EuCARD-2 Conductor Task

Summary of the activities @ UNIGE

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Outline

Activities on REBCO CCs @ UNIGE

Performance overview from manufacturers worldwide

- ***Critical surface and scaling relations***

  NEW: transport I_c above 1 kA

- ***Electromechanical properties***

  Also I_c vs transverse stress on OP Bi2212

- ***Thermophysical properties and NZPV studies***

Conclusions

Our collaborations on HTS

Towards 20 T accelerator dipoles for HEP

EuCARD² funded by CAPACITIES

ARIES funded by HORIZON 2020

coordinated by CERN

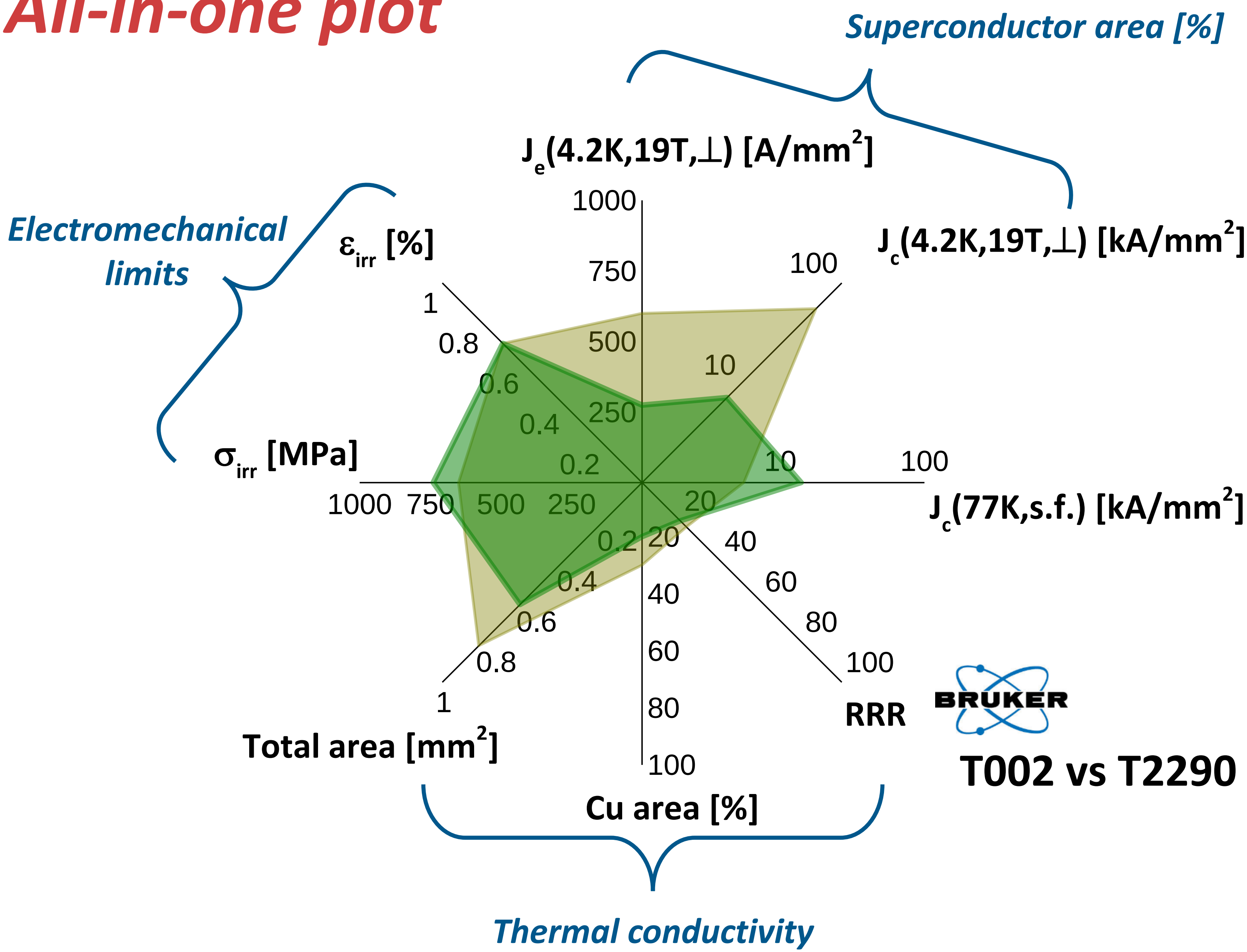
Towards all-superconducting 30 T-class solenoidal magnets

Funded by FNSNF Fonds national suisse Schweizerischer Nationalfonds Fondo nazionale svizzero Swiss National Science Foundation in collaboration with BRUKER

Scope : high resolution NMR spectrometers, high field laboratory magnets

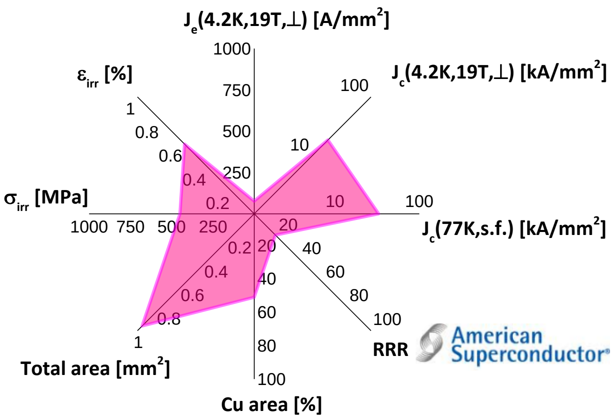
The EU Record : 25 T with REBCO in a 21 T LTS outsert

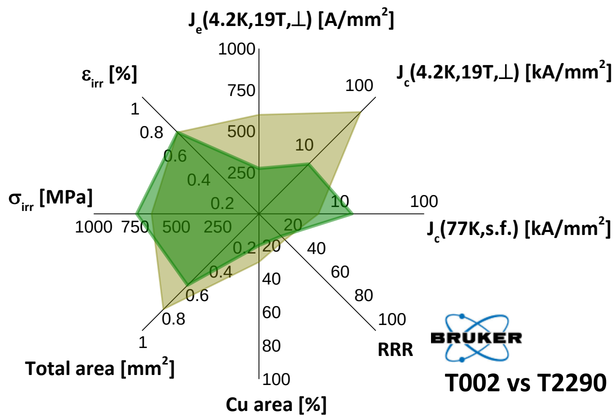
All-in-one plot

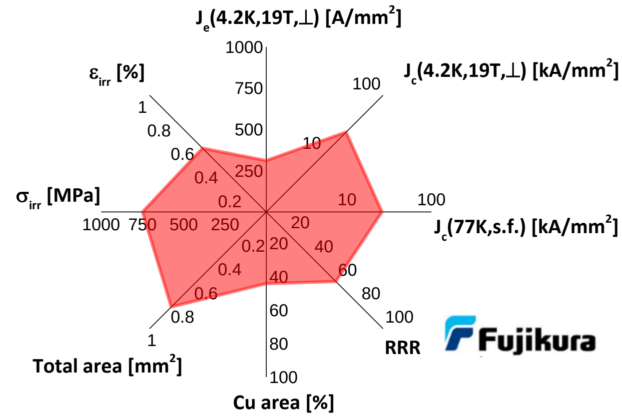


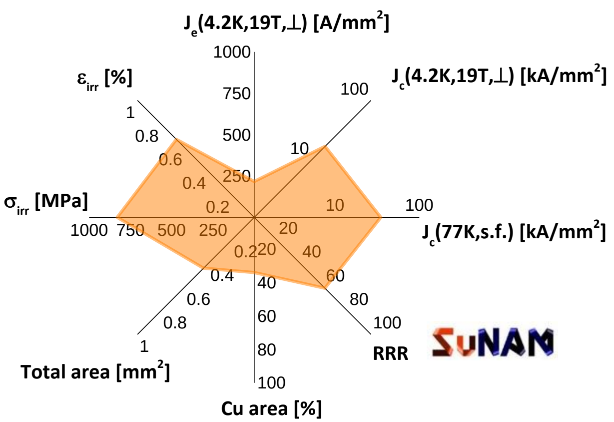
T002 vs T2290

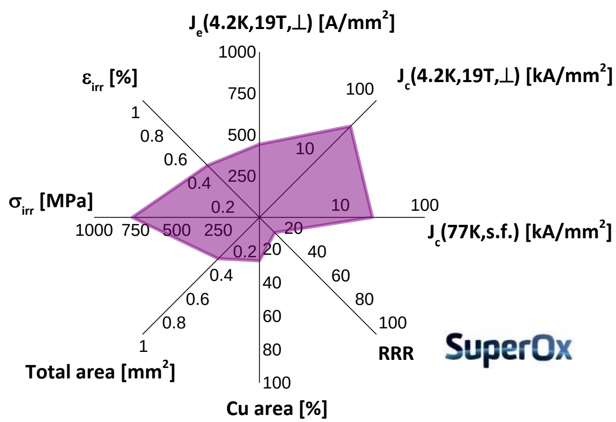
All-in-one plot for 6 manufacturers

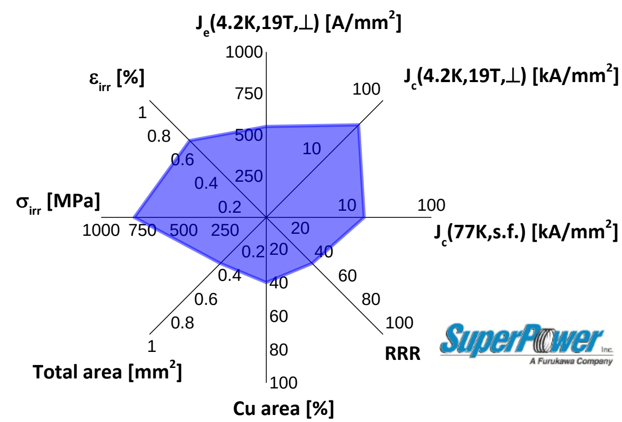












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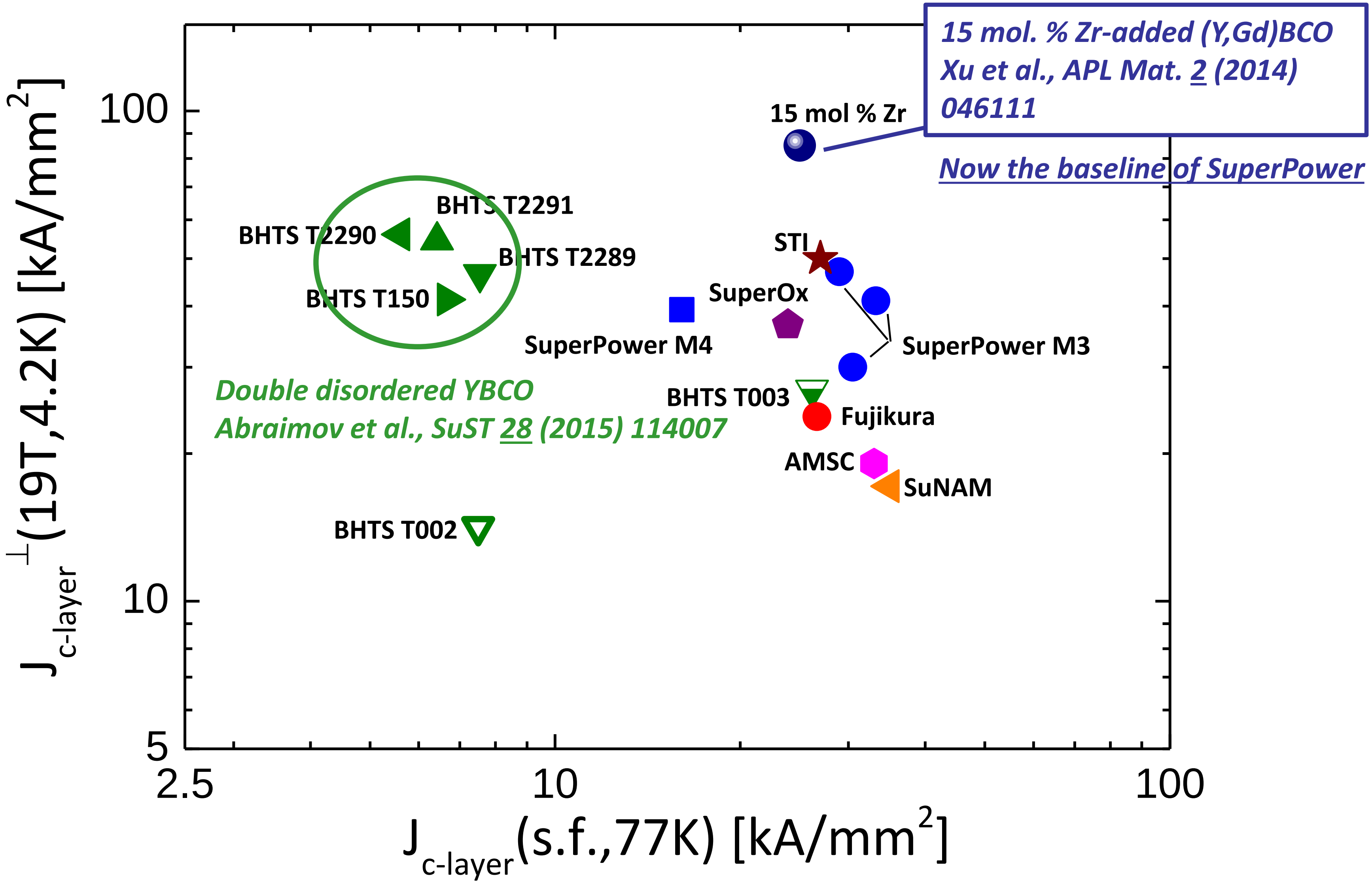
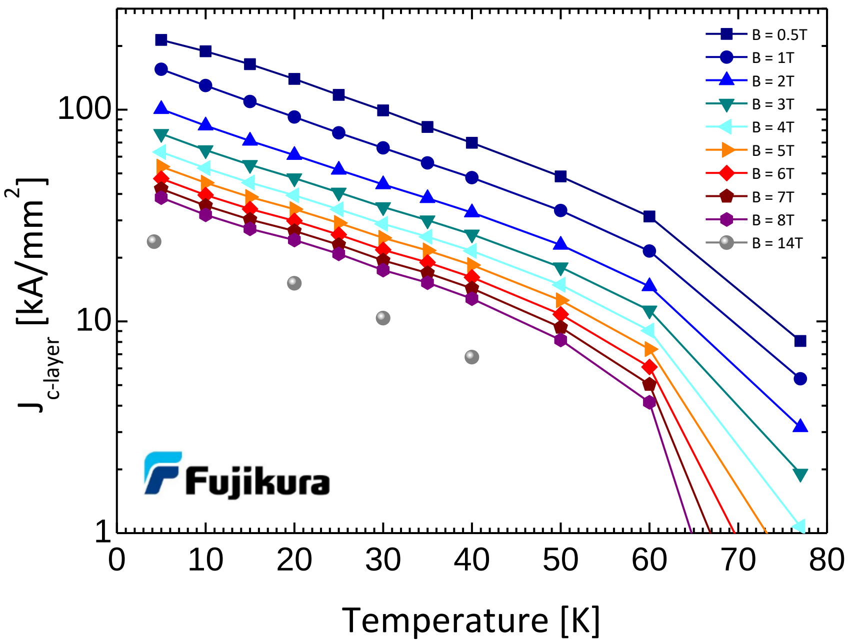
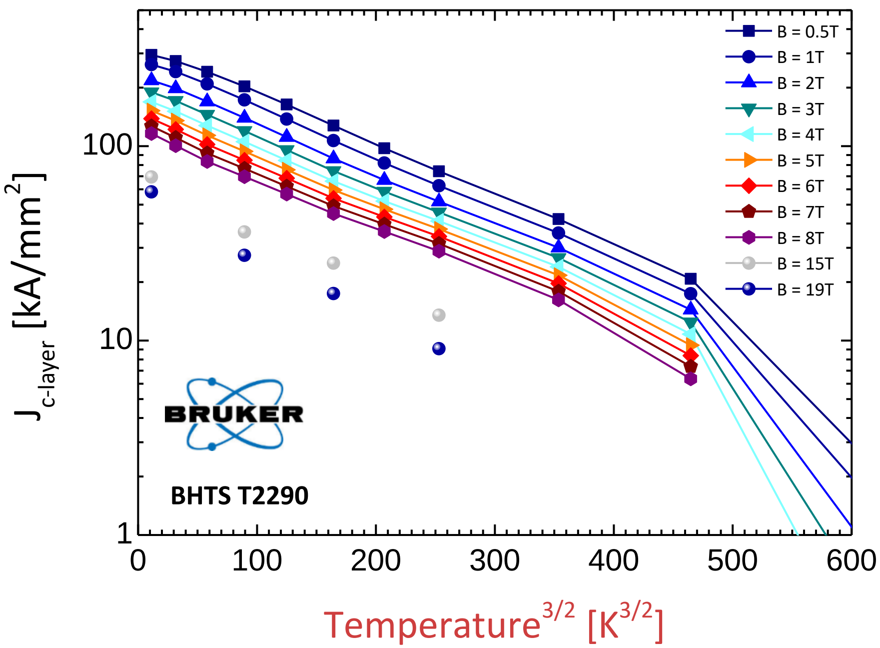
Performance overview: J_c(s.f.,77K) vs. $J_c^{\perp}$(19T,4.2K)



CS, C. Barth, M. Bonura, M. Kulich, G. Mondonico, SUST 29 (2016) 014002

Temperature dependence of J_c





GdBCO w/o AP by PLD

$$J_c(B,T) = J_c(B,T=0)\exp\left[-\frac{T}{T^*}\right]$$

T ranges between 15 K and 35 K and depends on field and orientation*

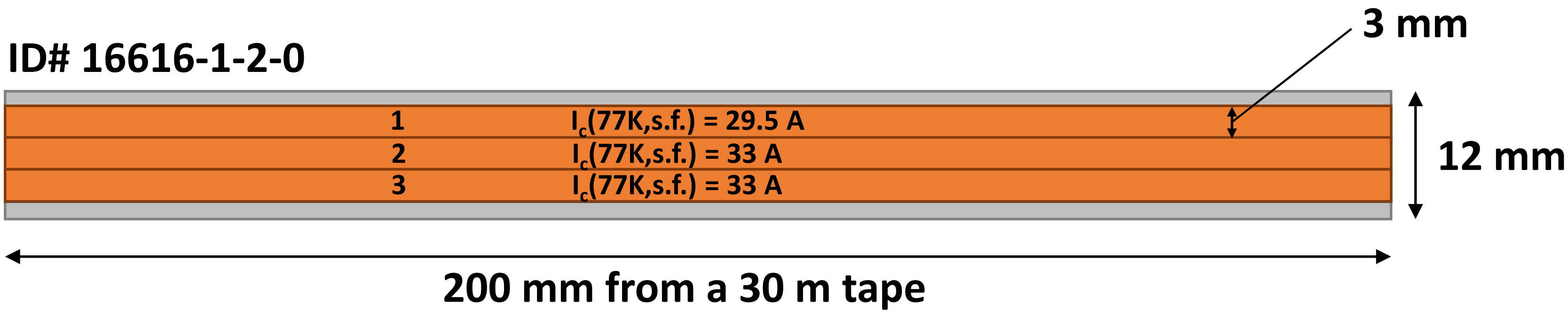
Double disordered YBCO by PLD

- *intrinsic disorder by modulation of oxygen pressure in PLD*
- *extrinsic disorder introduced via foreign atoms of Zr*

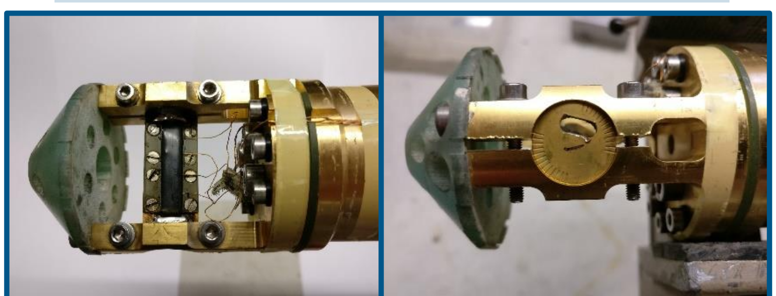
$$J_c(B,T) = J_c(B,T=0)\exp\left[-\left(\frac{T}{T^*}\right)^{\frac{3}{2}}\right]$$

IN PROGRESS

$I_c(B,T,\theta)$ of the EuCARD-2 BHTS tape



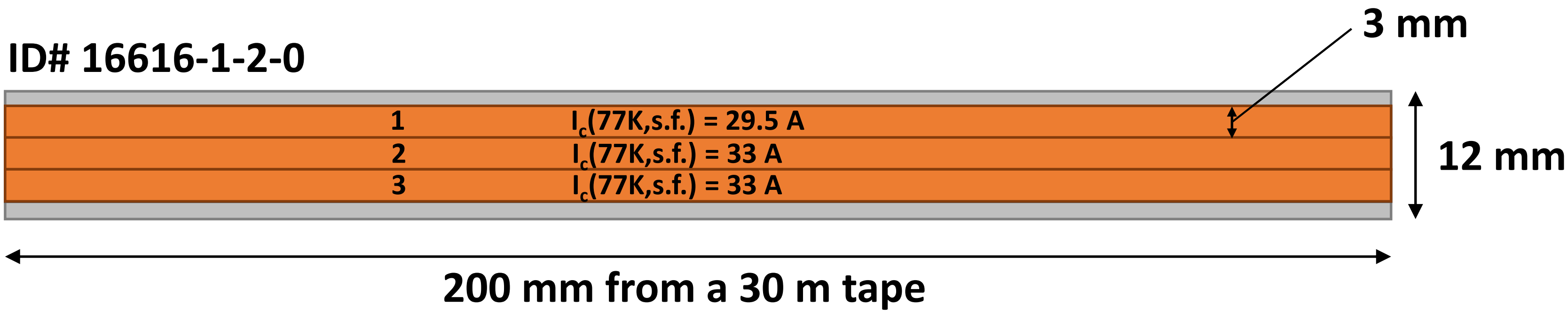
θ [°]	*0, 15, 30, 90*
T [K]	*4.2, 30, 40*
Maximum current ~ 700 A (4.2 K) *~ 200 A (>4.2K)*	

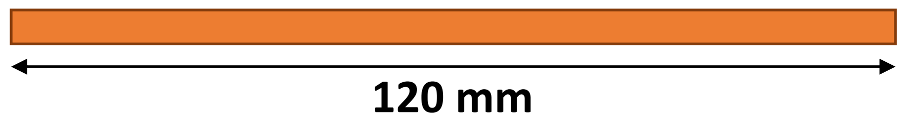


Samples prepared and tested in LN_2 by A. Usoskin and A. Rutt

$I_c(B,T,\theta)$ of the EuCARD-2 BHTS tape

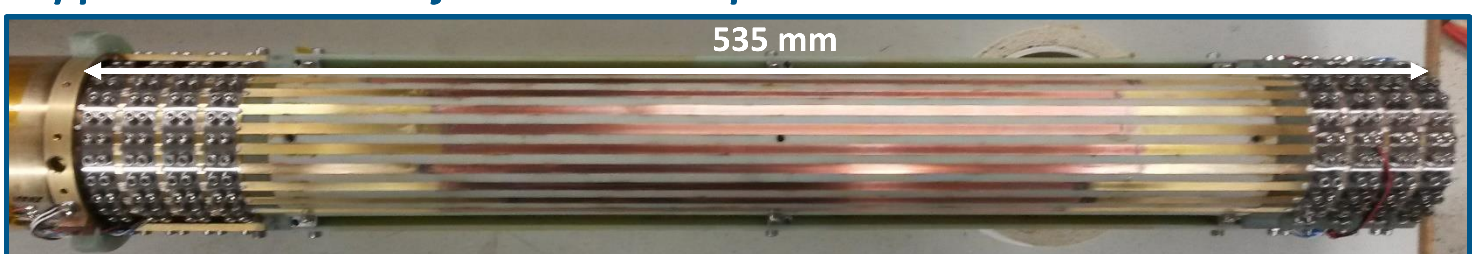
ID# 16616-1-2-0





θ [°]	*0*
T [K]	*4.2, 30, 40*
Maximum current ~ 2 kA (4.2K)	

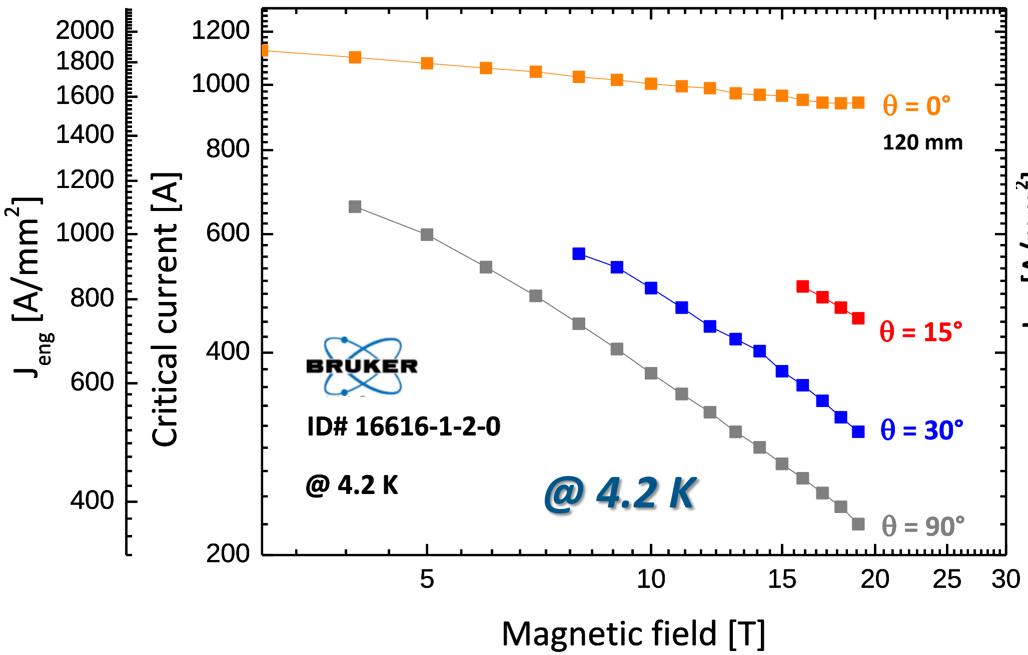
Upper current lead of the new 2 kA probe

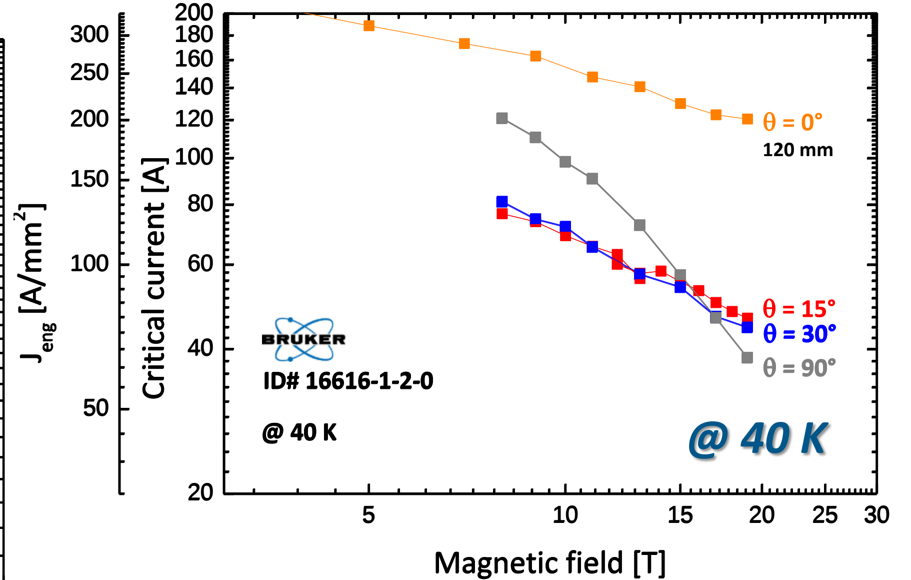


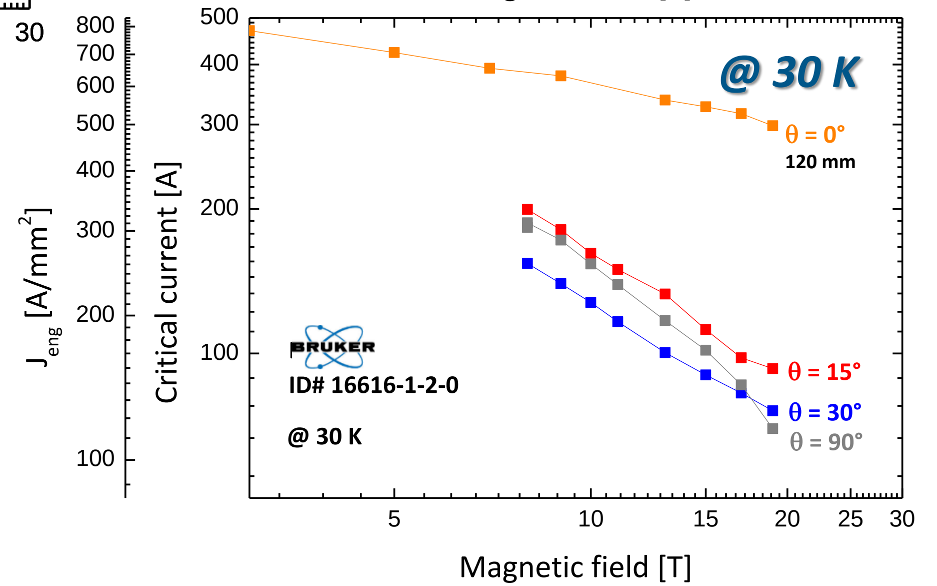
10 stacks of 4 tapes (4 mm wide) per current lead

IN PROGRESS

$I_c(B,T,\theta)$ of the EuCARD-2 BHTS tape







The effects of artificial pinning on the anisotropy of I_c become evident when increasing the temperature

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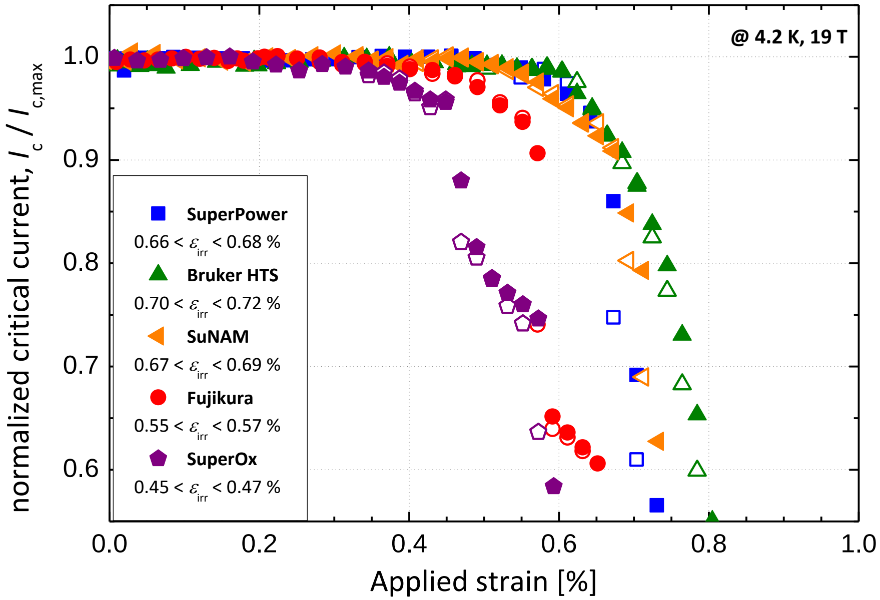
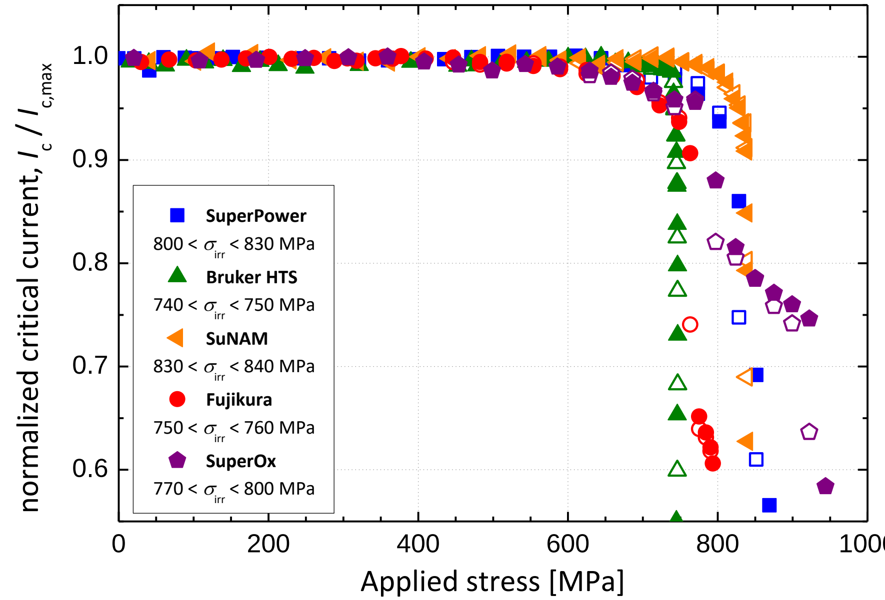
REBCO CCs: Dependence of I_c on axial loads

I_c vs. axial strain



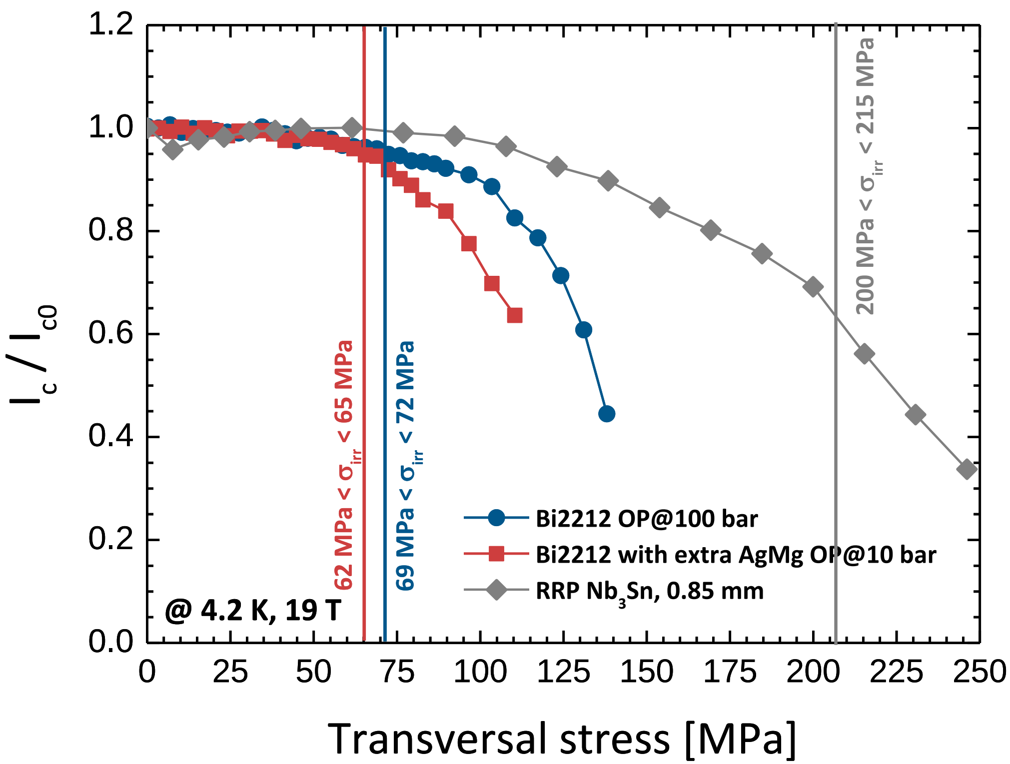
I_c vs. axial stress

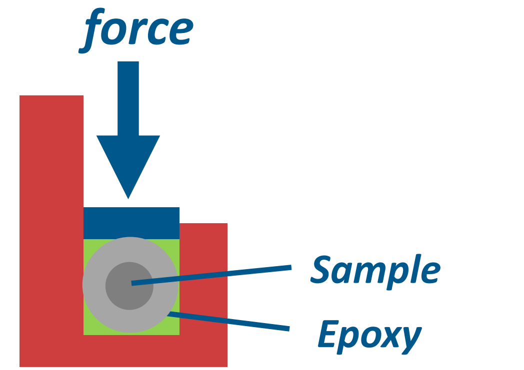


- *REBCO CCs are inherently strong, ~50% is a high strength alloy*
- *Very low stress effect → curves are flat in rev. region*
- *Irreversible stress limits above 500 MPa*
- *The only weakness is delamination...*

C. Barth, G. Mondonico and CS, SUST 28 (2015) 045011

Bi2212 wires: transversal stress sensitivity



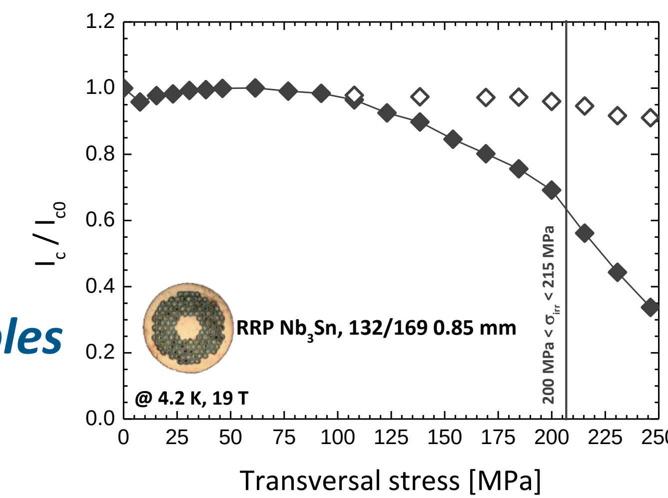


Wire impregnated with epoxy applied stress uniformly distributed

Irreversible stress limit at ~ 75 MPa

No substantial improvement with OP or extra Mg

Results consistent with old tests on Rutherford cables



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Normal zone propagation velocity

From the experimental investigation of κ, ρ, c, $J_c(T)$, we determined a simplified analytical expression for the NZPV

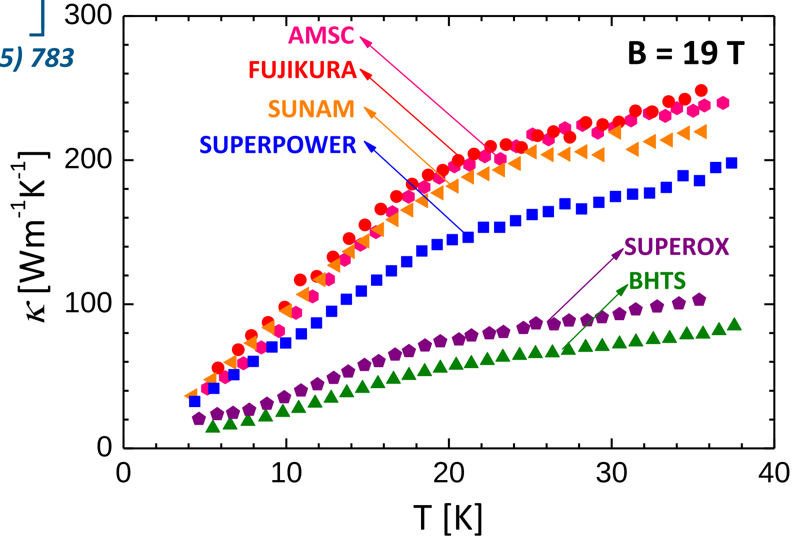
$$NZPV_L \approx \frac{I_{op}}{S_{tot}} \sqrt{\frac{\kappa(T_t)\rho(T_t)}{\int_{T_{op}}^{T_t} c_S(T)dT \left[c_n(T_t) - \frac{1}{\kappa(T_t)} \left.\frac{d\kappa}{dT}\right|_{T=T_t} \int_{T_{op}}^{T_t} c_S(T)dT \right]}} \quad \textit{where} \quad T_t = T_{CS} + \frac{T_C - T_{CS}}{2}$$

Whetstone and Roos, JAP 36 (1965) 783

T_t is ≈ 40 K and $\left.\frac{d\kappa}{dT}\right|_{T=T_t}$ is very small

The NZPV expression can be simplified

$$NZPV_L \approx \frac{I_{op}}{S_{tot}} \sqrt{\frac{LT_t}{c_n(T_t)\int_{T_{op}}^{T_t} c_S(T)dT}}$$



M. Bonura and CS, APL 108 (2016) 242602

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where $T_t = T_{CS} + \frac{T_C - T_{CS}}{2}$

Whetstone and Roos, JAP 36 (1965) 783

T_{CS} is determined by the $J_c(T)$ dependence

$$J_c(B,T) = J_c(B,T=0)e^{-\left(\frac{T}{T^*}\right)^{\frac{3}{2}}}$$

T_t is $\approx$40 K and $\frac{d\kappa}{dT}\Big|_{T=T_t}$ is very small

The NZPV expression can be simplified

$$NZPV_L \approx \frac{I_{op}}{S_{tot}} \sqrt{\frac{LT_t}{c_n(T_t)\int_{T_{op}}^{T_t} c_S(T)dT}}$$

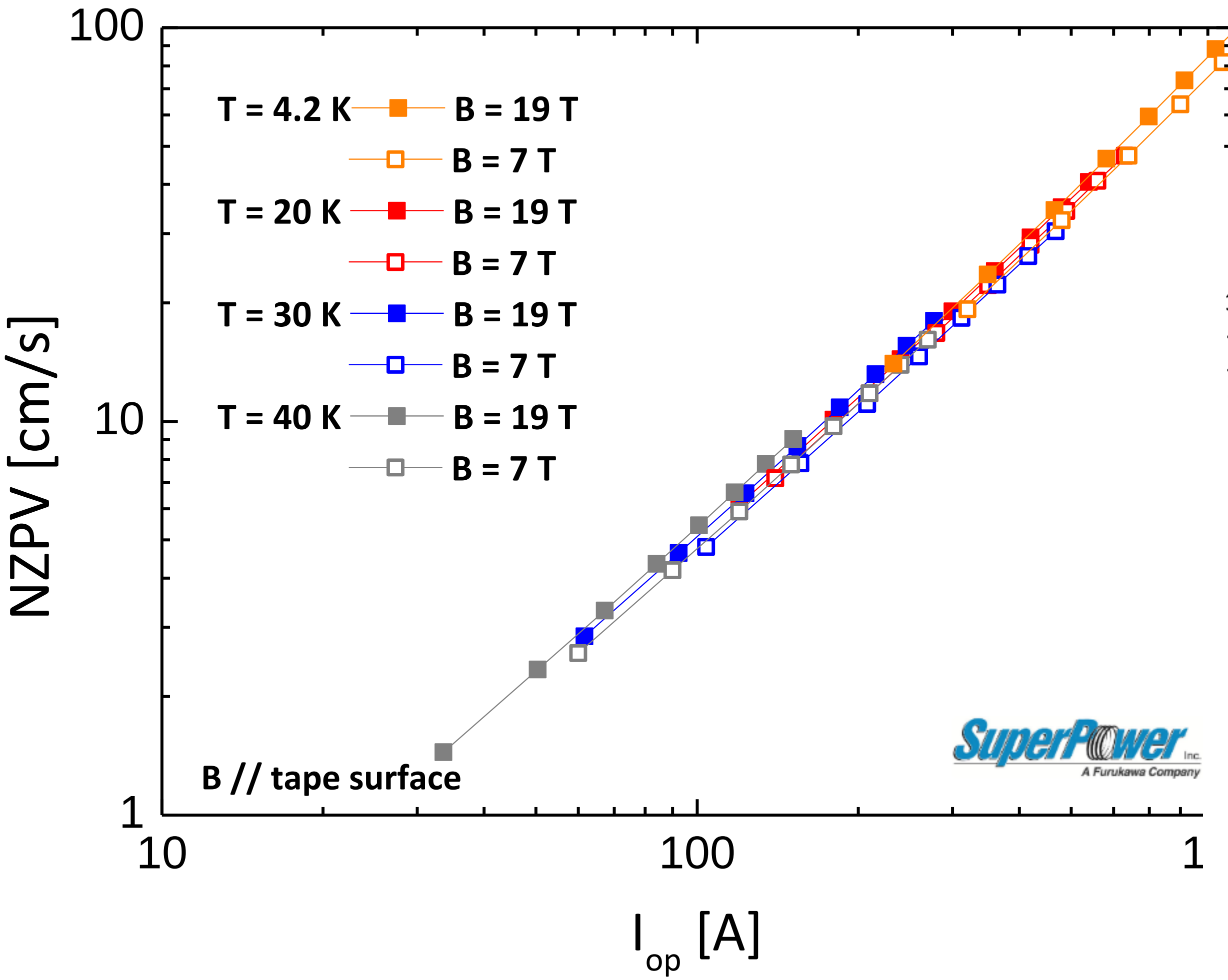
$$T_{CS} = T_{op} - T^* \ln\left[\frac{I_{op}}{I_c(B,T_{op})}\right]$$

$$T_{CS} = T^* \left\{ \left(\frac{T_{op}}{T^*}\right)^{\frac{3}{2}} - \ln\left[\frac{I_{op}}{I_c(B,T_{op})}\right] \right\}^{\frac{2}{3}}$$

M. Bonura and CS, APL <u>108</u> (2016) 242602

Normal zone propagation velocity

NZPV is found to depend only on the operation current following a power law



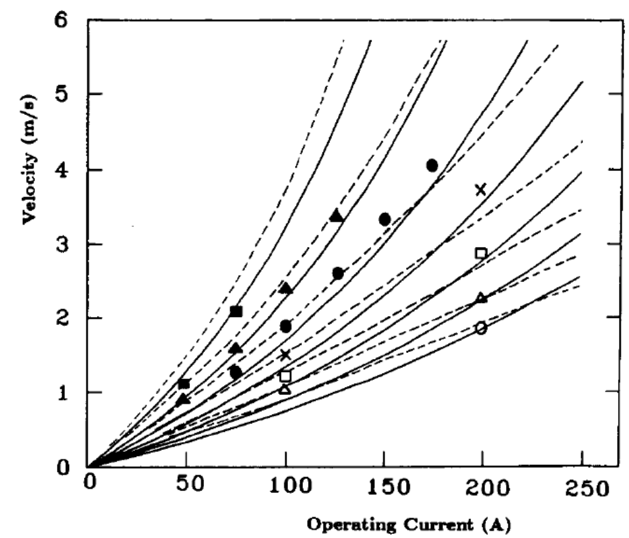


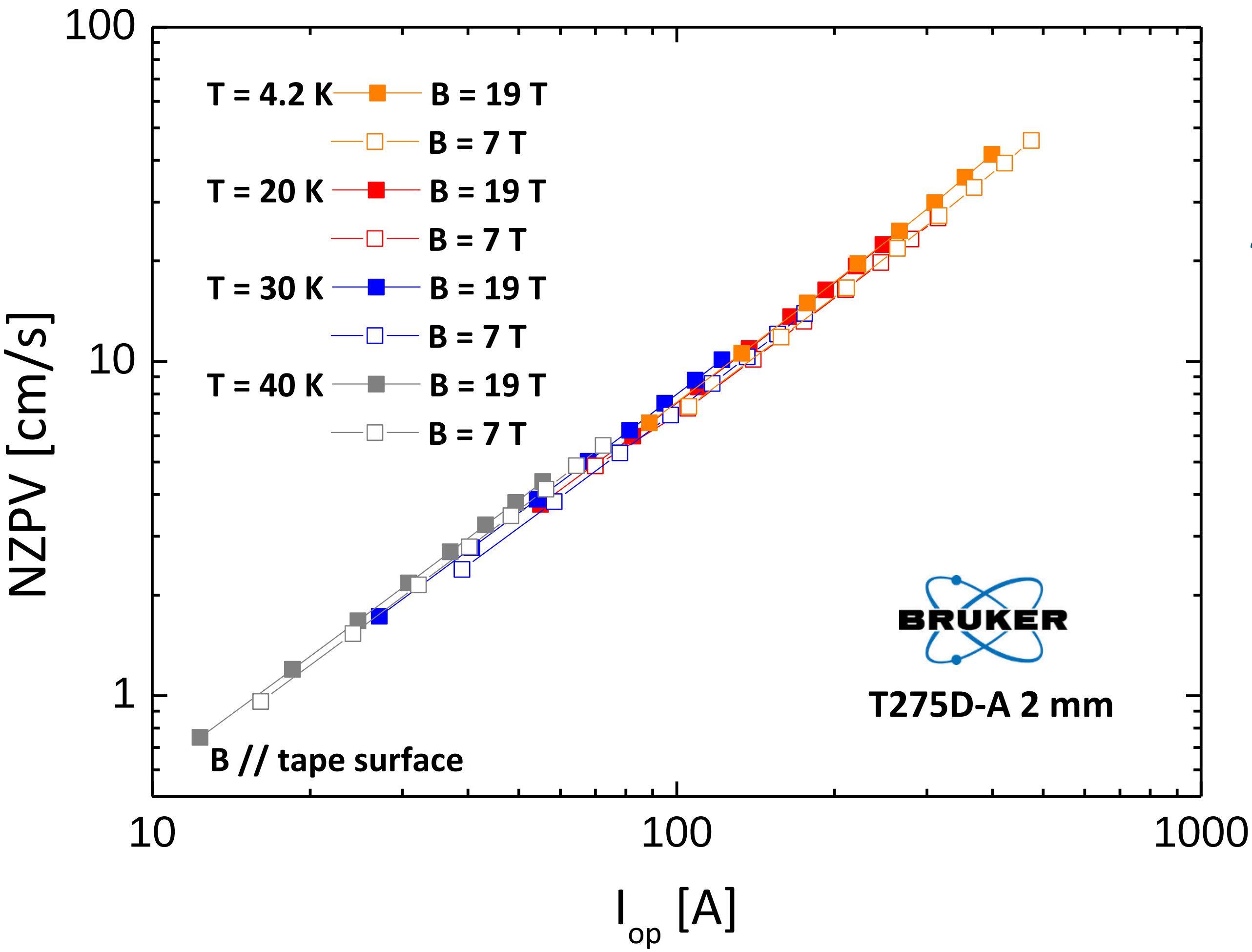
Figure 5 Comparison of the analytical results (——) and the experimental data[8] for U_l at T_∞ = 4.2 K for an Nb_3Sn composite under several ambient magnetic flux densities (in T): ○, 0; △, 2; □, 4; x, 6; ●, 8; ▲, 10; ■, 12. – – –, Analytical results presented in earlier work[8]. The wire diameter is 0.90 mm and the copper-to-superconductor ratio is 1.0

Zhao and Iwasa, Cryogenics 31 (1991) 817

M. Bonura and CS, APL 108 (2016) 242602

Normal zone propagation velocity

2mm tape from BHTS – quench experiments running at UTWENTE

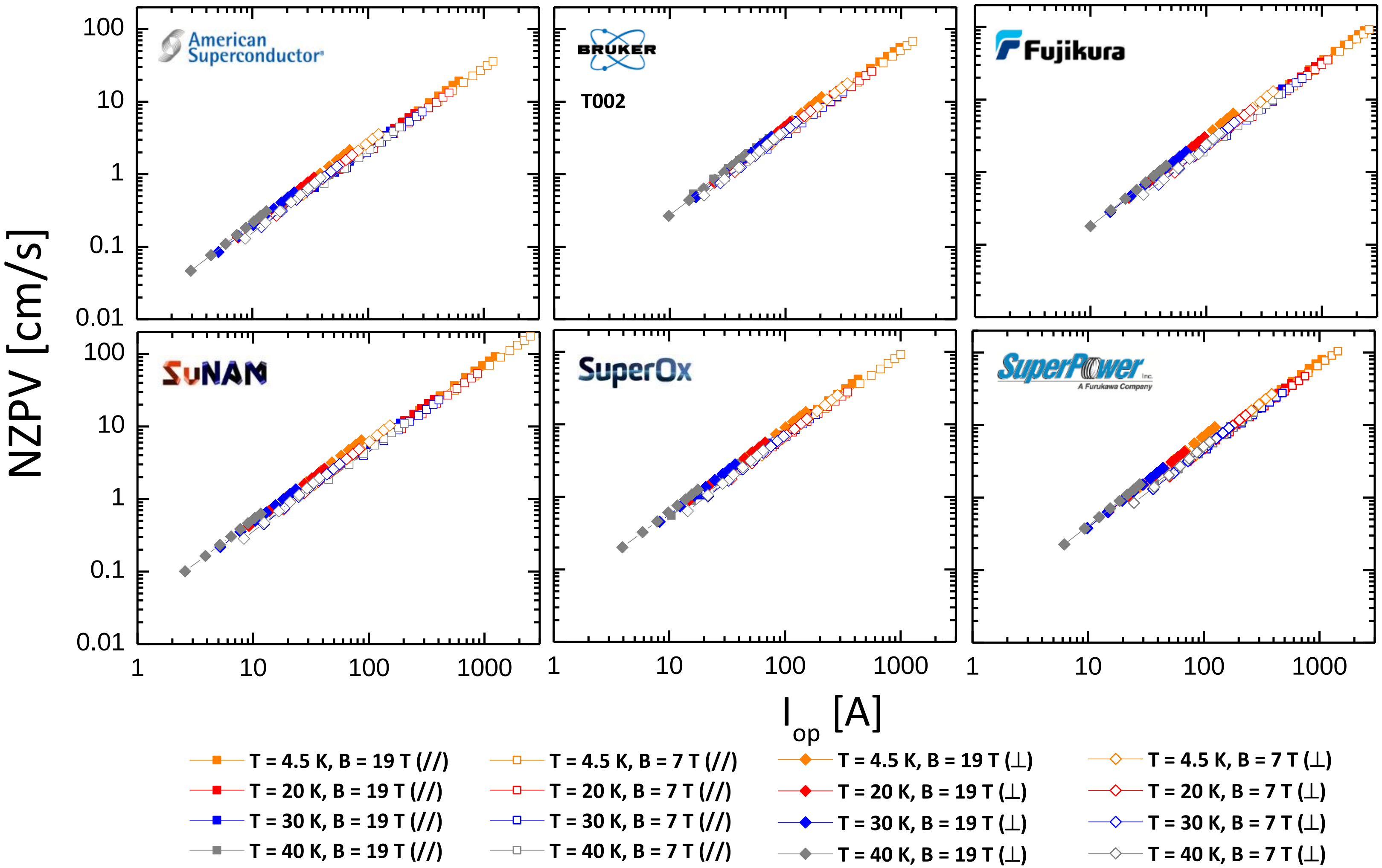


Double disordered YBCO

$$J_c(B,T) = J_c(B,T=0)\,e^{-\left(\frac{T}{T^*}\right)^{\frac{3}{2}}}$$

Normal zone propagation velocity

NZPV determined for B // and ⊥ to the tape surface



M. Bonura and CS, IEEE TASC 27 (2017) 6600705

To conclude…

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Thanks to EuCARD-2, UNIGE had the opportunity to learn a lot about coated conductors

The WAMHTS workshop series was a great showcase for our work

High performance coated conductors are on the market and available from multiple sources

Still there are concerns about delamination, quench propagation and protection, conductor costs

The follow-up of EuCARD-2, ARIES, will have to tackle (some of) these issues

Thank You !

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