
Side View of the Two Assembled and Impregnated Feather-M2 Poles

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Powering of an HTS Dipole Insert-Magnet Operated Standalone in Helium Gas between 5 and 85K

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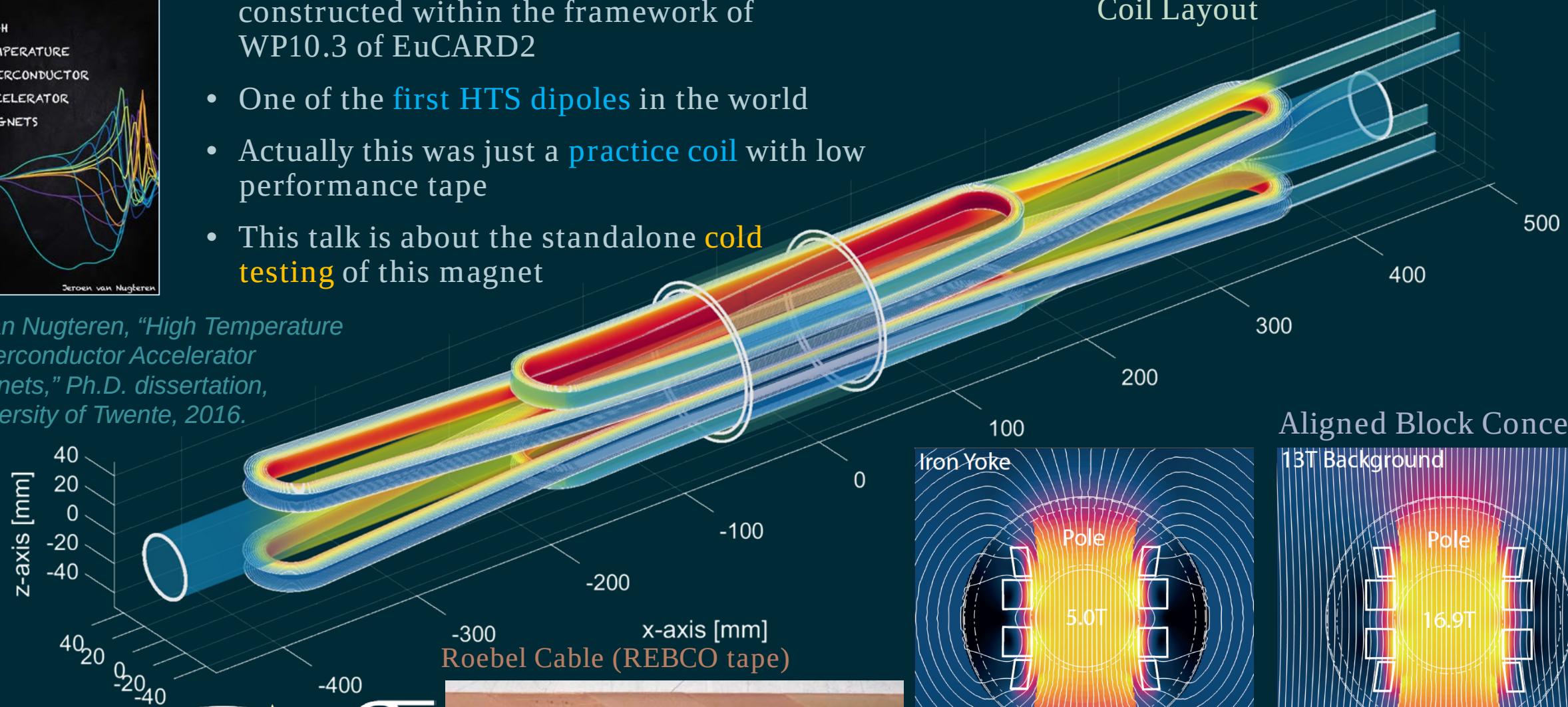
The Feather-M2.1-2 (SuperOx, Sunam)

Research Thesis

J. van Nugteren, "High Temperature Superconductor Accelerator Magnets," Ph.D. dissertation, University of Twente, 2016.

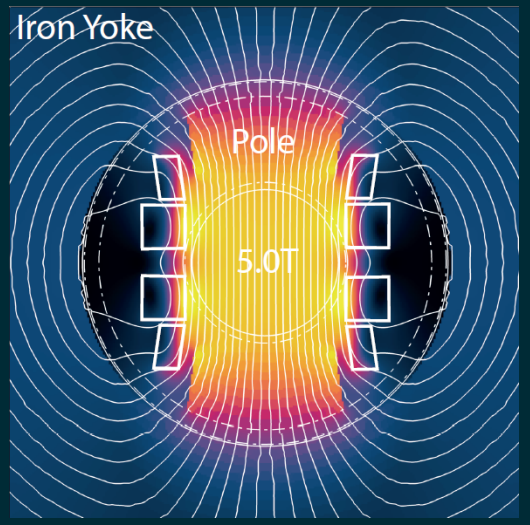
- Feather-M2.1-2 insert-magnet was constructed within the framework of WP10.3 of EuCARD2
- One of the first HTS dipoles in the world
- Actually this was just a practice coil with low performance tape
- This talk is about the standalone cold testing of this magnet

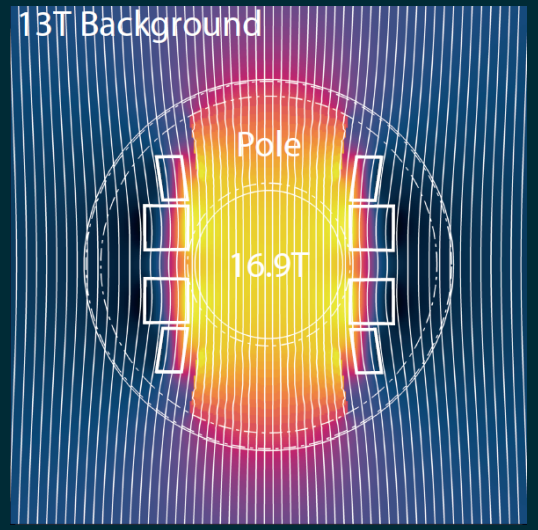
Feather-M2 Insert-Magnet Coil Layout



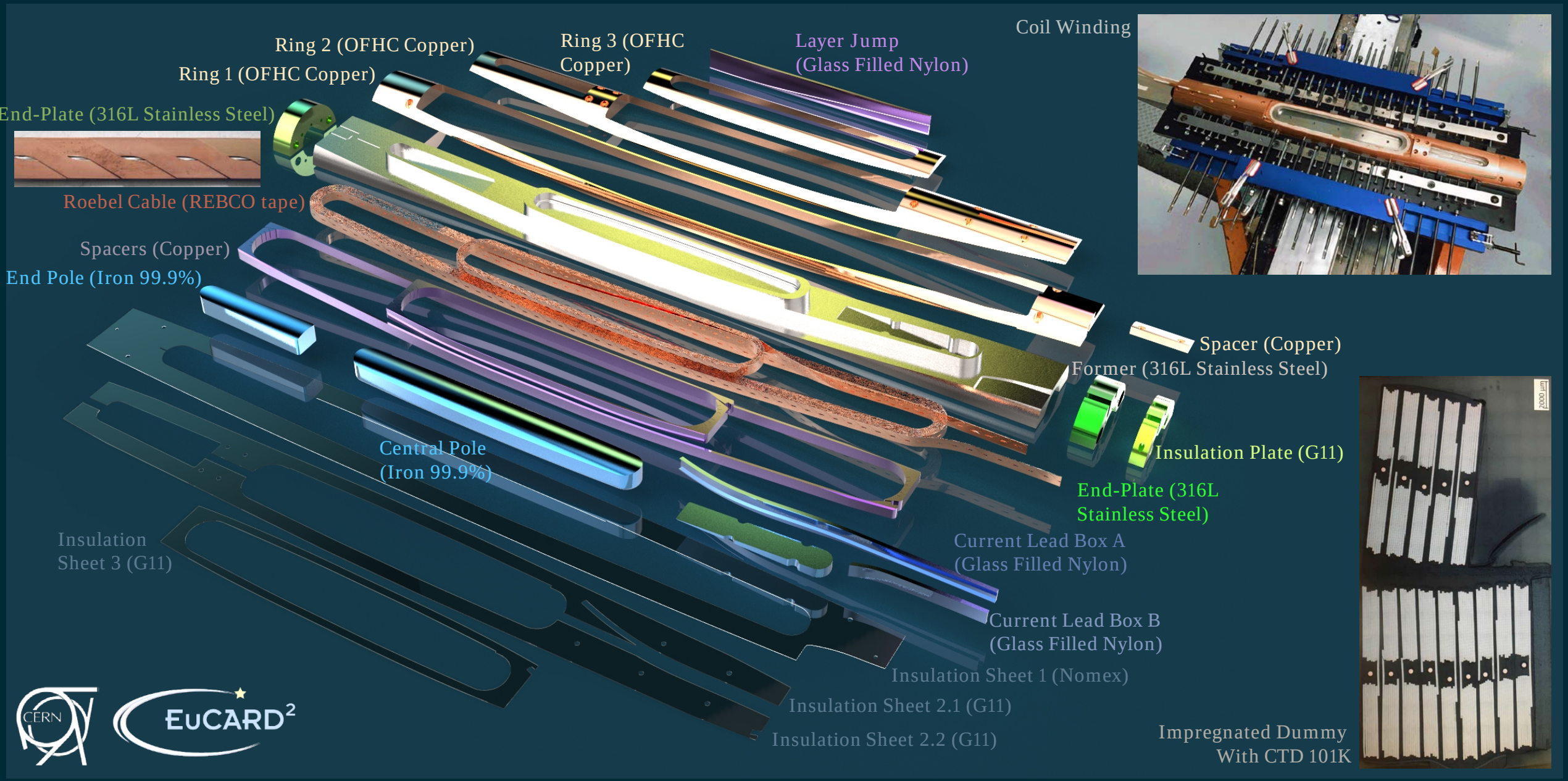
Roebel Cable (REBCO tape)

Aligned Block Concept

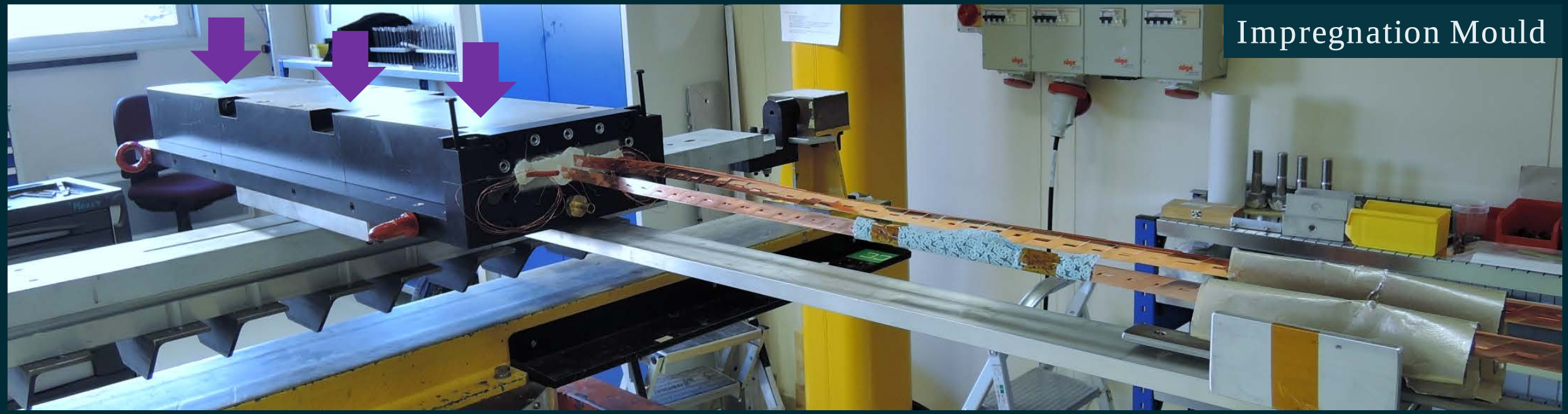




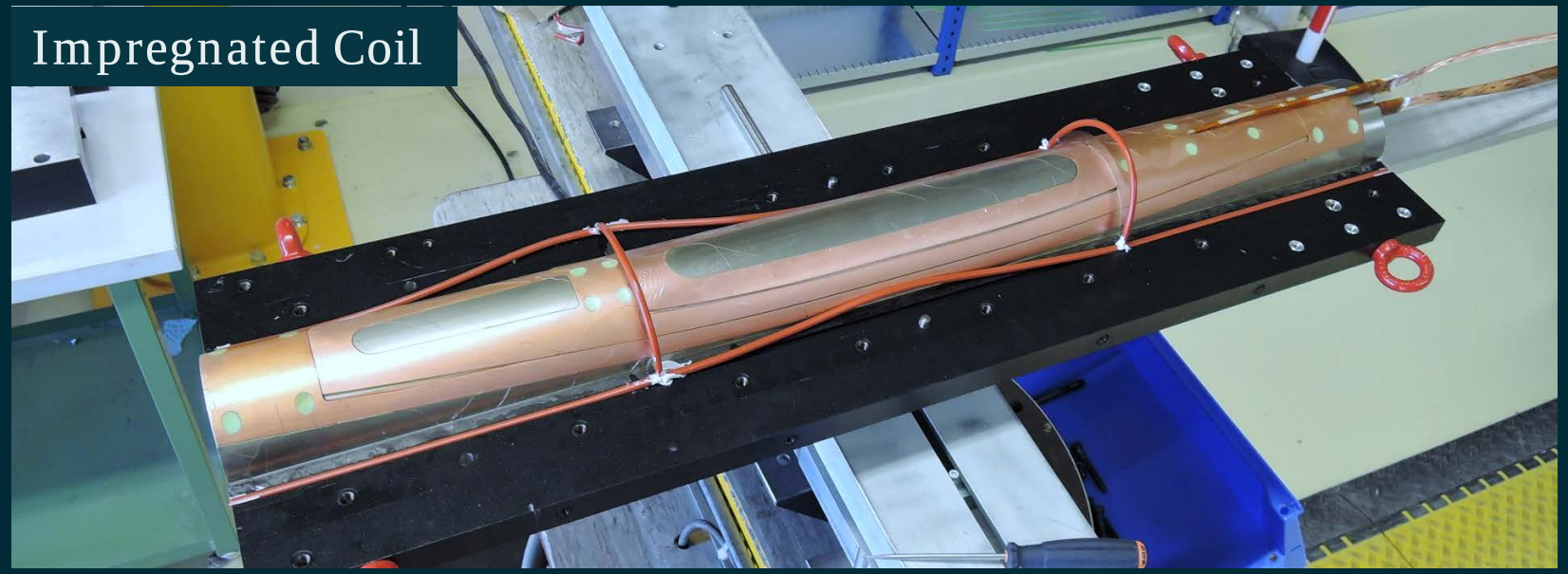
Winding, Impregnation and Assembly I



Winding, Impregnation and Assembly II



Impregnation Mould

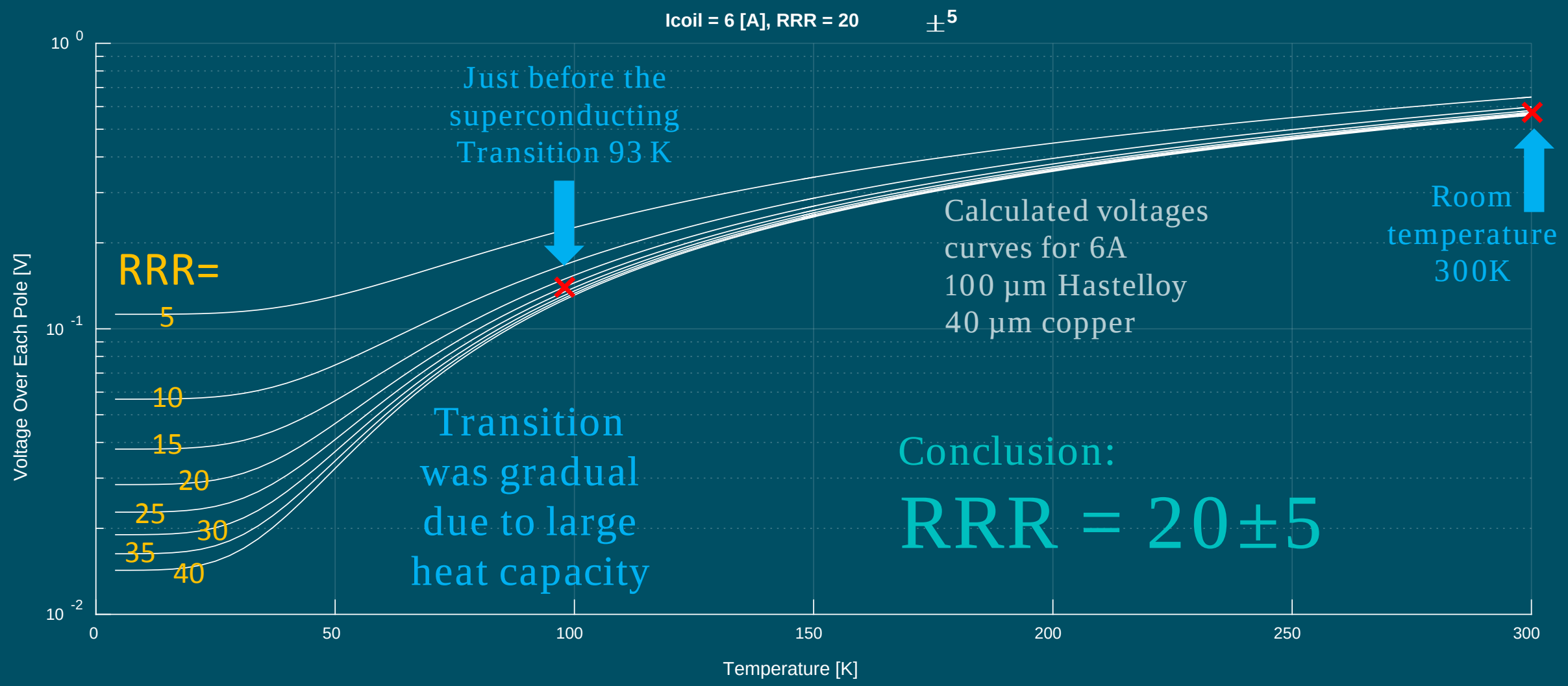


Impregnated Coil

Insertion in Support Cylinder

Magnet ready for Testing

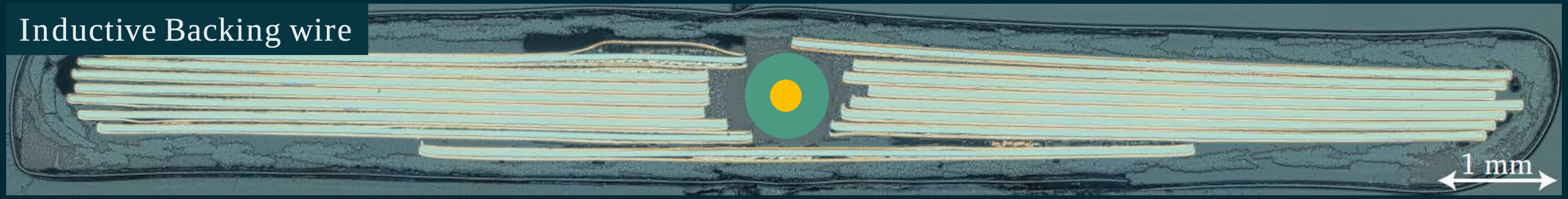
Cooldown Critical Temperature and Triple-R

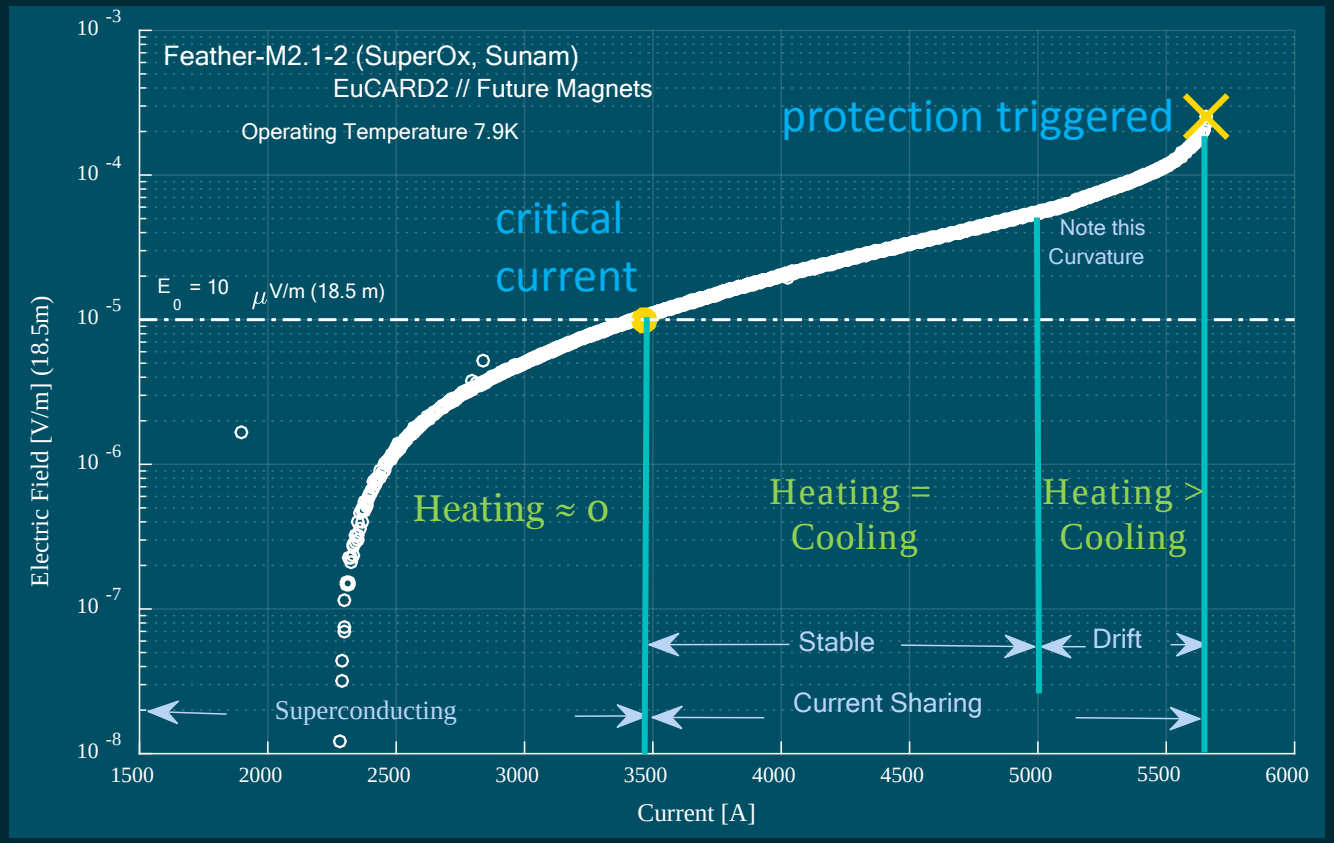


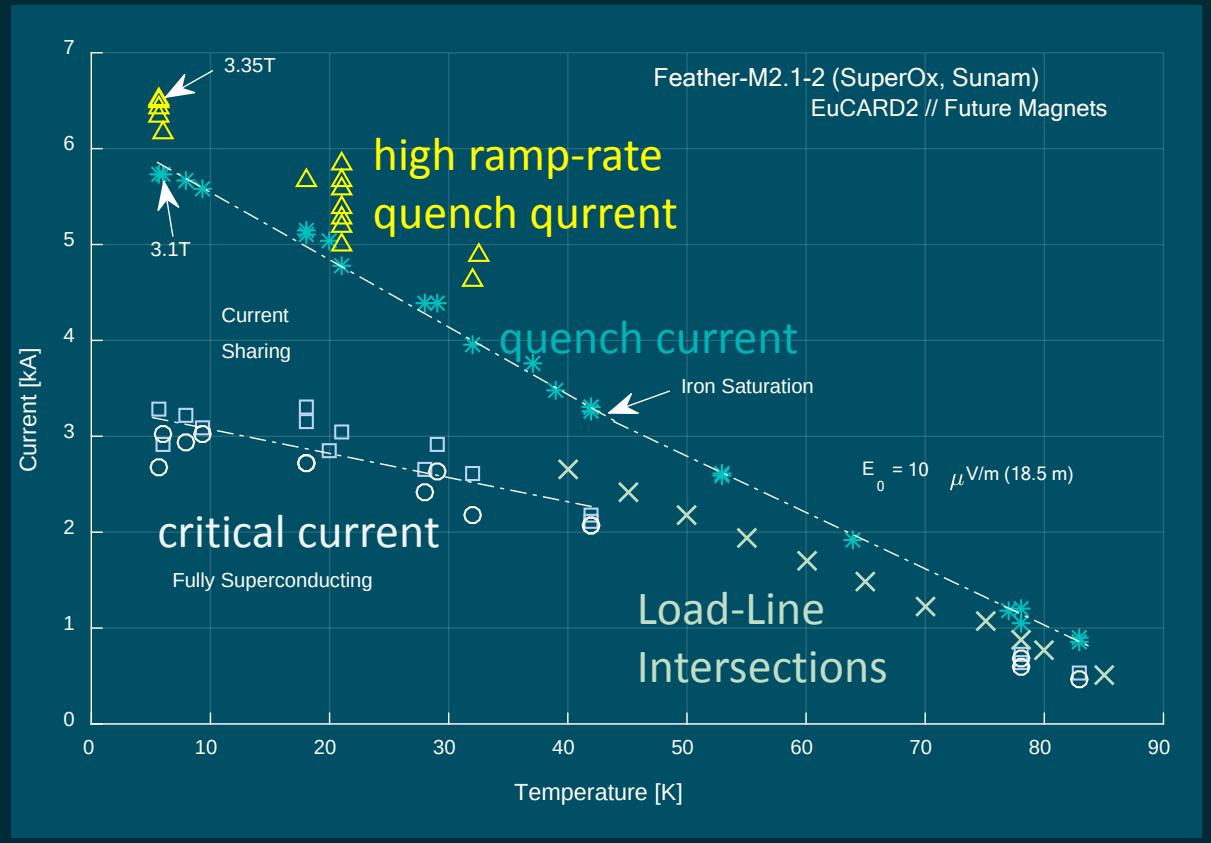
- Triple-R is defined between 10 and 273K
- Voltage only measured at 95 and 300K for a current of 6A

Superconducting Transition

Inductive Backing wire

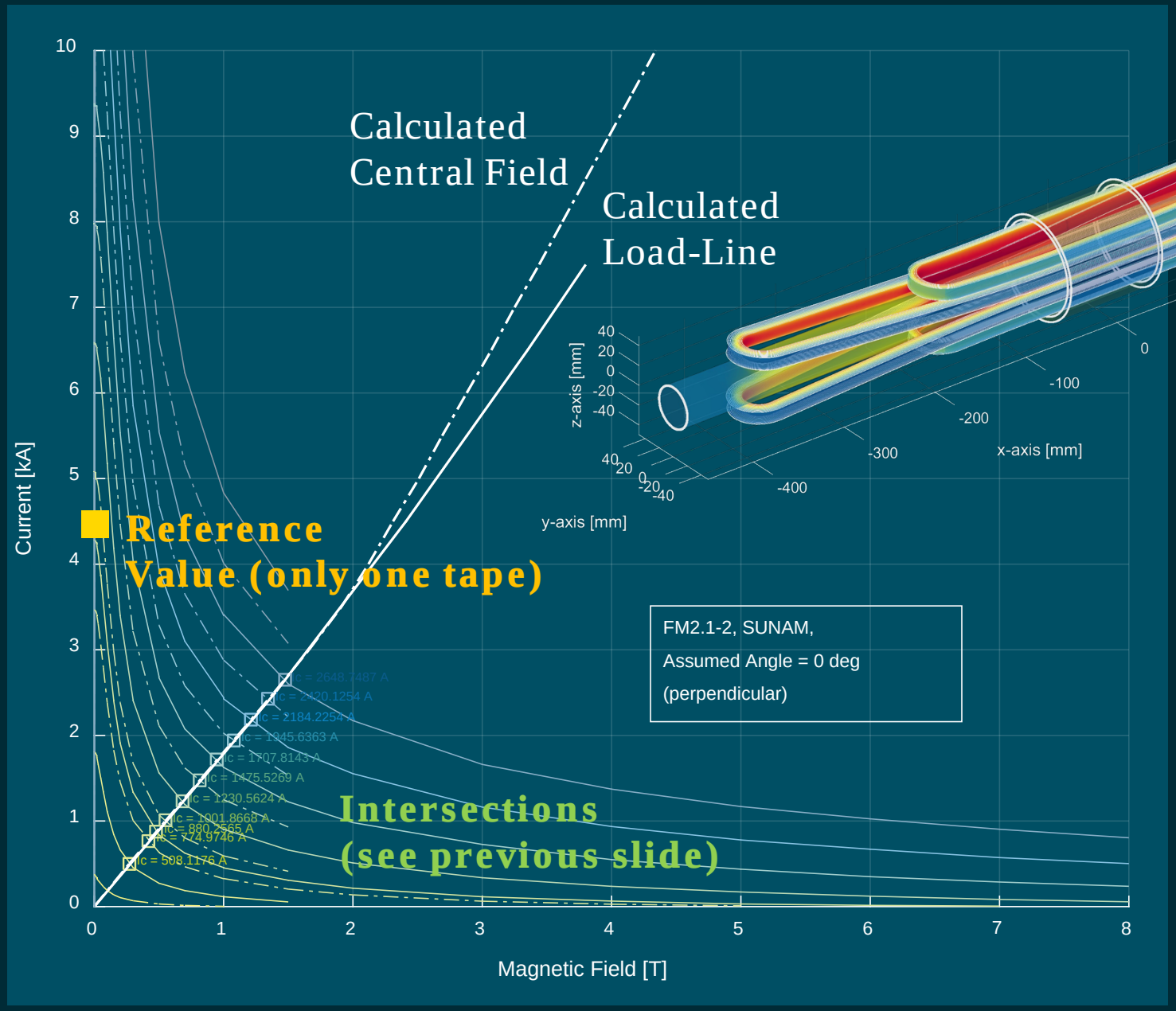


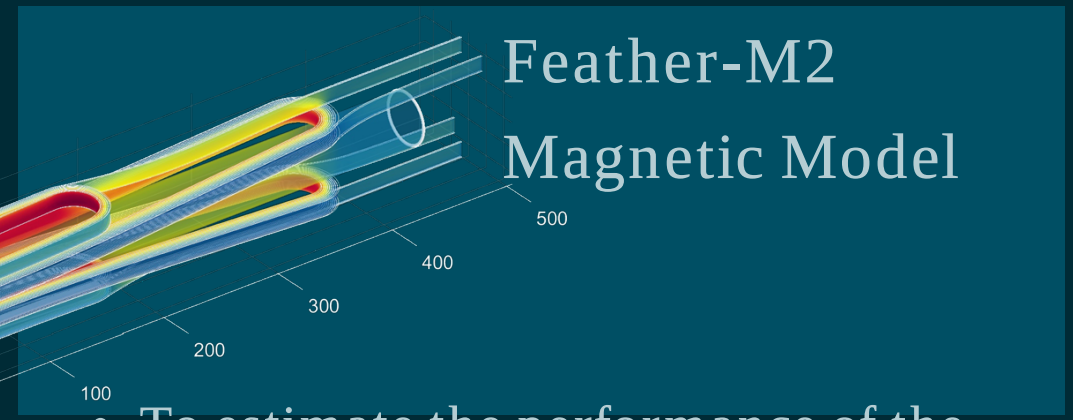




- 160% difference between critical current at 10 μV/m and quench current

Load-Line Intersections





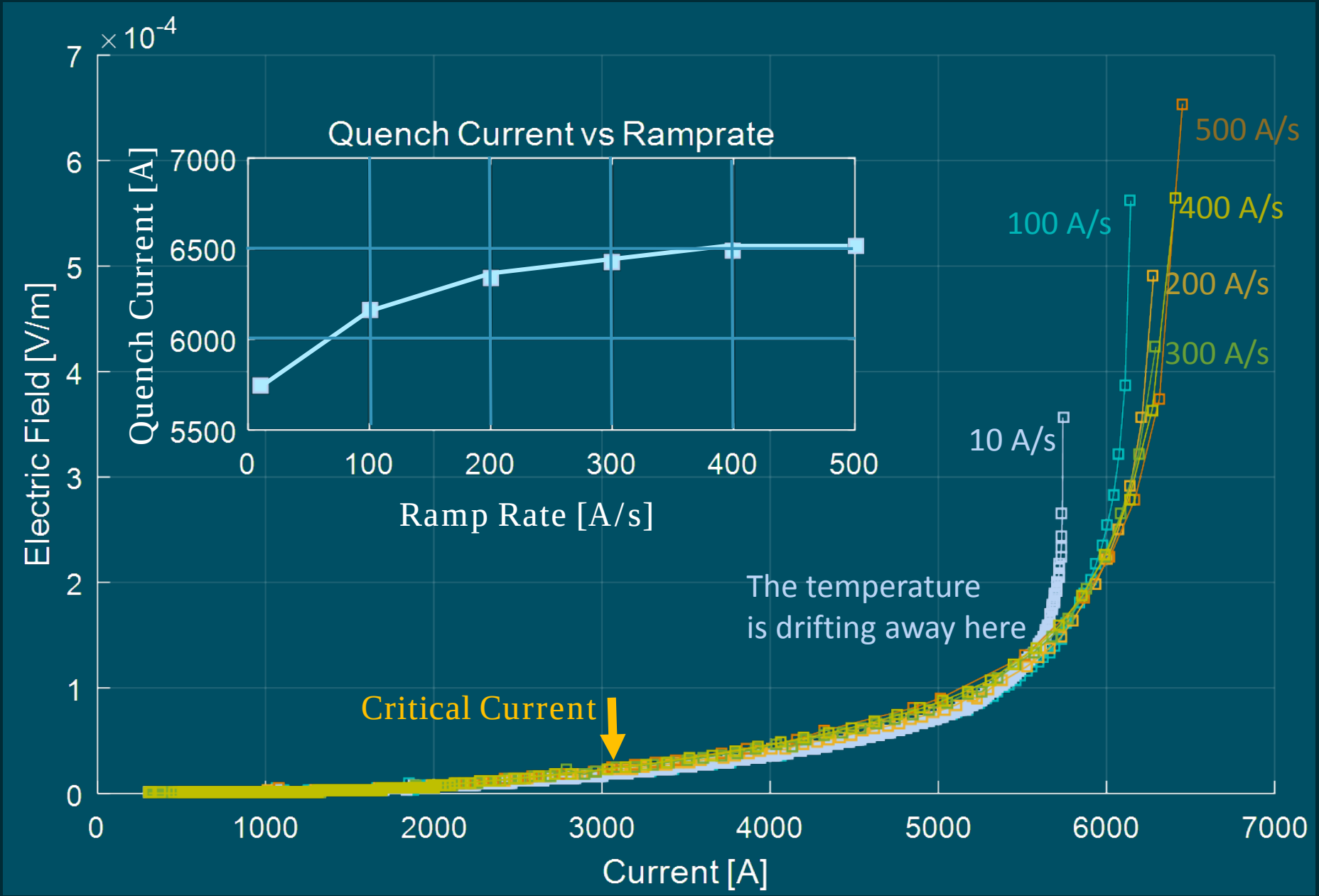
- To estimate the performance of the magnet the load-line intersections were calculated
- Critical surface from Victoria University assumed perpendicular magnetic field
- Measured reference value at 77 K self-field 300 A per tape 15 tapes in cable

- Conclusion:
  - No noticeable degradation occurred in the cable during winding, impregnation and assembly
  - This cable is not very suitable for use in a magnet. Much better performance on next magnet

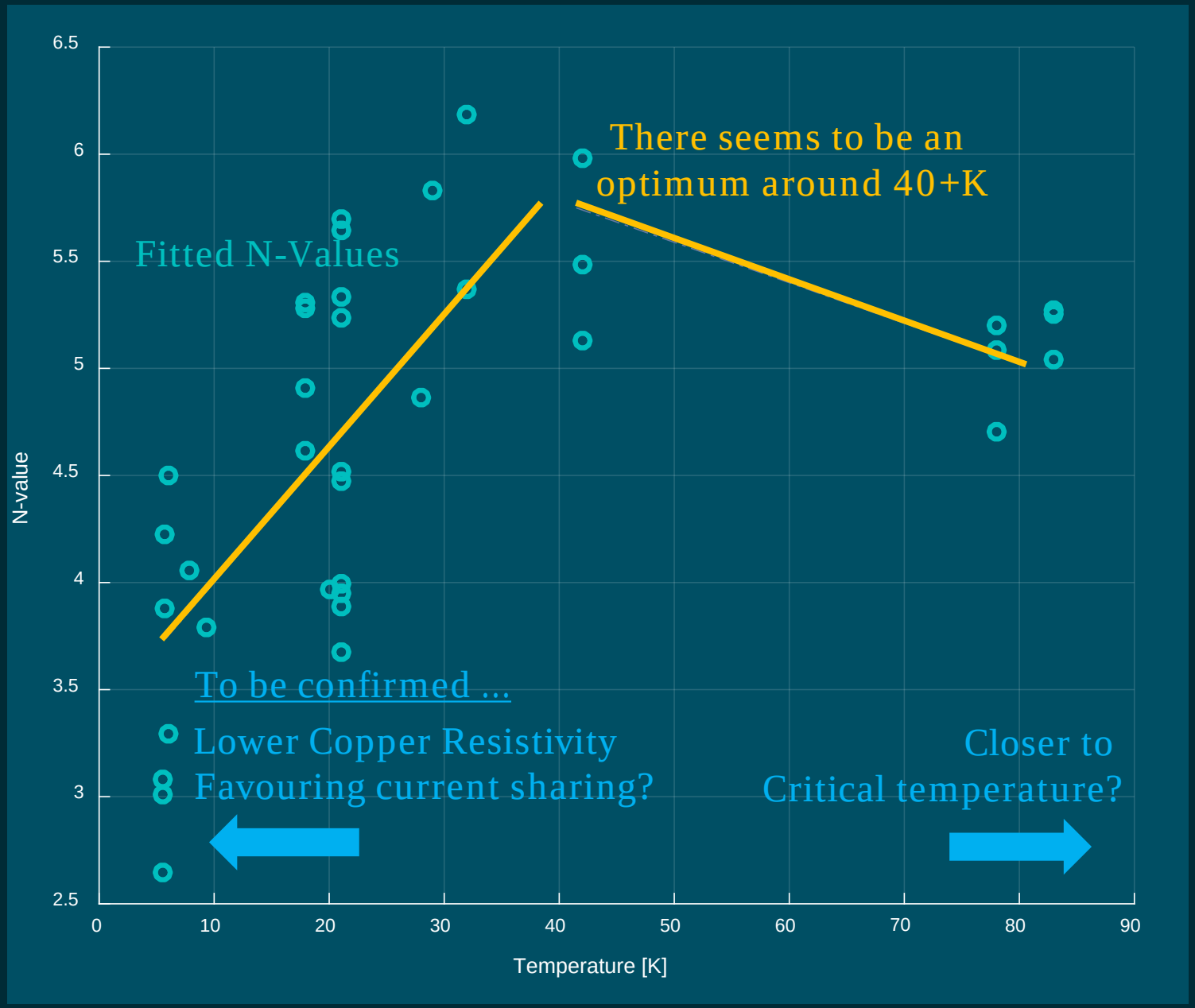
Superconducting Transition and Ramp-Rate

- Quench current increases when ramped fast
- Essentially we are skipping the drift regime
- Opposite result from LTS where coupling losses reduce the quench current
- HTS has much more margin and seems to be unaffected by coupling loss

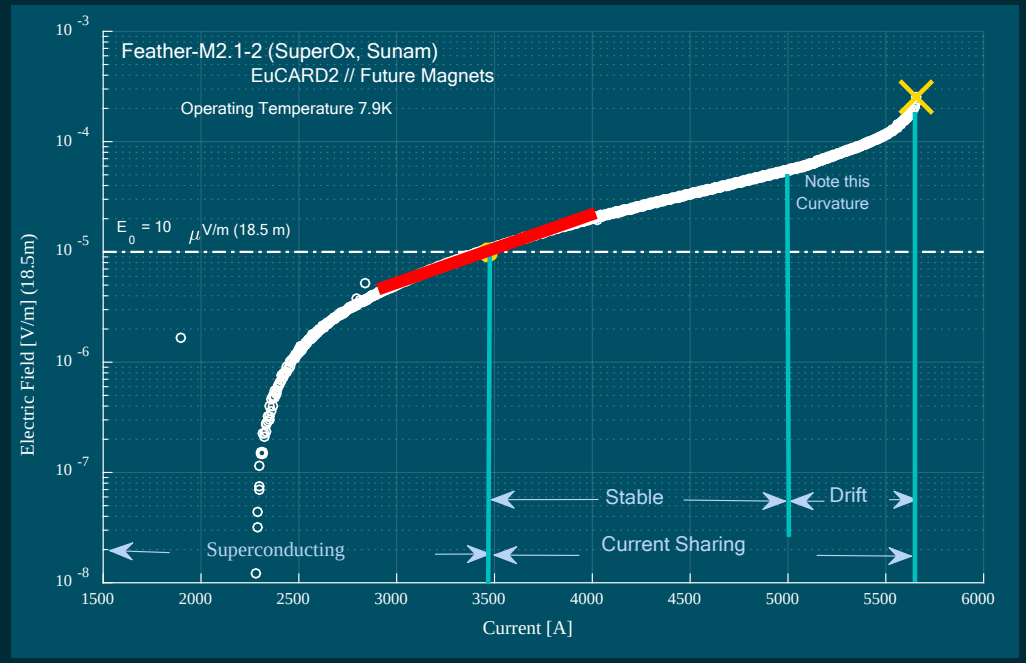
- Conclusion
  - The drift region implies temporal effects with respect to the quench current



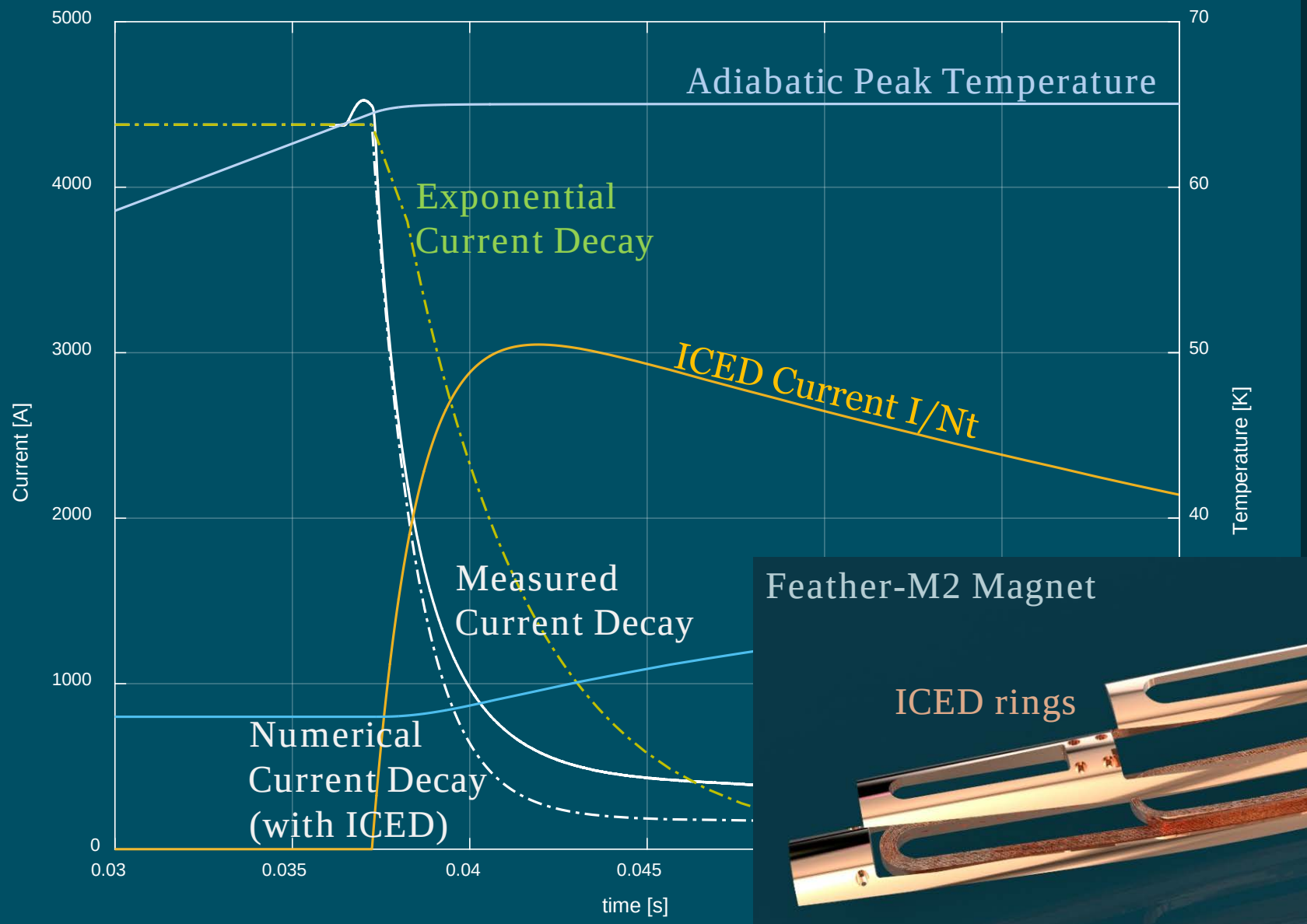
Measured N-Values



- The N-values were determined by fitting the power law to the measured electric field versus current
  - $E = E_0 \left[\frac{I}{I_c}\right]^N$
- In Essence it is the slope on log-log plot near the critical current
- N-values are very low. Likely an effect of current sharing and joint resistance



Measured Current Decay during Dump



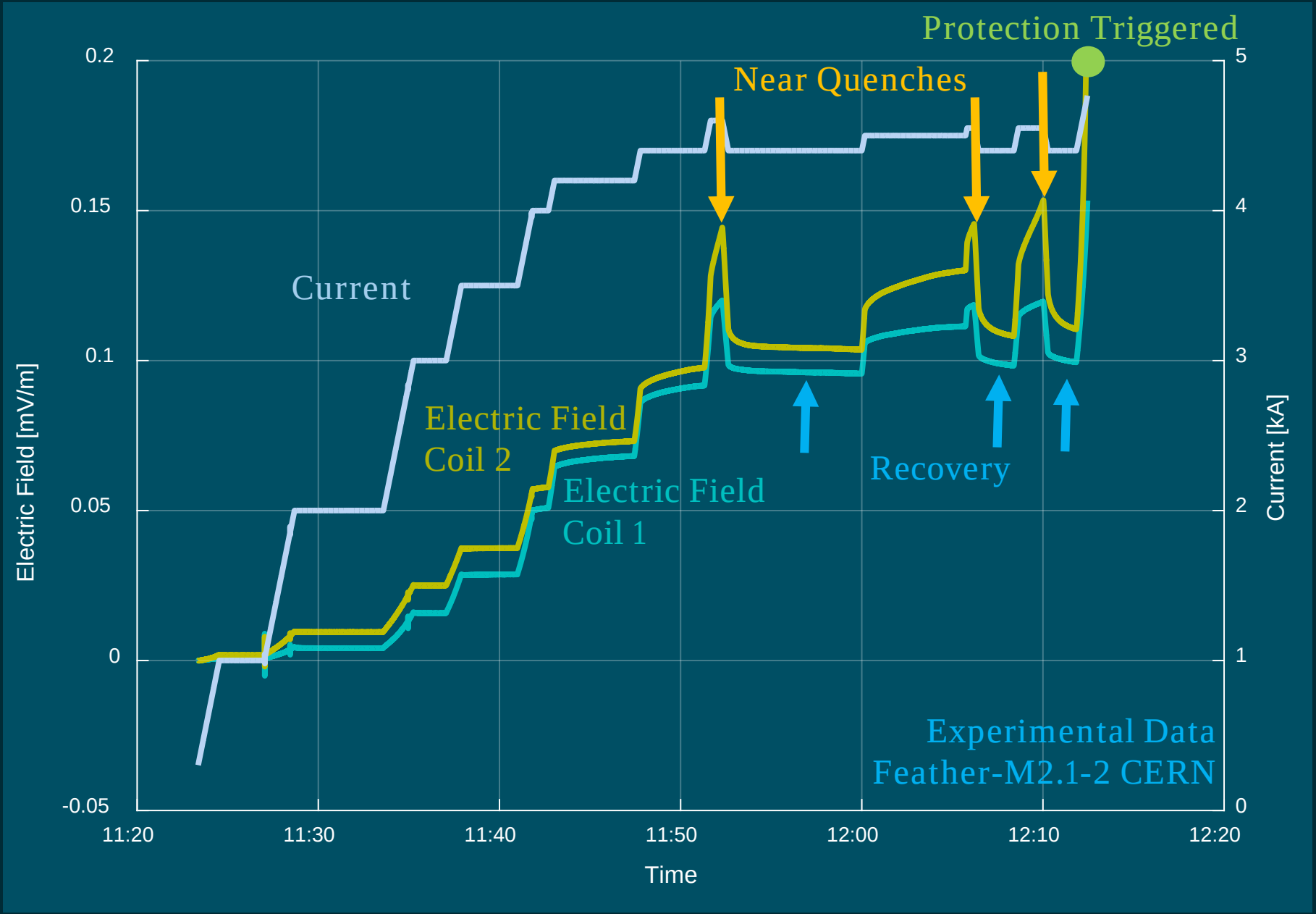
- Measured current decay is more similar to the numerical model with ICED than theoretical exponential decay.

- Conclusion
  - Part of the current is jumping into the ring when the protection is triggered: ICED works as expected.

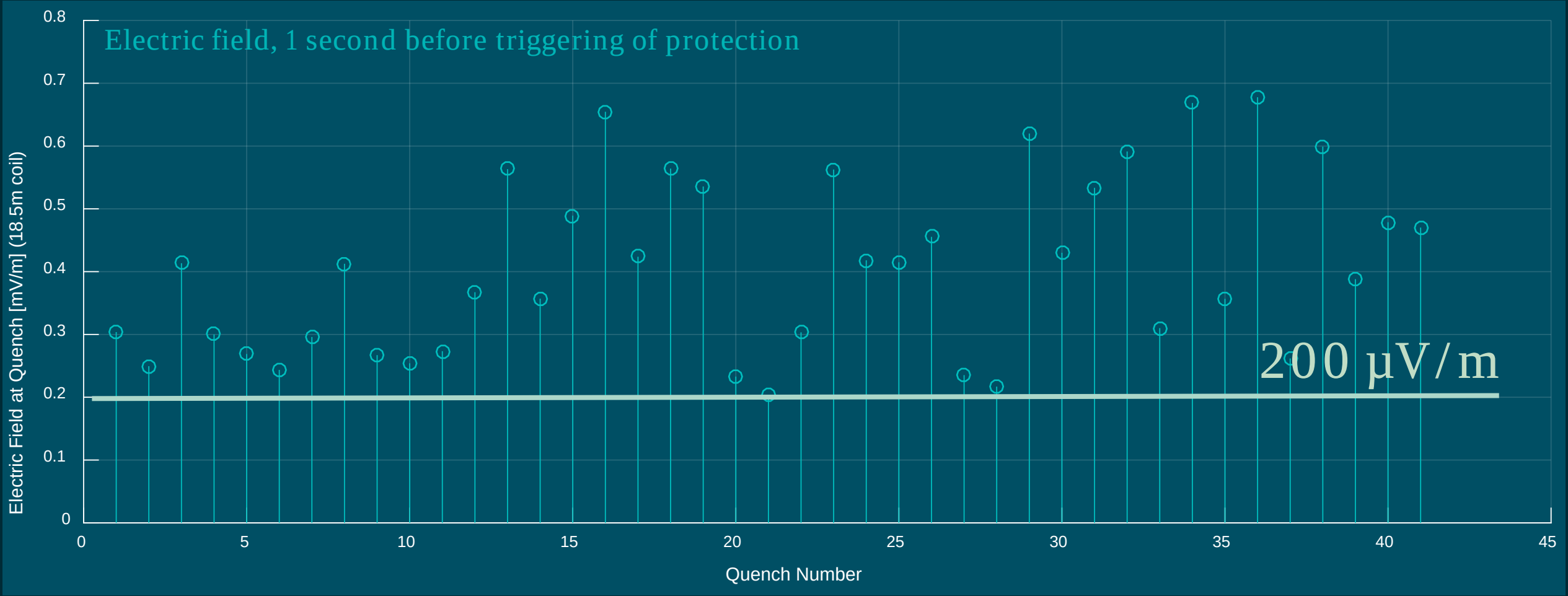
Detecting the Onset of a Quench I (electric field)

- Drift in the electric field is a clear indication that the magnet is about to quench
- If not ramped fast, the electric field starts drifting minutes ahead of time
- Reduction of only 100 A results in immediate recovery!

- Conclusion
  - If this behaviour is also present in higher current density magnets this could be a viable method for protecting future HTS magnets



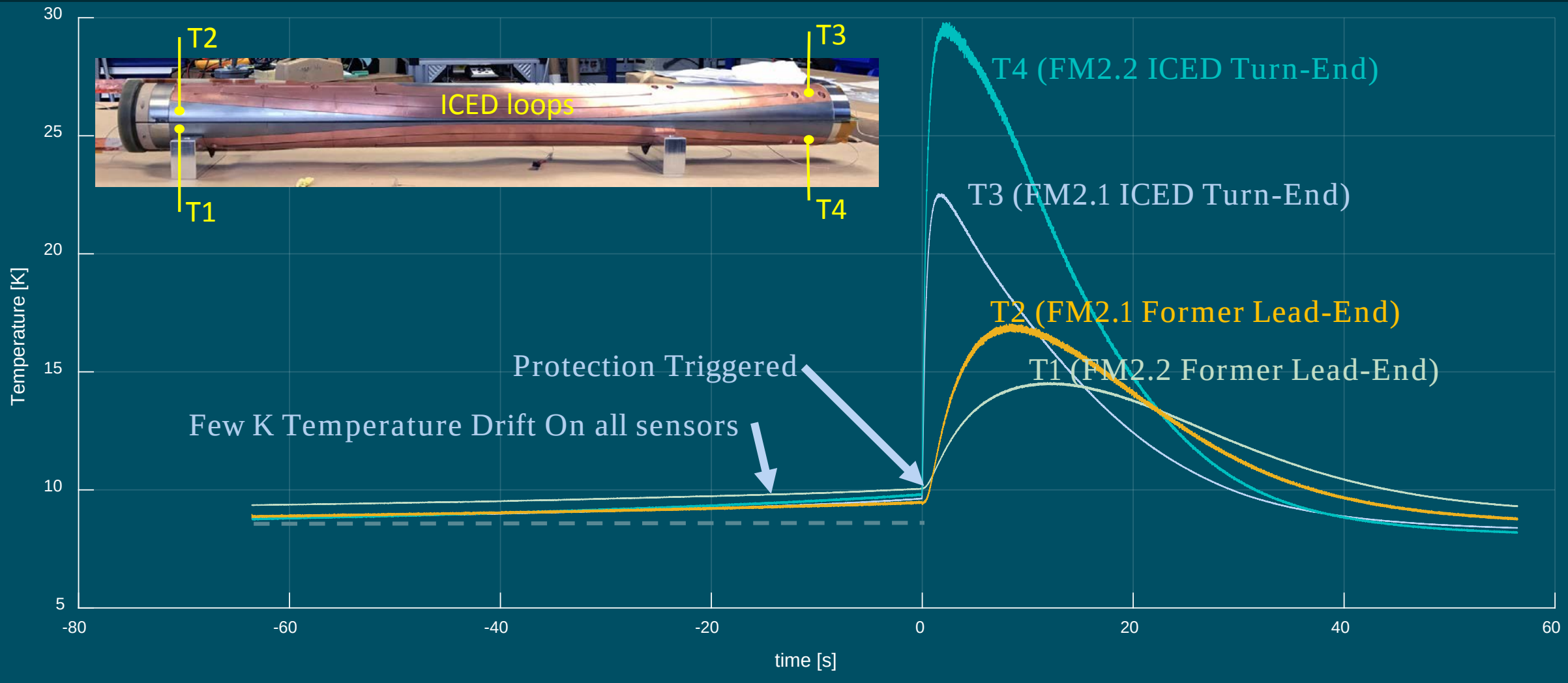
Detecting the Onset of a Quench II (electric field)



- All quenches occur over an electric field of 200 µV/m
- Only quenches due to exceeding critical current

- Conclusion
  - No unexpected quenches due to cracking of resin, flux jump, training etc.

Detecting the Onset of a Quench III (temperature sensors)



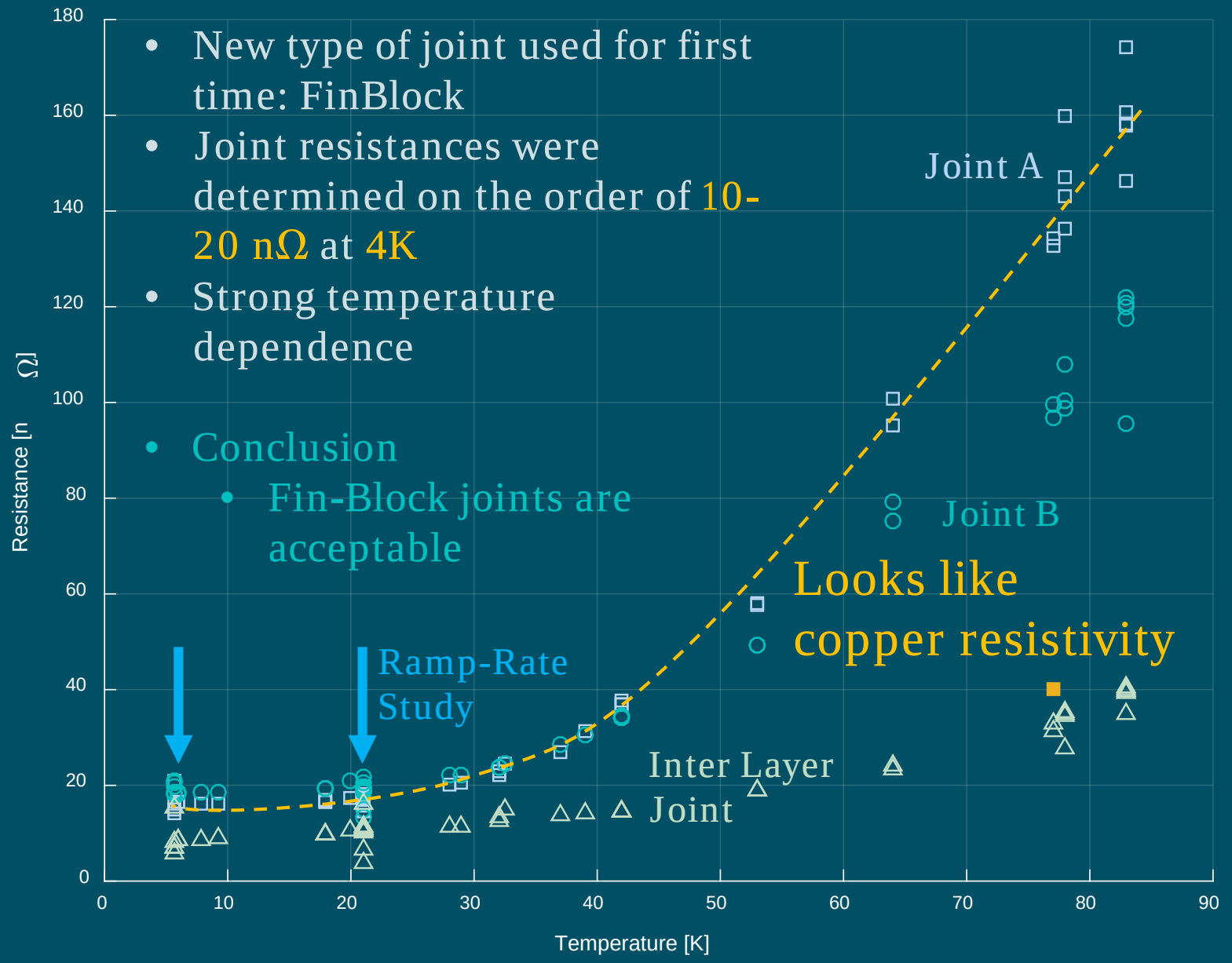
- Temperature drifts away before quench
- Having distributed temperature sensing (i.e. temperature map of the coil) should yield interesting results when magnet is in current sharing regime

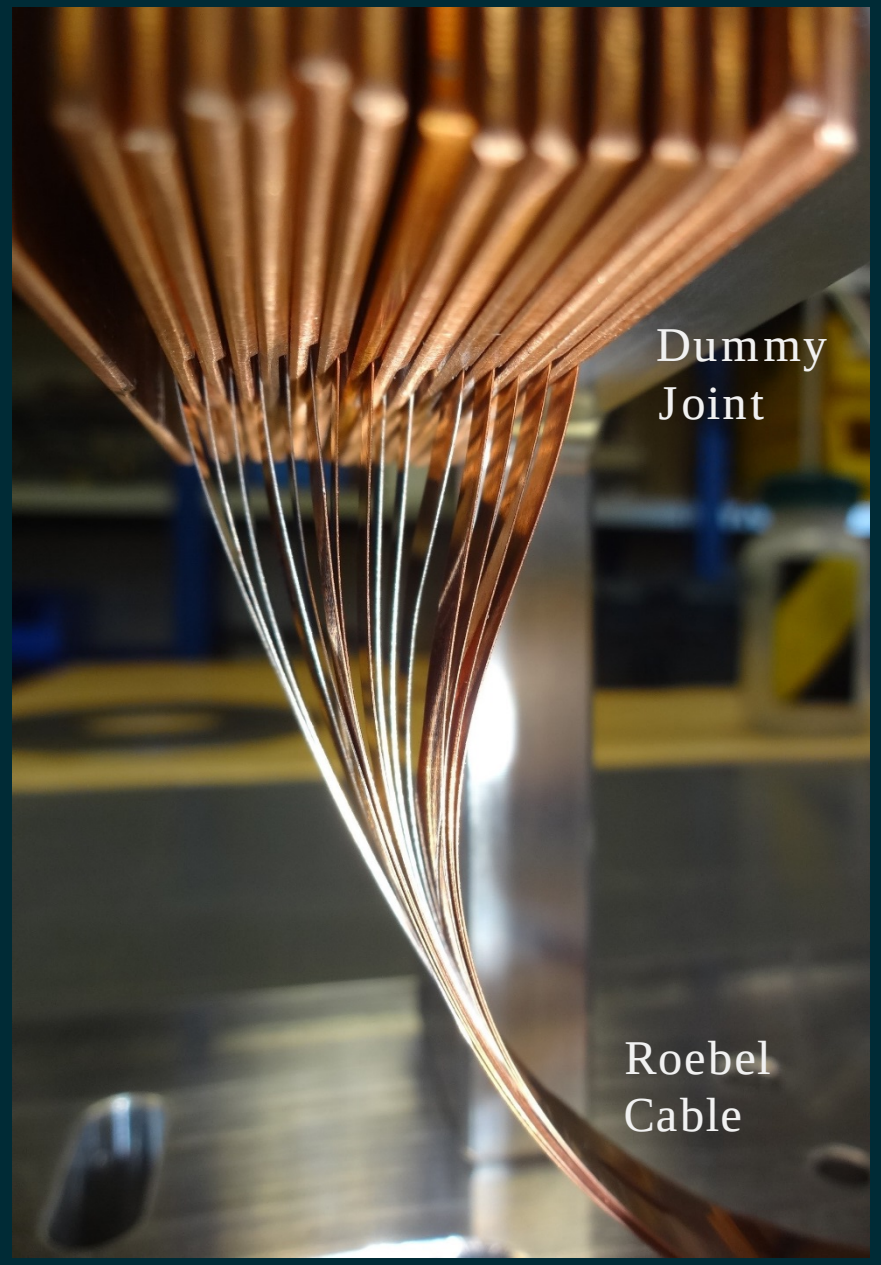
- Conclusion
  - Onset of quench also visible on temperature sensors

Joint Resistances (fin-block)

- New type of joint used for first time: FinBlock
- Joint resistances were determined on the order of 10-20 nΩ at 4K
- Strong temperature dependence

- Conclusion
  - Fin-Block joints are acceptable



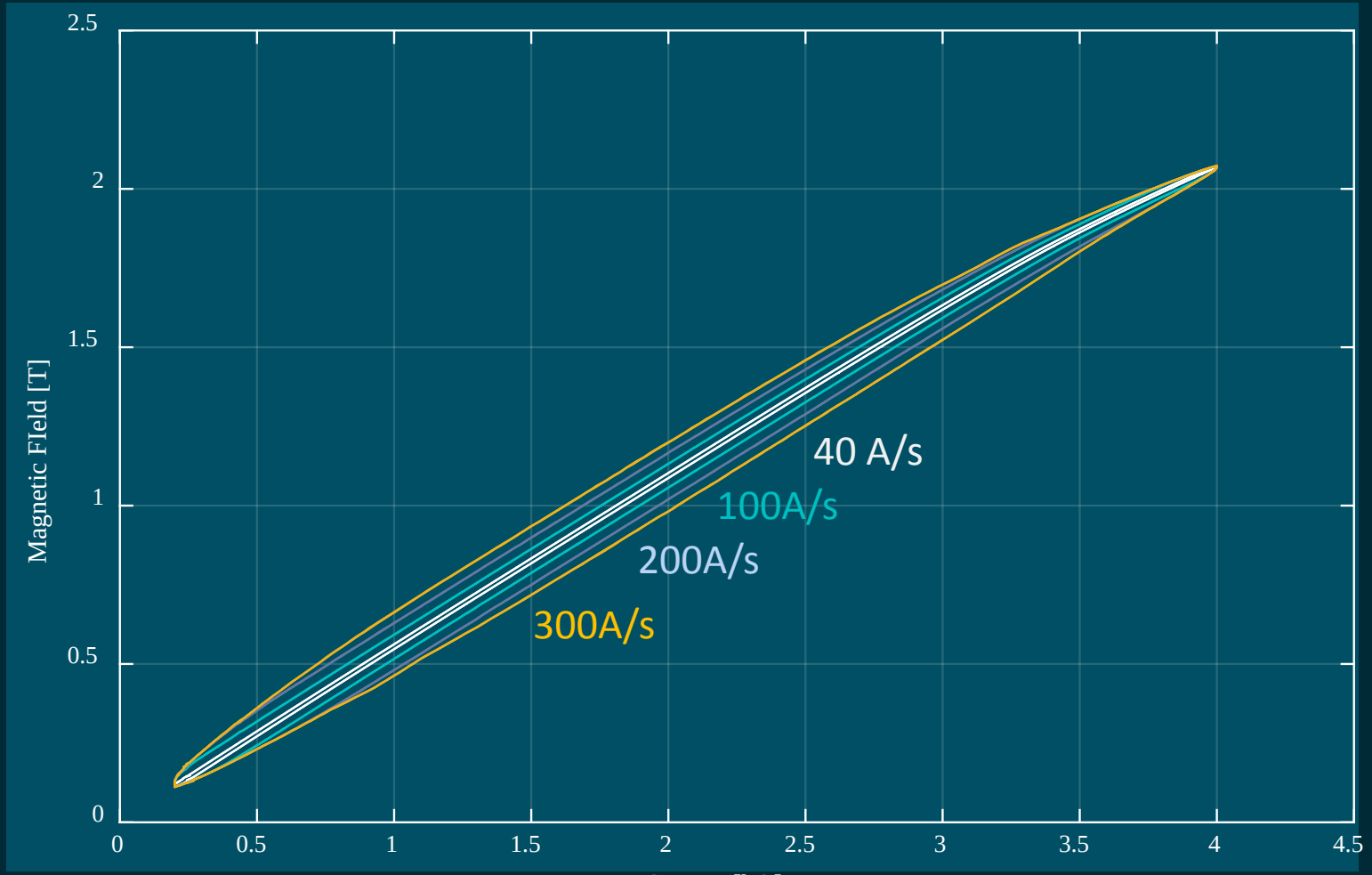


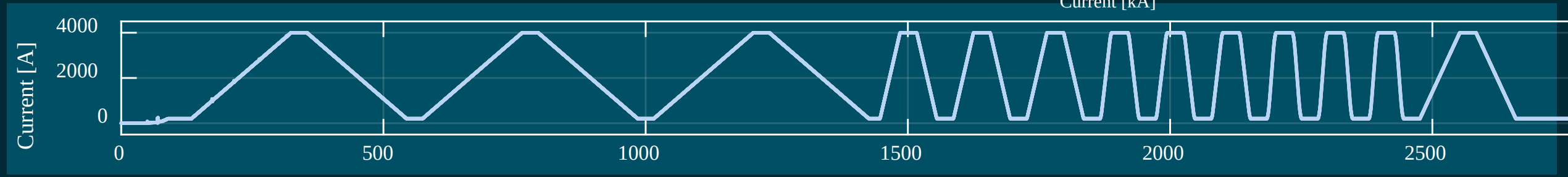
Magnetic Measurements I (resistive effect)

- Magnetic field in aperture was measured using Hall effect sensors
- Hall sensors were cross-calibrated with pick-up coils

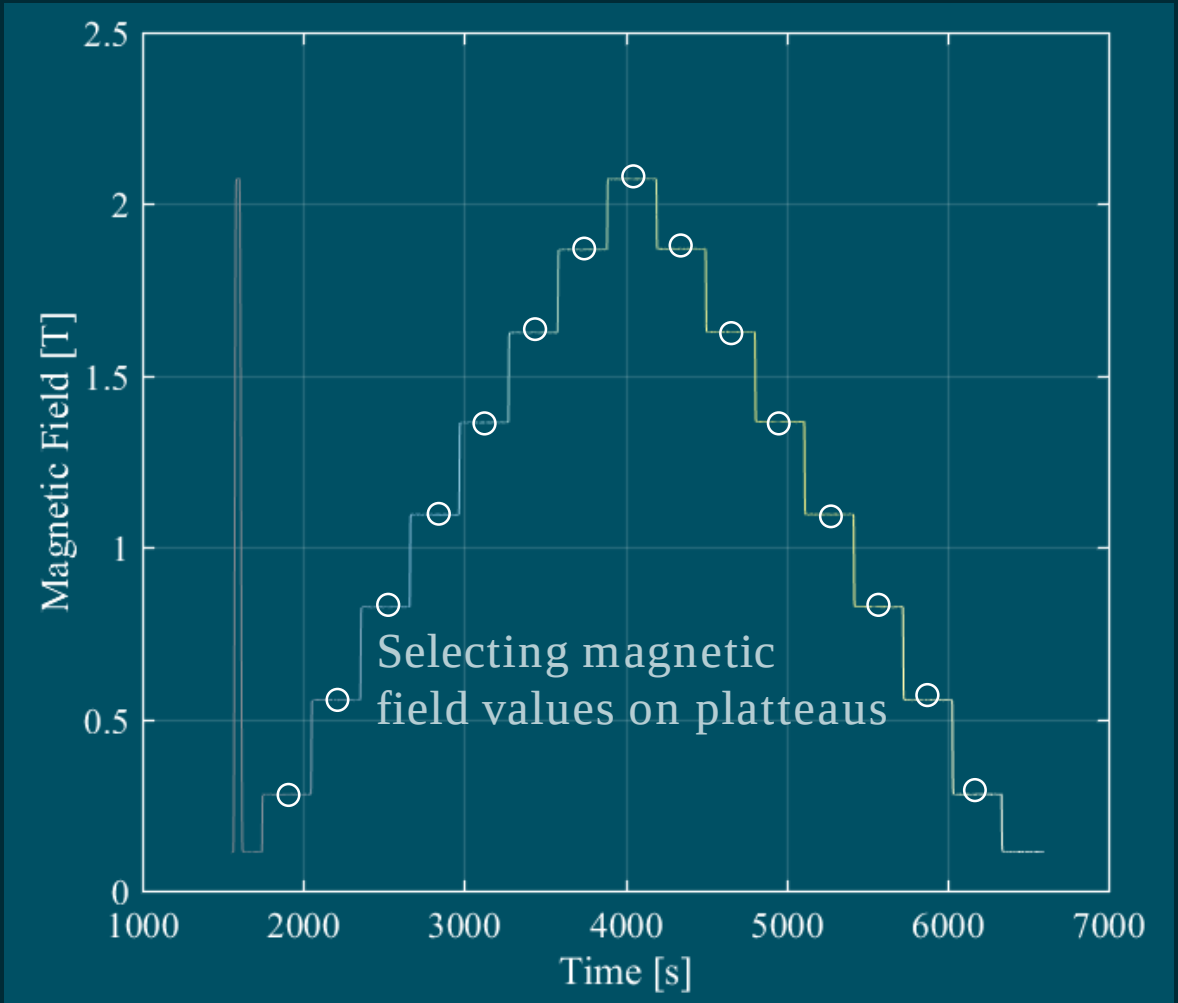
- The hysteresis (lagging behind) of the magnetic field with the transport current strongly depends on ramp-rate
- This is likely the current induced in the copper ICED ring due to the time-changing magnetic field
  - i.e. the ring tries to resist a change of magnetic field
  - Actually appears as coupling due to its frequency dependence

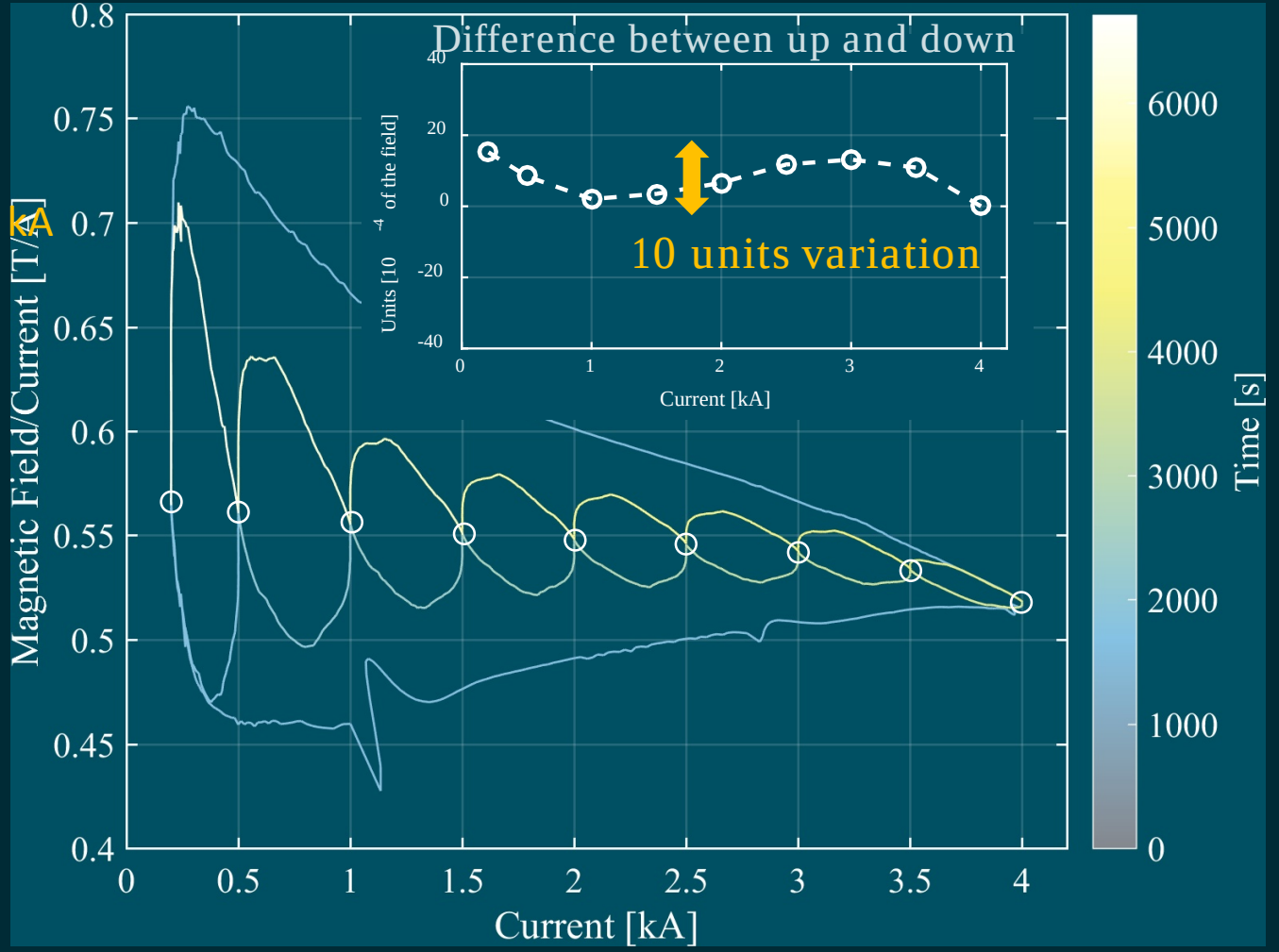
- More on this effect in EUCAS 2017 by Carlo Petrone





Magnetic Measurements II (persistent current effect)





- To measure only steady state effects a staircase ramp was performed
- The acceleration and deceleration of the power supply give interesting pearl necklace effect
- Difference between ramping up and down is persistent current effect
- Only 10 units variation, likely due to the alignment of the field by the iron

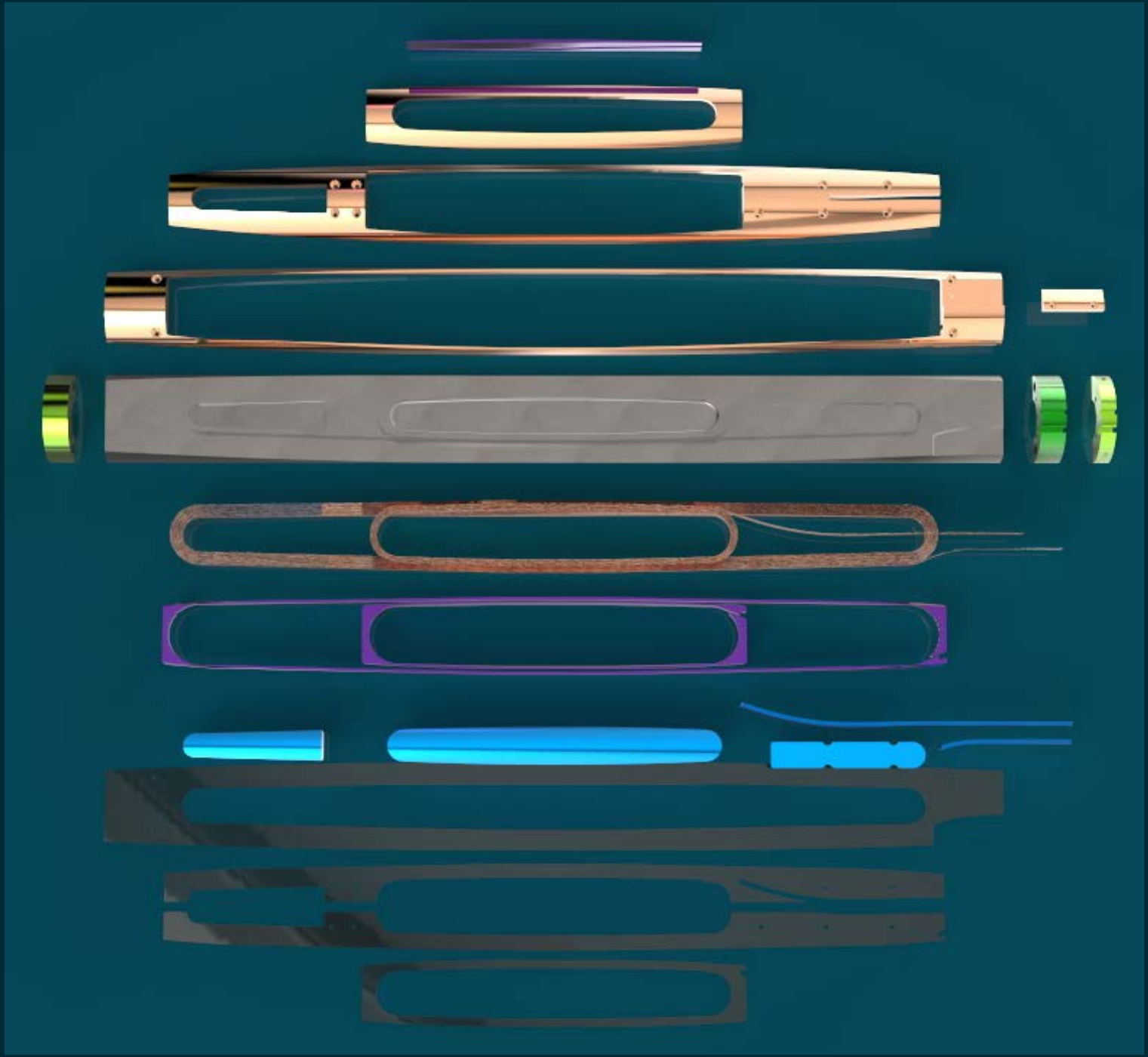
- Conclusion
  - Only 10 units variation due to persistent currents
  - More on this in EUCAS 2017 by Carlo Petrone

Conclusion

- The EUCARD2 Feather-M2.1-2 magnet with SuperOx cable assembled Sunam tapes was tested successfully
- The results from the test are interesting and provide valuable insight in the use of HTS in an accelerator magnet
- Detecting quenches minutes ahead of time may be possible
- The performance of the magnet was relatively low due to the batch of (cheaper) low performance tape used
- The next magnet Feather-M2.3-4 with Bruker tape has the potential of reaching very high currents/fields
- The future looks bright for HTS

strand no.	77K/SF	Ic 4.2 K/5T	length (m)
1	98	3050	29.2
2	98	3050	29.2
3	98	3050	27.1
4	81	3100	29.2
5	150	3097	27.4
6	140	3237	28.3
7	146	2304	25
8	210	2935	28
9	140	3237	28.3
10	123	2709	30
11	140	3237	28.3
12	140	3237	28.6
13	210	2935	28

39 kA @(4.2 K, 5 T, pp)
Estimated: 18 kA @(4.2 K, 20 T, pp)
Woah...(=



Thank You

for your attention