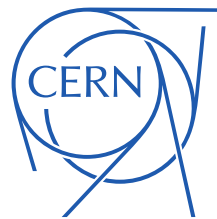


EuCARD2 WP10.2 main results and open issues

L. Bottura and C. Senatore
on behalf of WP10.2
February 15th, 2017



Initial targets (kick-off on 14 June 2013)

	parameter	units	targets
Tape	J_E (20 T, 4.2 K)	(A/mm²)	600
	σ (I_C) within a unit length	(%)	10
	M(1.5 T, 10 mT/s)	(mT)	300
	Range of $\sigma_{\text{transverse}}$	(MPa)	100
	Range of $\varepsilon_{\text{longitudinal}}$	(%)	± 0.3
	Unit length	(m)	100
	parameter	units	targets
Cable	I_C (20T, 4.2 K)	(kA)	10
	<i>Provisional width</i>	<i>(mm)</i>	<i>10</i>
	<i>Provisional thickness</i>	<i>(mm)</i>	<i>1.5</i>
	Effective contact resistance	($\mu\Omega$)	5

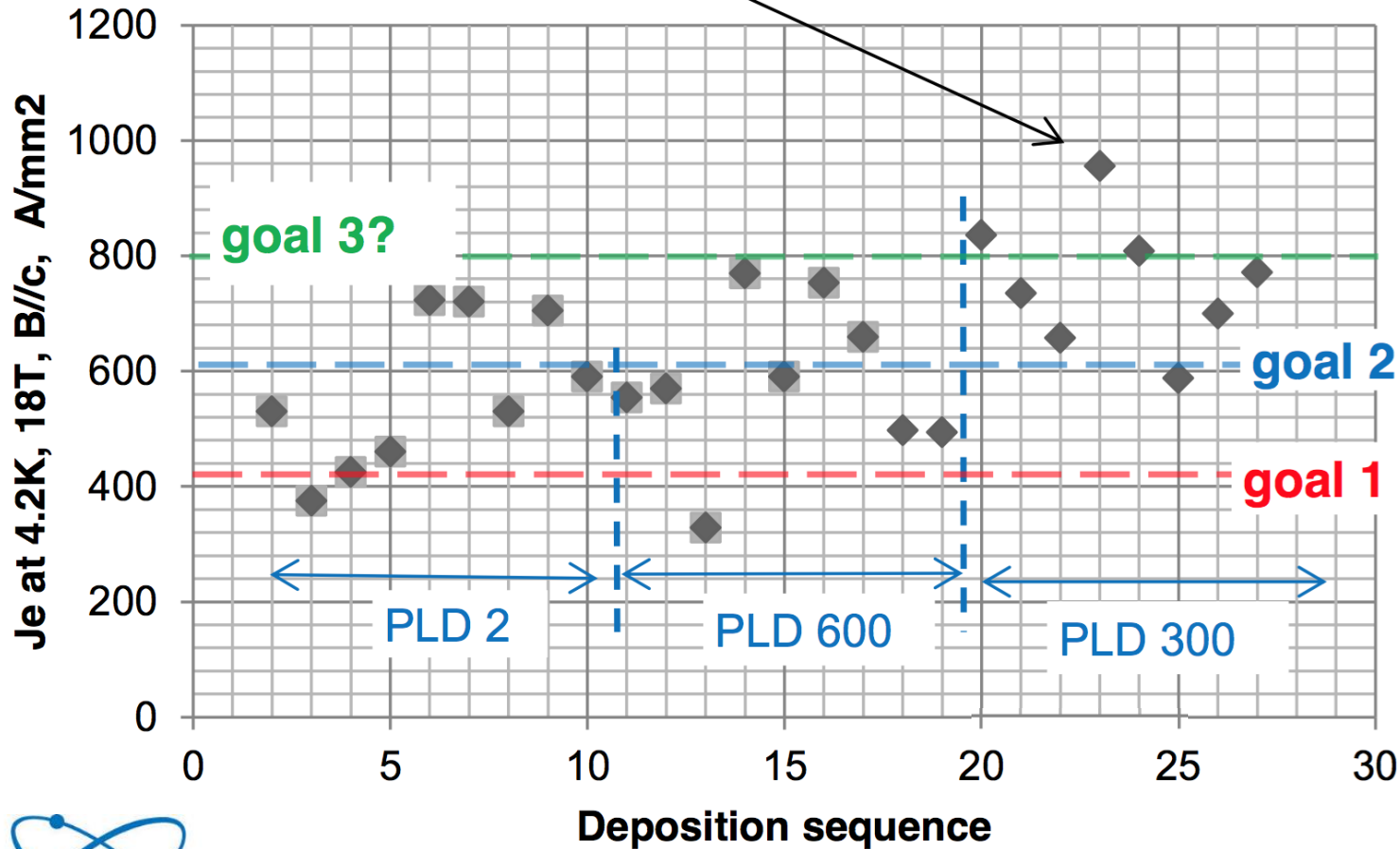
Record results

12 mm tapes

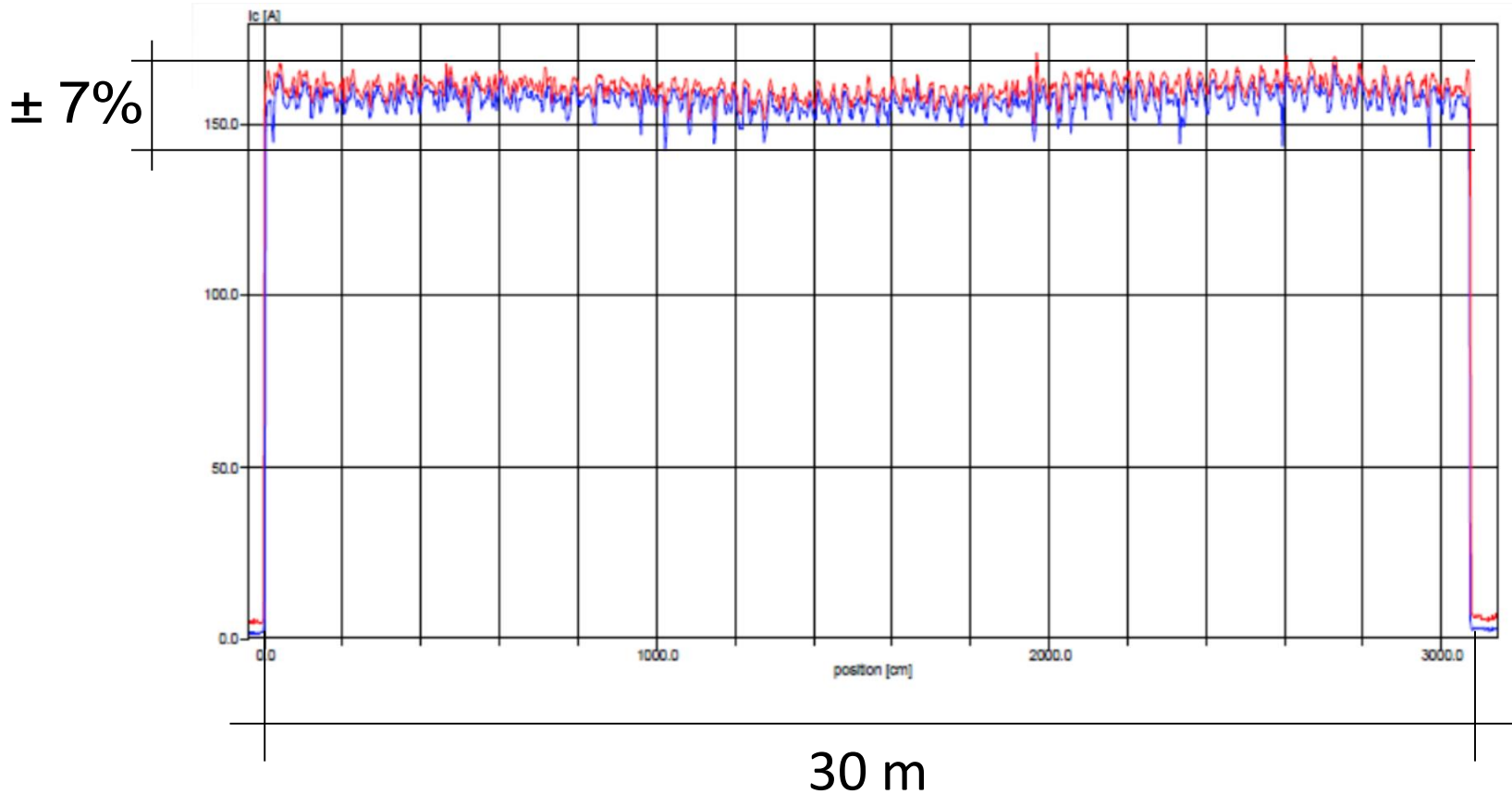
20 to 30 m processed unit length

90m tape production unit length

$I_c = 1338 \text{ A/4mm-w}$



Good homogeneity demonstrated



Courtesy of A. Usoskin, Bruker-HTS

PLD-300

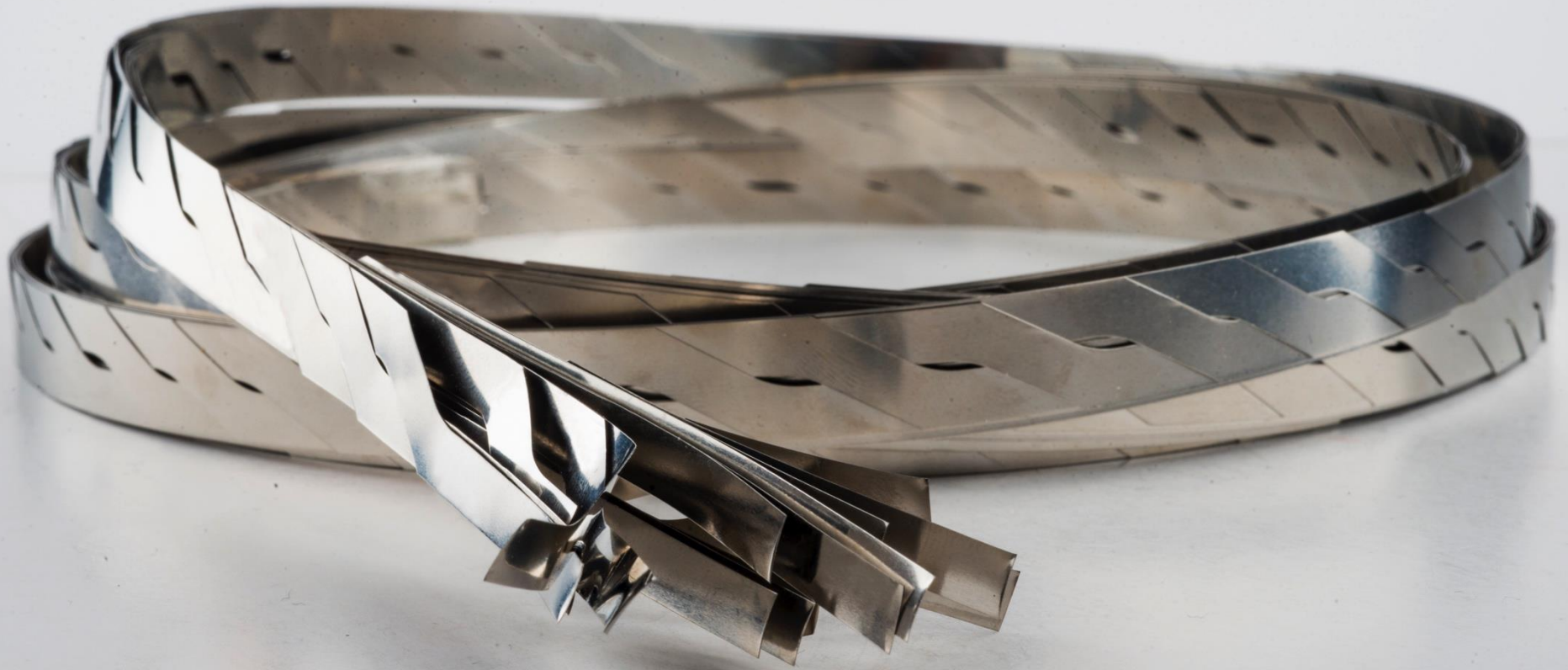


Courtesy of A. Usoskin, Bruker-HTS

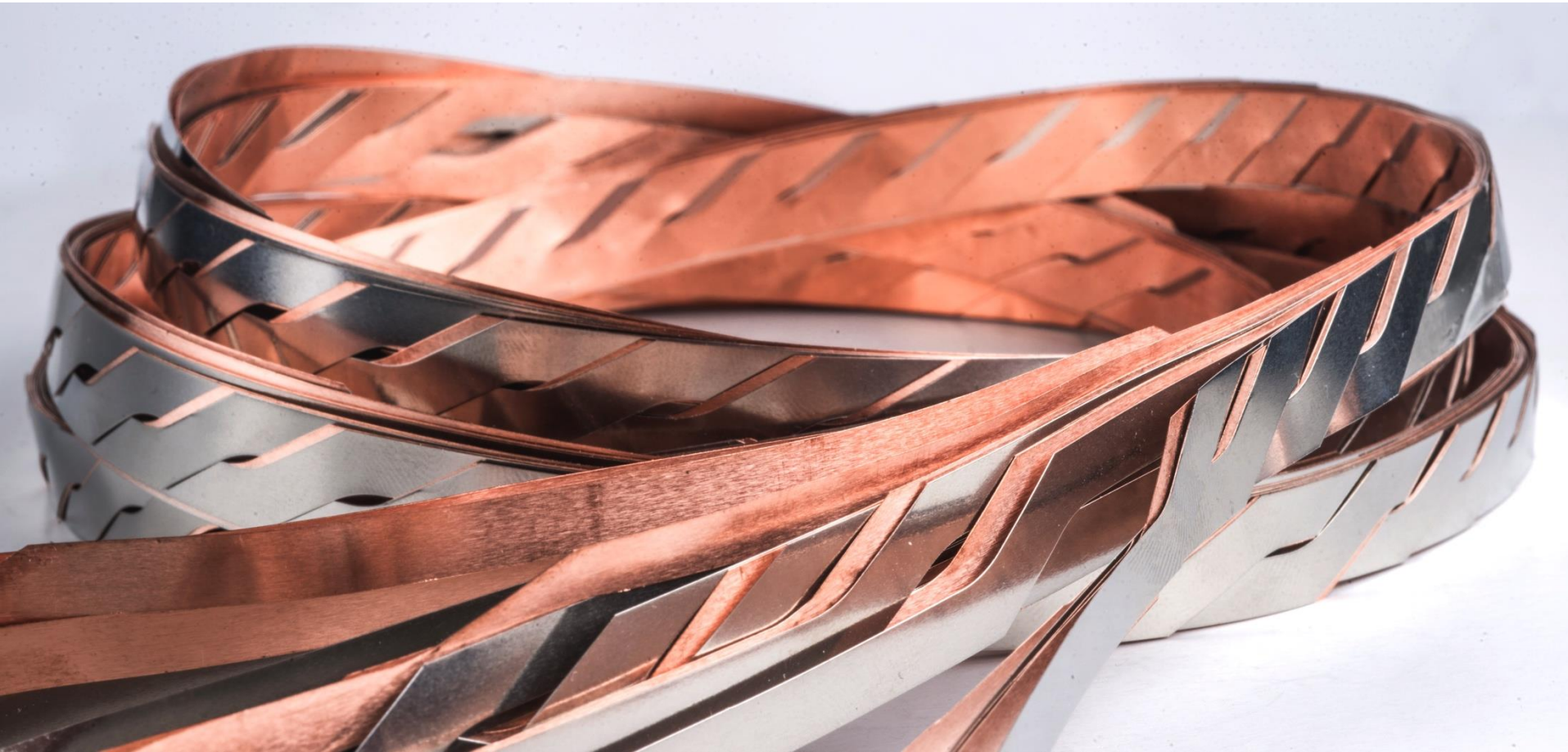
Status of work - tape

- Total 850 m of cable produced by partner Bruker-HTS, this completes the EuCARD2 contractual obligations, and with very good performance (exceeding largely the targets set in 2012)
- CERN has procured 800 m of tapes procured from alternative sources ([A. Ballarino](#))
 - 200 m SuperOx (June 2015) – 100 m cabled
 - 100 m Sunam (July 2015) – cabled
 - 300 m Fujikura (December 2015) – attempted cabling
 - 200 m (15% Zr) SuperPower (June 2016) – 100 m cabled
- Nearly 2 km of tape produced/procured
- Next step: CERN is procuring of a total of 3.1 km of tape ([A. Ballarino](#))

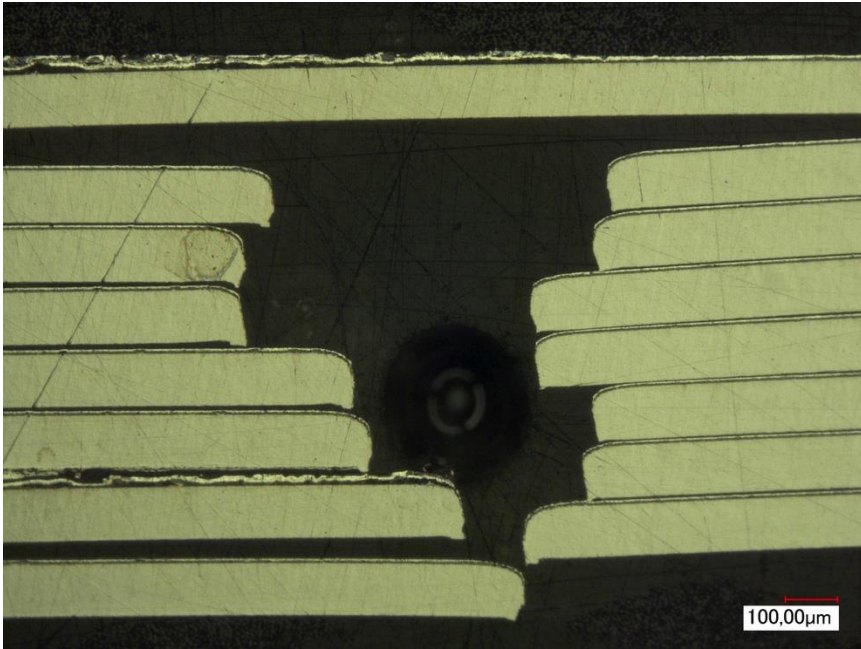
Cable dummies (April 2014)



Cable dummies (April 2014)



Cable technology

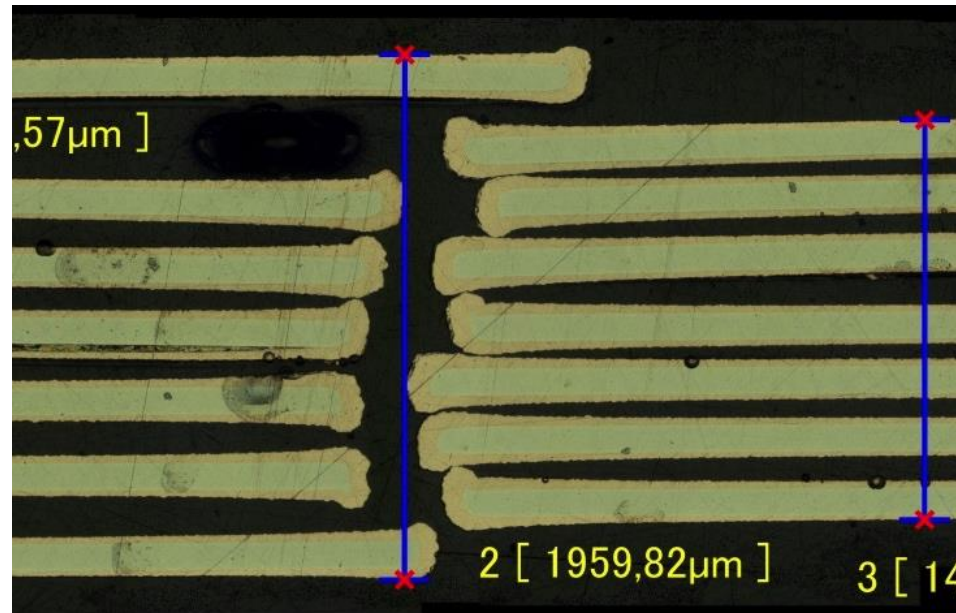


Burrs and delaminations

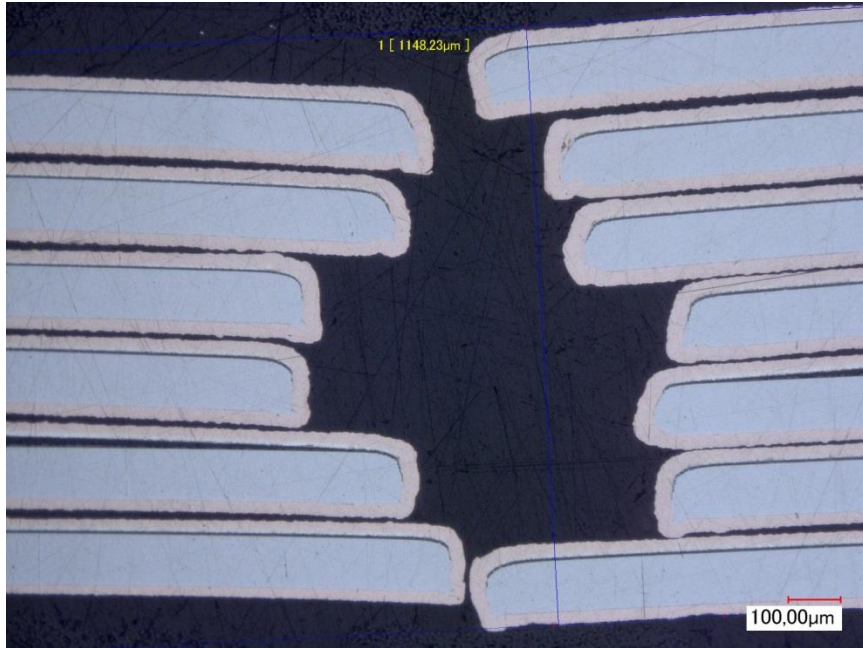
Punch-and-coat



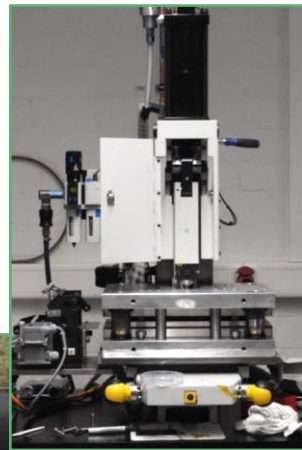
Dog-boning



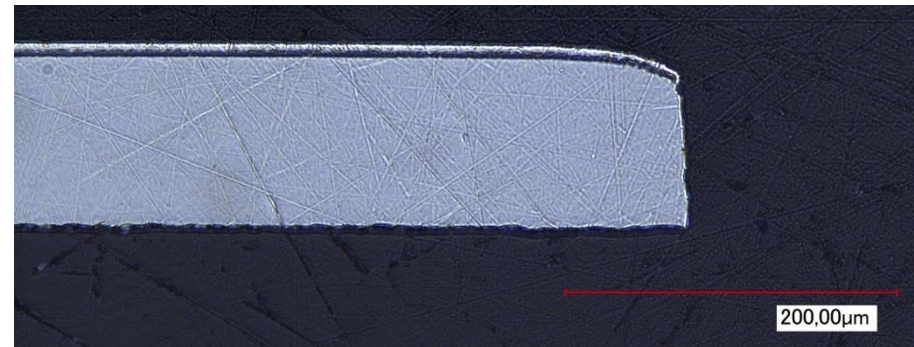
Cable technology



Optimal Cu-coating



New punching tool



Baseline cable designs (October 2015)

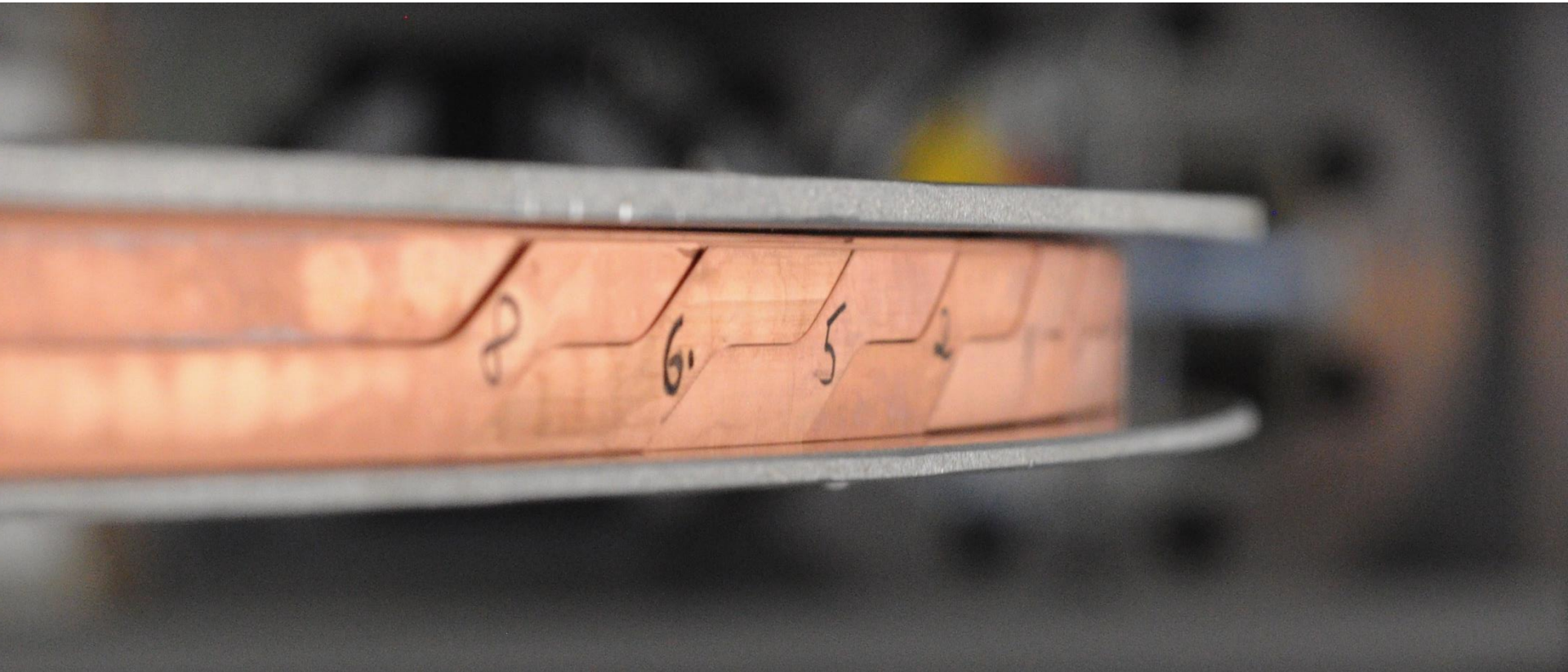
Skinny Roebel (AB) (out of 0.1 mm tapes)

Number of tapes	(-)	15
Width	(mm)	12
Thickness	(mm)	0.9±0.1
Transposition pitch	(mm)	300
Critical current (4.2 K, 20 T _{perpendicular})	(kA)	≥ 4.8

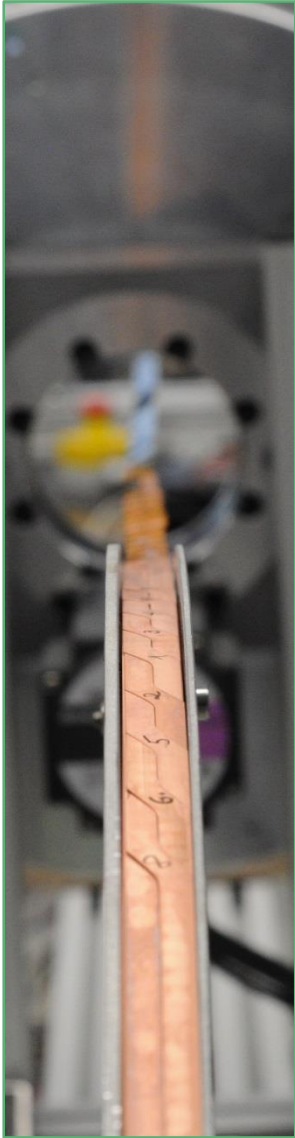
Fat Roebel (CT+AB) (out of 0.14 mm tapes)

Number of tapes	(-)	13
Width	(mm)	12
Thickness	(mm)	1.1±0.1
Transposition pitch	(mm)	300
Critical current (4.2 K, 20 T _{perpendicular})	(kA)	≥ 5.8

Final (and first) full length (January 2017)



Status of work - cable



- Cable production on-going at KIT ([A. Kario](#))
 - All Feather.M0 lengths produced and delivered
 - First Feather.M2 UL delivered to CERN
 - Short length for Ic test in FRESCA produced
 - Second Feather.M2 UL in production (March 2017)
- CERN has procured 32 m of Roebel cable from SuperOx (Sunam tape) ([A. Ballarino](#)) and 60 m of dummy from GCS
- Next step: production of additional UL's using optimized tooling at KIT (4 UL's, [A. Kario](#)), as well as SuperOx lengths (2 UL's, [A. Ballarino](#))



Further activities

- Ic surface characterization ([C. Senatore](#))
- Ic measurement on Roebel cables ([J. Fleiter](#))
- Transverse pressure experiment on Roebel cable ([M. Dhalle](#))
- AC loss, magnetization and R_c measurement and analysis ([M. Dhalle](#), [Y. Yang](#))
- Quench experiment ([M. Dhalle](#), [Y. Yang](#))
- BSCCO cable test ([LBNL](#), [NHMFL](#), [M. Dhalle](#))

$I_c(B, T, \alpha)$

- Samples delivered by Bruker-HTS, relatively small amount of material (we need to prepare more)
- Measurements have started at University of Geneva
- Very important measurement, it will provide a benchmark value for the EuCARD2 tape (not available at present)

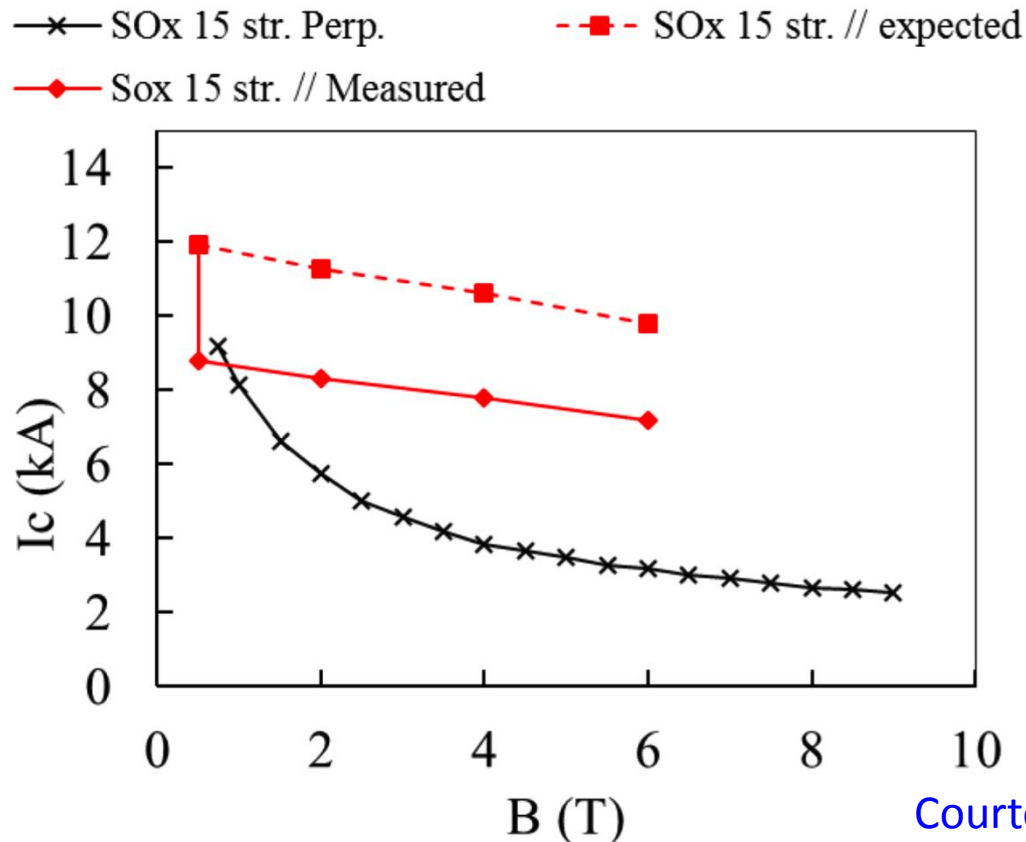
INSTITUTE	θ [°]	B [T]	T [K]
KIT	0-360	0.5	70, 77
UTWENTE	0-360	0.5, 1, 2	4.2, 10, 20, 30, 40
INPG CNRS	0, (15), 30, 60, 90	up to 25	4.2
UNIGE	0, (15), 30, 60, 90	up to 19	4.2, 20, 40, 60



Reference person: C. Senatore, U. Geneva

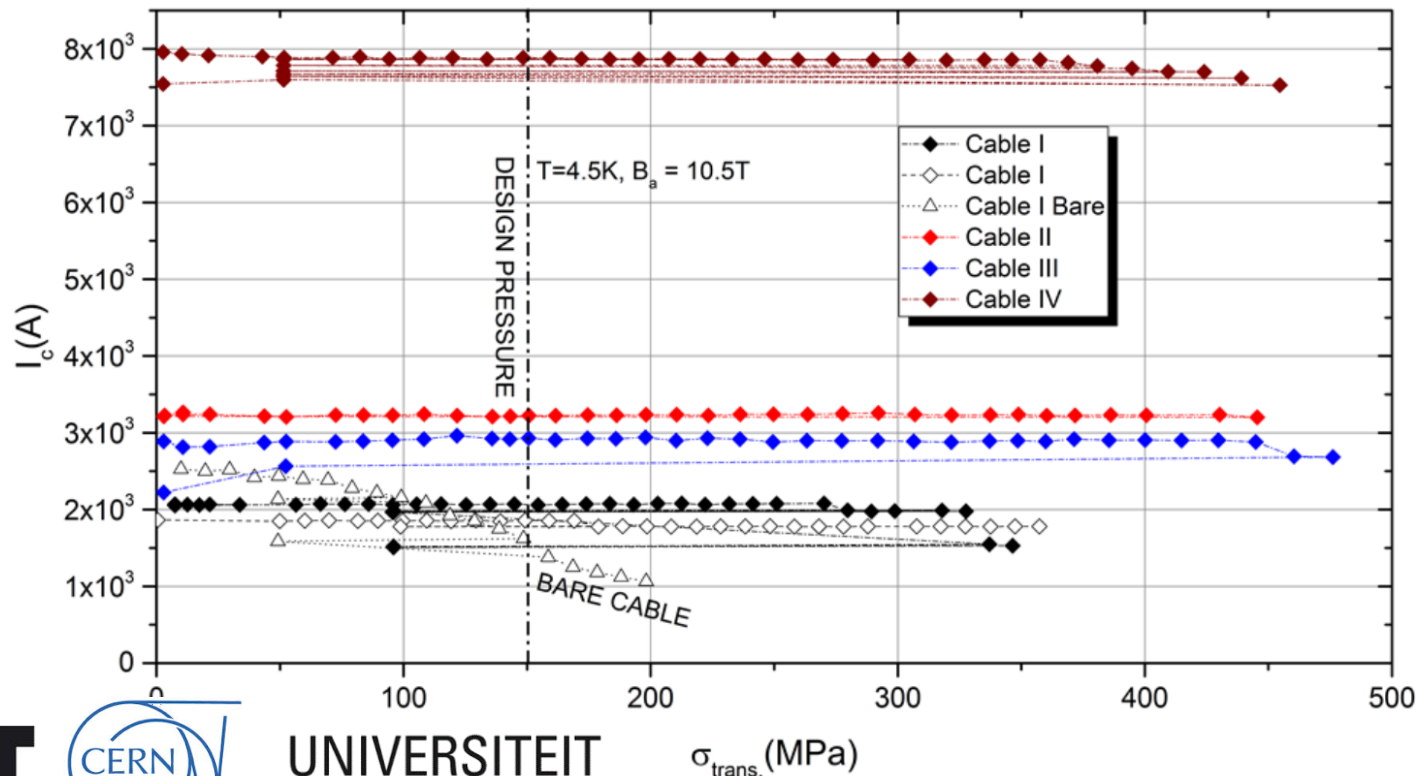
Ic measurement on Roebel cables

- SuperOx cable, 15 strands, provided as a short sample for testing
- Bruker-HTS/KIT cable has arrived at CERN



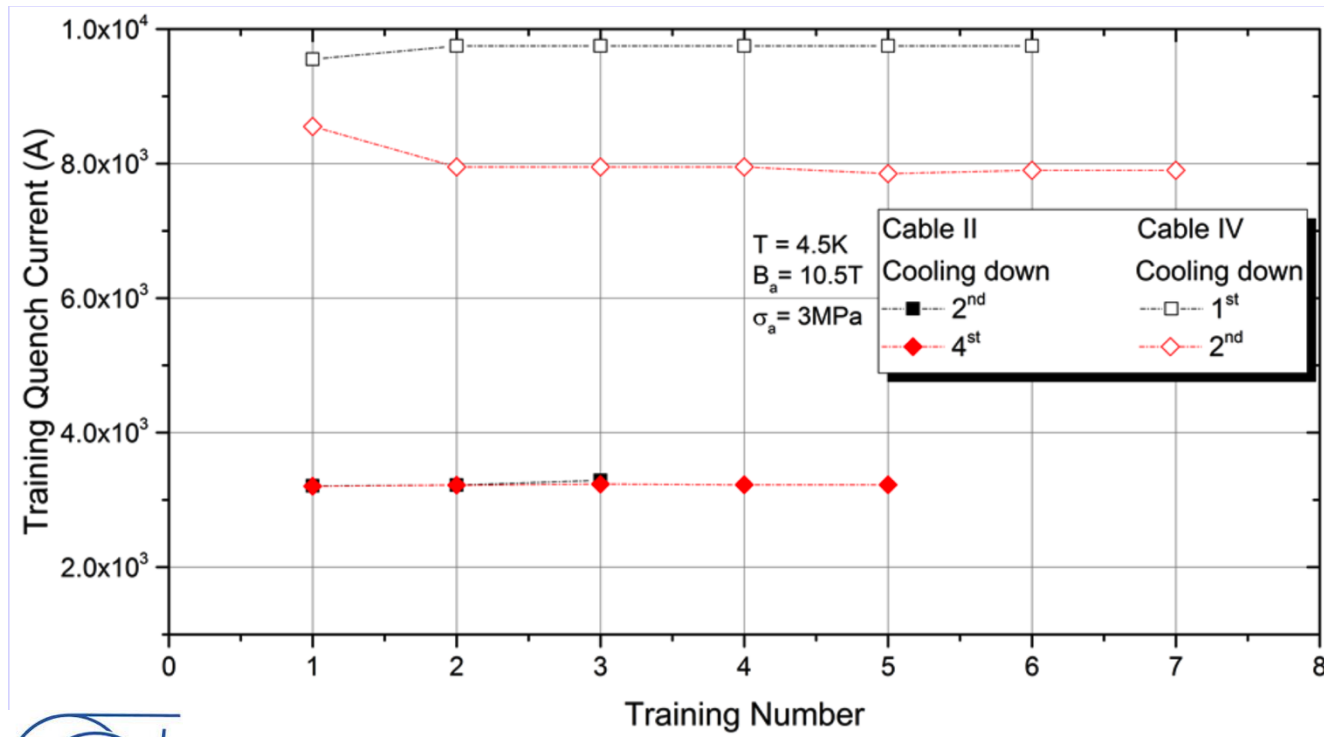
I_c vs. transverse pressure

- Program approaching completion of initial scope:
 - Cable I: SuperPower tape, L_p=126 mm, KIT impregnation
 - Cable II: SuperPower tape, L_p=226 mm, KIT impregnation
 - Cable III: SuperPower tape, L_p=226 mm, CERN impregnation
 - Cable IV: Bruker-HTS tape, L_p=226 mm, CERN impregnation



Open issue: degradation ?

- Significant loss of I_c observed after a thermal cycle
 - Is this a problem with the sample ?
 - Is this a problem with the insulation system ?



AC loss/Magnetization/Rc

- First measurement performed at U. Twente
- Surprisingly “low” Rc values observed

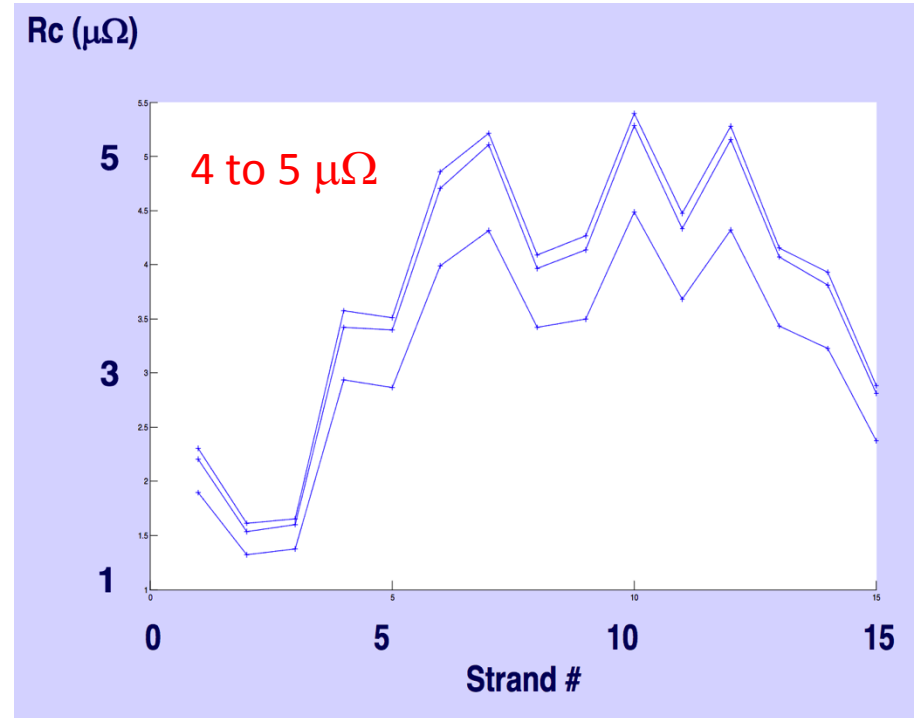
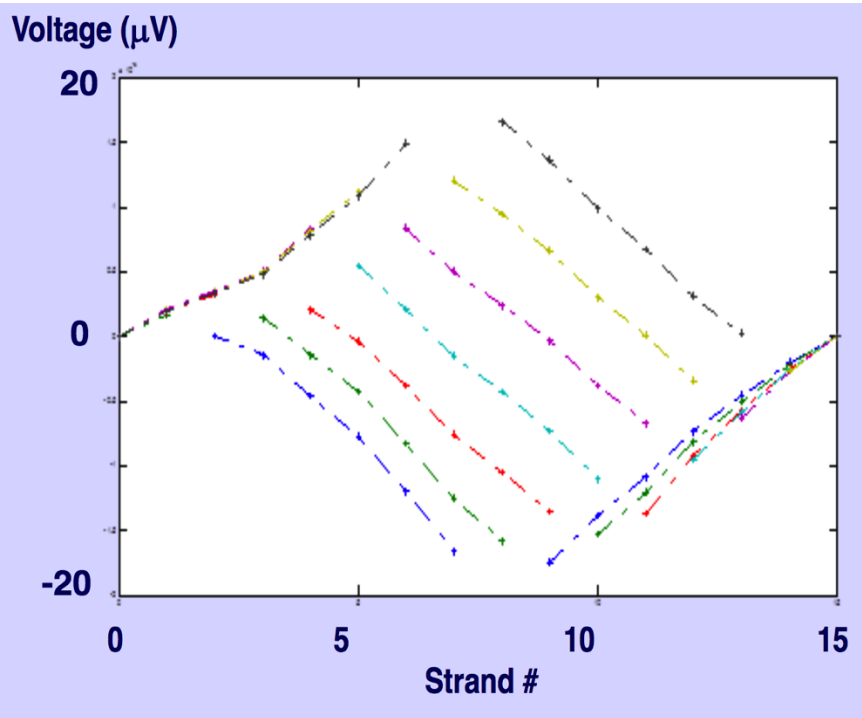


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Courtesy of M. Dhalle, U. Twente

AC loss/Magnetization/Rc



Liquid Nitrogen

Measurement current 2A

Potential referenced at strand 15

NOTE: measurements at 4.2 K show a reduction to 2 $\mu\Omega$



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Southampton

By courtesy of M. Dhalle, U. Twente

Quench experiment

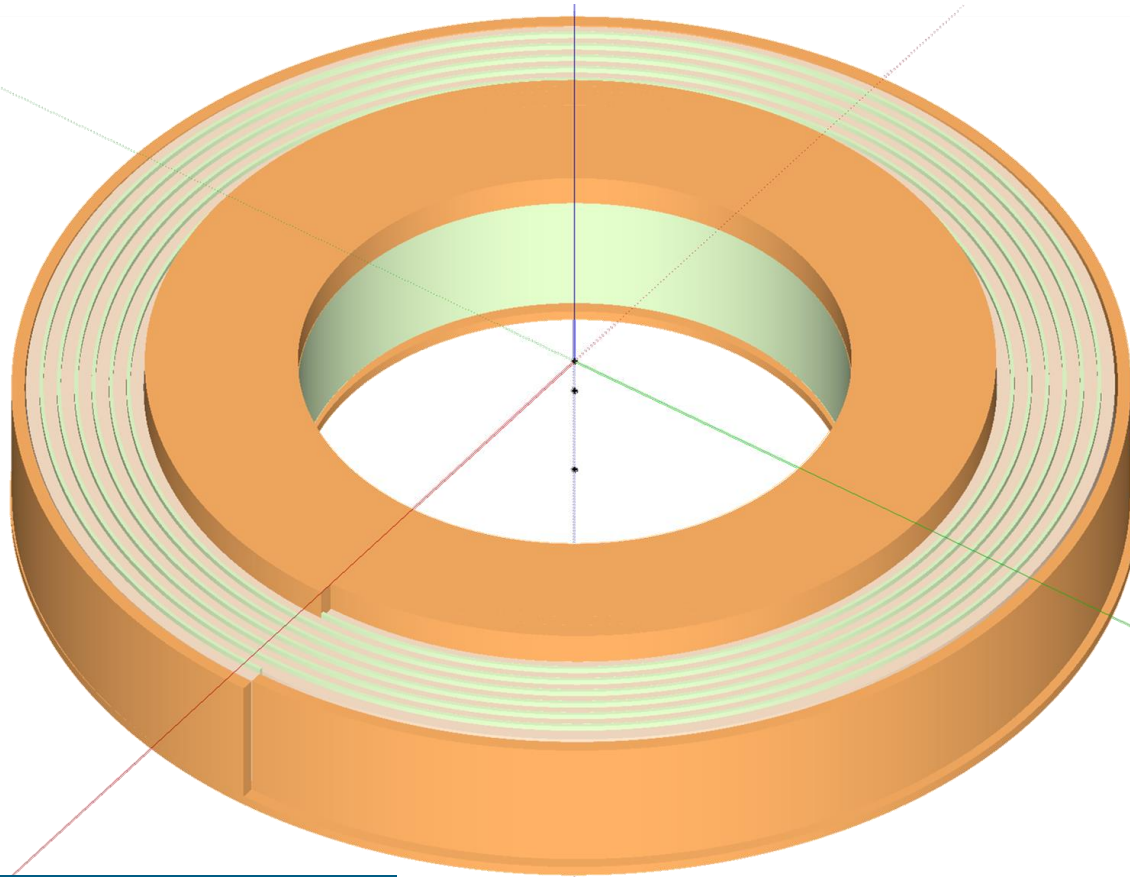
- 2-mm tape length (Cu-coated) at Twente (measurements in Spring 2017) ([M. Dhalle](#))
- 2m length of “Frankenstein” cable (E2B-15/5.5-003) shipped to Southampton to attempt a cable quench measurement at high temperature (self field) ([Y. Yang](#))



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Roebel Pancake Coil for Quench Measurements



1. G10 former with inner current injection terminal
2. Inner current contact to a whole turn, CNC machined to fit cable thickness
3. Soldering cable to contact and then start winding with fibre-glass insulation tape
4. Instrumentation/Heater attached during winding
5. Solder the outer contact to a whole turn
6. Attached outer terminal at the same time
7. Epoxy impregnation

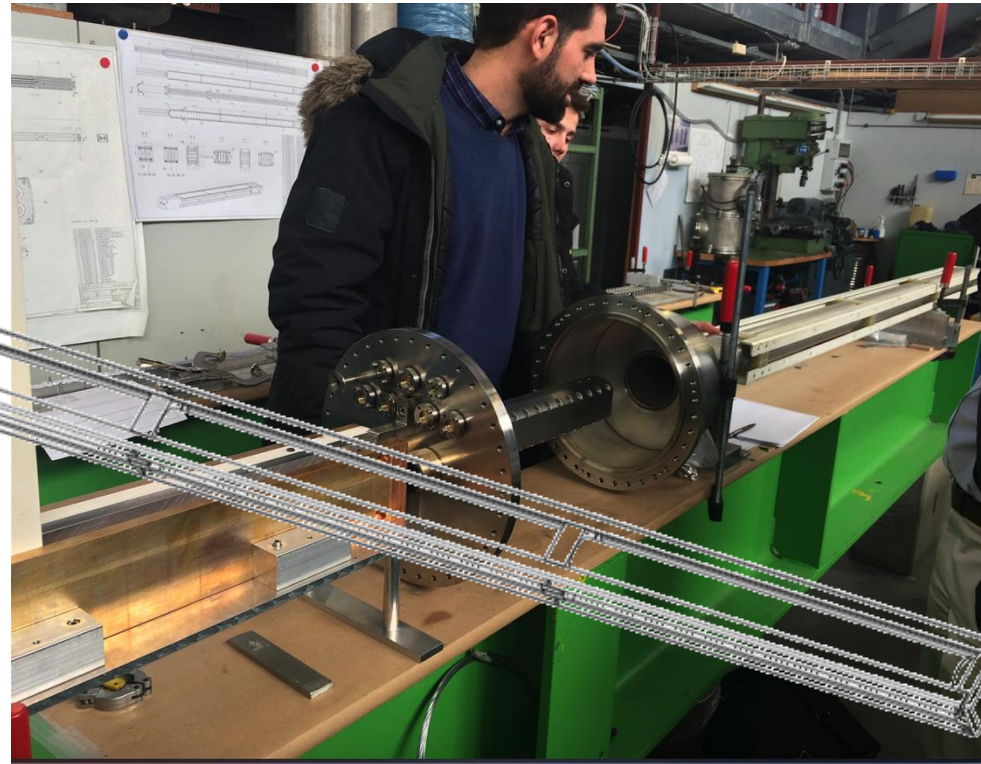
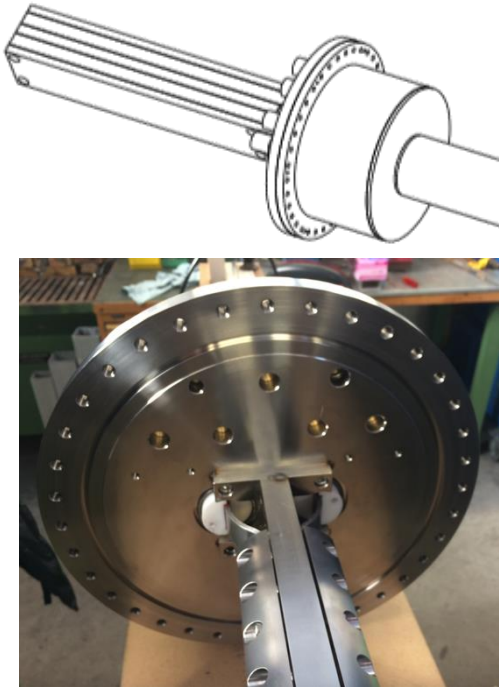
Bi-2212 cable test

- Activities restarted, thanks to [D. Larbalestier](#), [E. Hellstrom](#), [E. Bosque](#), ([A. Godeke](#)) (NHMFL) and [T. Shen](#) (LBNL)
- Cable HT on CERN sample holder, shipped to U. Twente for measurement

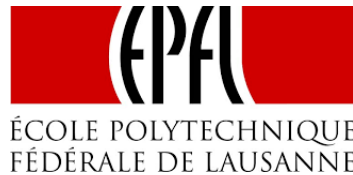


Other items (outside the scope)

- Test of Feather.M0 in SULTAN to profit from (unique) variable temperature and field conditions



Variable temperature insert in construction and commissioning at EPFL/SPC, Villigen PSI



Achievements

Tape

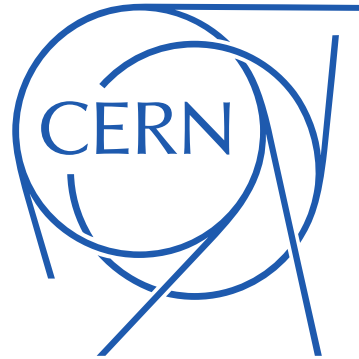
parameter	units	targets	
J_E (20 T, 4.2 K)	(A/mm ²)	600	✓
σ (I_C) within a unit length	(%)	10	✓
M (1.5 T, 10 mT/s)	(mT)	300	
Range of $\sigma_{\text{transverse}}$	(MPa)	100	✓
Range of $\varepsilon_{\text{longitudinal}}$	(%)	± 0.3	
Unit length	(m)	100	✓

Cable

parameter	units	targets	
I_C (20T, 4.2 K)	(kA)	10	✓
<i>Provisional width</i>	(mm)	10	12
<i>Provisional thickness</i>	(mm)	1.5	0.9...1.4
Effective contact resistance	($\mu\Omega$)	5	✓

What is left to do ?

- **Procure more material**, tapes and cables to feed the magnet program (see later presentations)
- Complete the validation of the final cable geometry
 - Ic test in FRESCA
 - Feather.M2
 - **Thermal cycles and check degradation**
- Quench detection and protection experiment
 - Measure temperatures (?), propagation speed and voltage waveforms
- Magnetization values (effect on field quality) and control
 - **Effect of striation (!?)**
 - Measurement of Bi-2212 cable
- **Longitudinal strain limits** for winding and operation



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