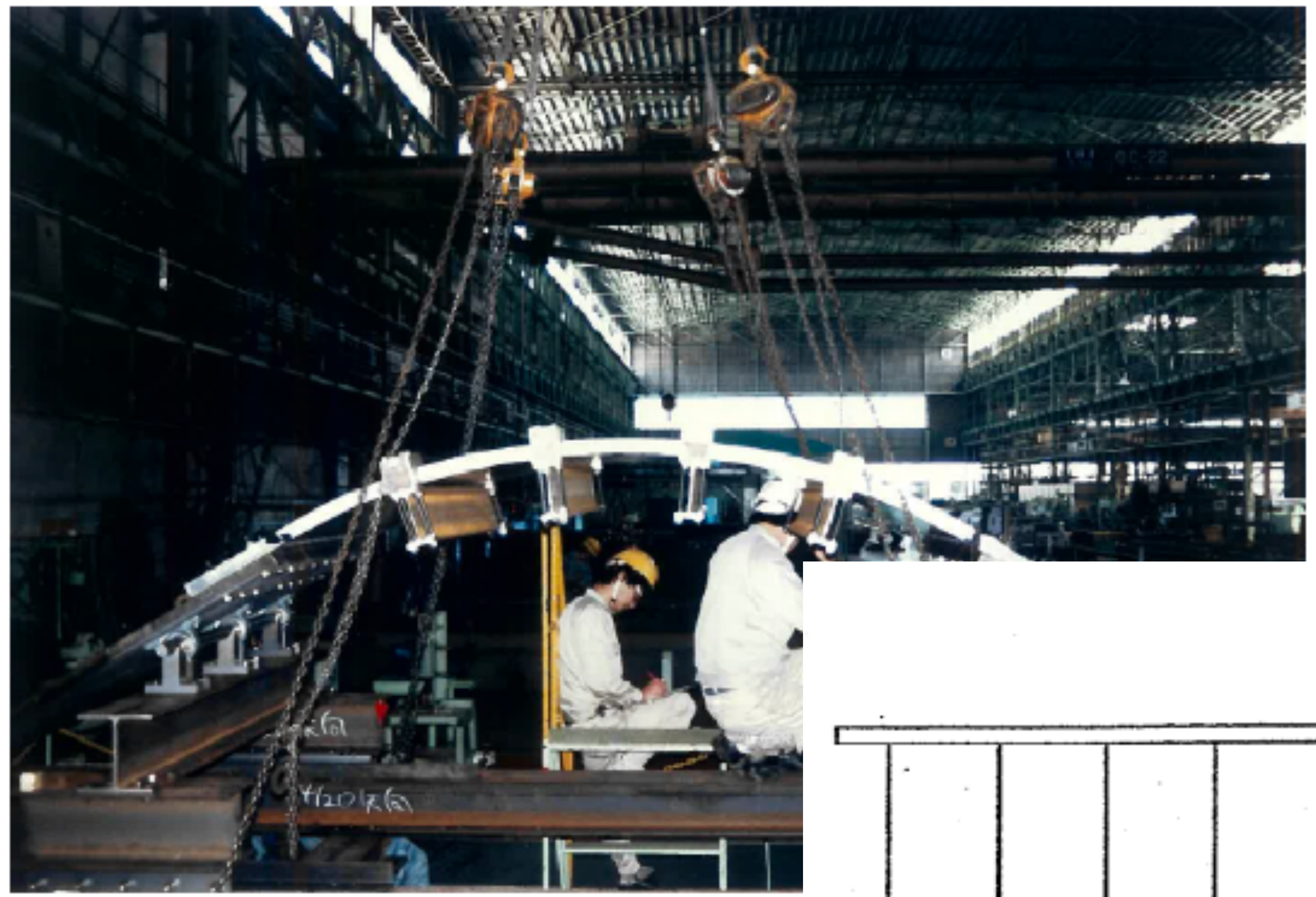
	Conductor	Support	
Parameter	Value	Value	Unit
Material	Ni-doped aluminium	Aluminium 6082	
Yield strength	147 (with NbTi) [3]	400 @ 4.2 K [4, 5]	MPa
Young's modulus	75×10^3	81×10^3	MPa





- 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]

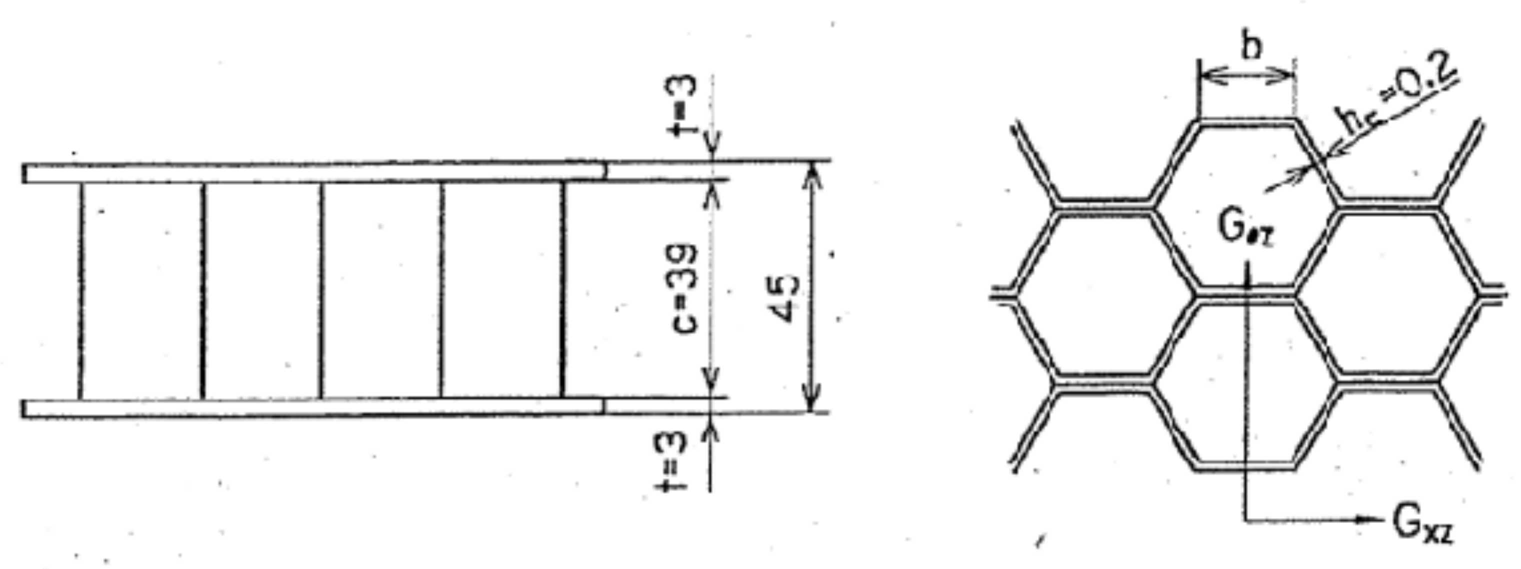
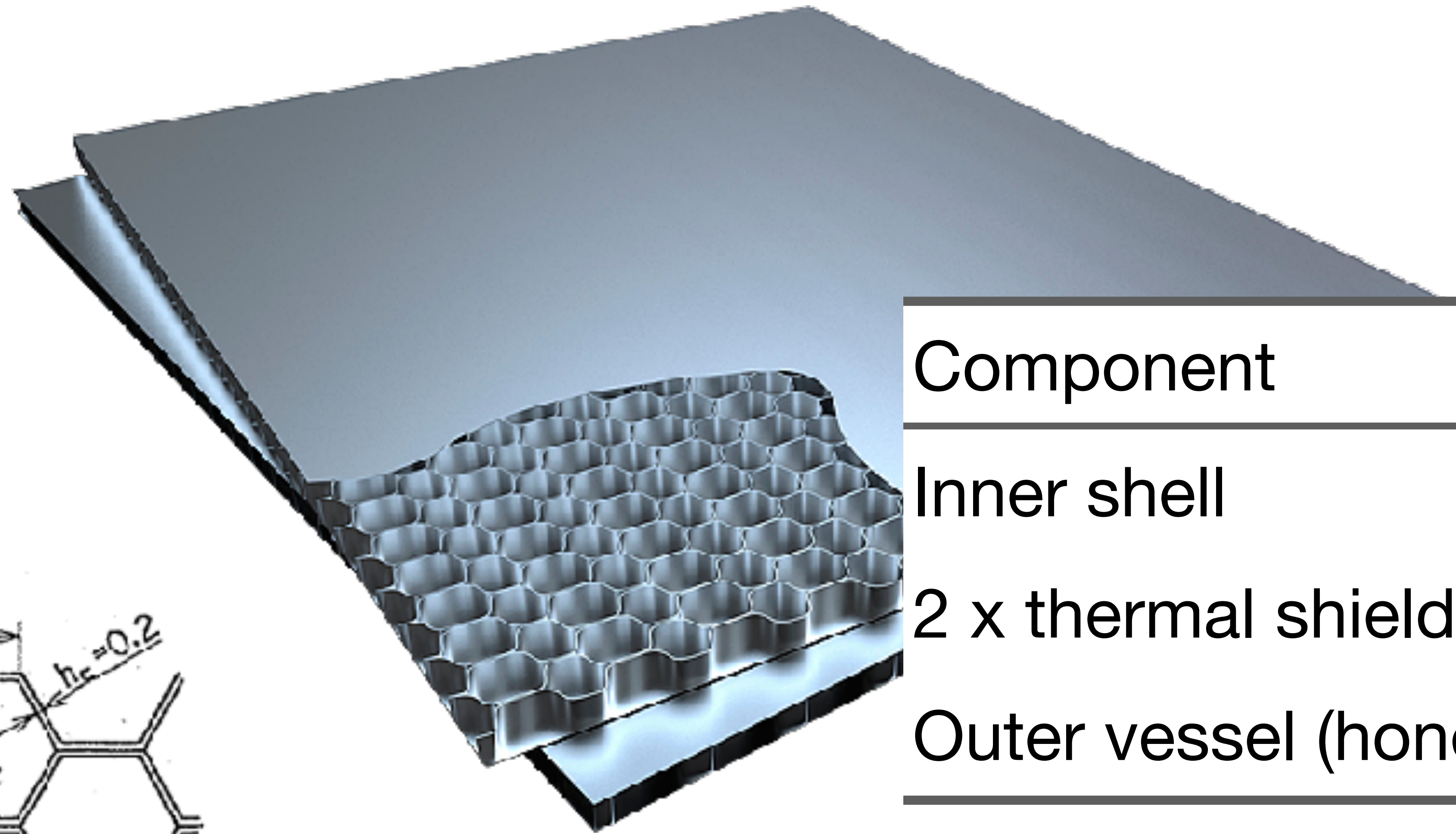
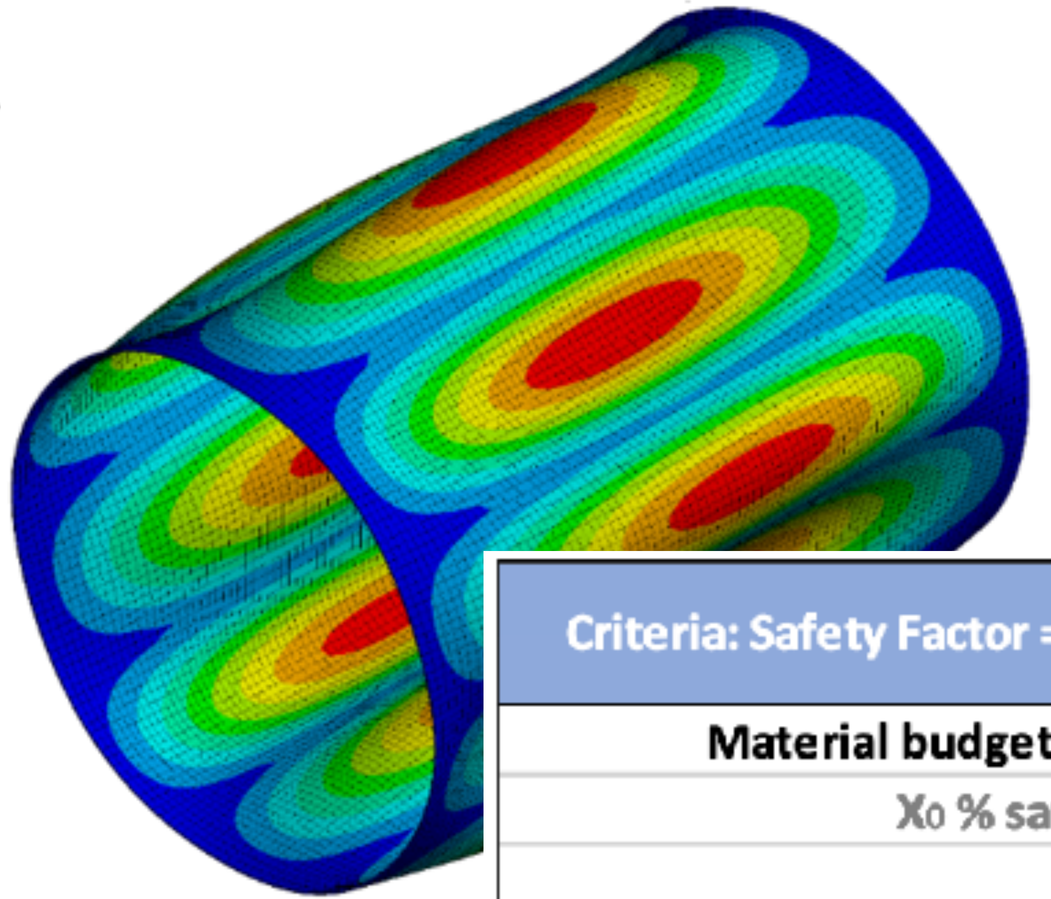


Figure 2. Honeycomb panel configuration in the preliminary design.



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/Xo	0.017	0.045	0.065	0.24
Xo % 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%

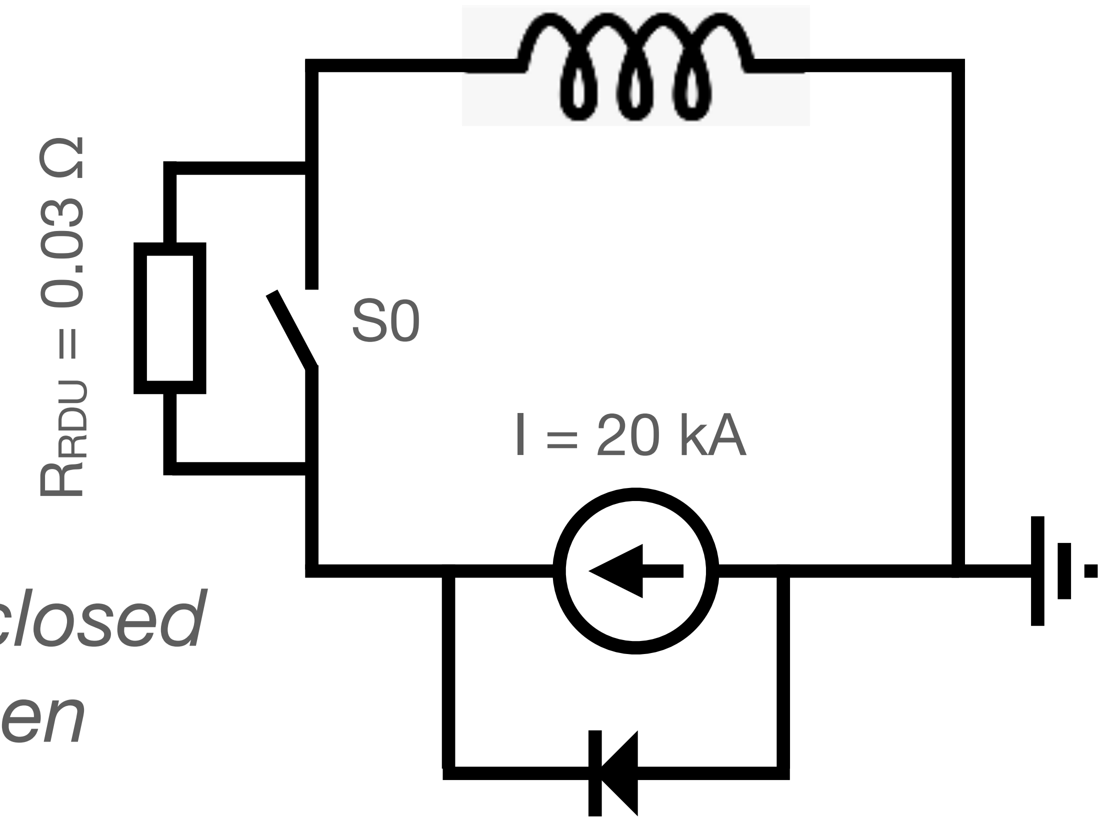
For vacuum vessel:

- 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]:** Towards carbon-based vacuum vessels

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

3D Quench simulations IDEA magnet

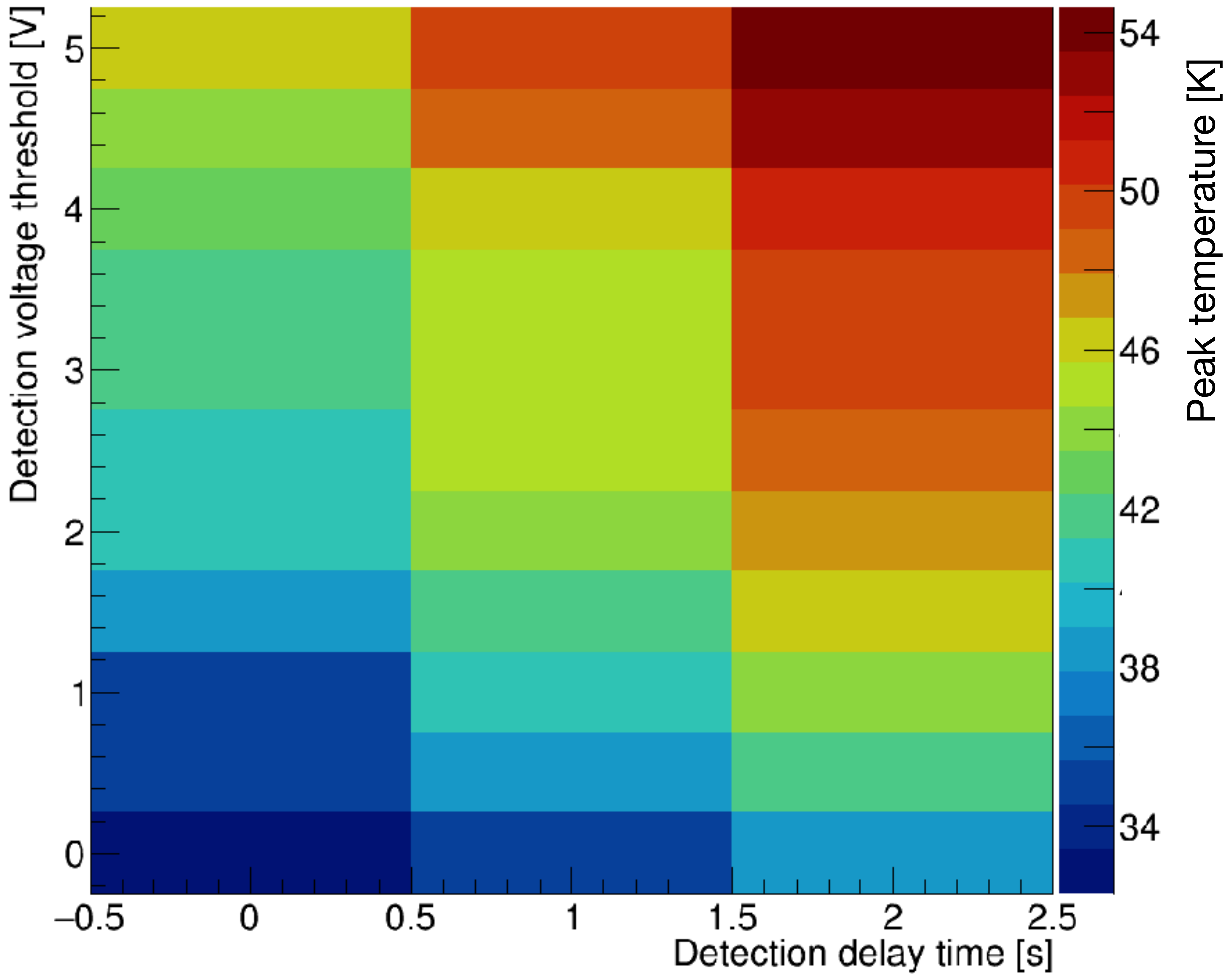
Quench detection



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

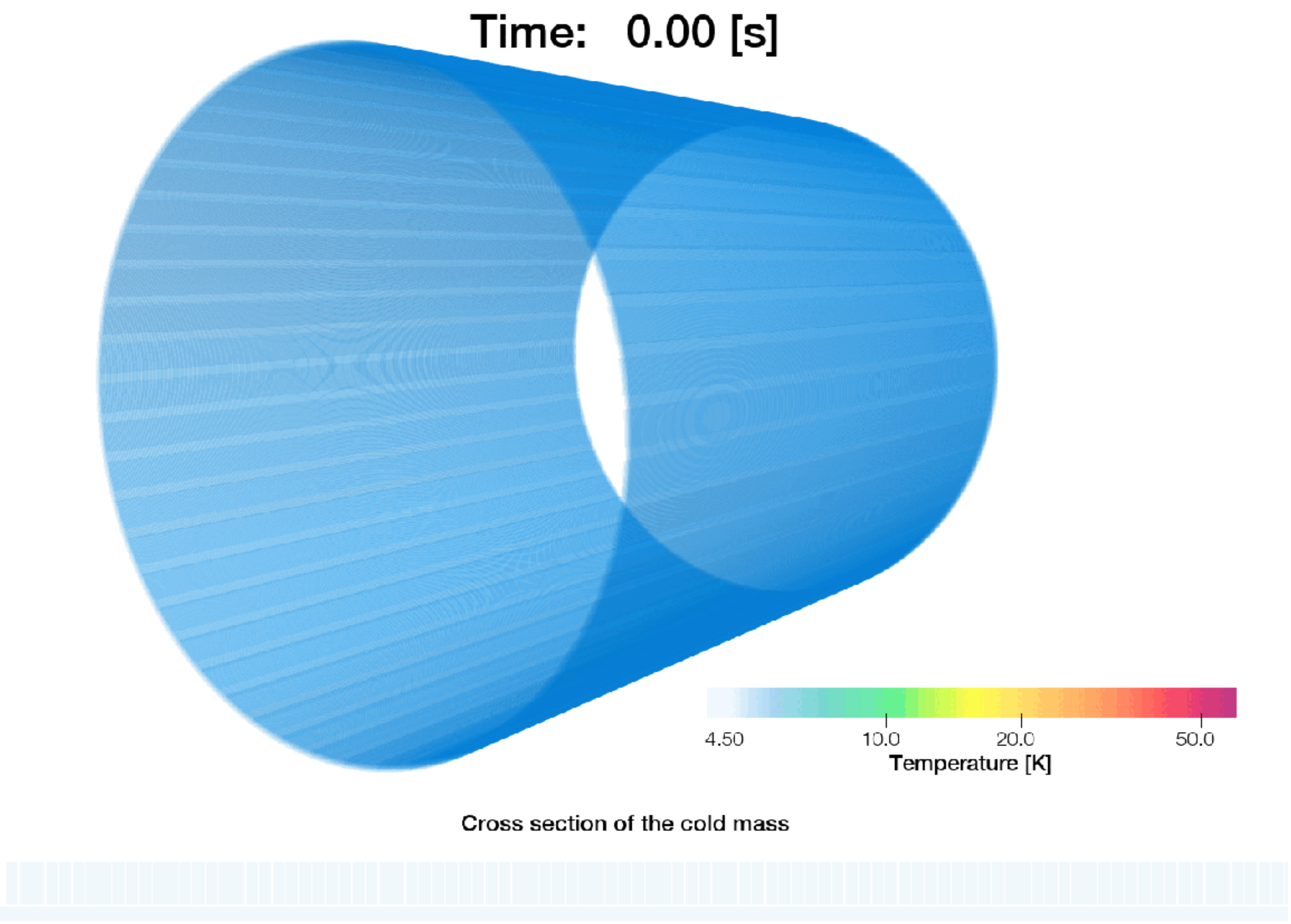
- 3D thermo-electrical network software called **Raccoon2** based on the work described in [9]
- Validated with data measured at the ATLAS Central Solenoid [10]
- **First detection: scan voltage threshold vs. delay**
- Experience with the ATLAS CS (delay 1.2s)

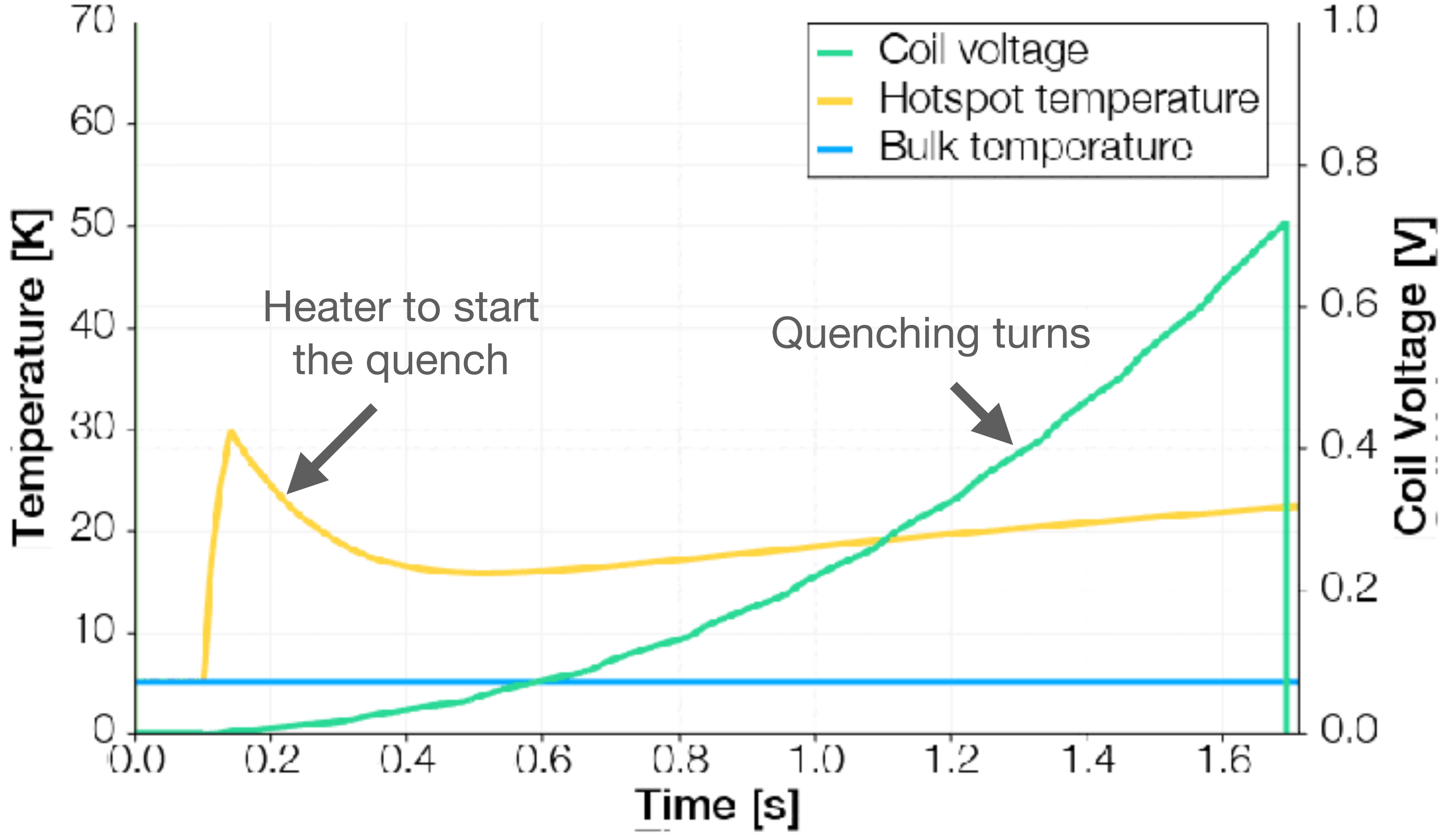
Choice for IDEA: threshold = 0.1V, delay = 1s

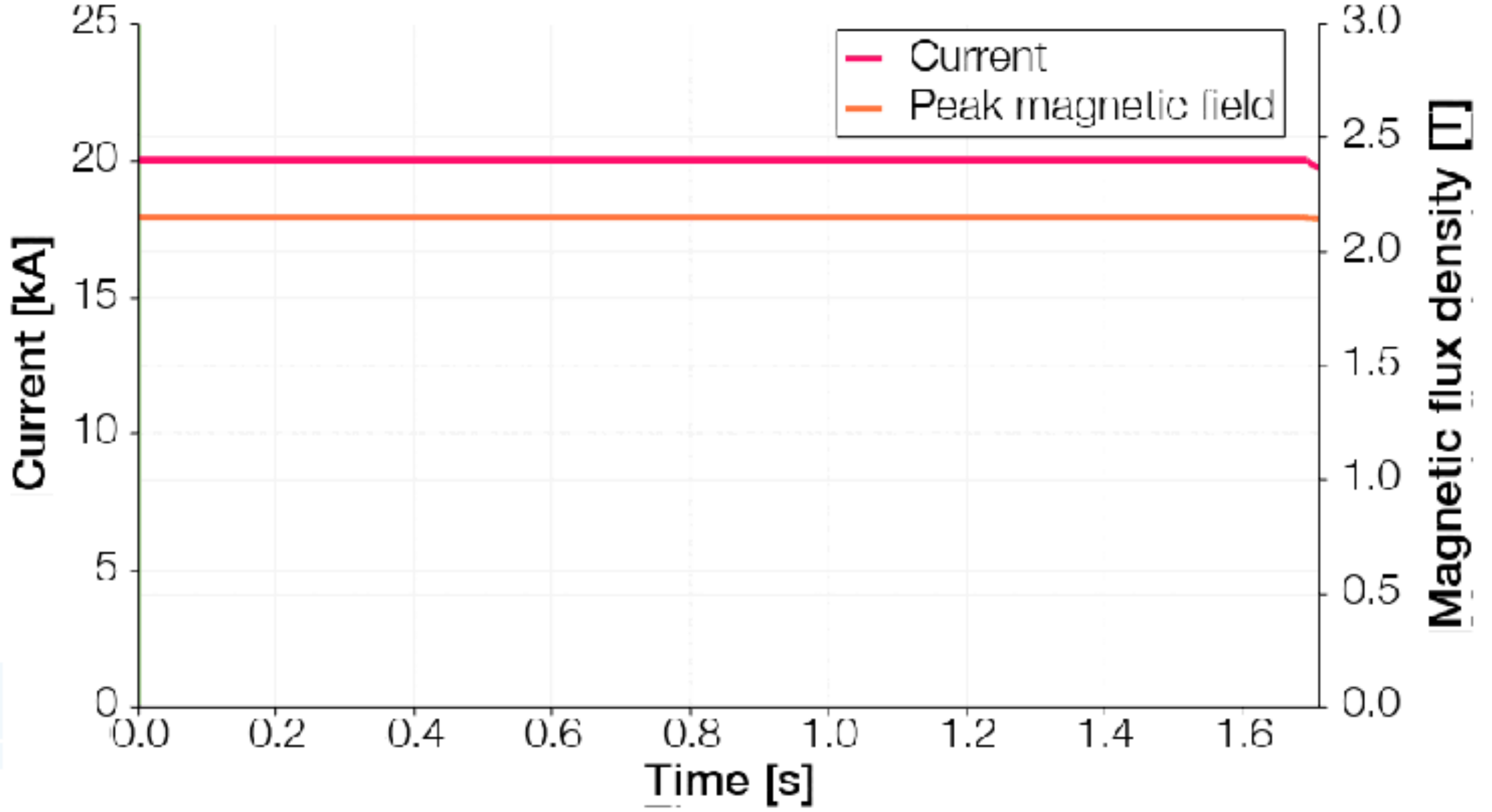


3D Quench simulations IDEA: RDU + QP strips

Initiating the quench

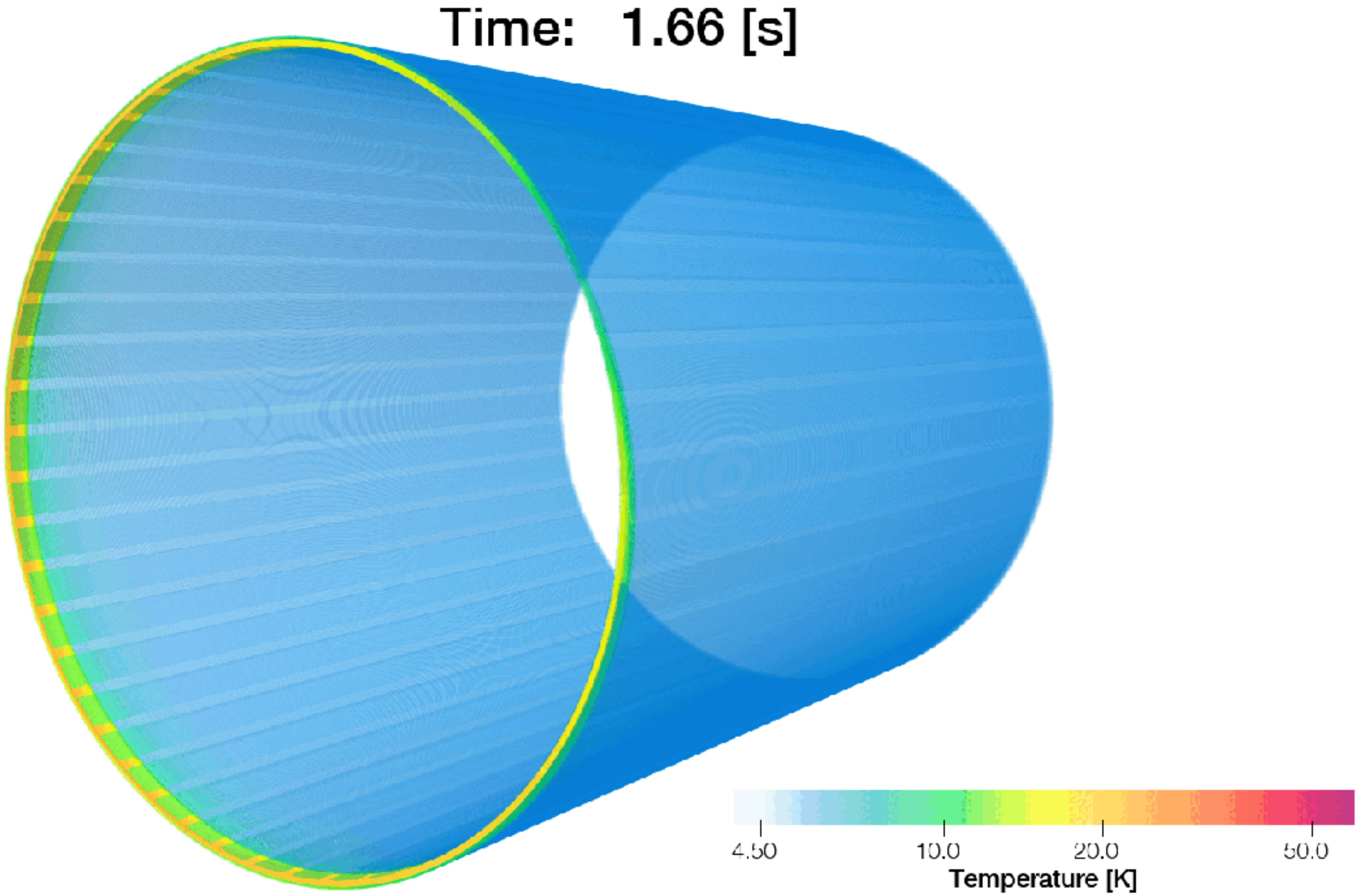




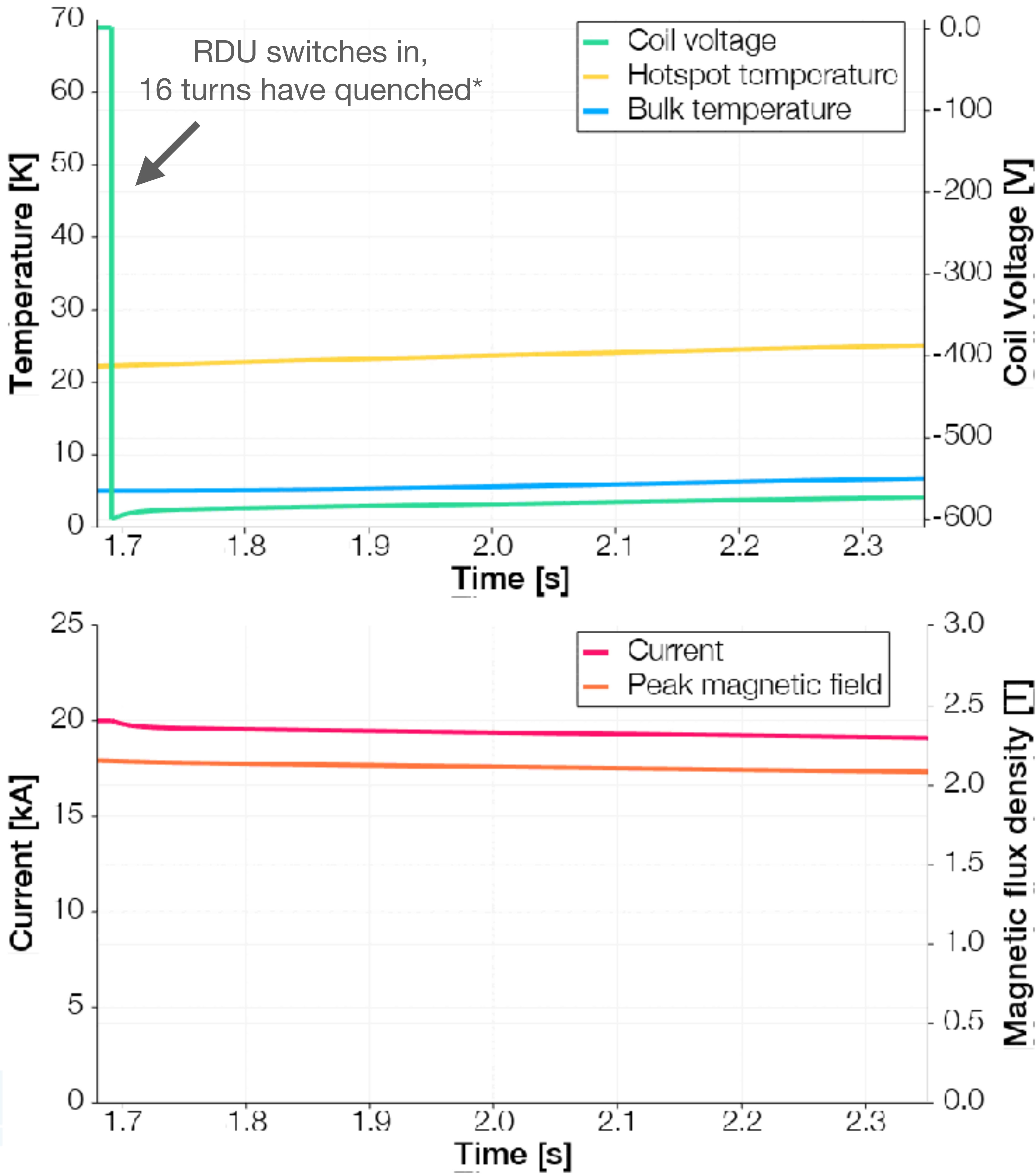


3D Quench simulations IDEA: RDU + QP strips

Switching in the extraction resistor



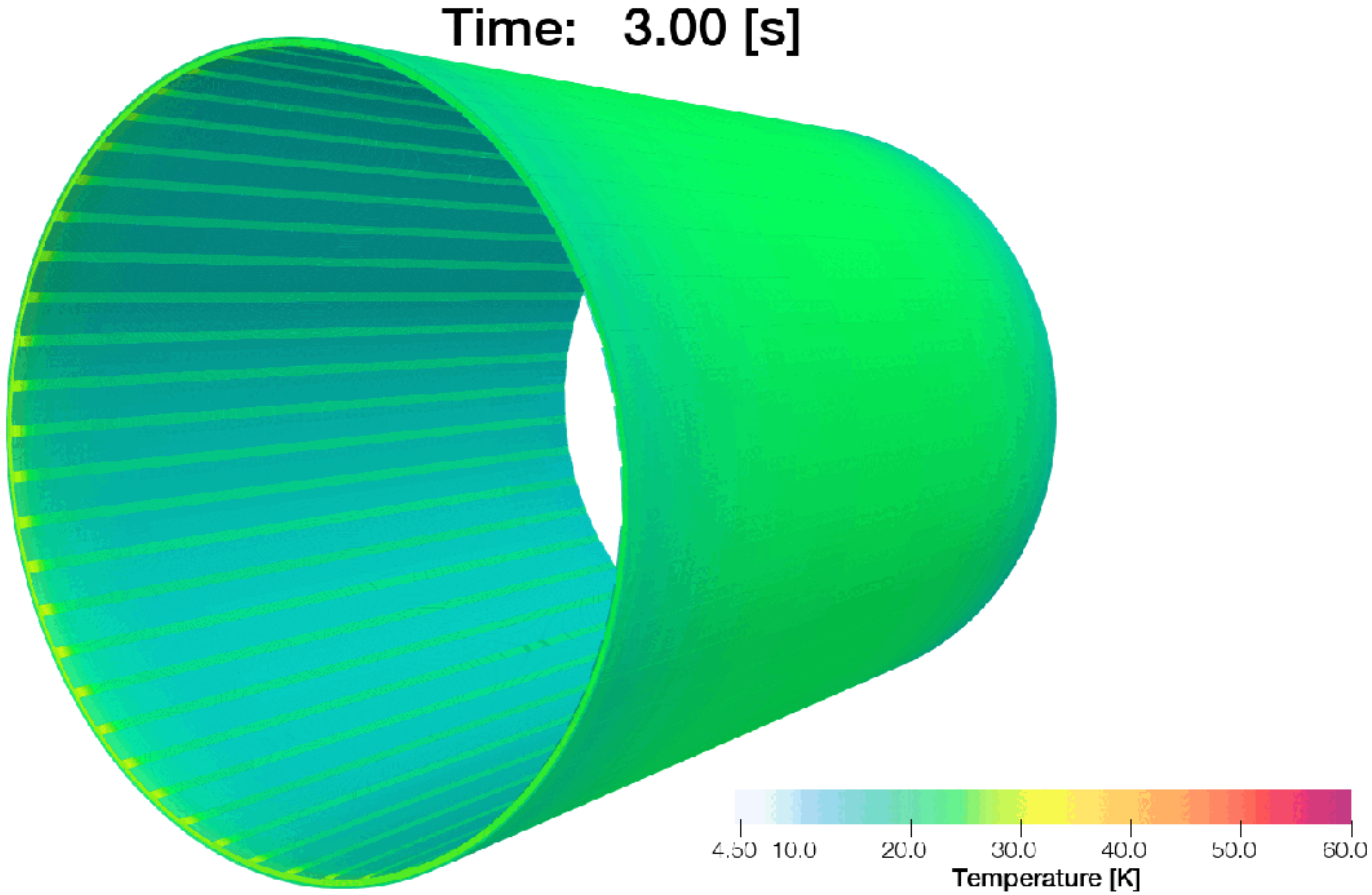
Cross section of the cold mass



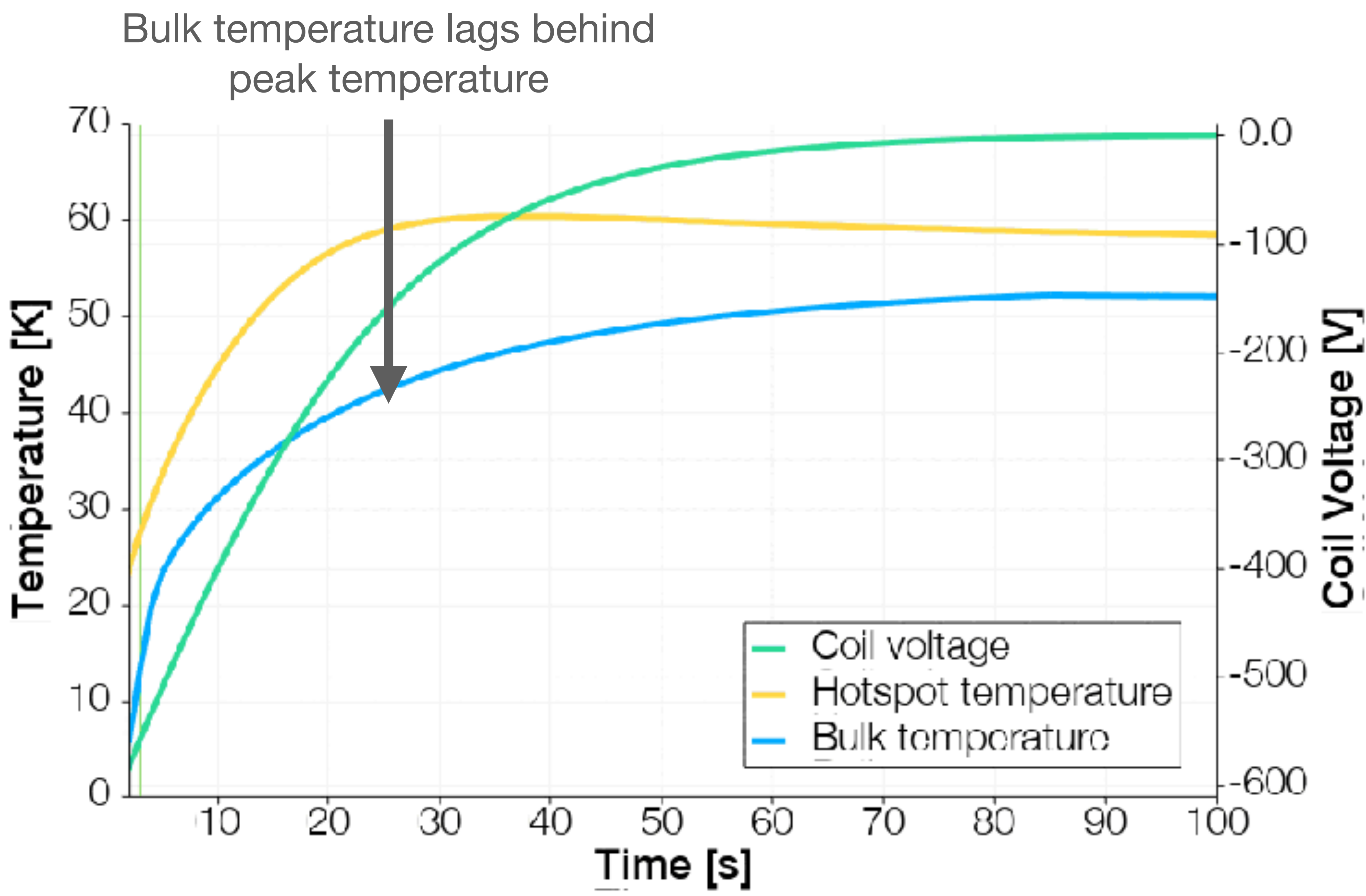
* With QP strips 16 turns quench before RDU, without strips 11 turns quench before RDU

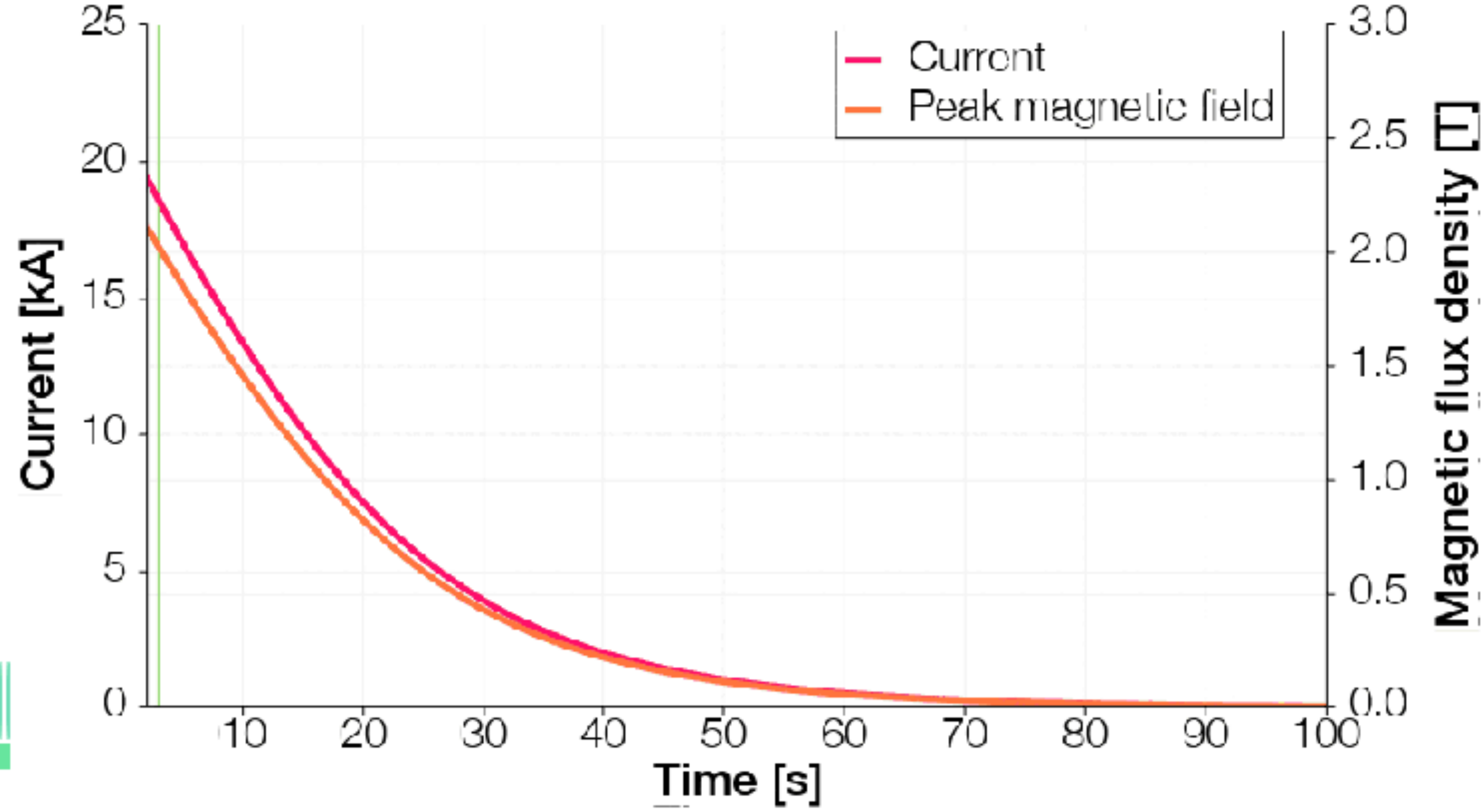
3D Quench simulations IDEA: RDU + QP strips

Extracting the energy from the magnet



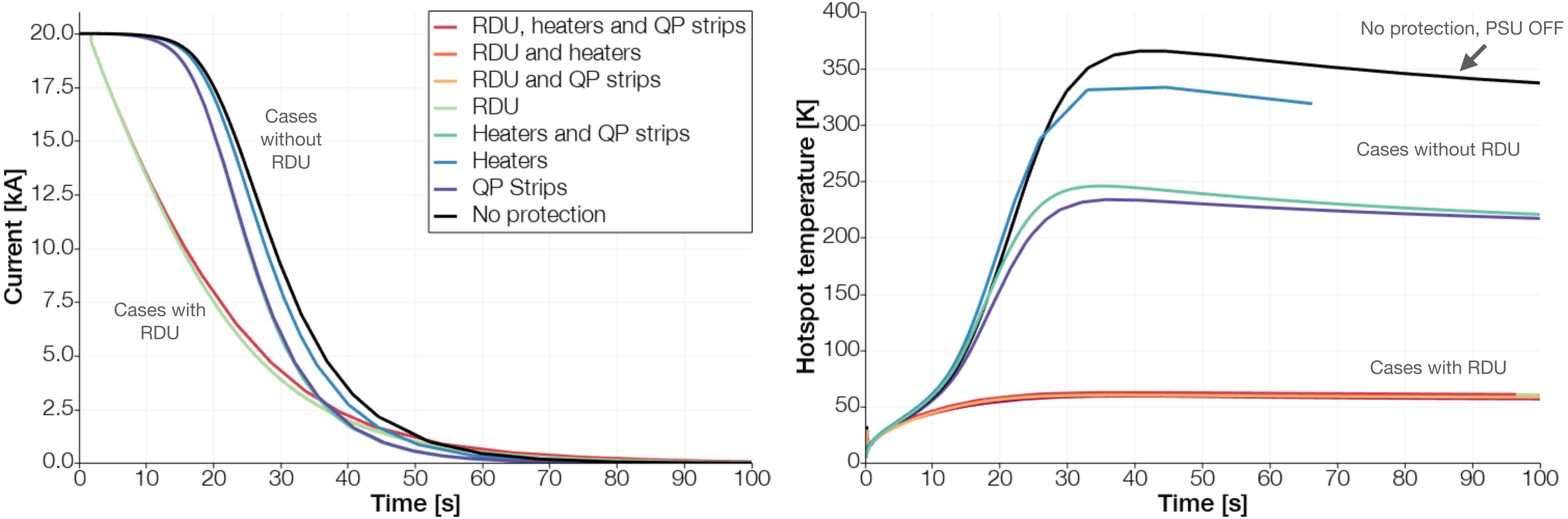
Cross section of the cold mass





Other quench protection methods for IDEA

- Study difference between protection w/wo **RDU, five heaters** (P = 10 W, t = 5s) and 1 mm thick pure aluminium (RRR = 3000) **quench propagation strips** (QP) along the length of the solenoid
- QP strips have **positive effect** on the peak temperature. **With QP 16 turns** quench before protection, **without QP 11 turns** quench before protection.
- Heater power, QP strips dimensions, and no protection to be studied in more detail: **promising results**



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]

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