GROUP OF APPLIED
SUPERCONDUCTIVITY

UNIVERSITÉ
DE GENÈVE

NZPV and MQE from electrical and thermal properties of commercial REBCO tapes

Marco Bonura and Carmine Senatore

WAMHTS 3 – Lyon – 11 September 2015

High-field κ studies in technical SCs

At University of Geneva, we developed a new experimental setup to investigate κ in superconducting wires and tapes with B up to 21T.

$$\kappa \propto \frac{Q}{\Delta T}$$

Control of all possible spurious thermal losses (conduction, convection, irradiation).

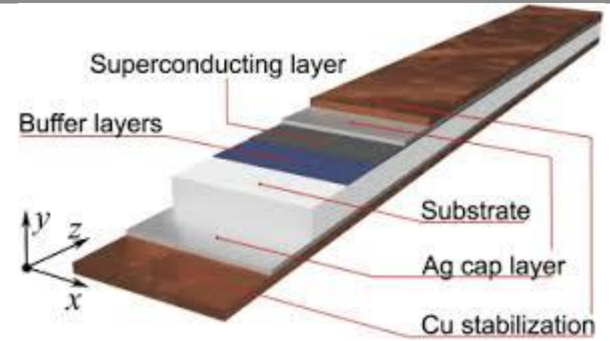
Very high sensitivity at T<40K.

ΔT ~1mK - 100mK.

High-field κ studies important for:

- Magnet design (stability);
- Tailoring conductors to meet specific requirements.

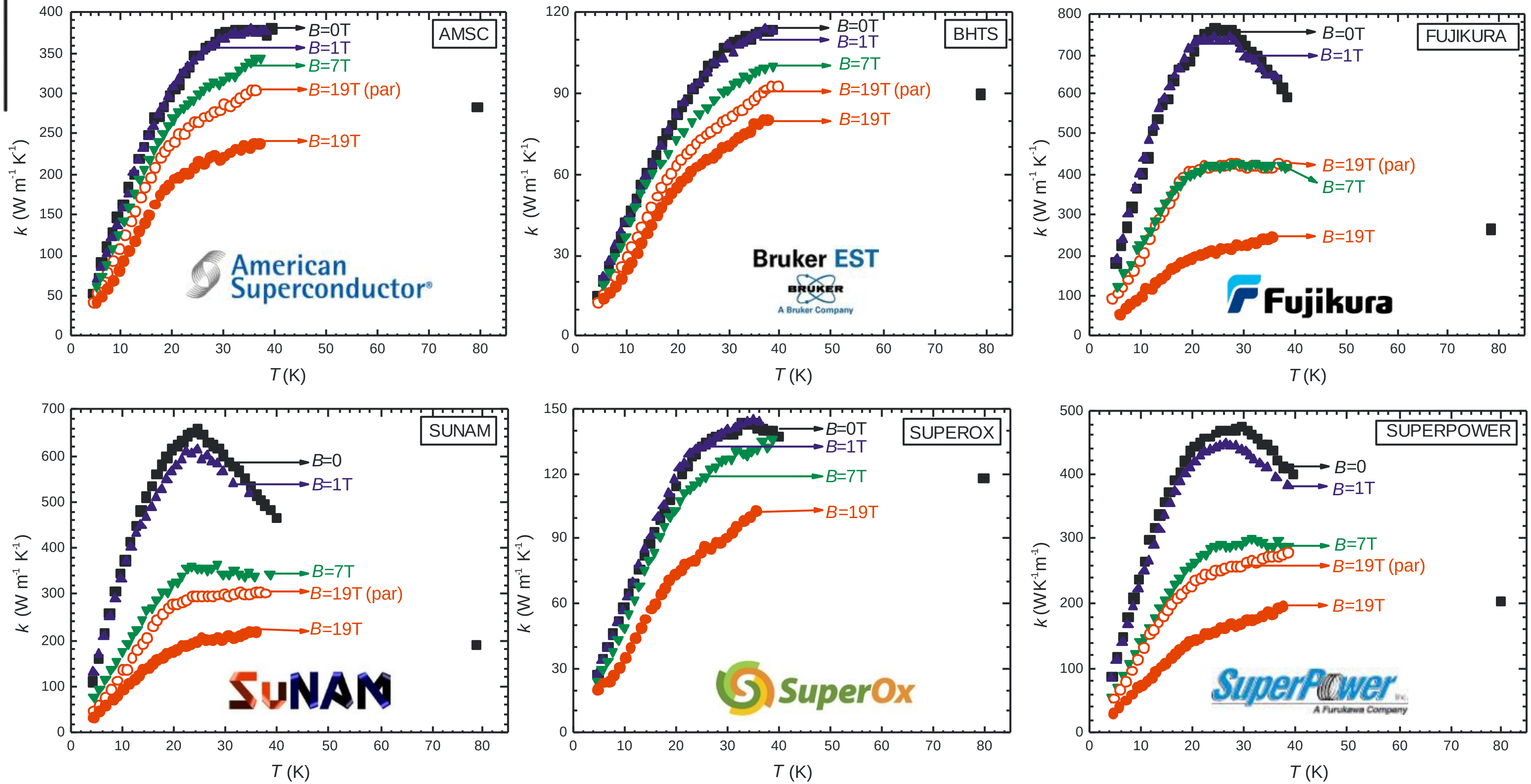
Investigated Coated Conductors



Manufacturer	Dimensions (w x t)	Substrate	Type of stabilization	% of Cu
AMSC	4.8 x 0.20 mm^2	NiW	Cu laminat. on 2 sides	51%
BHTS	4.1 x 0.15 mm^2	SS	Cu electroplated	20%
Fujikura	5.1 x 0.16 mm^2	Hastelloy	Cu laminat. on 1 side	44%
SuNAM	4.0 x 0.11 mm^2	Hastelloy	Cu electroplated	34%
SuperOx	4.0 x 0.09 mm^2	Hastelloy	Cu electroplated	27%
SuperPower	4.0 x 0.10 mm^2	Hastelloy	Cu electroplated	40%

In-field Longitudinal *k*

Measurements' Summary



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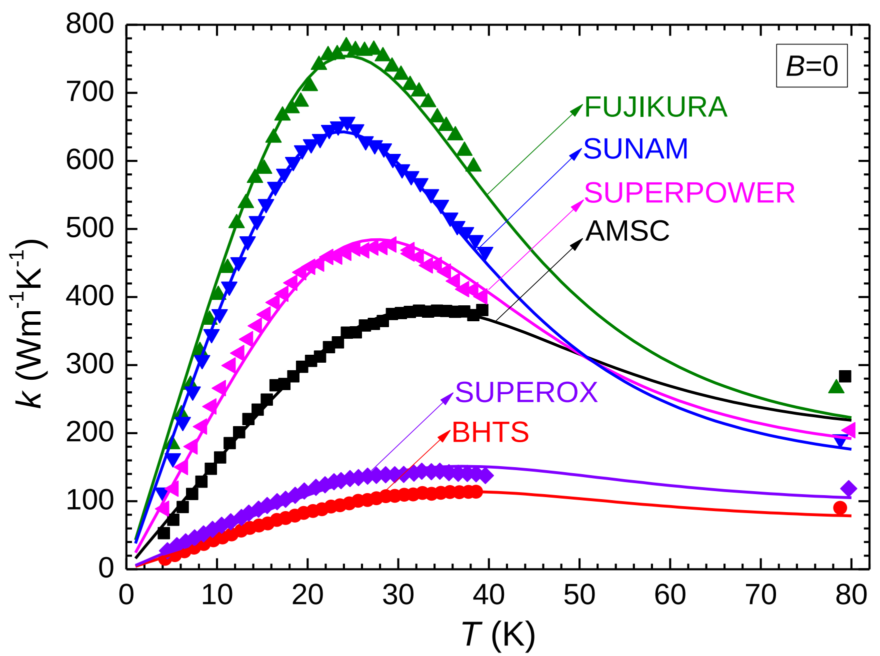
Longitudinal *κ at B=0*

Thermal Conductivity at $B = 0$



Manufacturer	RRR_{Cu} [*fit*]	RRR_{Cu} [$\rho(T)$]	$\frac{S_{Cu}}{S_{tot}}$
AMSC	20	19	0.51
BHTS	14	17	0.20
FUJIKURA	62	59	0.44
SUNAM	69	61	0.34
SUPEROX	13	14	0.27
SUPERPOWER	39	42	0.40

$$k_{meas} = \sum_i k_i \frac{S_i}{S_{tot}} \approx k_{Cu} \frac{S_{Cu}}{S_{tot}}$$

$$k_{Cu} = f(RRR_{Cu})$$

[N. J. Simon, NIST]

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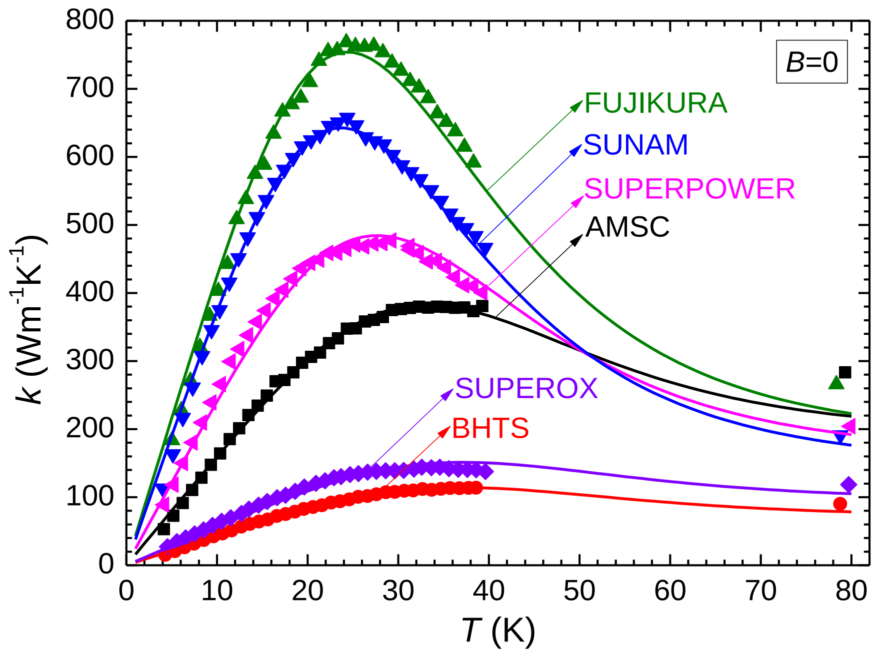
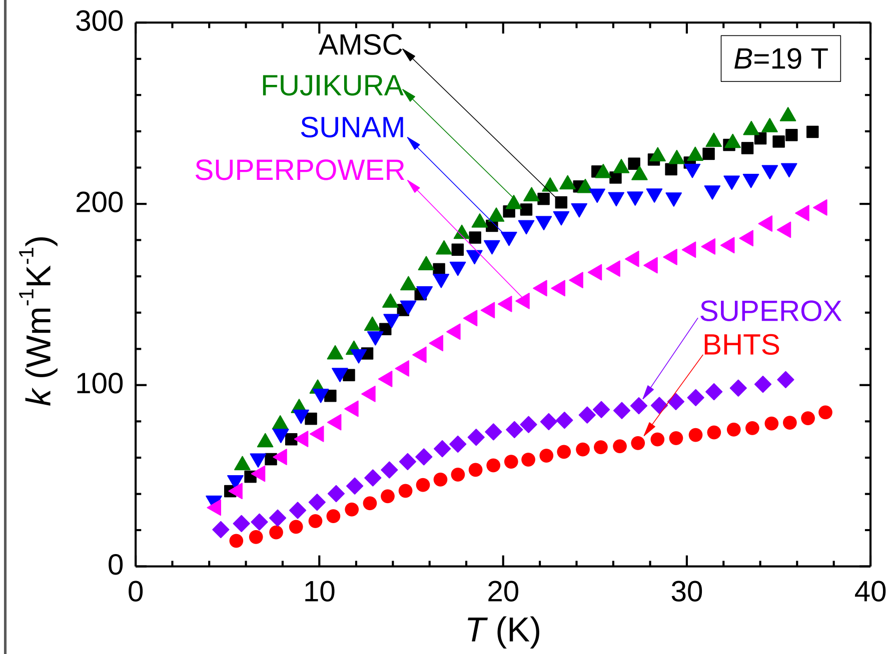
In-field Longitudinal *k*

Thermal Conductivity at $B = 0$



Thermal Conductivity at $B = 19$T



Cu/non-Cu and RRR_{Cu} determine different field-induced reductions

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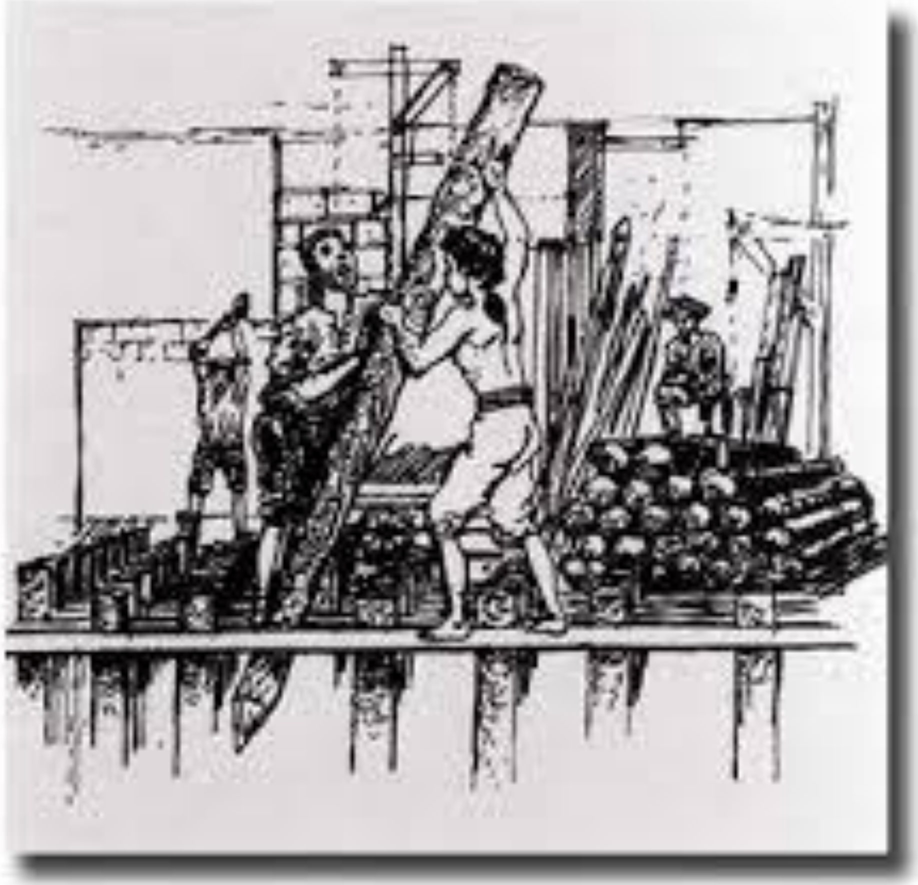
Thermal Stability Evaluation

May we deduce reliable information on MQE and NZPV from κ studies?



Works for foundation. Venice, XVI century.

Normal Zone Propagation Velocity

«Normal Zone Propagation in a YBCO Superconducting Tape»

Author: J. van Nugteren; Supervisor: Dr. M.M.J. Dhallé

Adiabatic theory for NZPV

From the solution of the transient heat conduction equation in an adiabatic environment assuming that the normal zone can be represented by a translating coordinate system moving at *NZPV*.

$$NZPV_L \approx \frac{I}{S_{Tot}}\left[\frac{1}{\rho(T_S)\kappa_n(T_S)}\left(C_n(T_S) - \frac{1}{\kappa_n(T_S)}\frac{d\kappa_n}{dT}\right]_{T=T_S}\int_{T_{Op}}^{T_S} C_S(T)dT\right)\int_{T_{Op}}^{T_S} C_S(T)dT\right]^{-1/2}$$

In case of T-independent parameters

$T_S = (T_{CS} + T_C)/2$

$$NZPV_L \approx \frac{I}{S_{Tot}}\left[\frac{\rho(T_S)\kappa(T_S)}{C_n C_s(T_S - T_{Op})}\right]^{\frac{1}{2}} \approx \frac{I}{S_{Tot}}\left[\frac{LT_S}{C_n C_s(T_S - T_{Op})}\right]^{1/2}$$

$\rho(T)$= constant in the T range of interest:

$$NZPV_L \approx \frac{I}{S_{Tot}}\left[\frac{1}{LT_S}\left(C_n(T_S) - \frac{1}{T_S}\int_{T_{Op}}^{T_S} C_S(T)dT\right)\int_{T_{Op}}^{T_S} C_S(T)dT\right]^{-1/2}$$

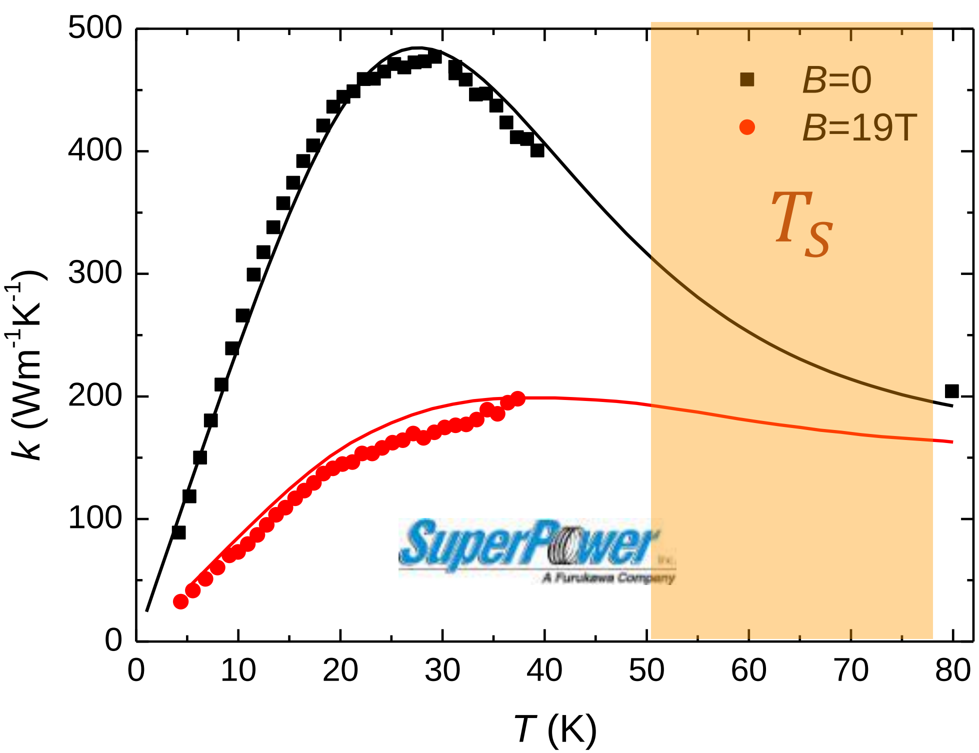
Ok for LTS and MgB_2

Whetston and Roos, J Appl Phys, **36** 783 (1965);
Zhao and Iwasa, Cryogenics **31**, 817 (1991);
Grabovickic *et al.*, IEEE Trans Appl. Supercond. 13 (2), 1726 (2003).

Adiabatic theory for NZPV

$\ll C_n(T_S)$ (applies to the term $\frac{1}{\kappa_n(T_S)}\frac{d\kappa_n}{dT}\Big|_{T=T_S}\int_{T_{Op}}^{T_S} C_S(T)\,dT$)

$$NZPV_L \approx \frac{I}{S_{Tot}}\left[\frac{1}{\rho(T_S)\kappa_n(T_S)}\left(C_n(T_S) - \frac{1}{\kappa_n(T_S)}\frac{d\kappa_n}{dT}\Big|_{T=T_S}\int_{T_{Op}}^{T_S} C_S(T)\,dT\right)\int_{T_{Op}}^{T_S} C_S(T)\,dT\right]^{-1/2}$$



$T_S=(T_{CS}+T_C)/2$

Good approximation for REBCO Tapes in high field

$$NZPV_L \approx \frac{I}{S_{Tot}}\sqrt{\frac{LT_S}{C_n(T_S)\int_{T_{Op}}^{T_S} C_S(T)\,dT}}$$

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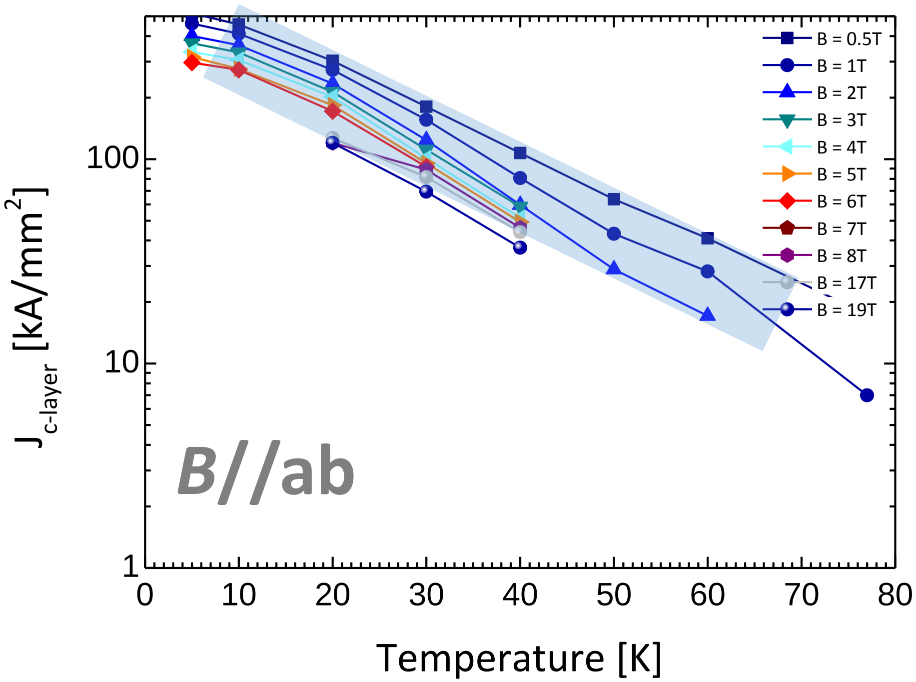
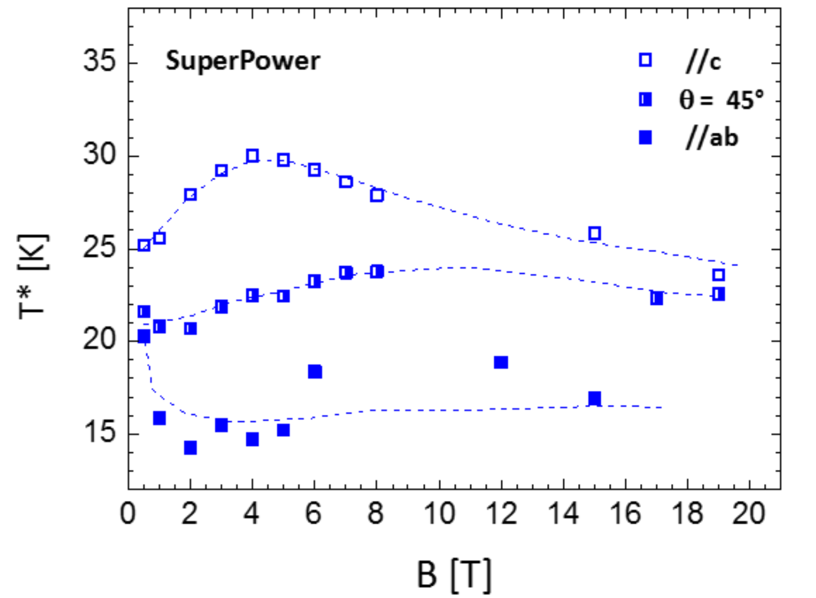
Critical Current: *Scaling Law*

Temperature scaling law $J_c(B,T) = J_c(B, T=0)e^{-\frac{T}{T^*}}$





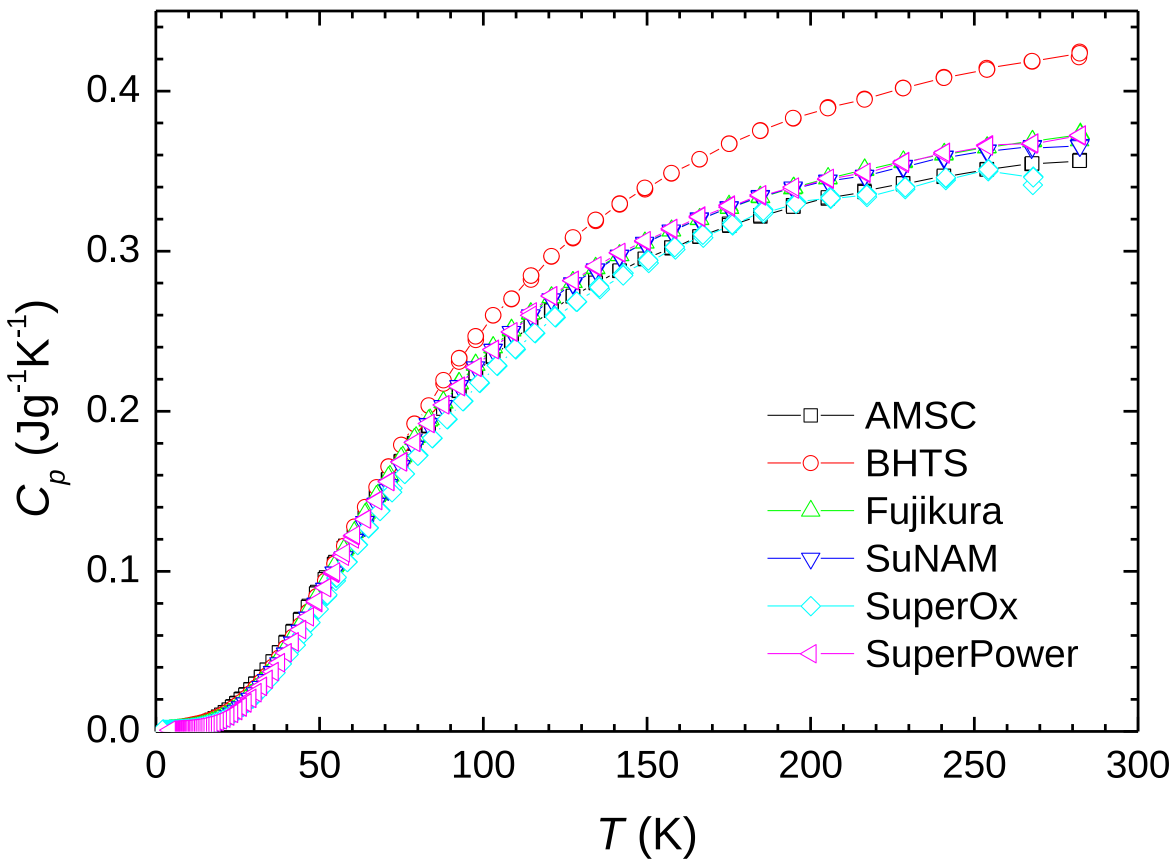
C. Senatore et al. Submitted to SUST

Analitical expression

$$T_{CS} = T_{Op} - T^* ln \frac{I_{Op}}{I_C(B, T_{Op})}$$

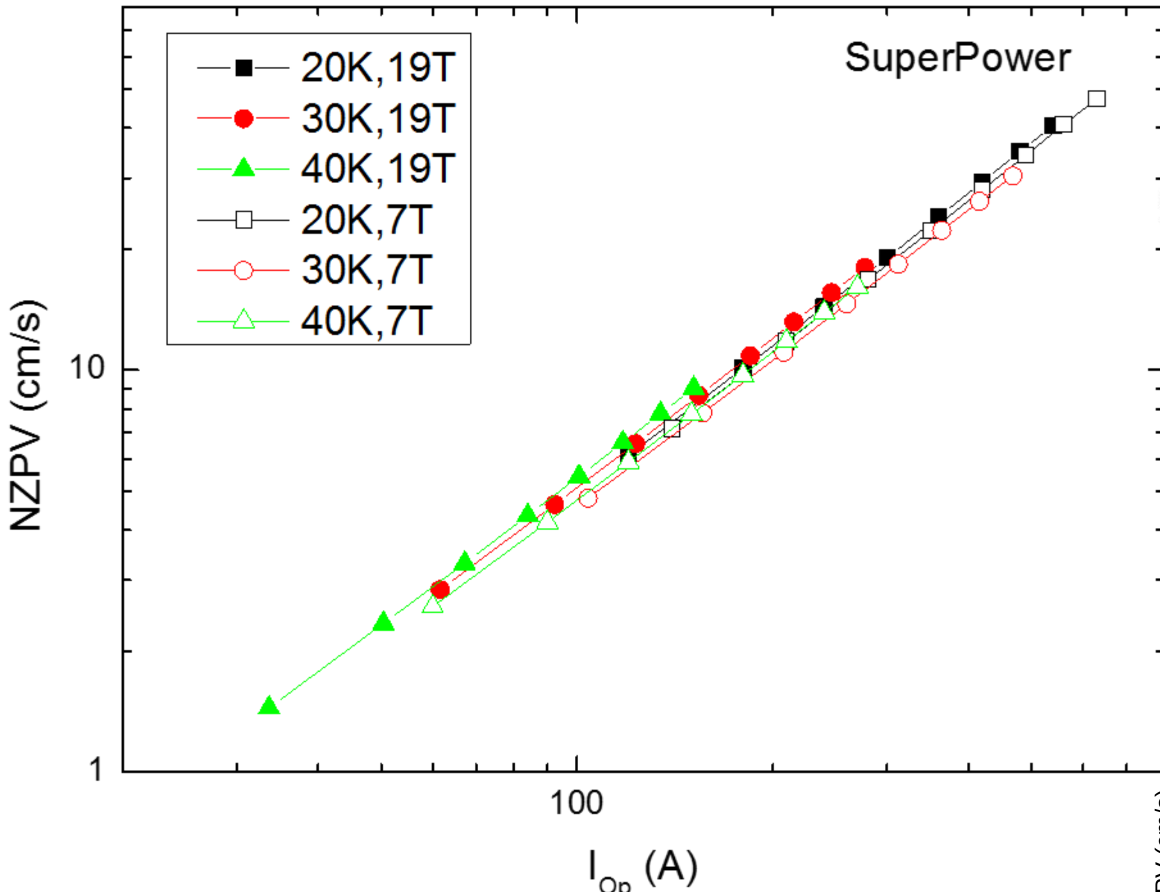
Specific Heat of REBCO tapes

Specific Heat data of REBCO CCs from different manufacturers

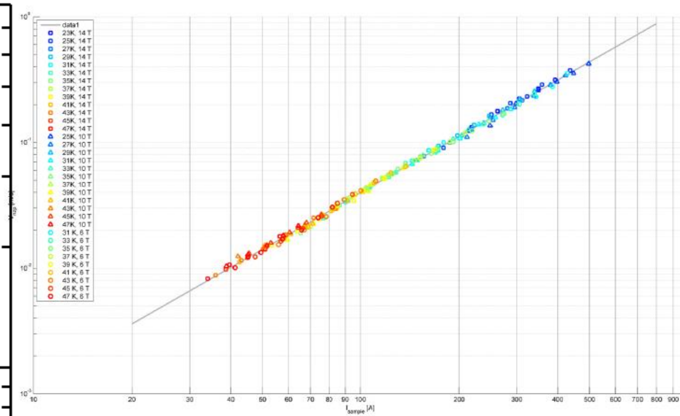


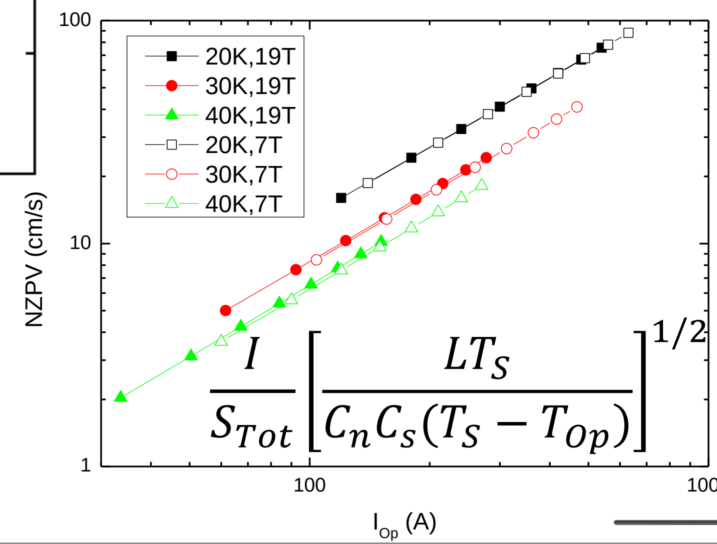
American Superconductor® · Bruker EST (BRUKER, A Bruker Company) · Fujikura · SuNAM · SuperOx · SuperPower (A Furukawa Company)

Calculated NZPV



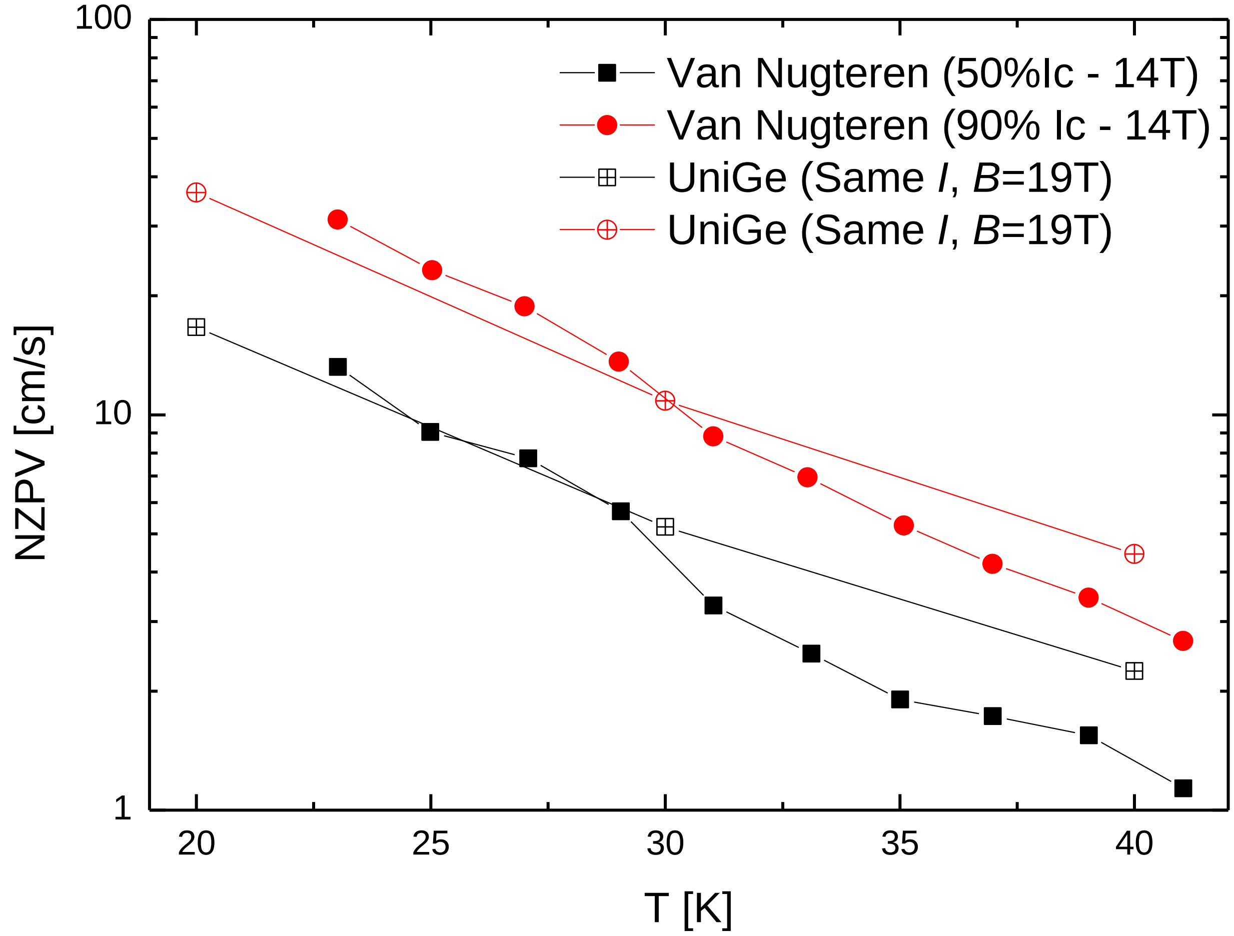
$$NZPV_L \approx \frac{I}{S_{Tot}} \sqrt{\frac{LT_S}{C_n(T_S) \int_{T_{Op}}^{T_S} C_S(T)dT}}$$





$$\frac{I}{S_{Tot}} \left[\frac{LT_S}{C_n C_S (T_S - T_{Op})} \right]^{1/2}$$

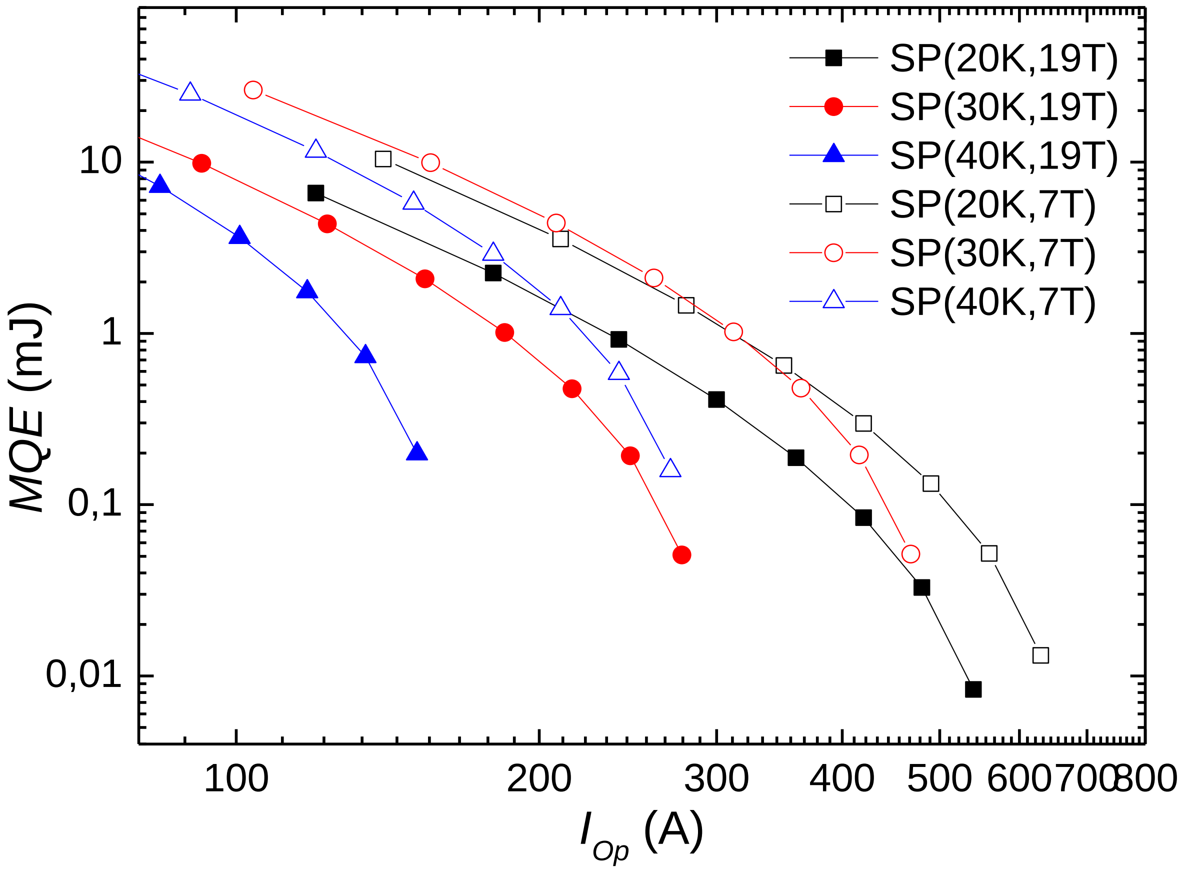
NZPV: comparison with experiment



SCS4050

Minimum Quench Energy

$$MQE \approx \frac{\kappa_L S_{Tot}^2}{I_{Op}} \sqrt{\frac{2 s_{Cu}(T_{CS} - T_{Op})}{L T_{CS}}} \int_{T_{Op}}^{T_{CS}} c(T)\,\mathrm{d}T$$



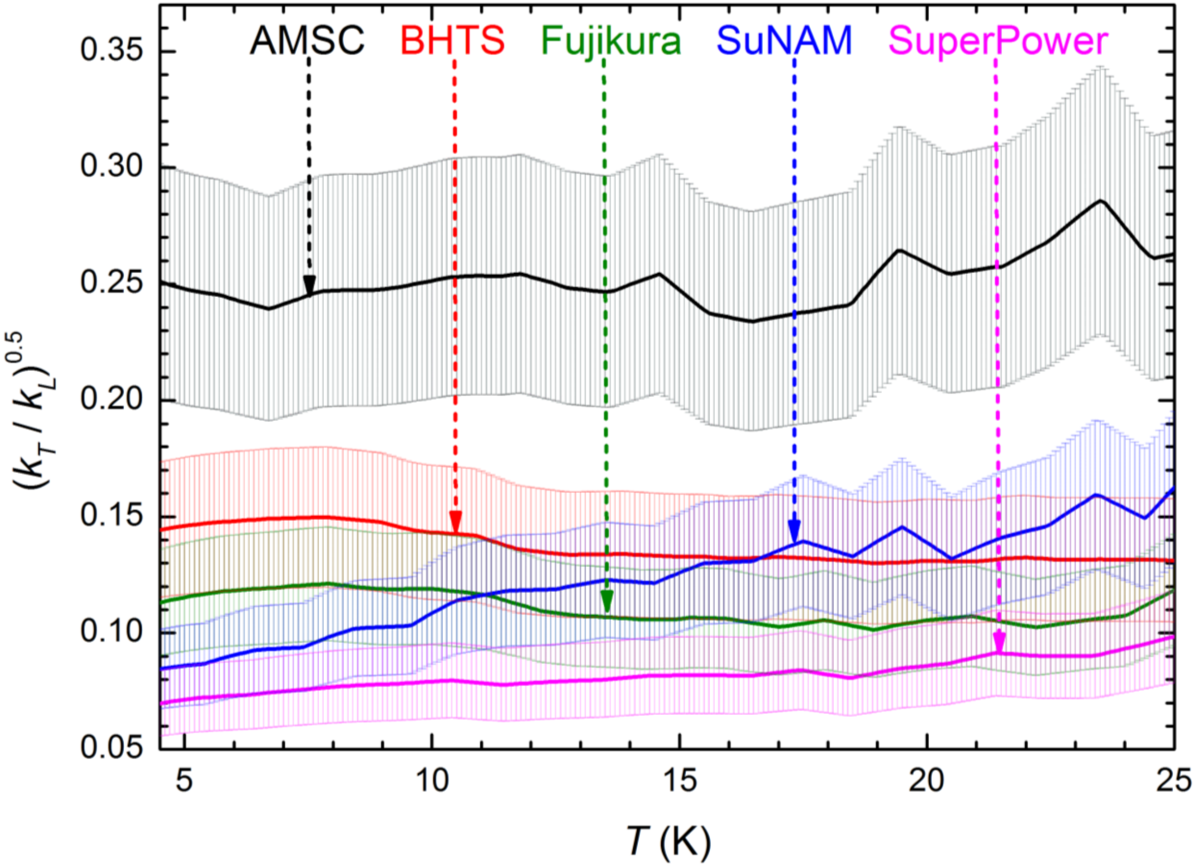
Many thanks for your attention

Marco Bonura

09/09/2015

Normal Zone Propagation Velocity

The experimental determination of $NZPV_T$ is much more complex than that of the longitudinal $NZPV_L$.



$$\frac{NZPV_{Transv}}{NZPV_{Long}} = \sqrt{\frac{k_T}{k_L}}$$

M. Bonura, C. Senatore IEEE TRANS APPL SUPERCOND 25 (3) 6601304 (2015)