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Development of high current CORC® cables, CICC, and low resistance demountable joints for fusion magnet applications

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MT29 2025, Boston, Massachusetts, July 5th, 2025

TYPE ONE ENERGY

cea

UK Atomic Energy Authority

BERKELEY LAB

Commercial development of CORC® cables for fusion applications

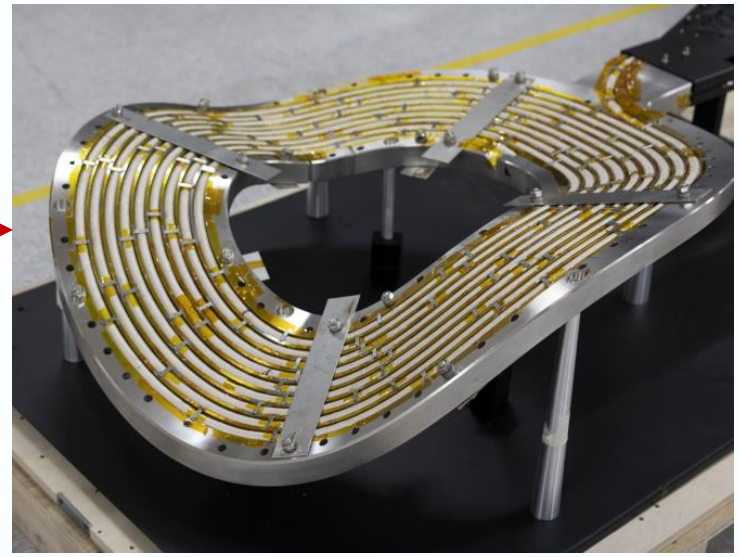
High tape count CORC® cables

CEA Cadarache (DEMO):

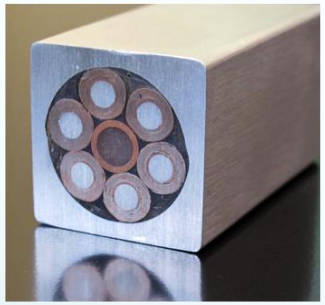
- 120-tape CORC® cable containing SnPb solder plating

Type One Energy Group (Stellarator magnets):

- 96-tape CORC® cable with bending flexibility down to 250 mm diameter



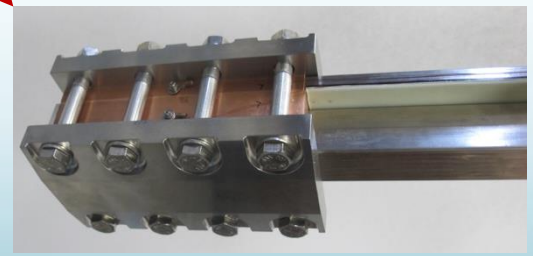
https://typeoneenergy.com/type-one-energy-begins-testing-fusion-magnet/

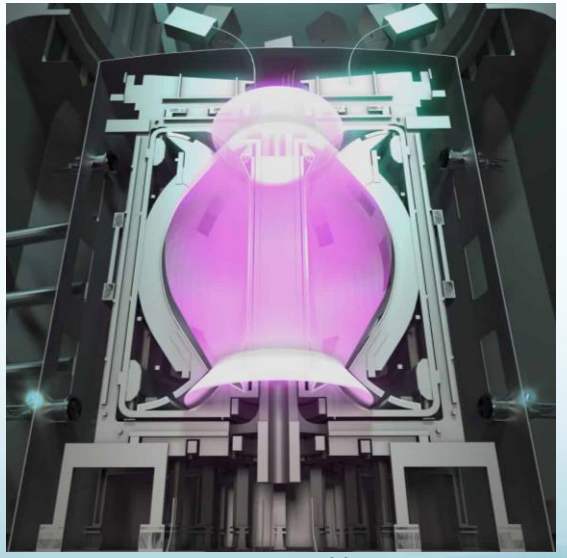


CORC®-CICC

UKAEA (STEP):

- CICC layouts for various magnets
- Demountable joints between CORC®-CICC for TF coils





https://step.ukaea.uk

TYPE ONE ENERGY

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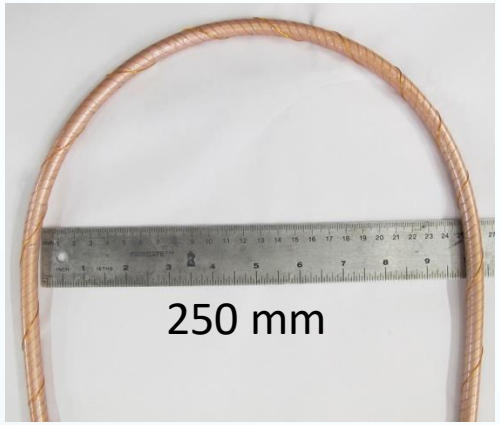
BERKELEY LAB

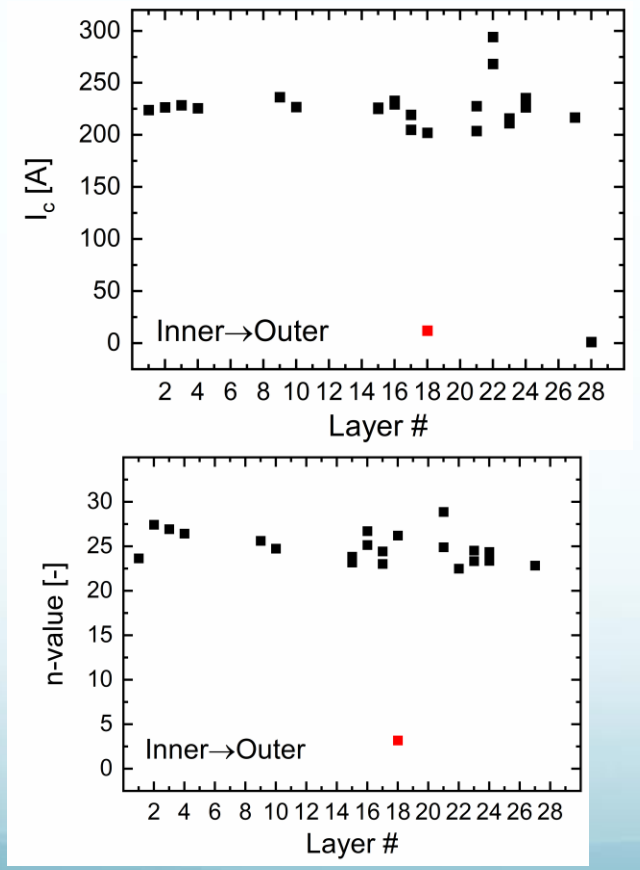
96-tape CORC® cable with high flexibility for Stellarators

TYPE ONE ENERGY

Type One Energy Group Stellarator magnets

- 96 tapes of 4 mm width wound into a 10.4 mm O.D. cable
- Continuous length of 56 meters
- Optimized for bending to 250 mm diameter
- **Extracted tape measurements show nearly 100 % I_c retention**





56 meters of CORC® cable

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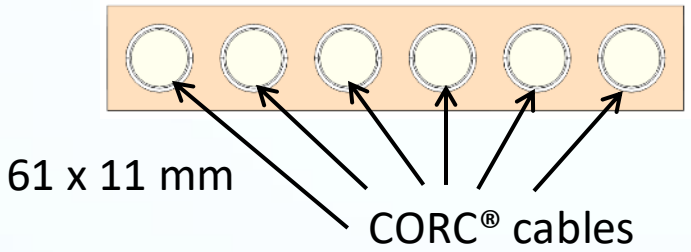
CORC®-CICC demountable joints copper-to-copper joints

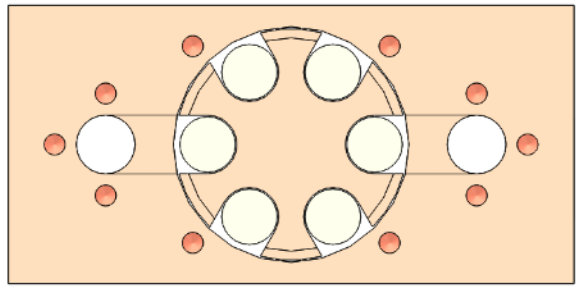
Two CORC®-CICCs

- 6 CORC® cables in-plane
- 6-around-1 CORC®-CICC

Termination cross-section



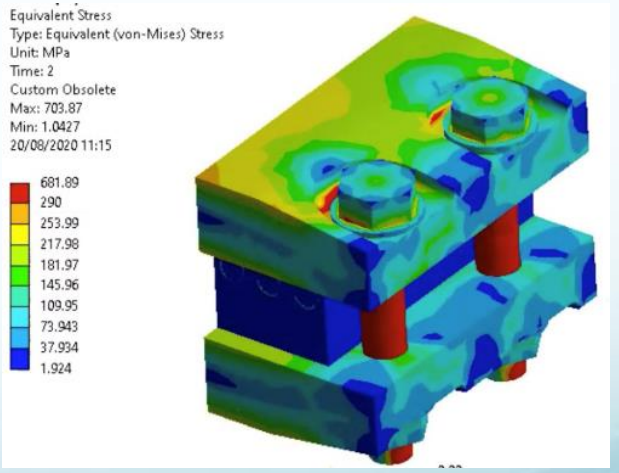
6x1 round CORC® CICC
(cables contain 12 tapes each)



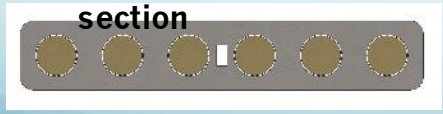
Joint: 61 x 30 mm
CICC: 30 x 30 mm

Joint design

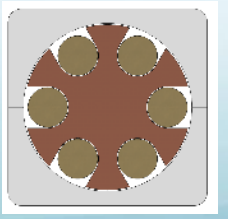
- Annealed copper plates
- Clamping structure to ensure 10 MPa contact pressure



CICC cross-section



CICC cross-section



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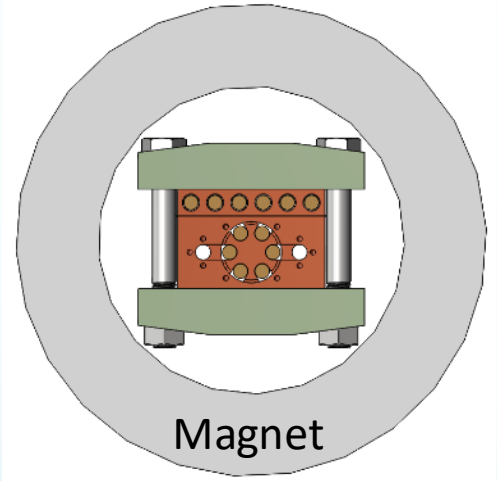
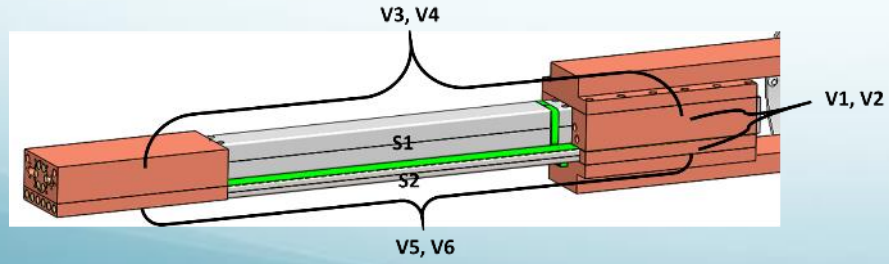
CORC®-CICC copper-to-copper joint performance at 4.2 K

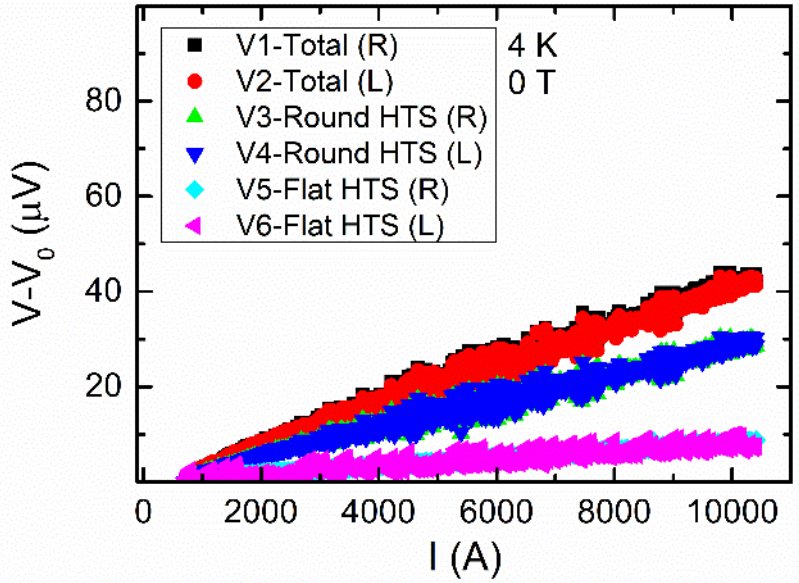
Joint test

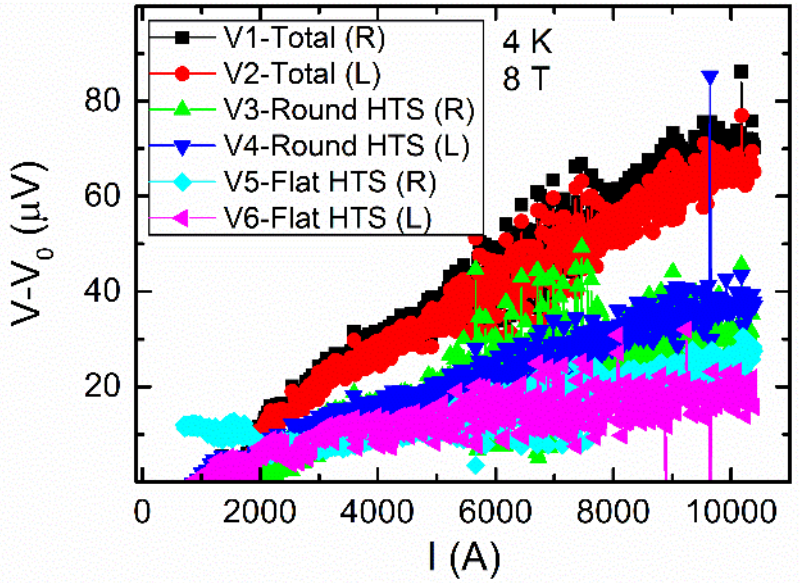
- In liquid helium (4 K)
- Joint in superconducting magnets (8 T)

HTS 6x1 to HTS plate joint









Pressure joint resistance around 1 nΩ at 4 K at currents as high as 10 kA

B [T]	Average Resistance (4 K) [nΩ]			
	Total (V1,V2)	Round HTS (V3,V4)	Flat HTS (V5,V6)	Joint
0	4.1	2.8	0.8	0.5
4	5.2	3.0	1.3	0.9
6	6.1	3.4	1.5	1.2
8	6.9	3.6	1.9	1.4

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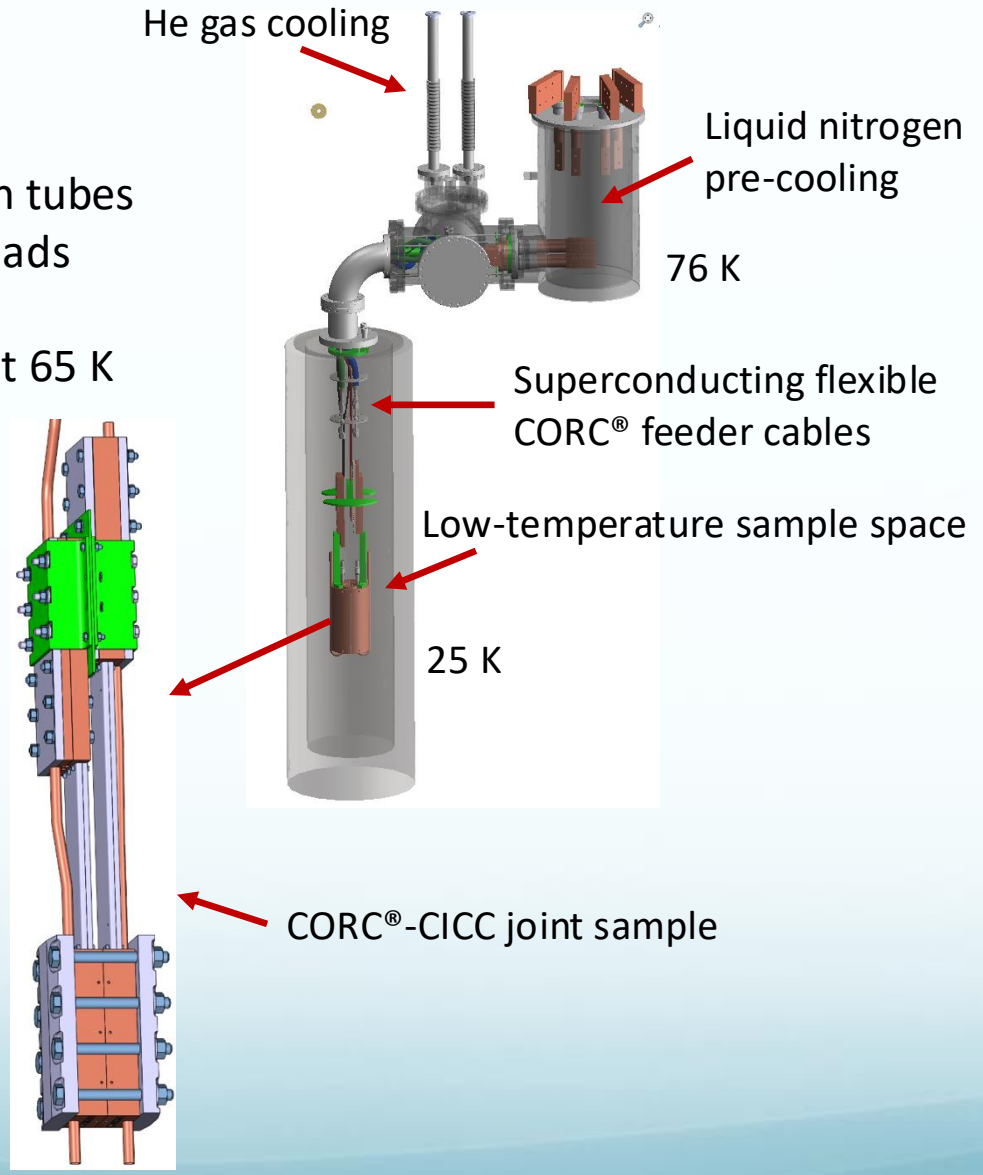
Testing CORC®-CICC joints at 25 K

Testing at up to 5 kA at 25 K

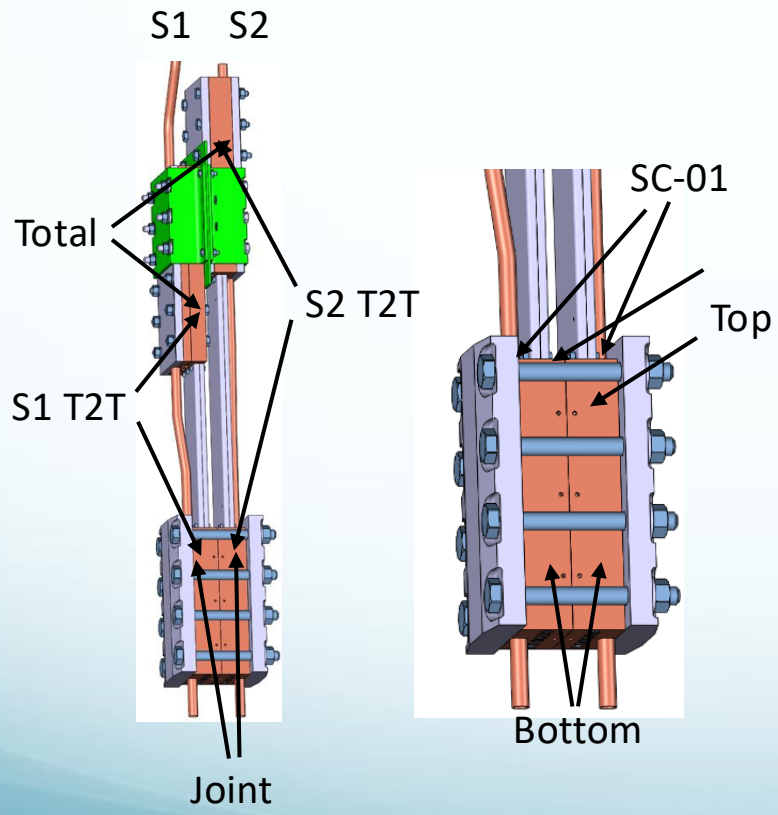
- Sample in vacuum space
- Cryogenic helium gas cooling through tubes
- Liquid nitrogen pre-cool of current leads from room temperature
- GHe CORC® feeder cables from LN_2 at 65 K to sample at 25 K



Test results at 25 K: Silver-plated copper interface

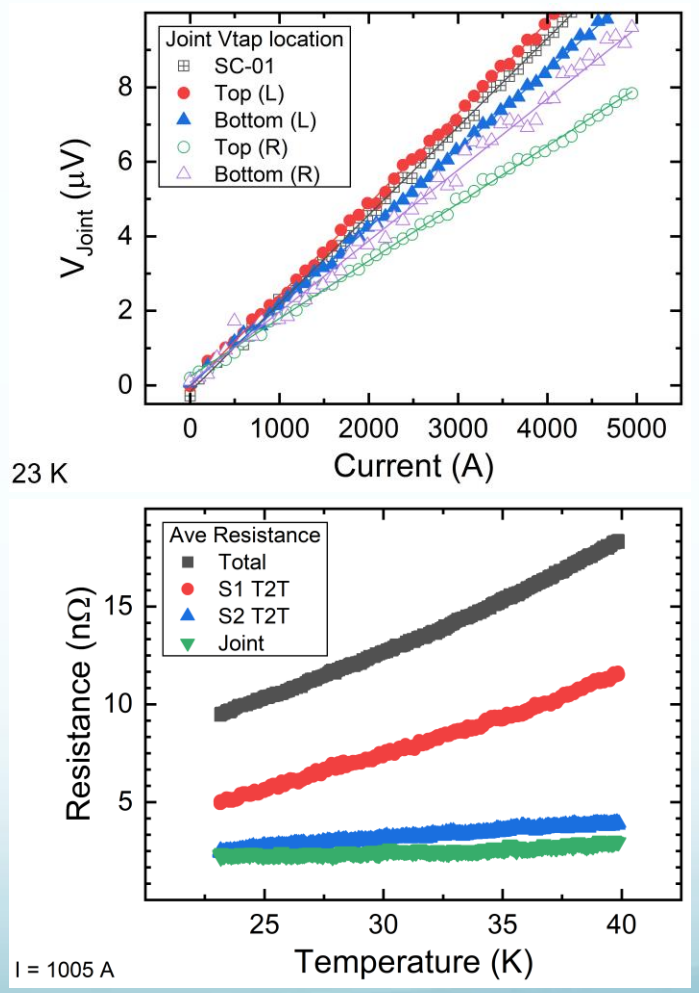
Sample details

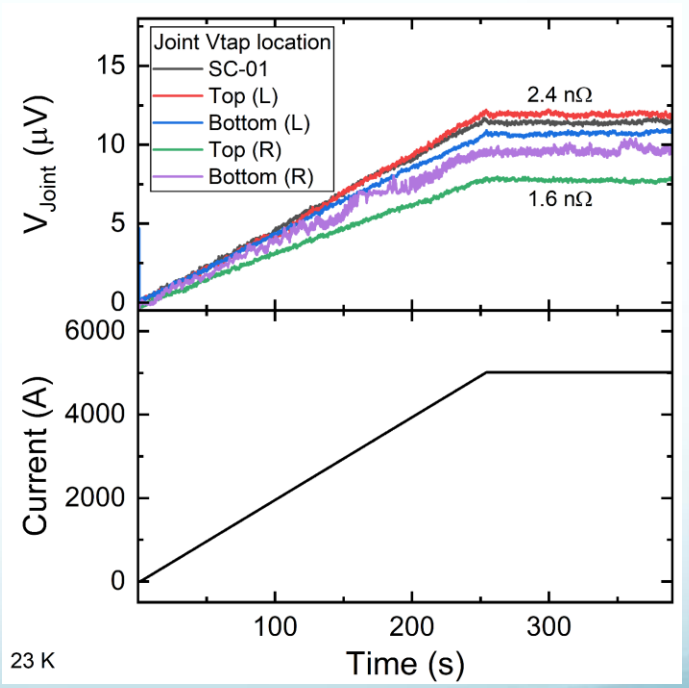
- Two samples with 6 CORC® cables in-plane
- Silver plated copper interface
- Clamped at 15 MPa



Name	Resistance (nΩ)
SC-01	2.4
Top (L)	2.4
Bottom (L)	2.1
Top (R)	1.5
Bottom (R)	1.9
Calculated*	2.3

*R(total) – R(S1 T2T) – R(S2 T2T)





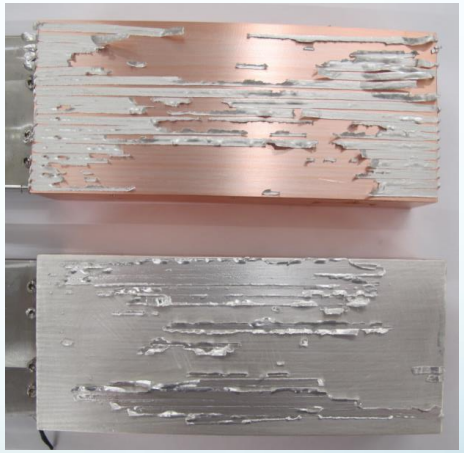
Test results at 25 K: indium wire interface

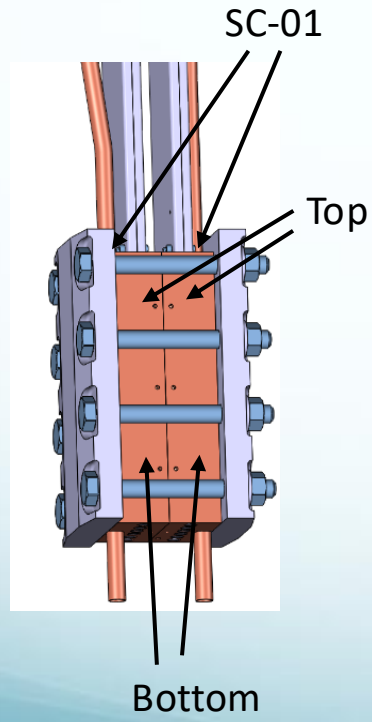
Sample details

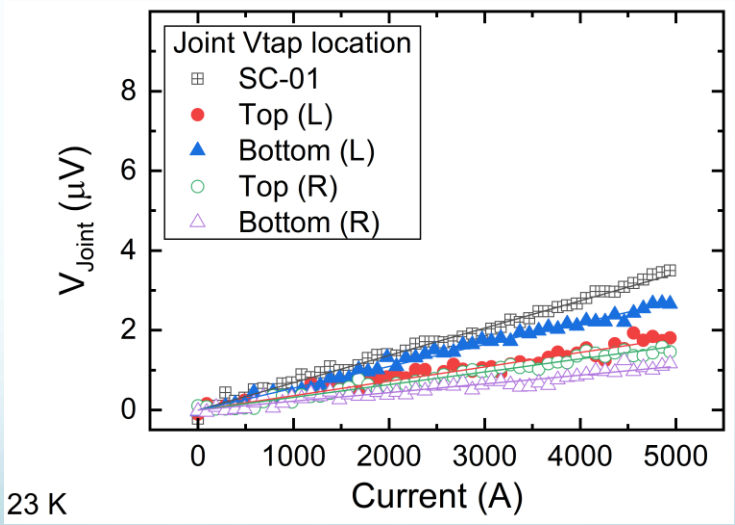
- Two samples with 6 CORC® cables in-plane
- Silver plated copper / copper interface
- Indium wire
- Clamped at 15 MPa

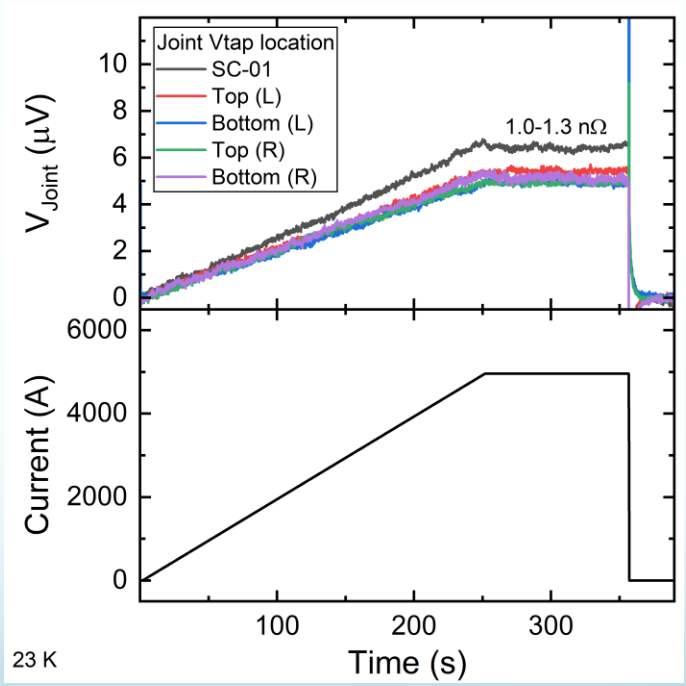
Name	Resistance (nΩ)
SC-01	0.7
Top (L)	0.4
Bottom (L)	0.5
Top (R)	0.3
Bottom (R)	0.2
Calculated*	0.2

*R(total) – R(S1 T2T) – R(S2 T2T)

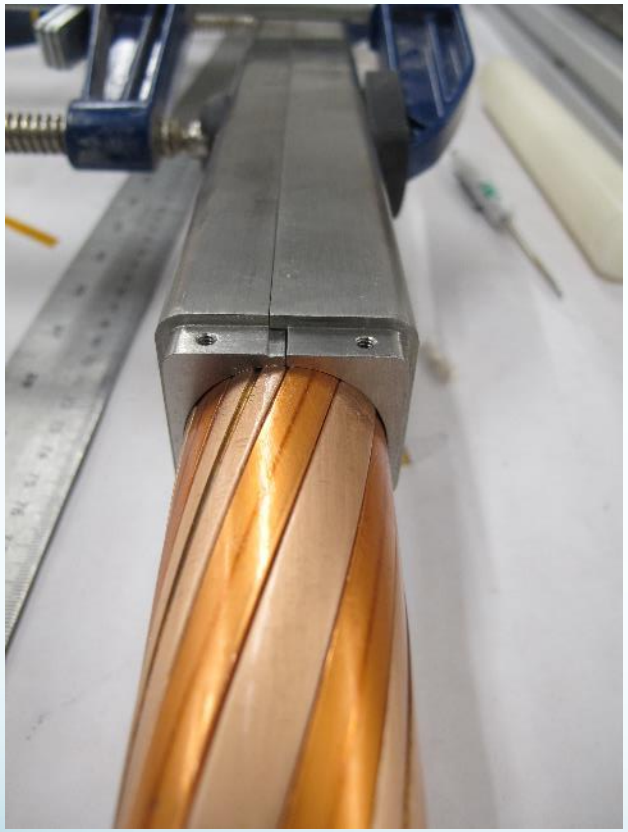






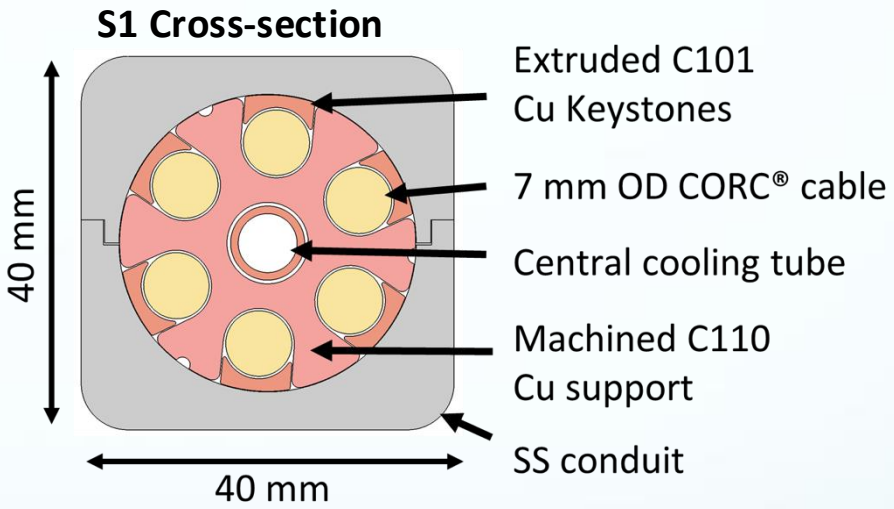


CORC®-CICC testing in SULTAN



CORC®-CICC design with mechanically decoupled cables

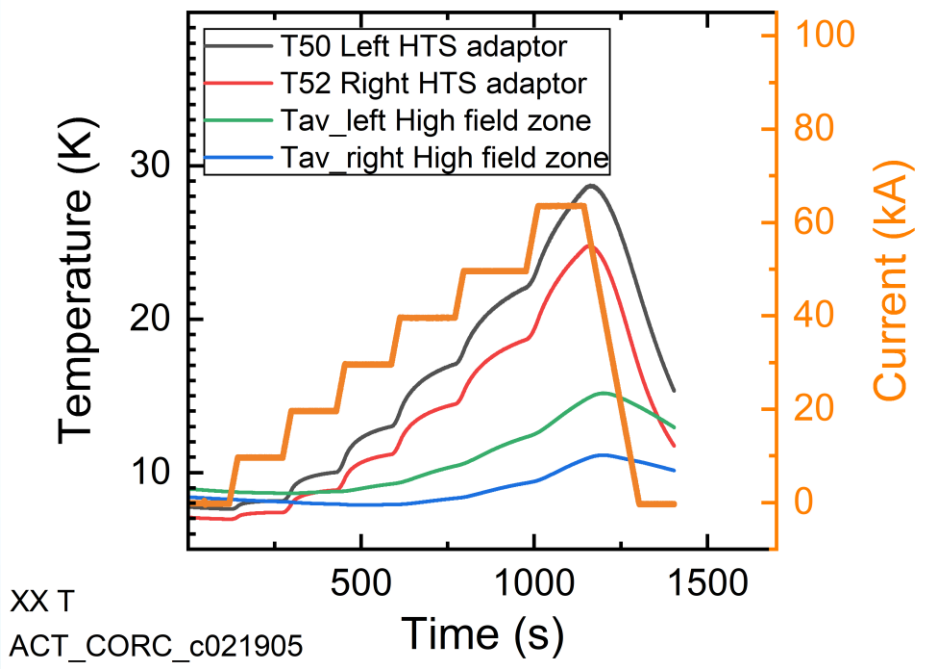
- **S1**: Six 36-tape CORC® cables (216 4 mm wide AP tapes)
- **S2**: Eight CORC® cables
- Each cable instrumented with voltage wires
- Designed for 80 kA at 10 T and 4.2 K
- Central copper support with grooves
- Single cooling central tube

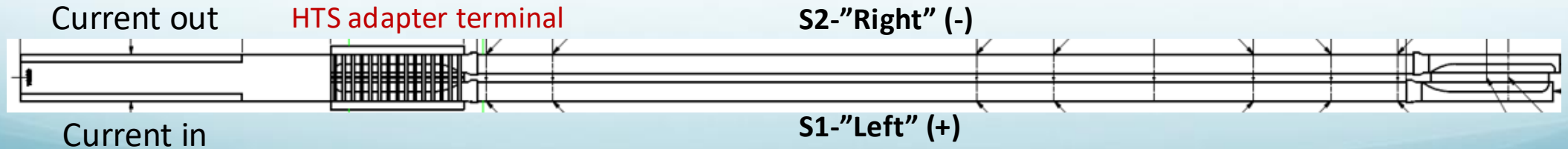


Temperature increase due to inadequate cooling

High current operation in self-field

- Current increased stepwise to 60 kA
- Temperature of HTS adapter increases significantly at high current





Thermo-electric voltages drive current redistribution in Sample 1

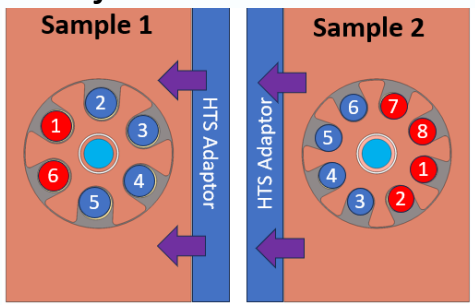
Thermoelectric voltages are driving current distribution

- Continuous current of 10 kA at 0 T field
- Increasing the temperature of both sample legs

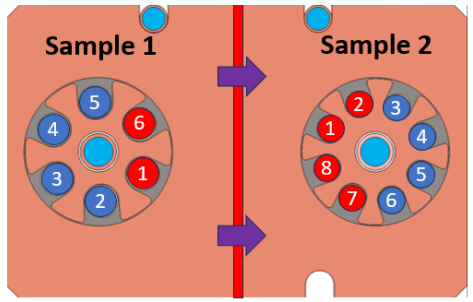
Sample 1

- Voltage goes negative for cables 1 and 6 at t = 800 s
- **Current in CORC® cables 1 and 6 reverses direction!**

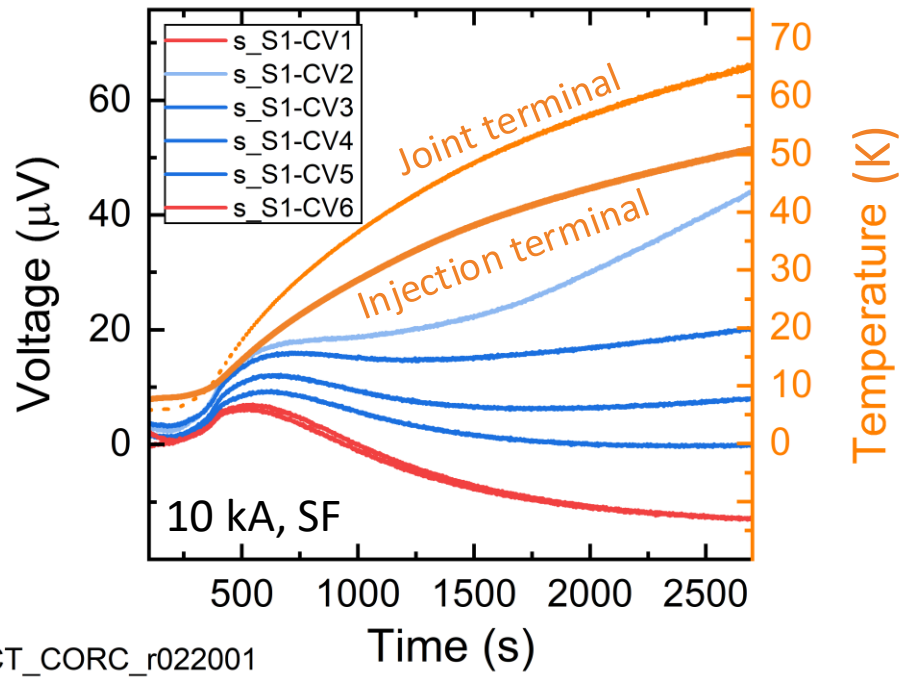
Injection terminals

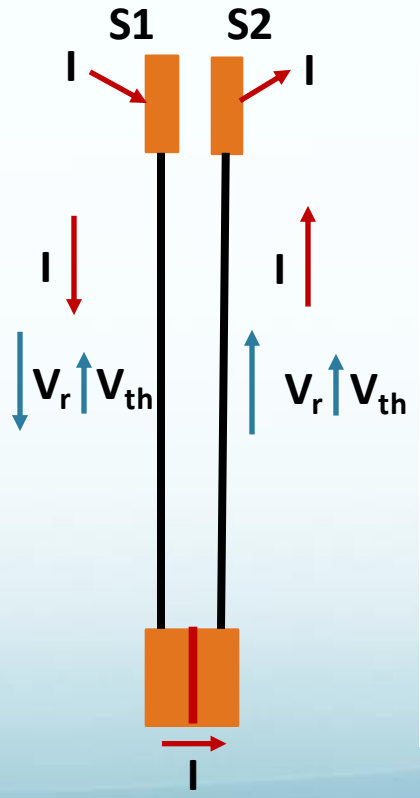


Joint terminal

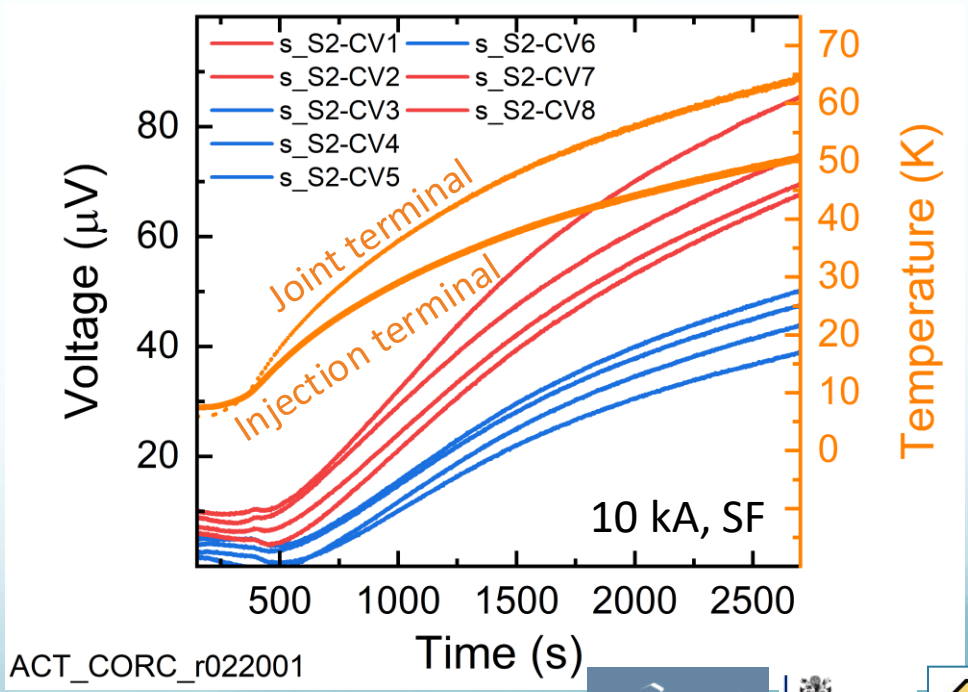


Sample 1: Negative thermoelectric voltage





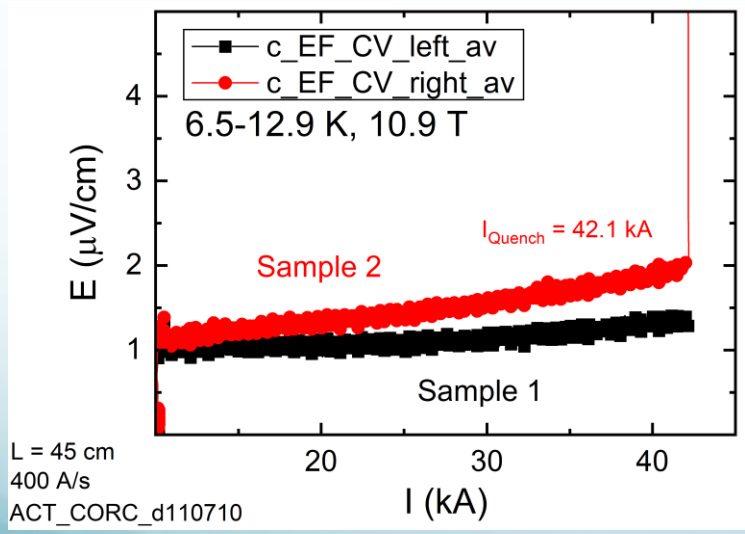
Sample 2: positive thermoelectric voltage

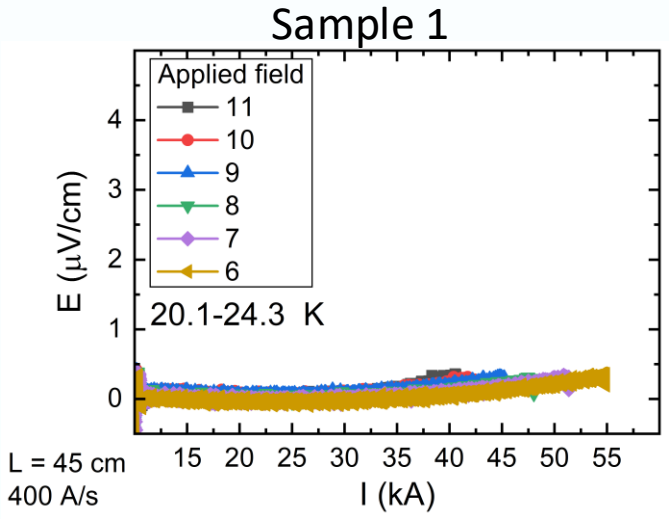


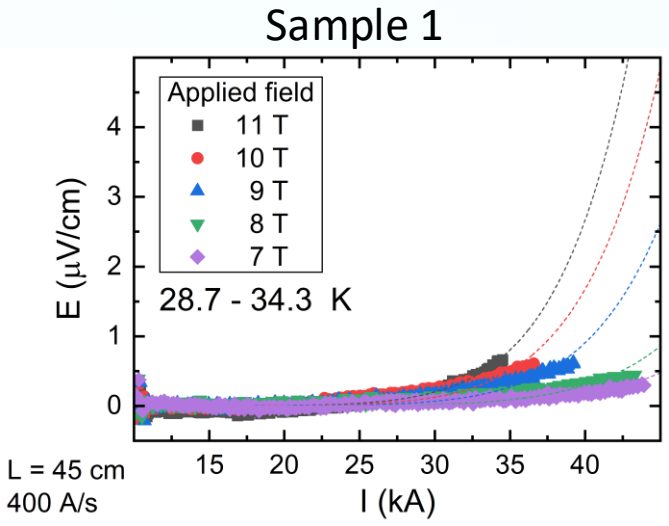
CORC®-CICC SULTAN test results

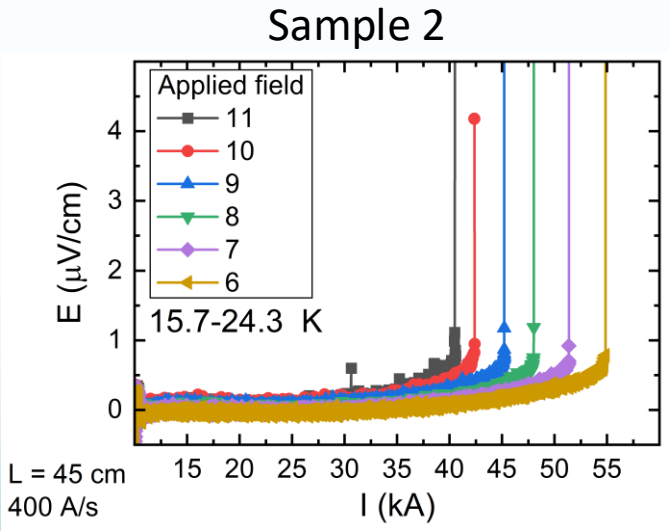
Performance tests

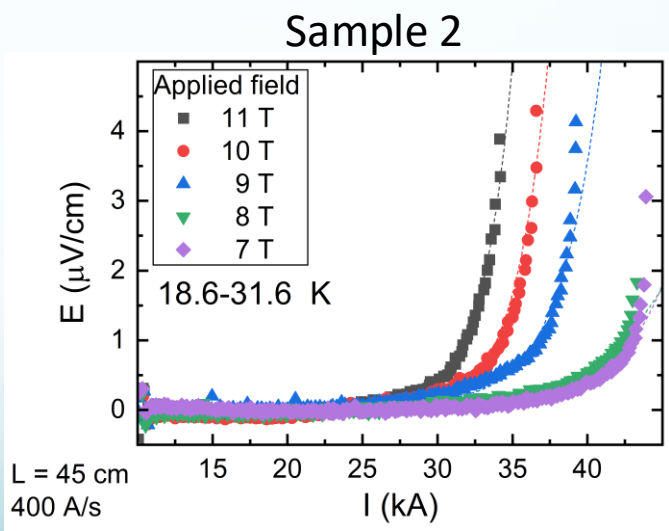
- Sample 2 limits the performance due to higher level of heating
- Only at higher temperatures, both legs are transitioning at the expected current



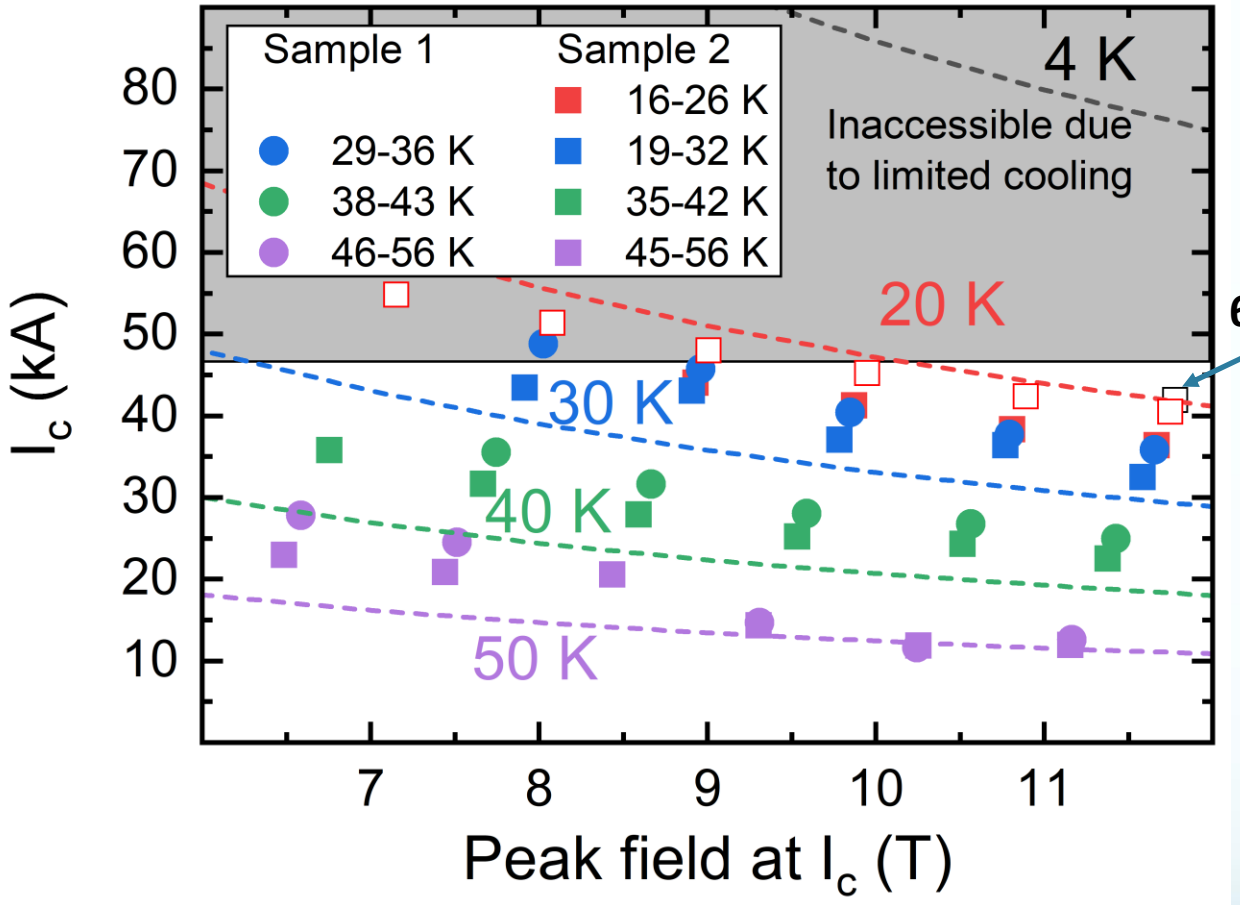








CORC®-CICC SULTAN test results summary



Results

- Dashed lines are 216 x 4 mm wide tape I_c(B) at 4.2 K scaled using SuperPower spec
- Below 20 K, Sample 2 (S2) tended to quench well below expected I_c
- Quenches at low temperature due to inadequate cooling of sample
- Testing at 4 K not possible, because the current heated the sample to 6.5 - 13 K
- No mechanical degradation

Summary

Expanding to high tape count CORC® cables

- 96-Tape CORC® cable with relatively high bending flexibility for Stellarator magnets
- 120-Tape CORC® cable wound from tapes with SnPb solder coating

CORC®-CICC joint development

- Demonstrated joint resistance of pressed copper interface between CORC®-CICCs of around 0.5 nΩ at 4 K in self-field and 1-2 nΩ at up to 8 T
- Demonstrated joint resistance between silver plated copper terminals of around 2 nΩ at 25 K
- Joint resistance could be reduced to and less than 0.5 nΩ at 25 K by applying indium wires to the interface

CORC®-CICC SULTAN test

- Performance of latest CORC®-CICC SULTAN sample limited by inadequate cooling due to poor thermal contact between cooling line and terminals
- Sample performed as expected at temperatures above 20 K
- Thermoelectric voltages drive current distribution in sample with very high temperature gradients
- Although only tested to about 50 % of design load, the sample showed no mechanical degradation