ARIES

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Le Palace

Recent progress on HTS conductors for high-field magnets: critical surface studies

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Outline

Activities on HTS for HEP magnets in EC programs

- ***R&D goals from FP7 EuCARD² to h2020 ARIES***

Overview of the measurement campaign on R&D YBCO tapes from BRUKER

- ***Transport I_c measurements up to 2 kA in variable temperature and at various orientations***

Very recent tests on new high-performance REBCO tapes from Fujikura and SuperOx

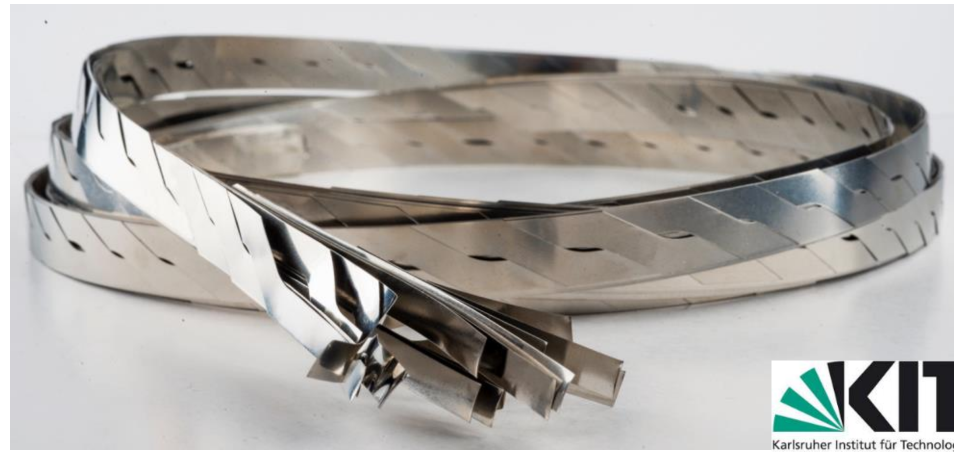
Conclusions

Towards 20+ T dipoles: the call for HTS

Advances in R&D from FP7 EuCARD² to h2020 ARIES

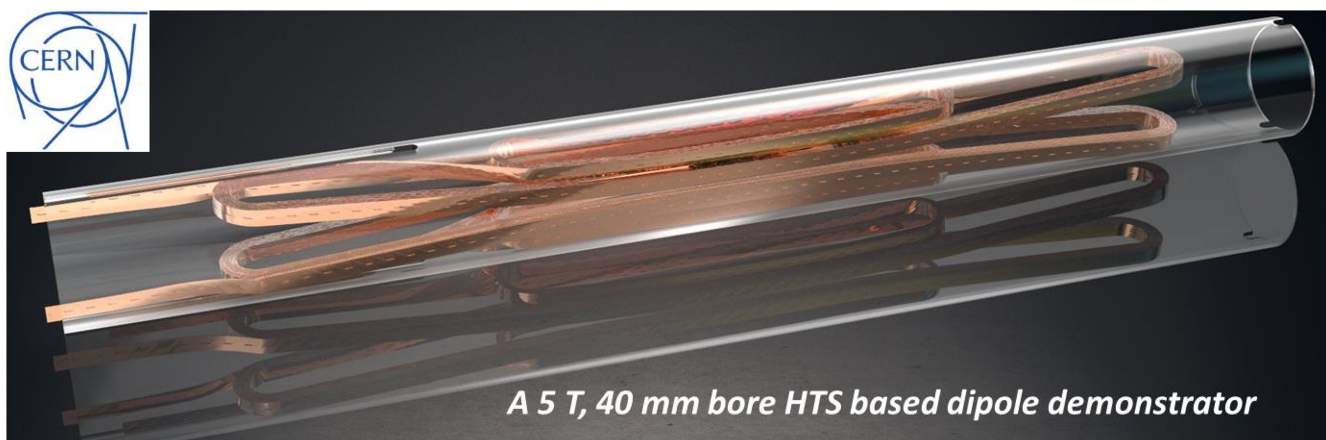
EuCARD² has developed

- ***a HTS CONDUCTOR for accelerator dipoles (10 kA-class cable)***



- ***a DIPOLE DEMONSTRATOR with accelerator quality (5 T, 40 mm bore)***

Tests of the coils as stand alone and in-field are ongoing



van Nugteren et al., SuST 31 (2018) 06502

ARIES is building on the shoulders of EuCARD²

The objectives of ARIES are:

- Set up a NEW process in BRUKER to:
  - Increase J_e by a factor 2 wrt EuCARD²

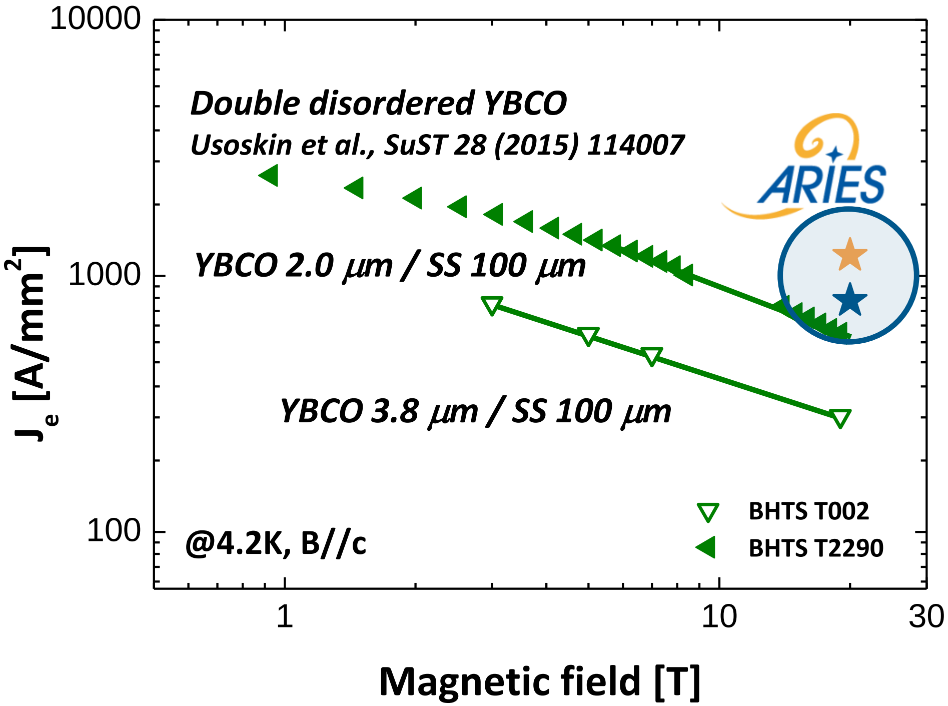
    from J_e (4.2 K, 20 T) = 400-600 A/mm^2

    to J_e (4.2 K, 20 T) = 800-1200 A/mm^2
- Produce in BRUKER some 600 m of tapes
- Use in a winding at CERN cea (very much like EuCARD²)
- Reduce the cost by a factor 2 in the production (at BRUKER)

The partners:

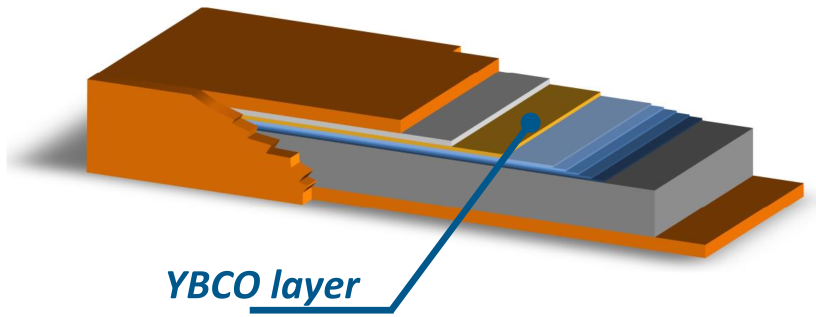
CERN	cea	UNIVERSITEIT TWENTE.	UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES	BRUKER
L. Rossi Task Leader	Th. Lecrevisse Deputy Task Leader	M. Dhallé	C. Senatore	U. Betz, A. Usoskin Industrial Partner

Performance target for ARIES



How to get there?

- *Increase the layer J_c of YBCO*
- *Increase the thickness of YBCO*
- *Reduce the thickness of the substrate 100 μm SS → 50 μm SS*

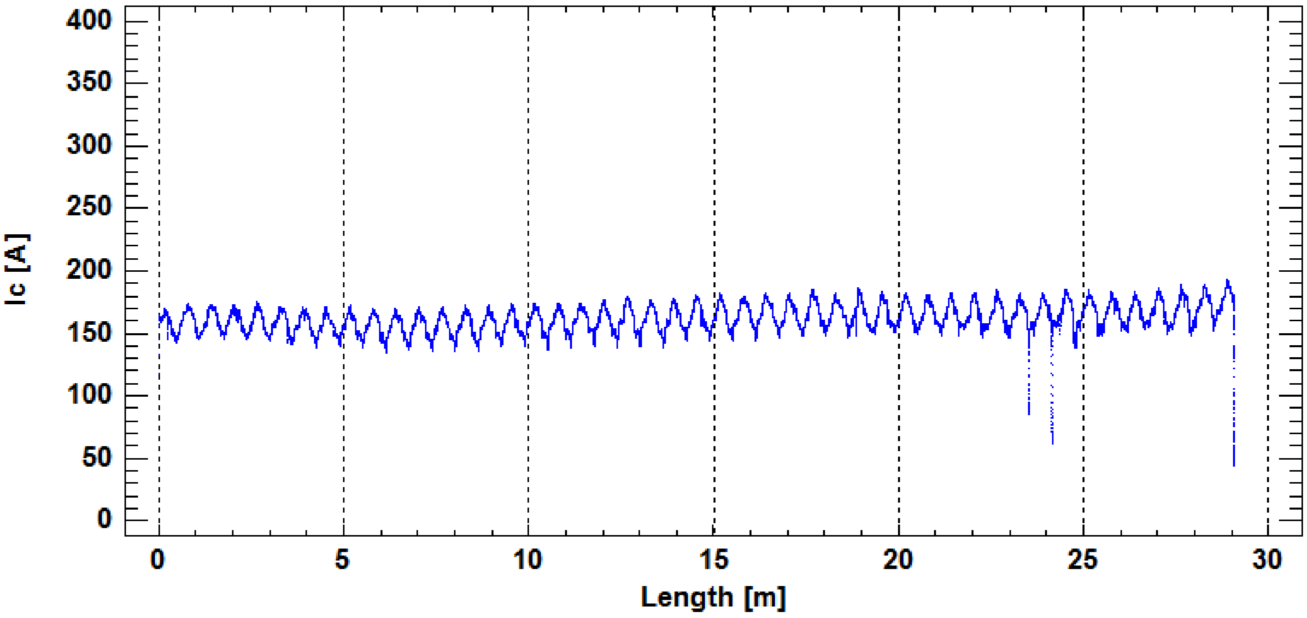


ARIES project @ Bruker HTS

BRUKER

PROCESSING 50 µm x 12 mm x 29 m HTS tape

- I_c measurement from tape sample (start position) I_c(77 K, s.f.) = 174 A
- Average I_c value from Hall-Probe-Measurement (TapeStar) of the 29 m long HTS tape I_c(77 K, s.f.) = 161 A
- 2 x I_c drops detected in the range 23-25 m



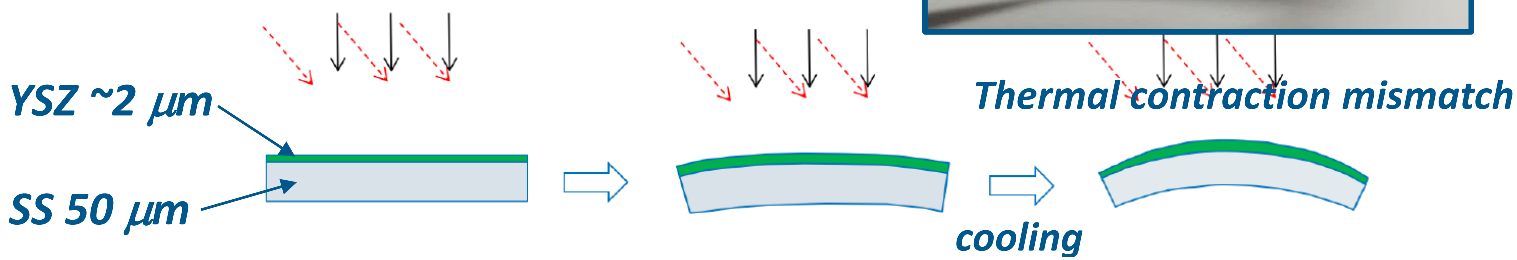
Courtesy of A. Usoskin, BHTS

ARIES project @ Bruker HTS

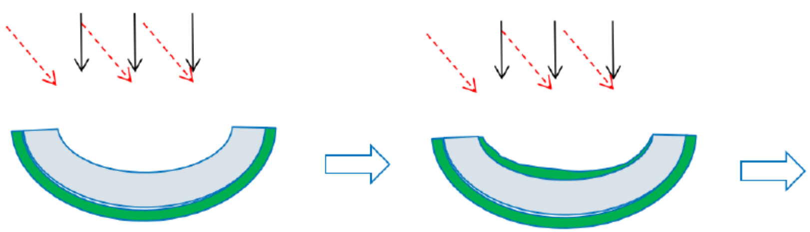
General appearance of HTS tapes with 50 µm SS substrates

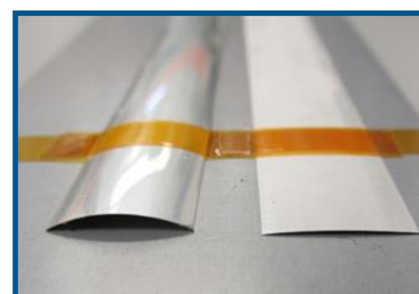
The new tapes reveal a strong curvature across the width (tape bow)

In the ABAD process biaxial texturing is achieved in a ~2µm-thick YSZ layer (IBAD uses a thinner MgO layer)



Reduce the bow by depositing YSZ on the two sides of the tapes





Curvature does not exceed the critical one: no deterioration of I_c is observed

Courtesy of A. Usoskin, BHTS

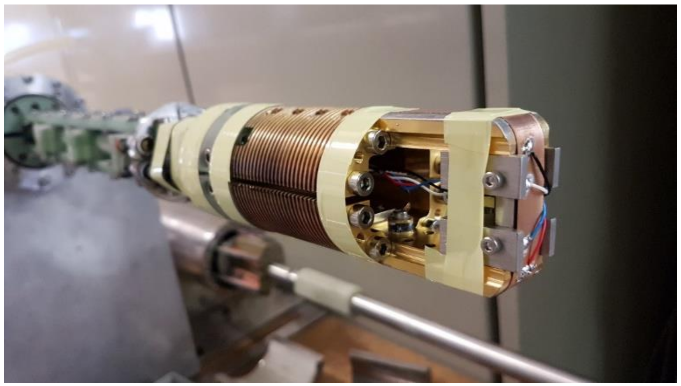
Measurement campaign on the ARIES tapes

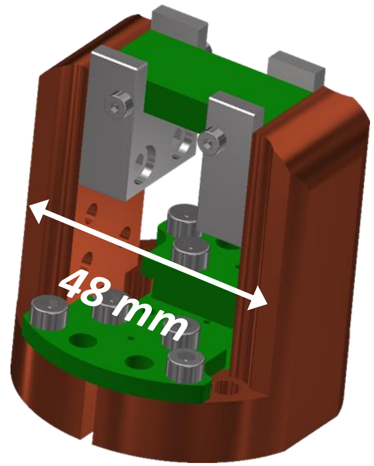
Tape ID	Width	DD-YBCO thickness	Stabilizer	Orientation	Temperatures
Q023	12 mm	1.95µm	2x 20µm Cu	90°	4.2K – 20K – 30K – 40K
Q056	4 mm	1.78µm	2x 20µm Cu	90°	4.2K – 20K – 30K
				10°	4.2K – 20K – 30K
				0°	4.2K – 10K – 20K– 30K – 40K
Q064	12 mm	1.9-2.0µm	2x 20µm Cu	90°	4.2K – 10K – 20K– 30K – 40K
				0°	40K
Q065	12 mm	1.9-2.0µm	2x 7µm Cu	90°	4.2K

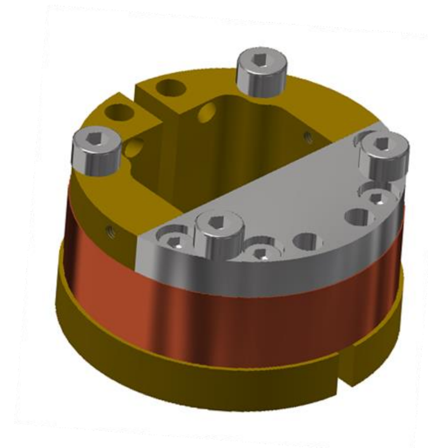
All BRUKER tapes with the new 50µm-thick stainless steel substrate

Critical current tests up to 2 kA on 12mm tapes

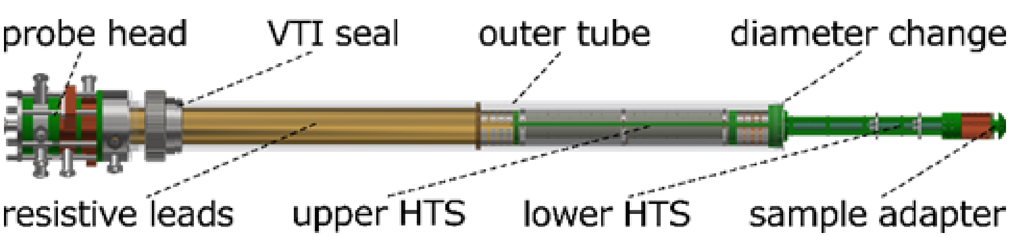
Magnetic fields up to 19 T (21 T) and temperatures up to 40 K

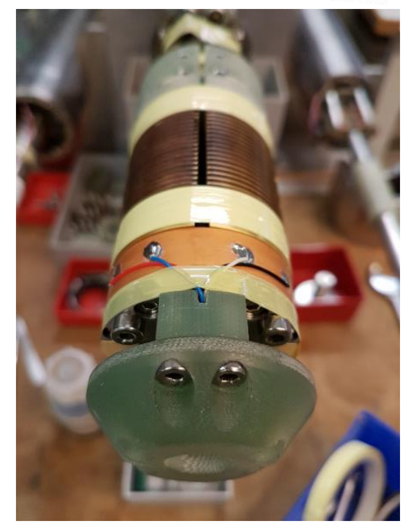






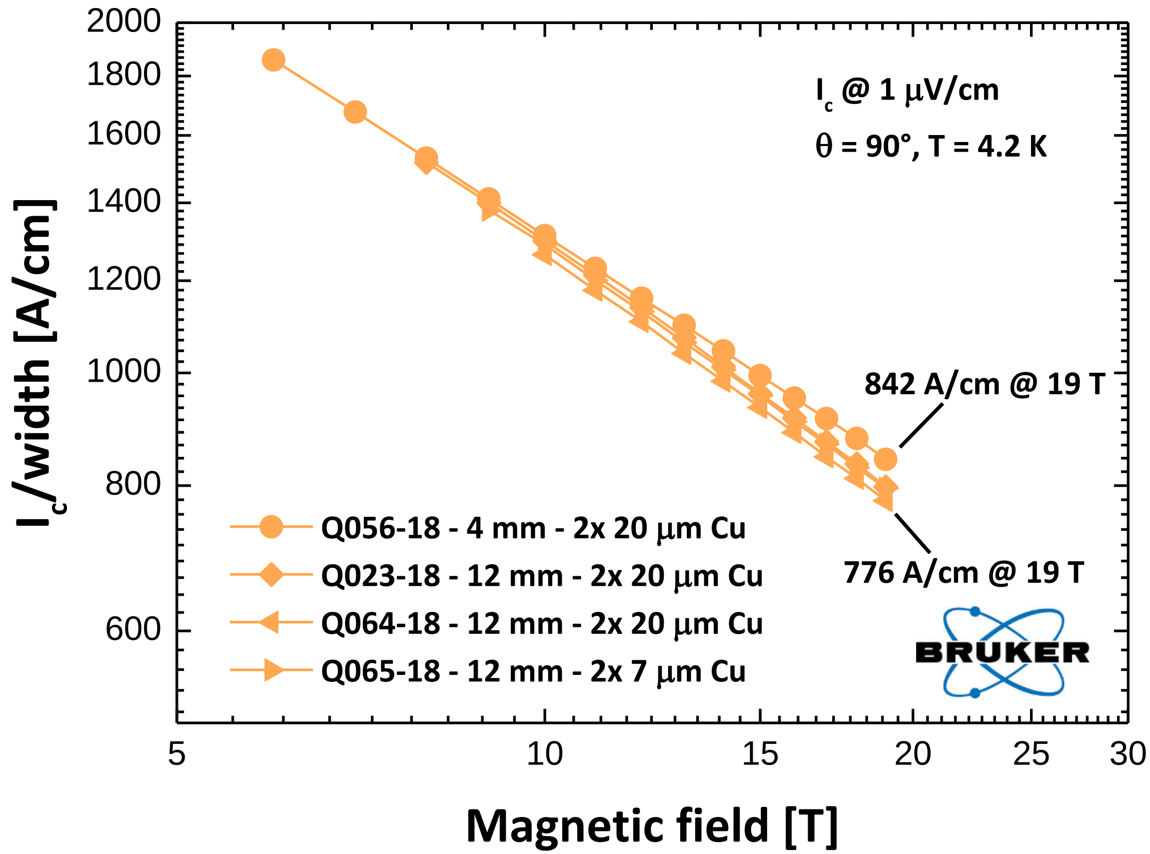
- *Possible to test long samples (> 120 mm) at various angles: θ = 0°, 5°, 7.5°, 10° and 90°*
- *Active stabilization of the sample temperature*

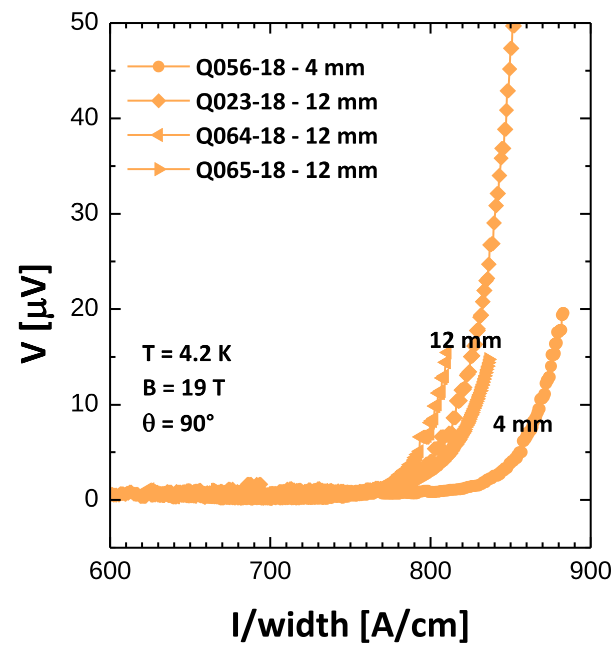




C. Barth, M. Bonura, and CS, IEEE TASC 28 (2018) 9500206

Reproducibility of performance: $I_c(B,\theta=90°,T=4.2\ K)$

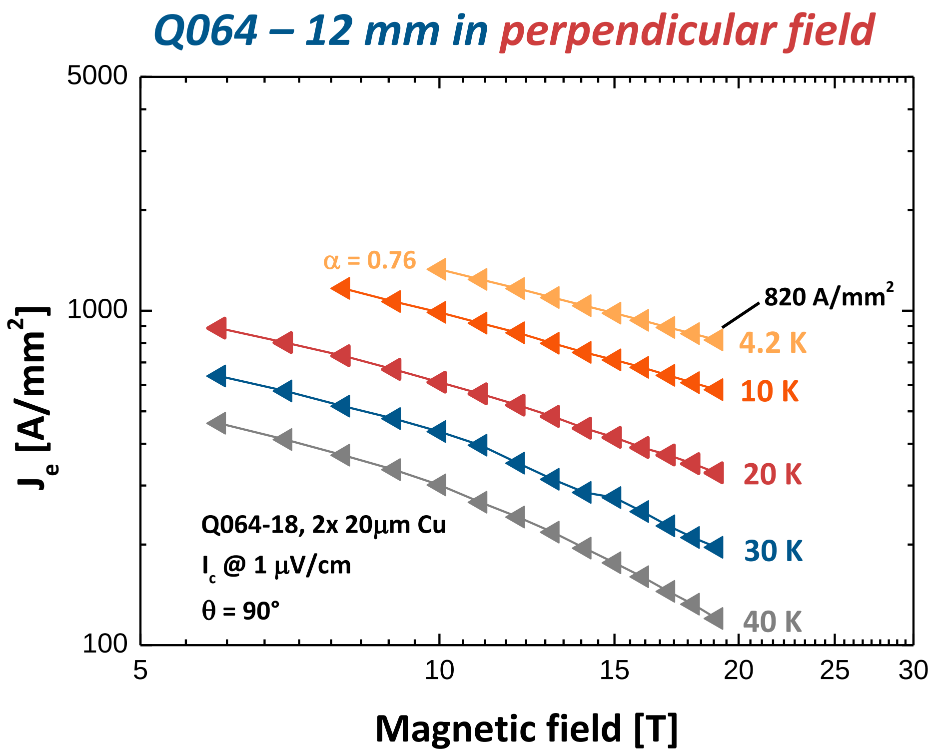


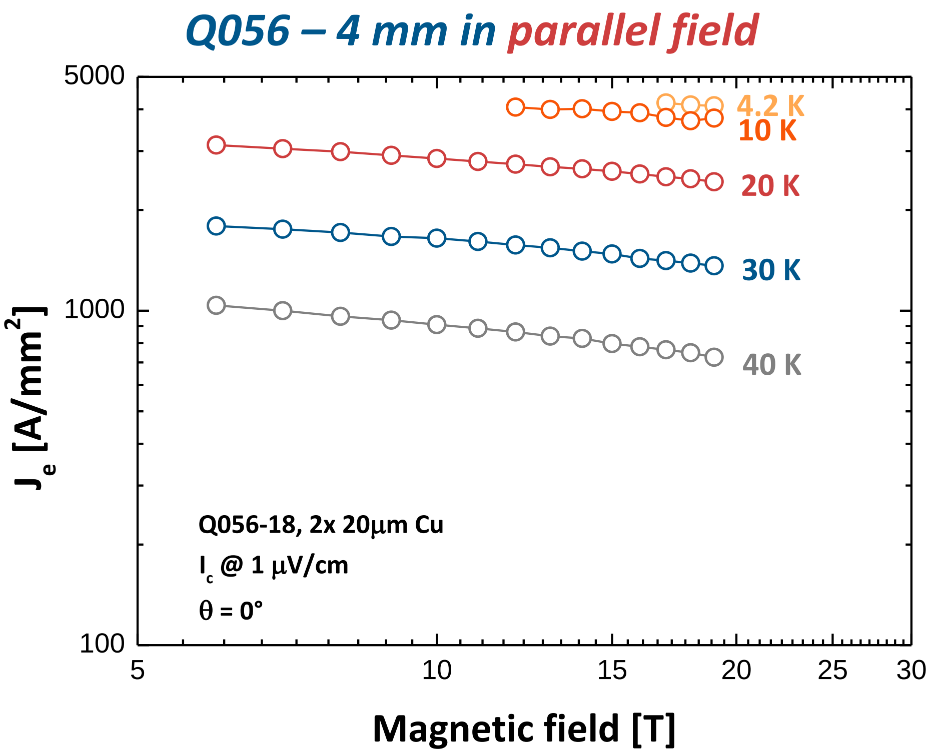


The 4mm tape has a slightly lower decrease of I_c with B

The maximum measured spread in I_c is ~10% (at 19 T)

Engineering current density $J_e(B)$ – Temperature dep.





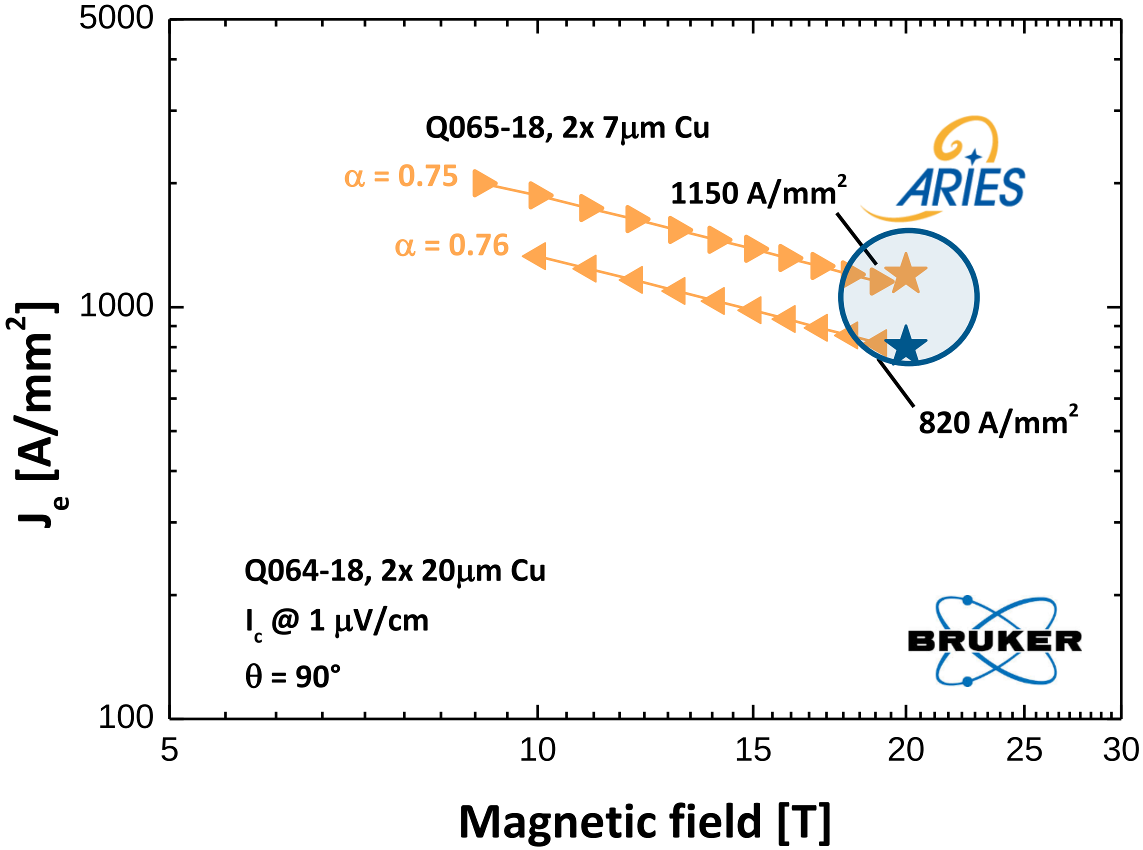
Reducing the temperature by 10 K, J_e is increased by

- *a factor 1.6 in perpendicular orientation*
- *a factor 1.7 in parallel orientation*

** Exponential temperature dependence of I_c → CS et al., SuST 29 (2016) 014002*

Engineering current density $J_e(B,T=4\ K)$

Performance target



Tape Q065-18 (with 2x 7µm Cu) reached 1150 A/mm^2 at 4.2 K, 19 T, 90°

Very recent high-performance REBCO tapes from Fujikura and SuperOx

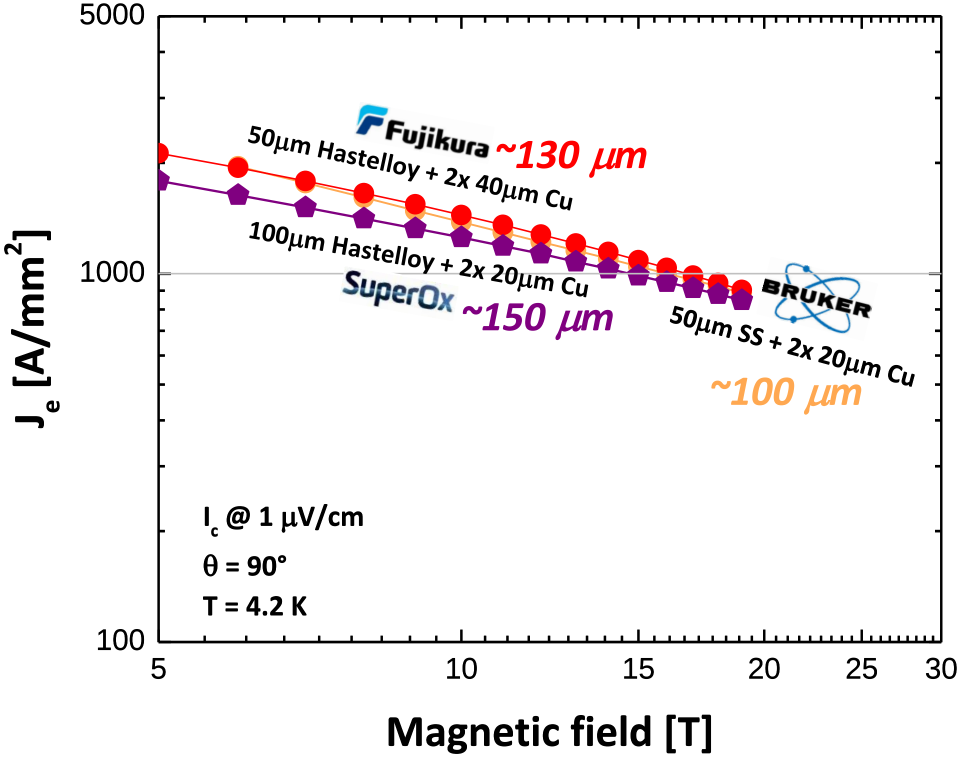
	Tape ID	Width	REBCO thickness	Substrate/ Stabilizer	Orientation	Temperatures
Fujikura	FESC-SCH04(40) 19-0008	4 mm	2.5 μm	50 μm Hastelloy 2x 40 μm Cu	90°	4.2K – 20K
	FESC-SCH04 19-0007	4 mm	2.5 μm	50 μm Hastelloy 2x 20 μm Cu	Ongoing tests	
SuperOx	#287-L	4 mm	3.1 μm	100 μm Hastelloy 2x 20 μm Cu	90°	4.2K – 20K
	#337-R	4 mm	2.7 μm	40 μm Hastelloy 2x 5 μm Cu	90°	4.2K – 20K

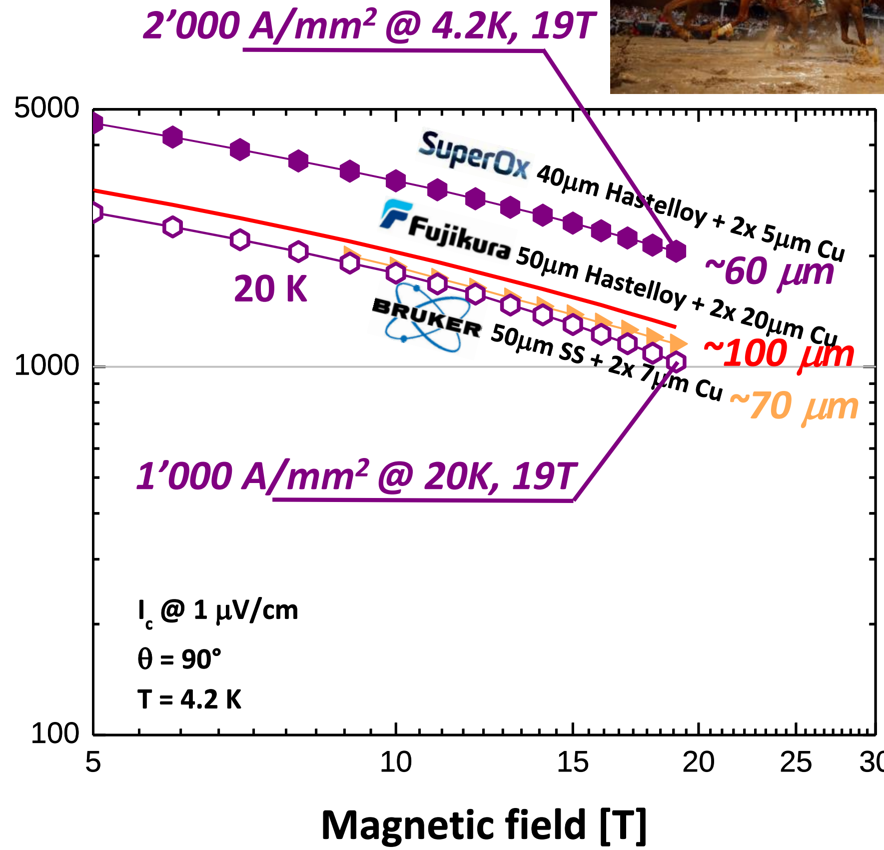
New SuperOx tapes courtesy of Alexander MOLODYK

Fujikura tapes courtesy of Simon RICHARDSON and Masanori DAIBO

Engineering current density $J_e(B,T=4\ K)$

Comparison of 3 manufacturers





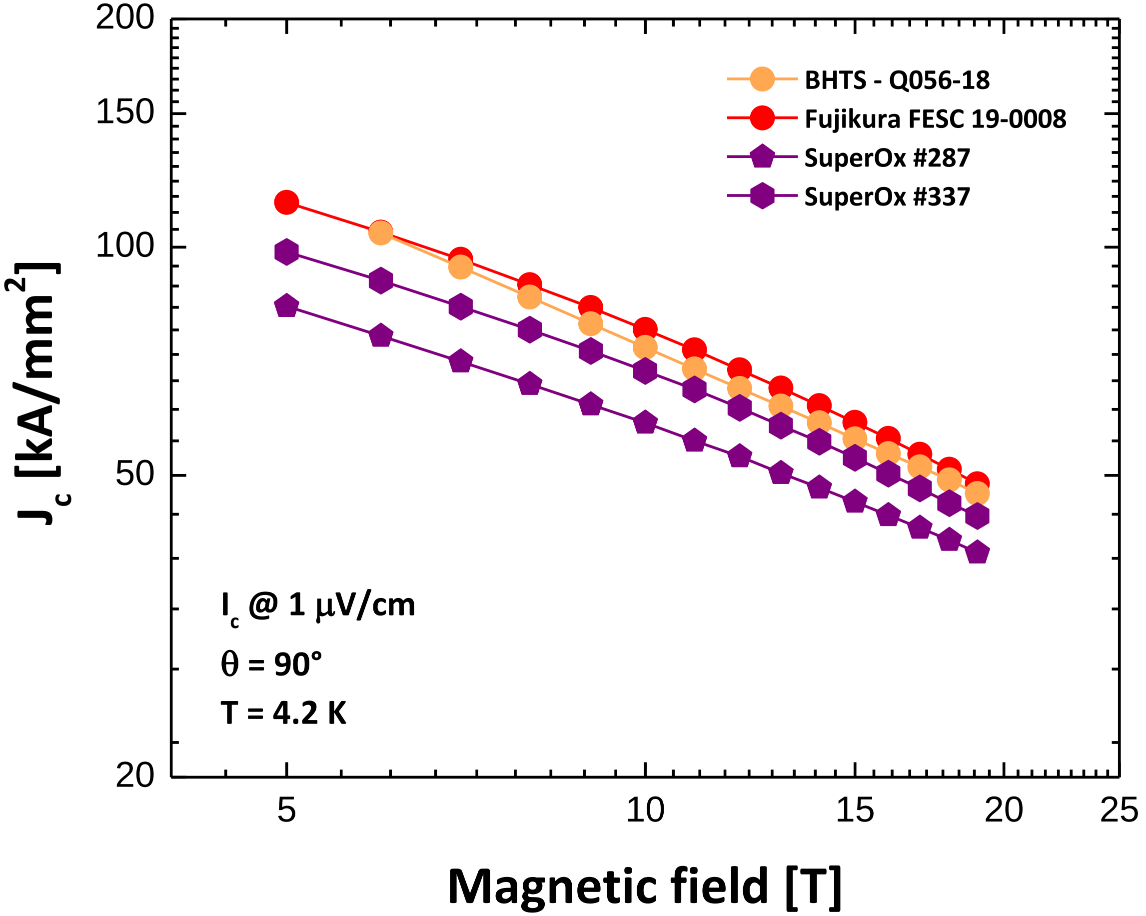
The REBCO layer is deposited by PLD for the three manufacturers

Fujikura FESC tape is based on EuBCO with BHO APC

SuperOx introduced a new composition, still undisclosed

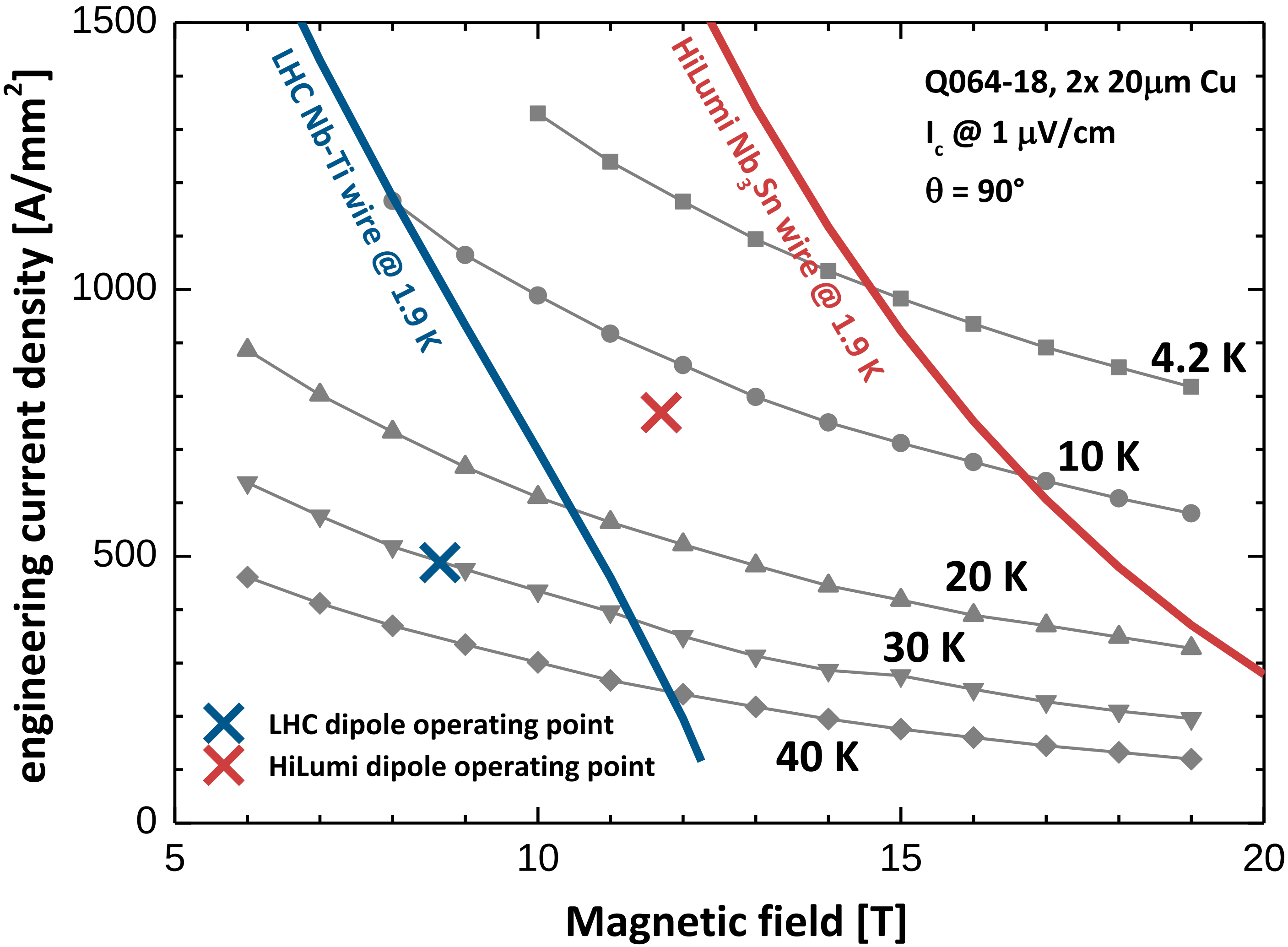
Layer critical current density $J_c(B,T=4\ K)$

Comparison of 3 manufacturers



At 4.2 K, 19 T the tapes do not differ significantly in terms of layer is J_c
All lie between 40 and 50 kA/mm^2

Towards HTS-based dipoles operating at T >1.9 K ??



BRUKER *tape Q064-18, 50µm stainless steel, 2x 20µm Cu, 2µm YBCO*

Engineering current density in perpendicular field orientation

Summary

- *High-J_e HTS conductors are setting the grounds for accelerator magnets in the 20 T range*
- *The ARIES R&D tapes with thinner substrate (50 μm stainless steel) from BRUKER exhibit very reproducible performance*
- *In spite of the tape shape, we got $J_e \approx 1150$ A/mm² @ 4.2 K, 19 T*
- Fujikura *new tape with EuBCO + BHO, with $J_e \approx 1300$ A/mm² @ 4.2 K, 19 T, is a commercial product*
- SuperOx *implemented a new composition and its new tape reached $J_e \approx 2000$ A/mm² @ 4.2 K, 19 T and 1000 A/mm² @ 20 K, 19 T*
- *In light of the present results, should we target also accelerator magnets operating at higher temperatures?*

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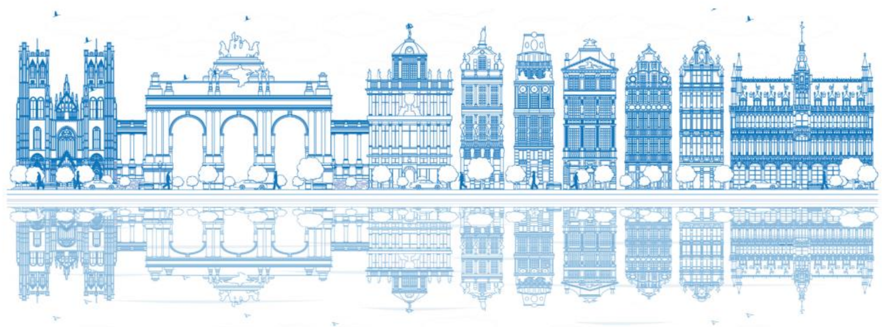

WRITING the FUTURE
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Thank you for the attention !

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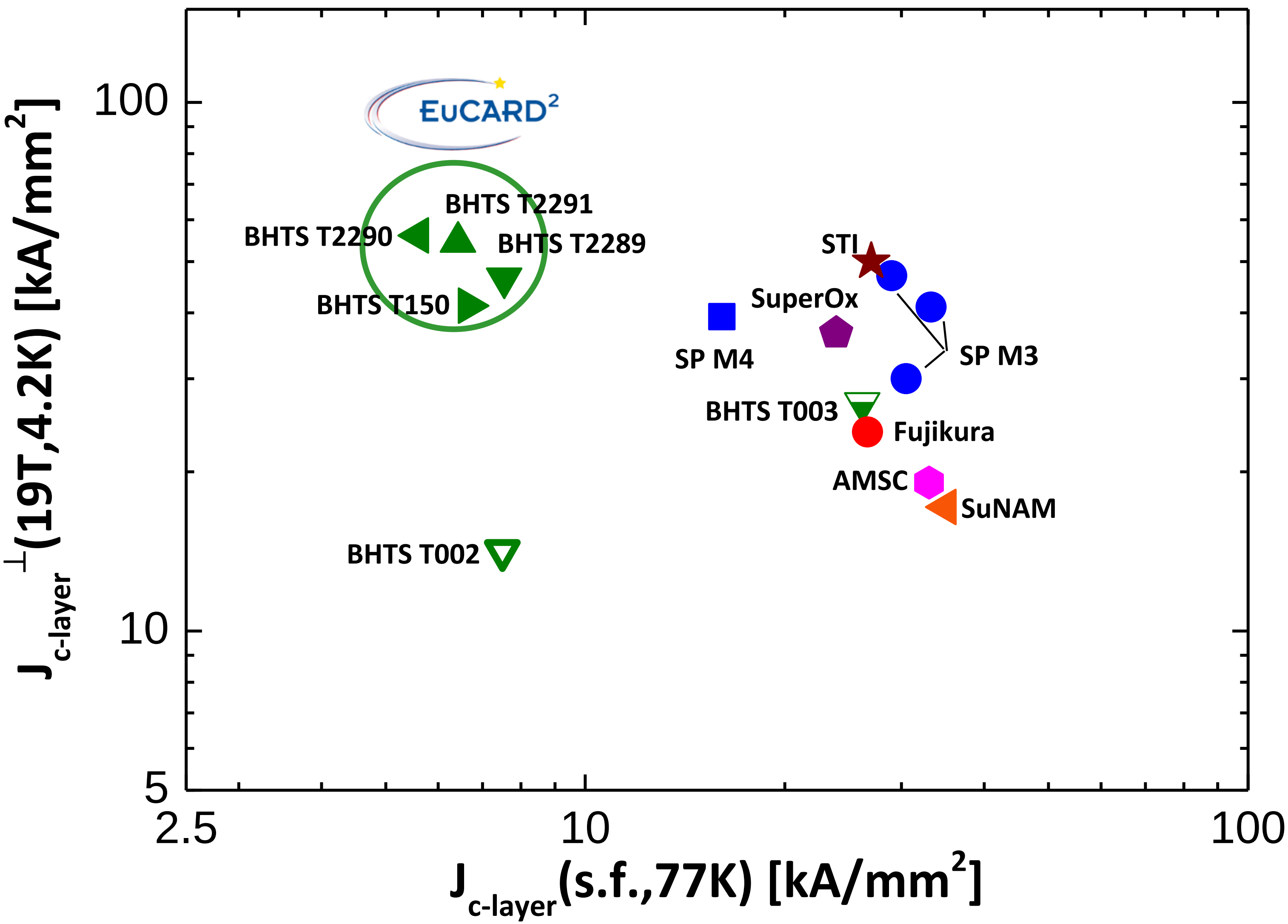
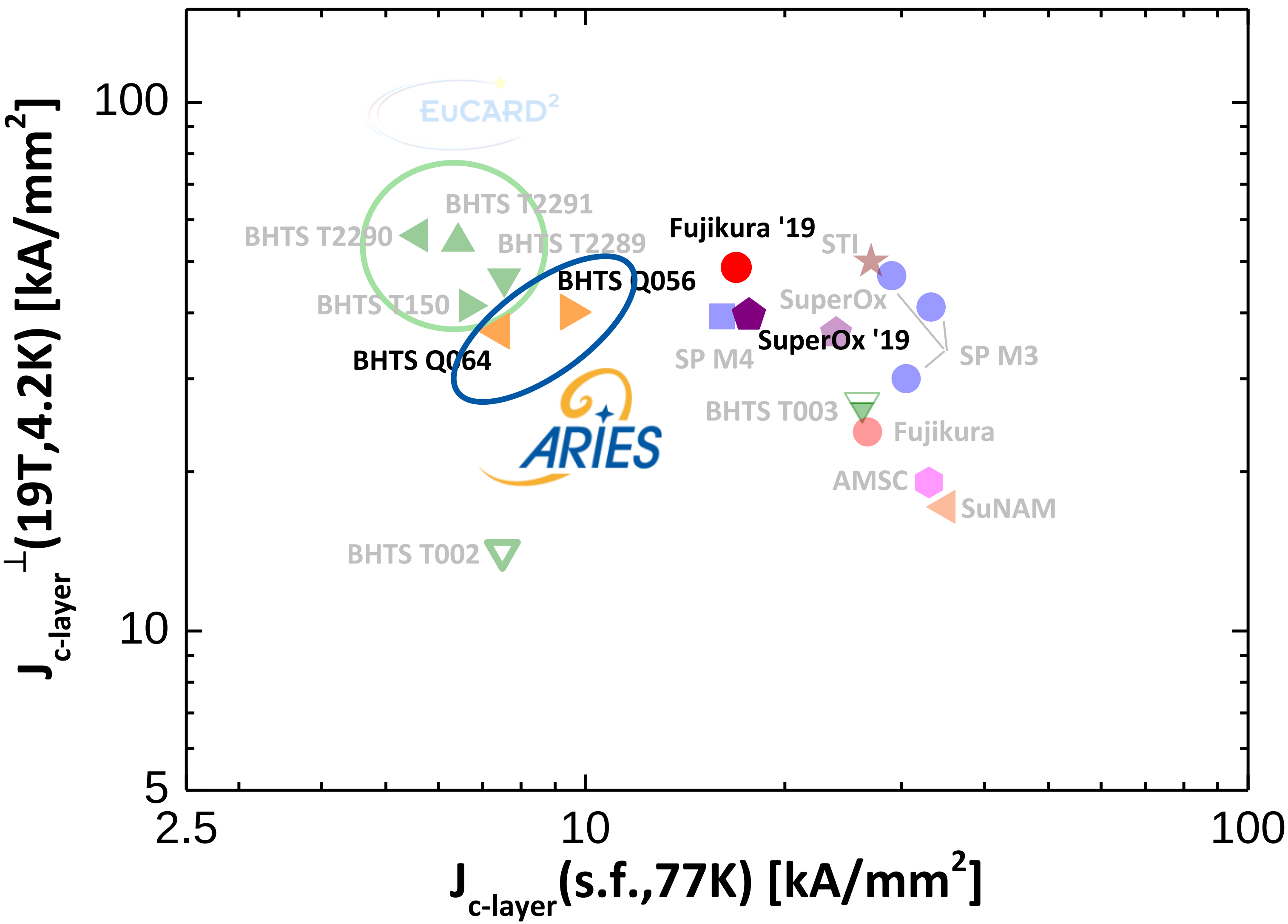
Performance overview (2016): J_c(s.f.,77K) vs. $J_c^{\perp}$(19T,4.2K)

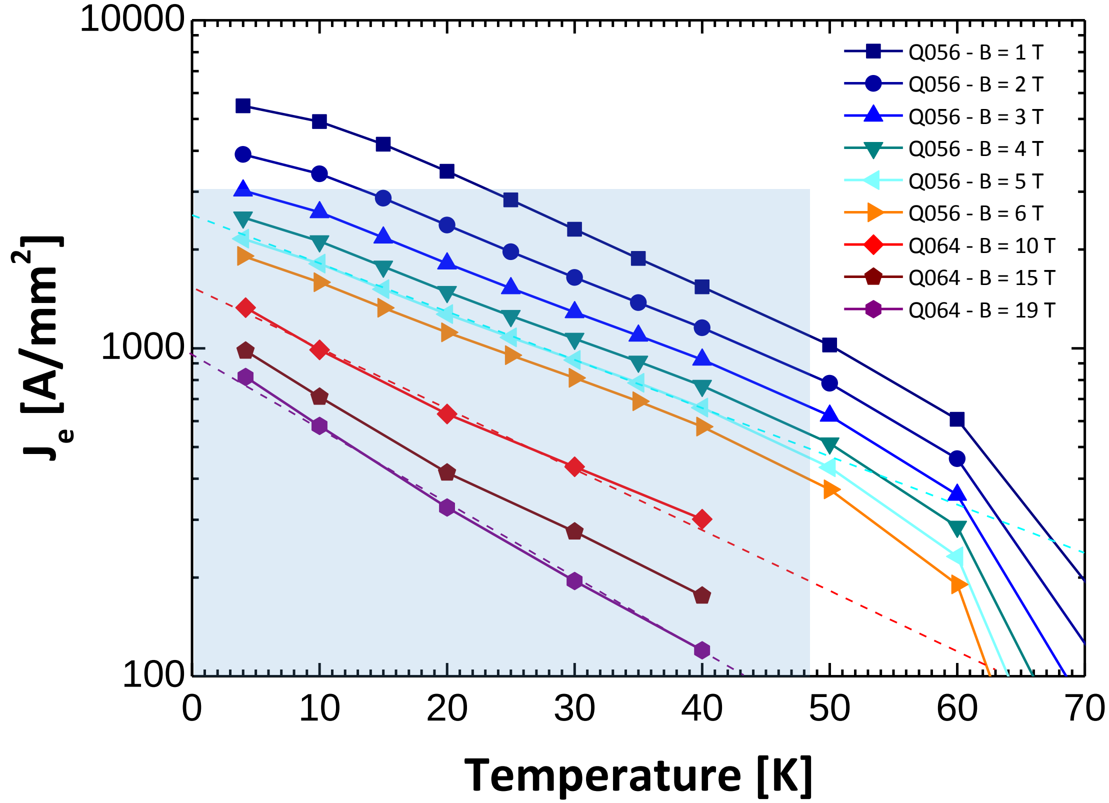


Performance overview (2016): J_c(s.f.,77K) vs. $J_c^{\perp}$(19T,4.2K)

Updated with the most recent results (2019)



Temperature dependence of J_e

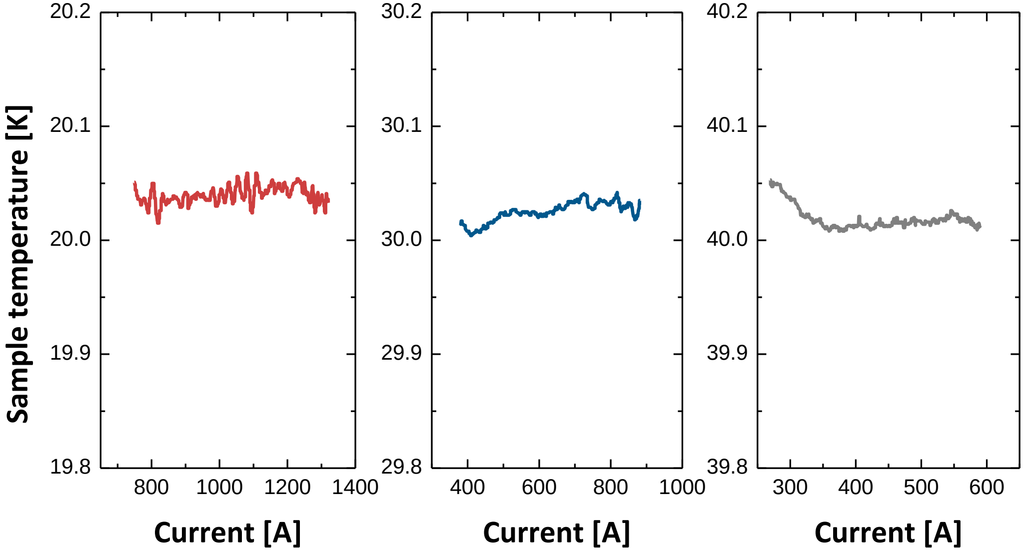


Temperature scaling $J_e(B,T) = J_e(B,T=0)\exp\left[-\frac{T}{T^*}\right] \Rightarrow \frac{J_e(B,T_1)}{J_e(B,T_2)} = \exp\left[-\frac{T_1 - T_2}{T^*}\right]$

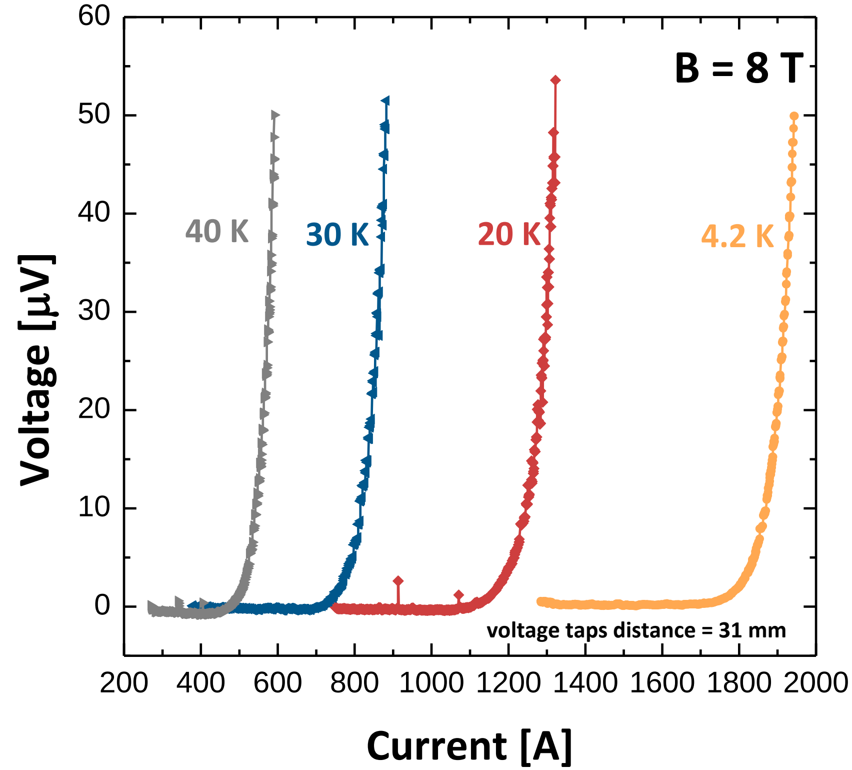
T^* ranges between 18 K and 29 K, with a maximum at 4 T

I_c tests in gas flow

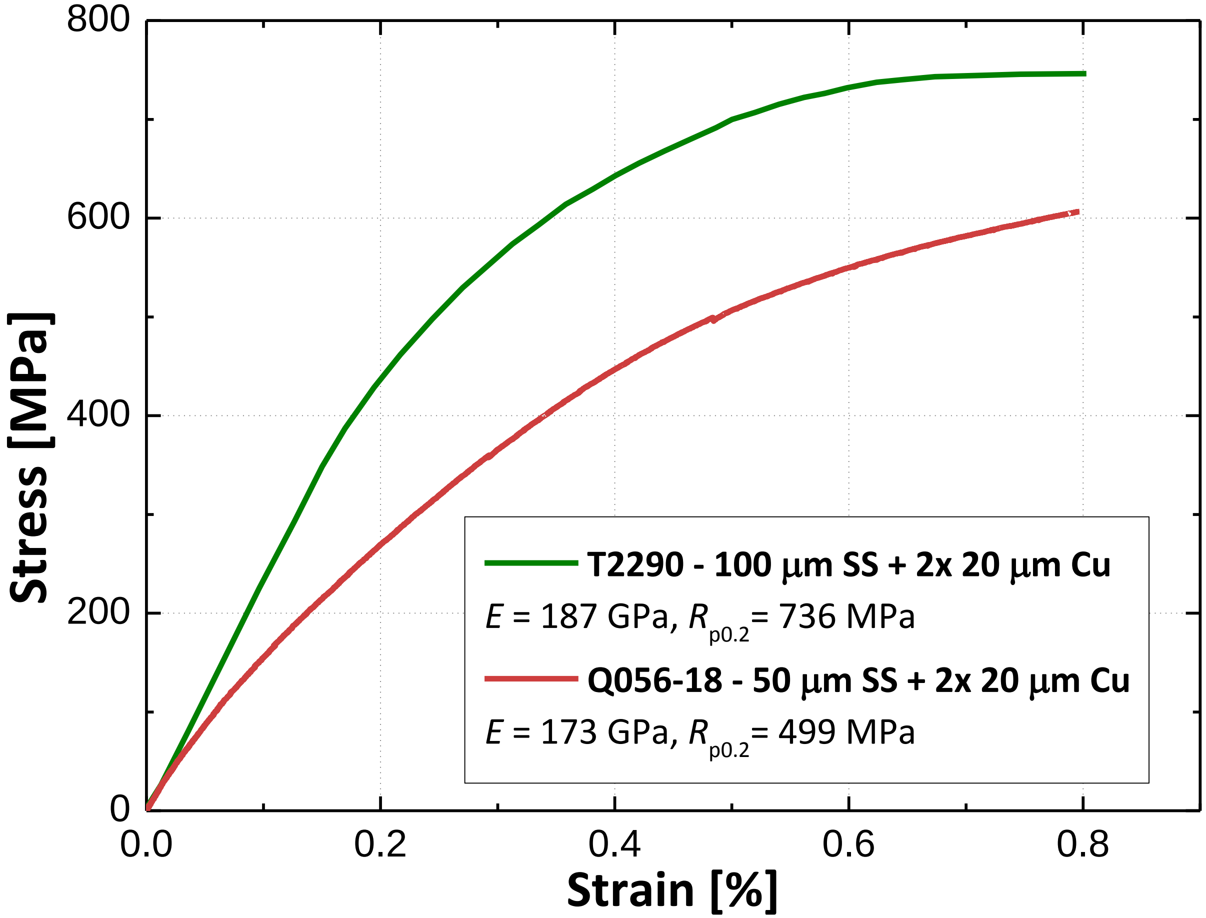
Active temperature stabilization



Q023 – 12 mm in perpendicular field



Q056-18: 4 mm, 50 µm SS + 2x 20 µm Cu



	RRR
T2290	23
Q056-18	57