Status of WP10.2

Presented by L. Bottura

WAM-HTS3, September 10th - 11th, 2015

Outline

- Recall of specifications and targets
- Status of production and procurement
- Issues

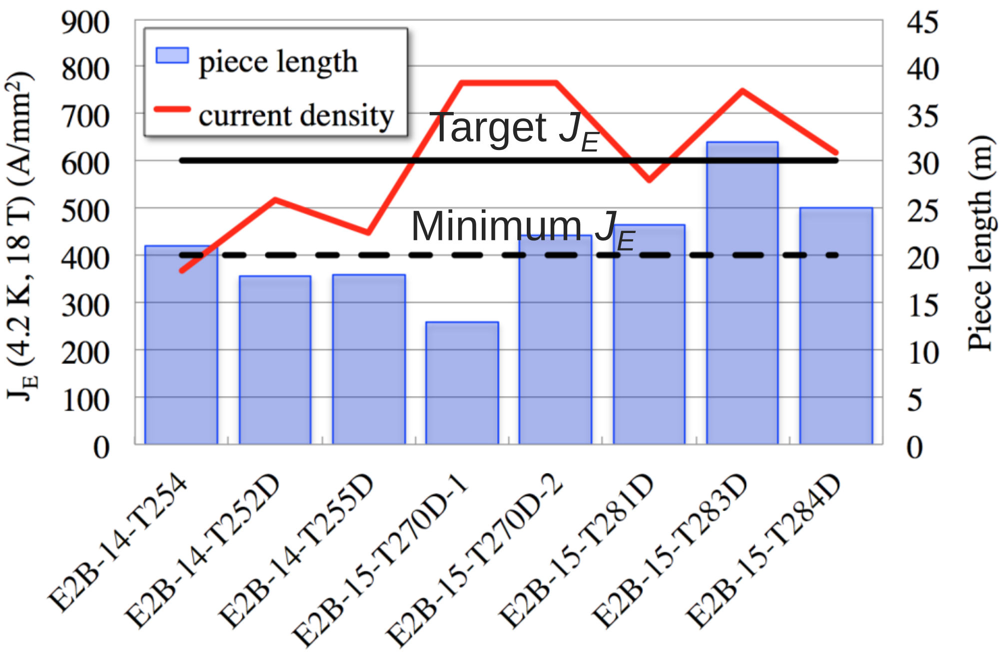
Target performance

Parameter		R&D target	Minimum
J_E (4.2 K, 20 T)	(A/mm^2)	600	**400**
Unit length	(m)	100	**50**
$\sigma(I_c)$	(%)	10	
M (1.5 T, 10 mT/s)	(mT)	300	
Minimum $\sigma_{transverse}$	(MPa)		**100**
Range of $\varepsilon_{longitudinal}$	(%)		**±0.3**

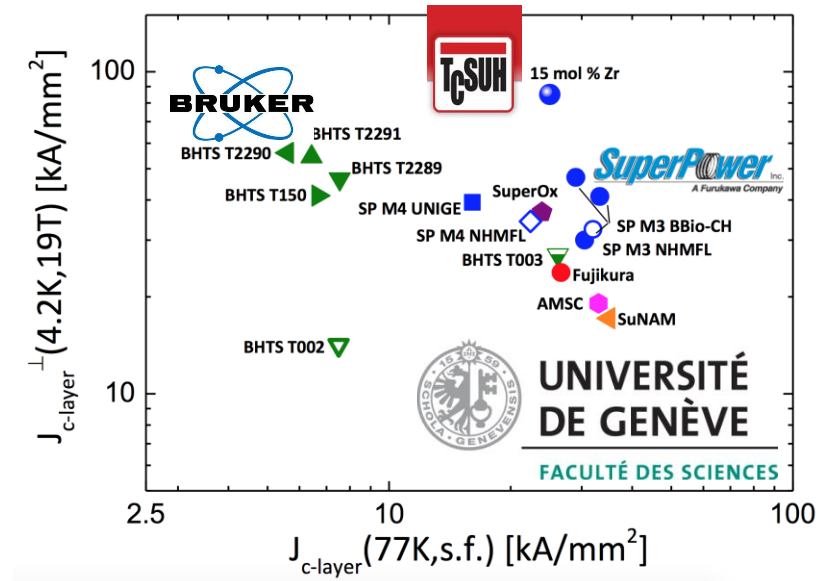
Target cable I_C in the range of 10 kA

Tapes

Tape production for EuCARD2



Master plot (C. Senatore, U. Geneva)



Approximately 250 m of 12 mm tape produced:

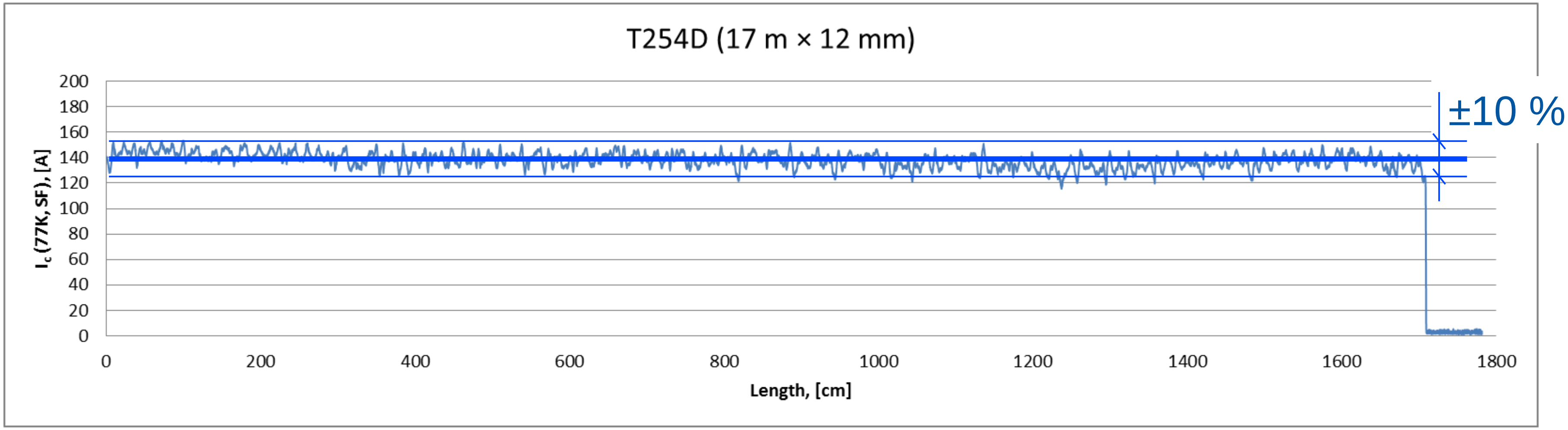
- all above minimum (400 A/mm²)
- most at target (600 A/mm²)
- some up to J_E (4.2 K, 18 T) ≈ 800 A/mm²

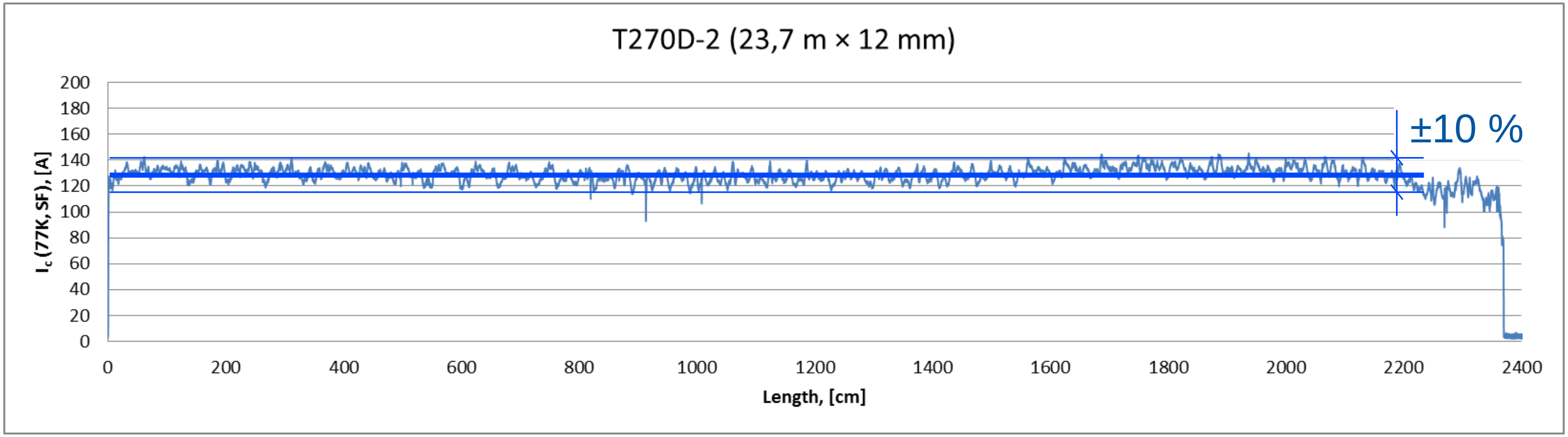
Highest layer J_C obtained in an industrial process

CERN

J_E achieved, piece length to scale up

Homogeneity





homogeneity achieved

Tape catalog

Tape ID	Delivery	Length	Width	Thickness	Substrate	REBCO	Cu	Ic(77 K, s.f.) minimum	Ic(77 K, s.f.) average	Ic(4.2 K, 18 T)	Je(4.2 K, 18 T)	Comments and use
		(m)	(mm)	(mm)	(mm)	(mm)	(mm)	(A)	(A)	(A)	(A/mm**2)	
E2B-T003	13.6.2013	2	4.05	130	97	1	30		110	120	228	test material (distributed CERN, UniGe)
E2B-T002-C	19.7.2013	2	4.05	150	97	3.8	50		130	235	387	test material (distributed CERN, UniGe)
E2B-T053-C	8.2.2014	1.5	12	160	97	2.2	30		210			punching test (KIT)
E2B-T189D-C	8.2.2014	22	4	150	97	1.7	25		52	334	557	benchmark material (CERN, UniGe, UniTwente, CNRS)
E2B-T190D-C	24.3.2014	2	4.2	195	97	2	45		47	502	613	high-performance tape (CERN, UniGe)
E2B-T191D-C	11.4.2014	2	4.2	200	97	2	50		54	420	500	high-performance tape (CERN, UniGe, ASC-NHMFL)
SP-KIT-2013030			12	100				362	364			tape used for KIT cable E2S-15/5.5-005
SP-KIT-20130729			12	100				278	283			tape used for KIT cable E2S-15/5.5-006
E2B-14-T254	11.12.2014	21	12	155	97	1.3	20		125	684	368	Roebel qualification (punching and assembly tests, delivered to KIT, 17.8 m in reserve)
E2B-14-T252D	18.12.2014	17.8	12	150	97	1.5	20		145	933	518	Roebel sample E2B-15/5.5-008 manufacturing (delivered to KIT)
E2B-14-T255D	18.12.2014	18	12	150	97	1.3	20		126	808	449	Roebel sample E2B-15/5.5-008 manufacturing (delivered to KIT)
E2B-15-T270D-1	8.1.2015	13	12	140	97	1.8	20		130	1284	765	Roebel sample E2B-15/5.5-008 manufacturing (delivered to KIT)
E2B-15-T270D-2	8.1.2015	22.1	12	140	97	1.8	20		130	1284	765	Roebel sample manufacturing E2B-15/5.5-008 (delivered to KIT)
E2B-14-T253	3.6.2015	20	12									Scrap material for tests and leads (stored at CERN)
E2B-15-T280D	Q1 2015	20	12						129	913		Scrap material for punch-and-coat test (Bruker and KIT)
E2B-15-T281D	30.4.2015	23.2	12		97				133	940		Roebel sample E2B-15/5.5-008 manufacturing (delivered directly to KIT from BHTS)
E2B-15-T283D	Q1 2015	32							177	1258		For final cable validation (punch-and-coat) at KIT
E2B-15-T284D	Q1 2015	25							146	1036		For final cable validation (punch-and-coat) at KIT
E2B-T278D	26.6.2015	7.3	4.2	195	97	1.7	47		47	343	419	test material for cable stacks (stored at CERN)
M	Q3 2015	100	12									Roebel qualification and benchmark tests (at CERN)
X	Q3 2015	200	12									Roebel qualification and benchmark tests (at CERN)
S	Nov-15	200	12									Roebel qualification and benchmark tests (ordered)
F	Q4 2015	200	12									Roebel qualification and benchmark tests (ordered)
B	Q2 2015 (TBD)	750	12									cable production for magnet winding
B	Q3 2015 (TBD)	750	12									cable production for magnet winding (CERN order)
–	Q2 2015 (TBD)	750	12									cable production for magnet winding
–	Q3 2015 (TBD)	750	12									cable production for magnet winding (CERN order)

Ordered material incoming

Need to take action for the final production

Baseline cable design

REBCO Tape

Tape width (before punching)	(mm)	12
SC layer	(µm)	1 … 2
Cu layer	(µm)	2 x 20
Substrate	(µm)	50 … 100
Tape thickness	(mm)	0.1 … 0.15
Critical current (4.2 K, 20 T perpendicular)	(A)	≥ 670

Roebel cable

Number of tapes	(-)	≤ 15 *(17)*
Width	(mm)	12
Thickness	(mm)	0.8 … 1.2
Transposition pitch	(mm)	226
Critical current (4.2 K, 20 T perpendicular)	(kA)	≥ 4.2

Cable catalog - dummies

Name	Length (m)	Delivery	Width (mm)	Pitch (mm)	Thickness (mm)	SC Tapes (-)	Cu Tapes (-)	Tape origin	Tape width (mm)	Tape thickness (mm)	Comments
E2D-15/5.5-001	3	4.4.2014	12	226	0.8	15	0	dummy SS	12	0.1	Dummy 3 m for winding tests
E2D-15/5.5-002	3	4.4.2014	12	226	1.5	15	15	dummy SS	12	0.1	Dummy 3 m with 1:1 Cu tapes for winding tests
E2D-15/5.5-003	20	13.5.2014	12	226	0.8	15	0	dummy SS	12	0.1	Dummy 20 m for winding tests
E2D-15/5.5-004	6	6.11.2014	12	226	0.8	15	0	dummy SS	12	0.1	Dummy 6 m for winding tests
E2S-15/4.5-005	13	1.10.2014	10	426	0.8	15	0	dummy SS	10	0.1	Dummy 13 m for winding tests at CEA-Saclay
E2D-15/5.5-006	**20????**							dummy SS			Dummy 20 m for winding tests sent directly to Saclay
E2D-15/5.5-007	**32**	**Aug-15**	12	300	0.8	15	0	dummy Hastelloy+Cu	12	0.1	Dummy for Feather-M0 test (procured at GCS)
E2D-15/5.5-008	**32**	**Aug-15**	12	300	0.8	15	0	dummy Hastelloy+Cu	12	0.1	Dummy for Feather-M2 test (procured at GCS)
E2D-15/5.5-009	**5**	**Aug-15**	12	226	0.8	15	0	dummy SS	12	0.1	Dummy for Feather-M0 test
E2D-15/5.5-010	**5**	**Aug-15**	12	226	0.8	15	0	dummy SS	12	0.1	Dummy for Feather-M0 test
E2D-15/5.5	40	Aug-15									Dummy for Feather-M2 test, SS with Cu coating
E2D-15/5.5	20	Oct-15									Dummy for Cos-theta-pole 1, SS with Cu coating
E2D-15/5.5	20	Oct-15									Dummy for Cos-theta-pole 2, SS with Cu coating

Use these dummies for the validation of the manufacturing process

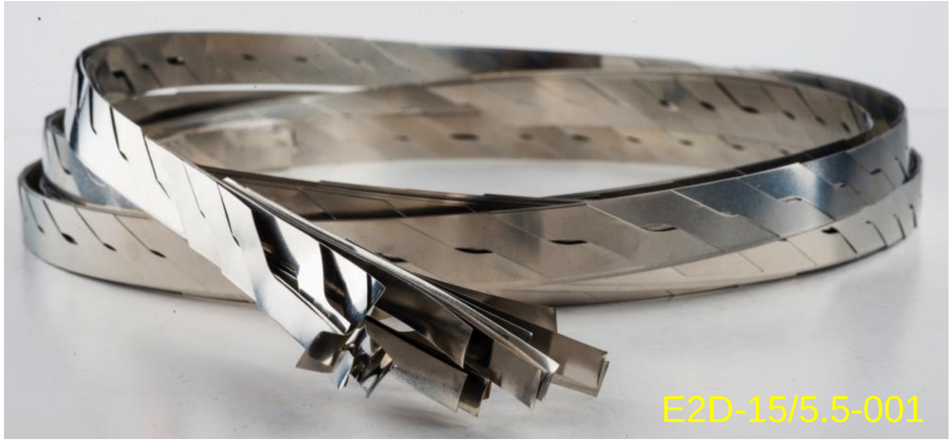
Cable catalog - SC

Name	Length	Date	W	Lp	t	SC Tapes	Cu Tapes	Tape origin	Tape width	Tape thickness	Tape Ic 77 K, s.f.	Tape Ic 4.2 K, 20 T	Expected cable Ic 77 K, s.f.	Expected cable Ic 4.2 K, 20 T	Comments
	(m)		(mm)	(mm)	(mm)	(-)	(-)		(mm)	(mm)	(A)		(A)		
E2S-15/5.5-001	1.6	6.11.2014	12	226	0.8	15	0	SP-KIT-2013030	12	0.1	362		1443		Cable sample for layer jump tests - AC loss samples (0.6 m)
E2S-15/5.5-002	1.8	6.11.2014	12	226	0.8	15	0	SP-KIT-20130729	12	0.1	278		1126		Cable sample for impregnation tests - G. Kirby
E2B-15/5.5-003	5	1.5.2015	12	226	1.12	15	0	E2B-14-T252D, E2B-14-T255D, E2B-15-T270D-1, E2B-15-T270D-2, E2B-15-T281D	12	0.14	133	1050	896	4253	Frankenstein: delivery of first cable length (Feather-M0-1)
E2B-15/5.5-004	2	Sep-15	12	226				E2B-15-T283D	12	0.14	177	1258	1198	5095	Final verification for critical current test FRESCA
E2B-15/5.5-005	2	Sep-15	12	226				E2B-15-T284D	12	0.14					Final verification for transverse pressure test UTwente
E2S-15/5.5	10	Sep-15													Feather-M0-2
E2X-15/5.5	10	Oct-15													Feather-M0-3
E2M-15/5.5	6	Oct-15													Feather-M0-4
E2F-15/5.5	10	Oct-15													Feather-M0-5
E2_-15/5.5	**30**	**Dec-15**													**Feather-M2-pole 1 - MILESTONE (MS66)**
E2_-15/5.5	30	Dec-15													Feather-M2-pole 2
E2_-15/5.5	30	Dec-15													Feather-M2-pole spare
E2_-15/5.5	20	Feb-16													Cos-theta-pole 1
E2_-15/5.5	20	Feb-16													Cos-theta-pole 2

Work to start soon on further 6 m length cable

We will be late for the nominal delivery of the first winding UL (3 months ?)

Roebel cables



15 SS tapes (0.1 mm), 3 m

Total of ≈ 140 m produced/procured

15 SS+15 Cu tapes (0.1 mm), 3 m

15 BHTS tapes (0.14 mm), 5 m
Expected I_C (4.2 K, 20 T) ≈ 4.2 kA

Total of ≈ 10 m produced

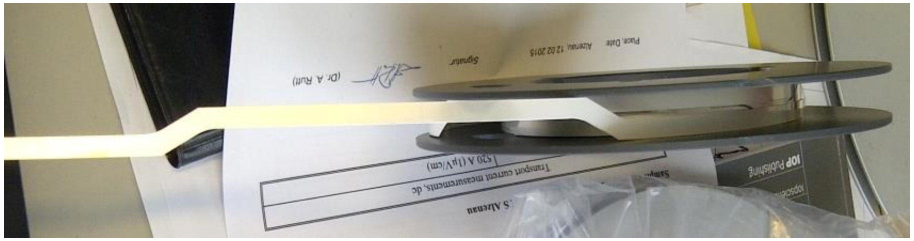
15 BHTS tapes (0.14 mm), 2 m
Expected I_C(4.2 K, 20 T) ≈ 5.1 kA

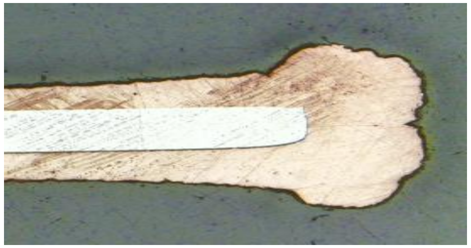
Cable length OK, can be wound

Punch-and-coat

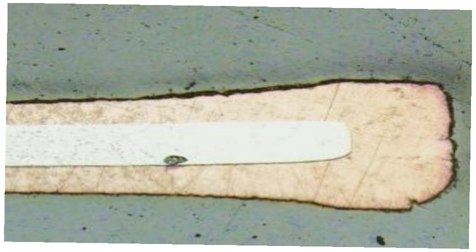
- Standard Roebel production sequence
  - Produce Cu-coated tape
  - Punch meanders
  - Assemble cable
- Modified Roebel production sequence
  - Produce Ag-capped tape
  - Punch meanders (less than 5% I_C degradation !)
  - Cu-coat (dog-boning !)
  - Assemble cable

Ag capped punched tape

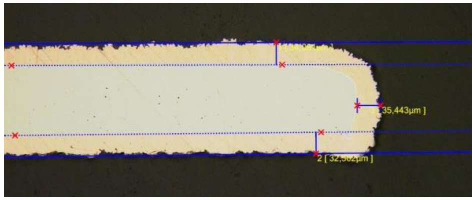




2x40 μm coating



2x20 μm coating



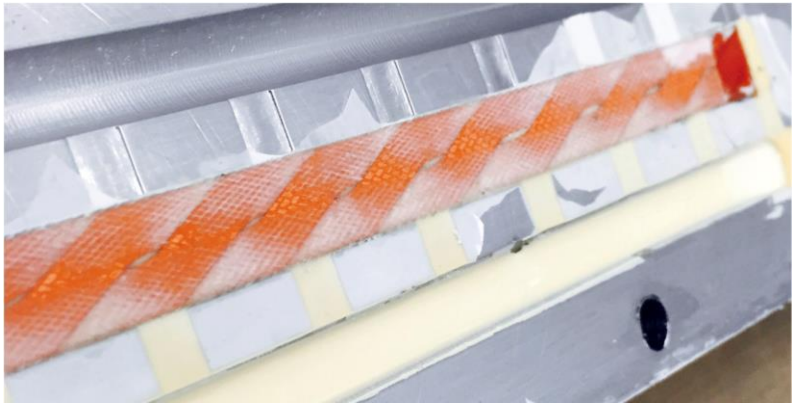
Optimized 2x20 μm coating

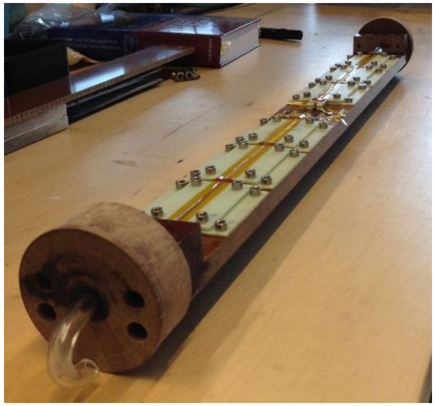
Use punch-and-coat as baseline, validate Cu-coating

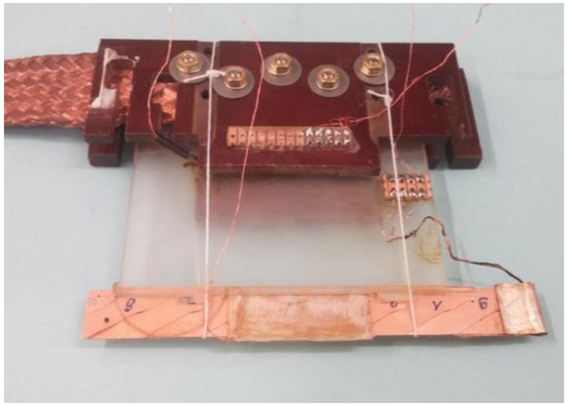
Magnetization

4.2 K, 400 mT

4.2 … 100 K, 350 mT







CERN Impregnated (CTD101G) Roebel cable sample, 226 mm

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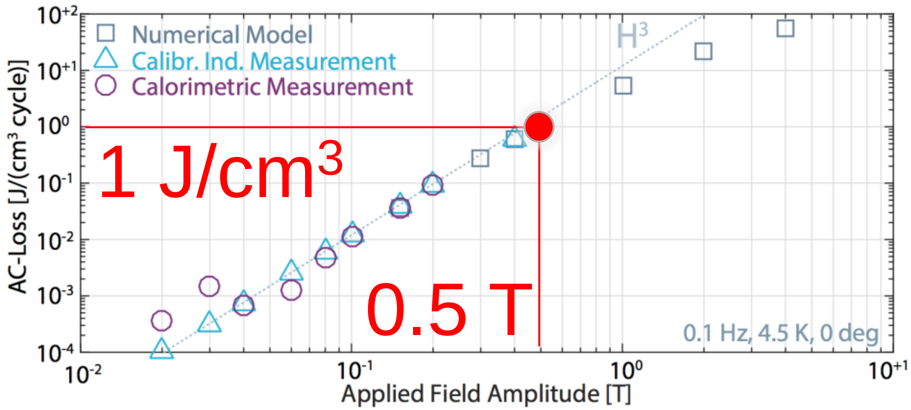
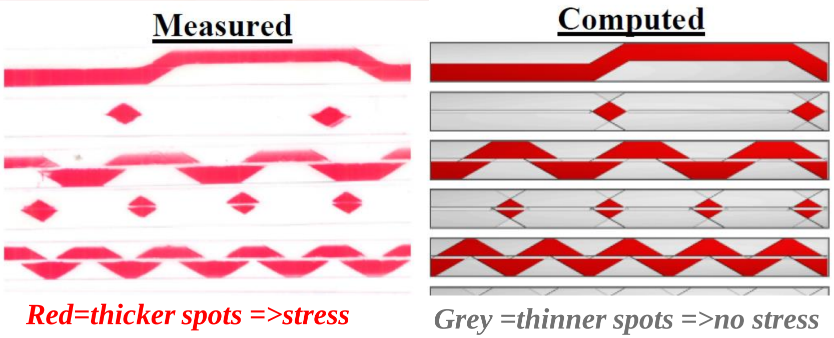
UNIVERSITY OF Southampton



- As expected, the cable has large loss and magnetic moment
- Penetration field is o(1T)
- **Work in progress** as to the understanding and evaluation of field quality in the various magnet design

Magnetization will be large, deal with it

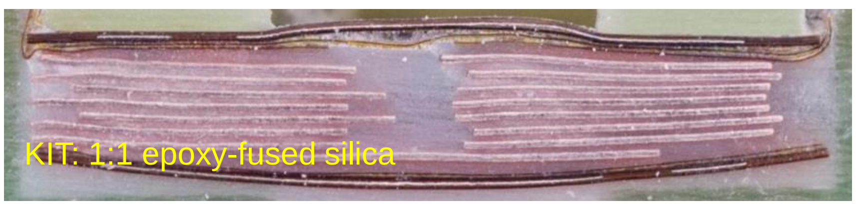
Transverse forces



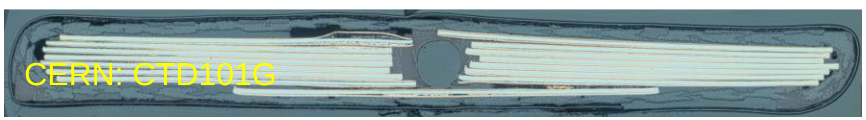
J. Fleiter, C. Lorin. A. Ballarino, 2015

Benefit of impregnation

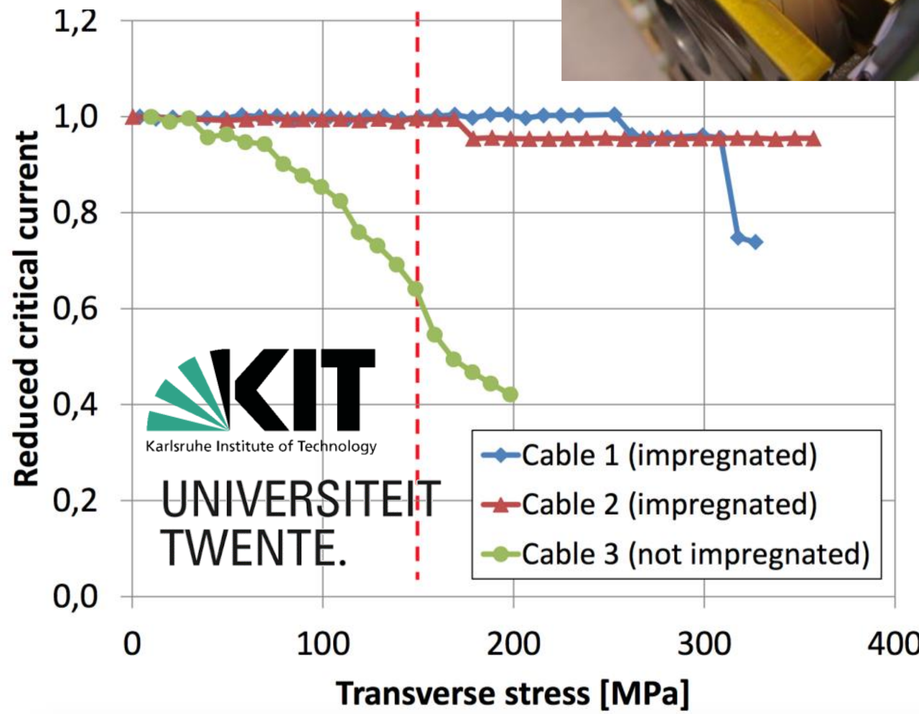
Ch. Barth



G. Kirby, J. van Nugteren



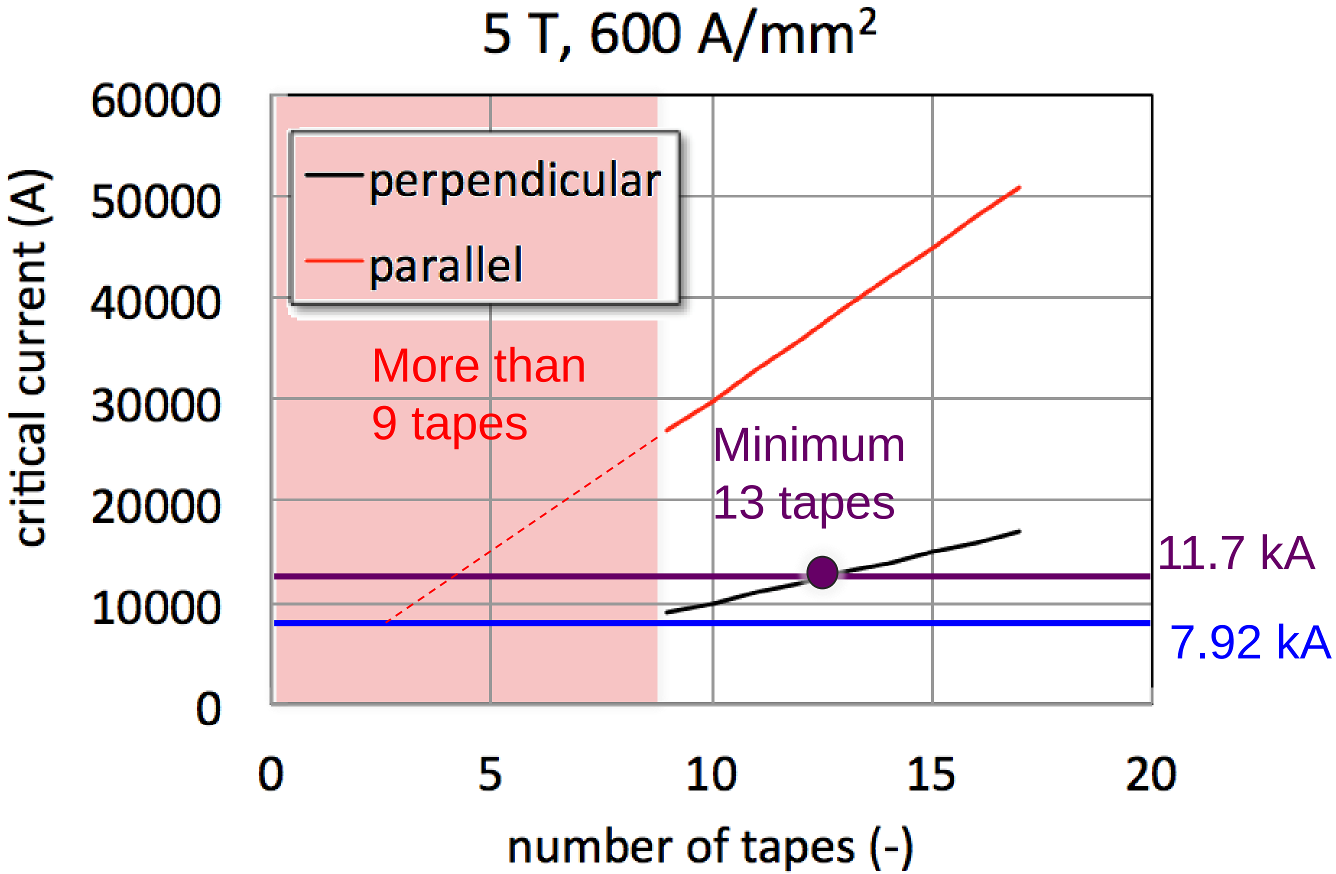
Measurement in the cable press at the University of Twente



S. Otten et al., 2015

Transverse mechanics looks OK

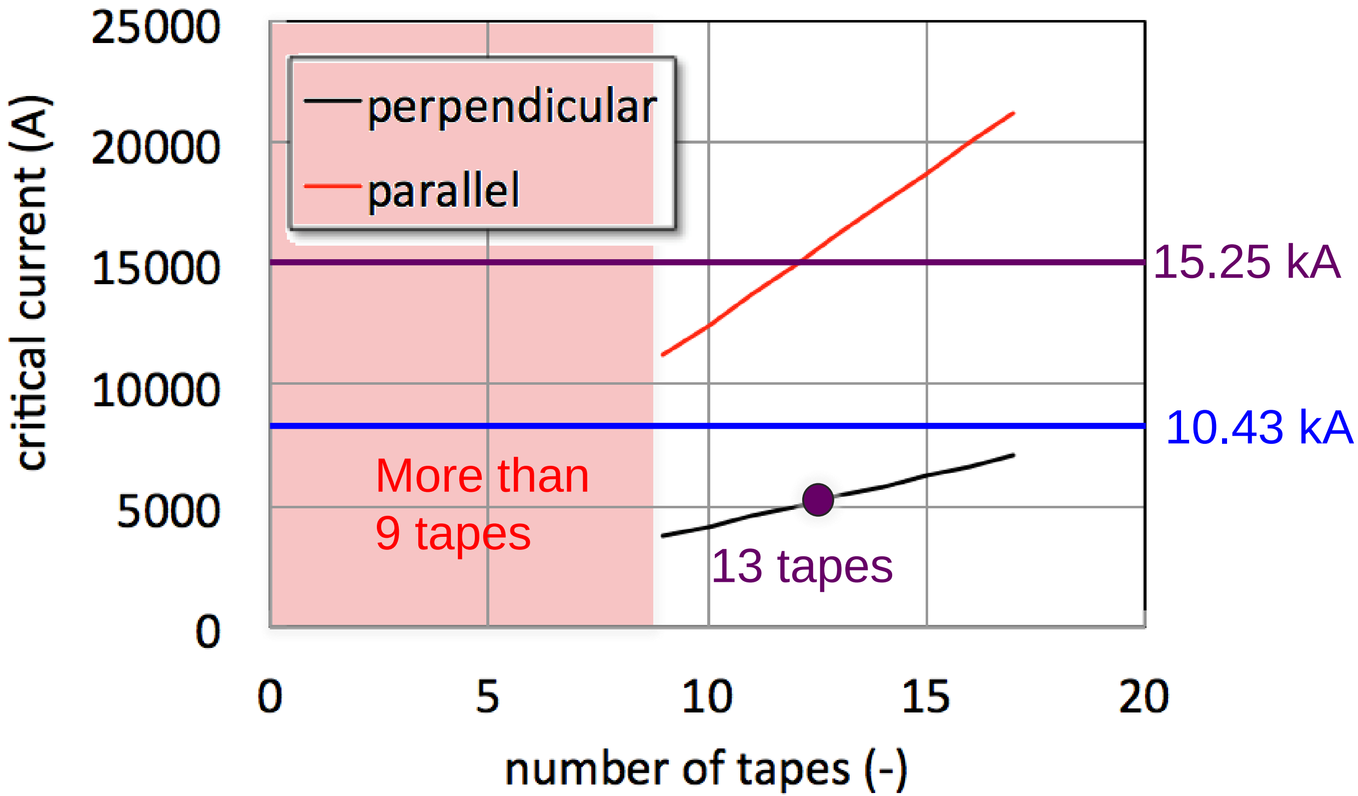
Cable dimensions



9 x 5.5 ≈ 4 x 12
EuCARD2 = EuCARD ?!?

Cable dimensions

20 T, 600 A/mm² 15 T +5 T from the insert



Cable dimensions

- Consider these three configurations:
  - 0.1 mm (std J_c^{layer}), 15 tapes, t=0.8 mm
    - Ic(5 T) = 10.7 kA (32.1 kA) *CT(4.5 T)* / AB
    - Ic(20 T) = 4.5 kA (13.5 kA) *CT(1.5 T)* / AB
  - 0.14 mm (high J_c^{layer}), 15 tapes, t=1.12 mm
    - Ic(5 T) = 15 kA (45 kA) CT / AB
    - Ic(20 T) = 6.3 kA (18.9 kA) CT(2 T) / AB
  - 0.14 mm (high J_c^{layer}), 13 tapes, t=0.98 mm
    - Ic(5 T) = 12.9 kA (38.7 kA) CT / AB
    - Ic(20 T) = 5.4 kA (16.2 kA) CT(1.8 T) / AB

We could change to 13 tapes, instead of 15 – worth it ?

J_{Copper}

Aligned blocks, I_{op}=7.9 kA

Cable option	w	t	J_{cable}	f_{copper}	J_{copper}
	(mm)	(mm)	(A/mm²)	(-)	(A/mm²)
15/0.1	12	0.8	825	0.40	2063
13/0.14	12	0.98	673	0.29	2357
15/0.1	12	1.12	589	0.29	2063

Cos theta, I_{op}=11.7 kA

Cable option	w	t	J_{cable}	f_{copper}	J_{copper}
	(mm)	(mm)	(A/mm²)	(-)	(A/mm²)
15/0.1	12	0.8	1219	0.40	**3047**
13/0.14	12	0.98	995	0.29	**3482**
15/0.1	12	1.12	871	0.29	**3047**

Issues and plan

- Continue procurement and cabling with the material as it comes
  - Finalize cable dimensions (need a benchmark on "real" cable dimensions, after insulation) – possibly at the end of WAM-HTS3 ?
  - Steel dummies, punch-and-coat procedure validation
  - Re-baseline the final production of cable (need 1.5 km tape within the next 3 months)
- Other critical steps in the next half term
  - Validate cable performance in FReSCa and by transverse pressure test
    - Compare different materials and cables (e.g. SuperOX)
    - Needs final insulation scheme for transverse test (FReSCa sample ?)
  - Design magnet joint (geometry, materials, procedure)
  - Quench detection and protection with the actual tape and cable geometry and properties
  - Complete magnetization study, understand implications