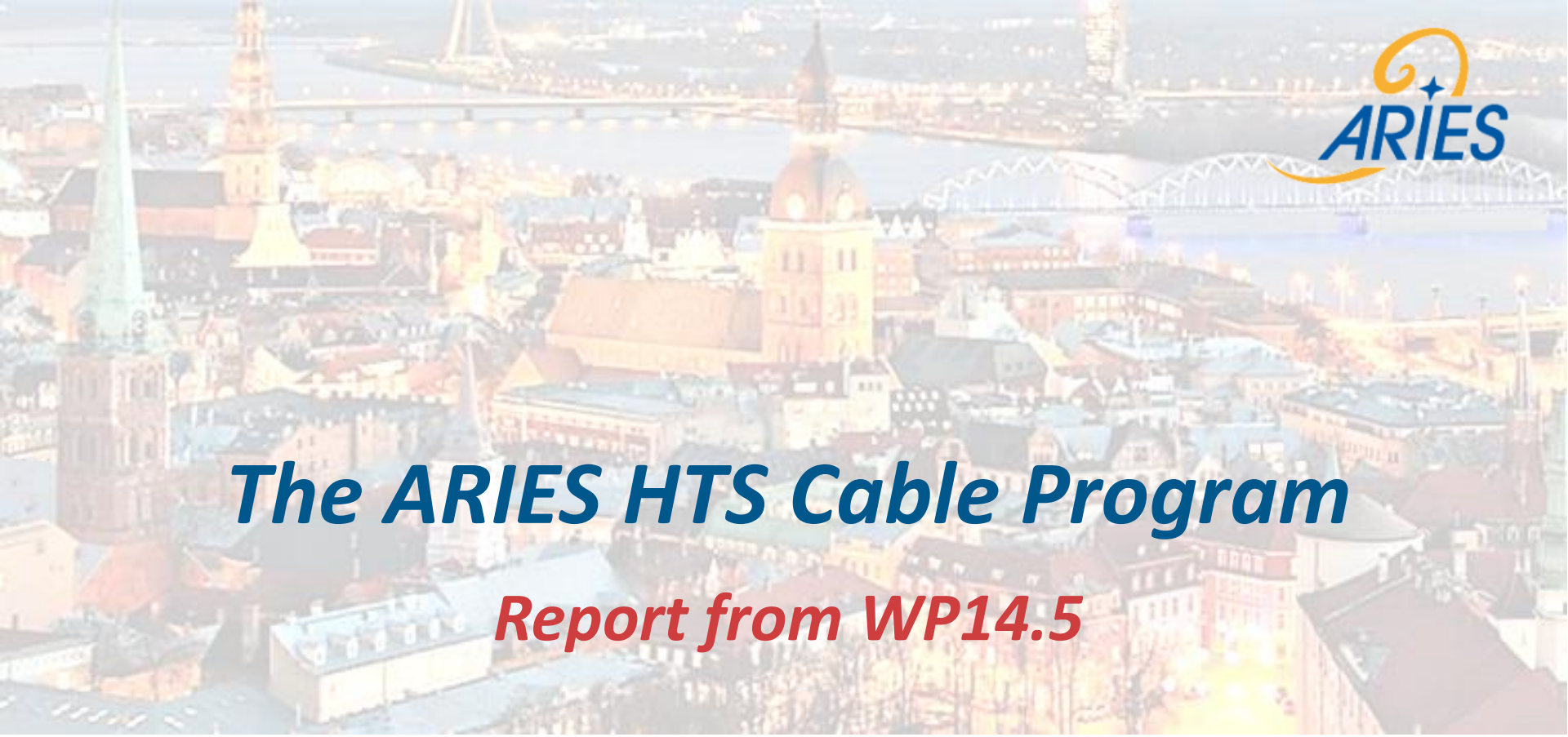


The ARIES HTS Cable Program

Report from WP14.5

Carmine SENATORE

Department of Quantum Matter Physics
University of Geneva, Switzerland

On behalf of the many collaborators

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

http://supra.unige.ch

WP14 Promoting Innovation

WP14.5 High Temperature Superconducting (HTS) innovative process for accelerator magnet conductor

Lucio ROSSI – Task Leader

Thibault LECREVISSE – Deputy Task Leader

Alexander USOSKIN – Industrial Partner

UNIVERSITEIT TWENTE.

Marc DHALLÉ

Carmine SENATORE

Contribution possibly also from

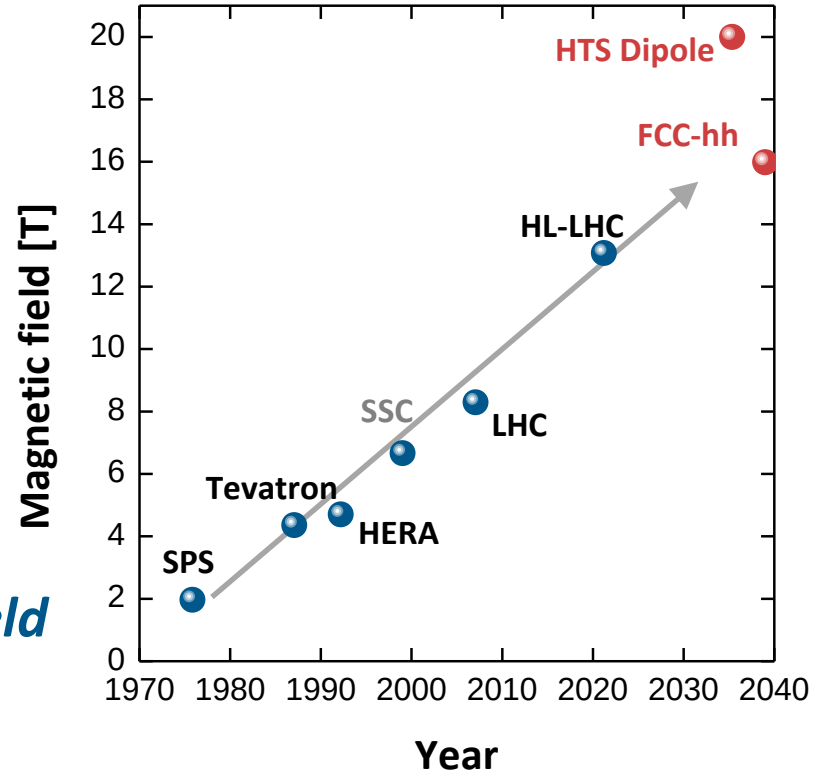
Setting the scene

The goal of 20 T in an accelerator quality dipole calls for HTS

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



ARIES is building on the shoulders of EuCARD²

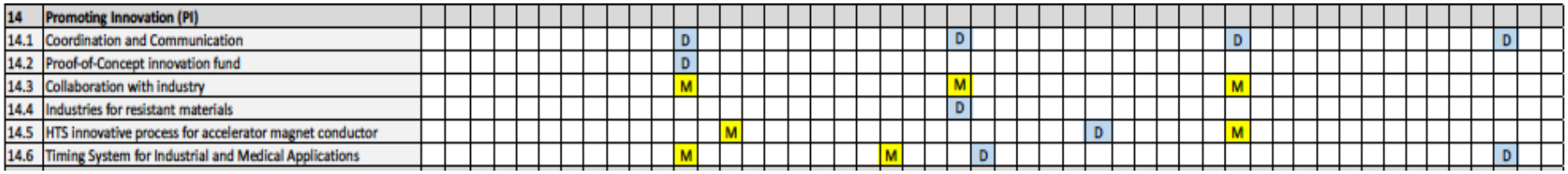
Scope of the work of WP14.5

- *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/mm²

    to J_e (4.2 K, 20 T) = 800-1200 A/mm²
- *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*)*
- *Electrical, magnetic, mechanical and thermal properties tested at* UNIVERSITEIT TWENTE. *and* UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

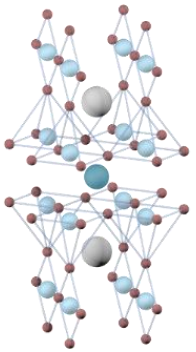
WP14 timeline of deliverables and milestones

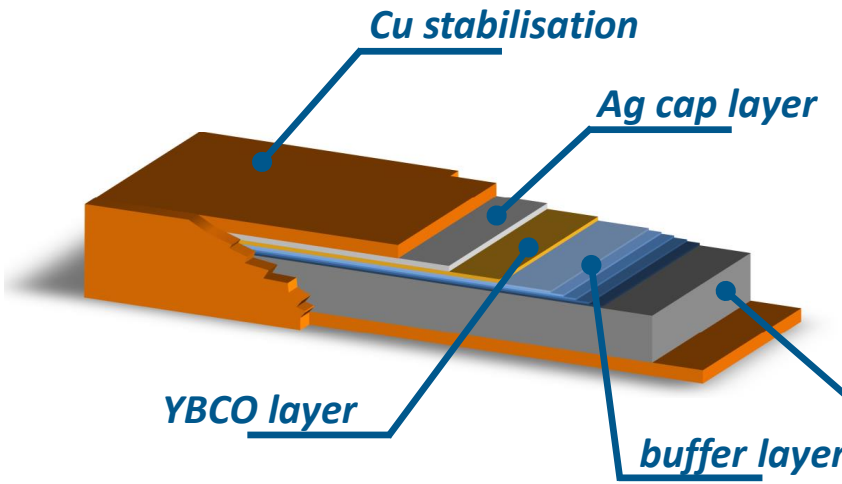


D14.1	Set-up of the Proof-of-Concept innovation-funding scheme	14.2	CERN	R	PU	M12
D14.2	Academia meets industry event 1	14.3	CERN	R	PU	M24
D14.3	Production of material samples of carbon-based composites and metal-diamond composites	14.4	CERN	DEM	PU	M24
D14.4	First long length industrial High Temperature Superconductor	14.5	CERN	DEM	PU	**M14**
D14.5	Real-time Event Distribution Network brought to openly accessible "product grade level"	14.6	COSYLAB	Other	PU	M46

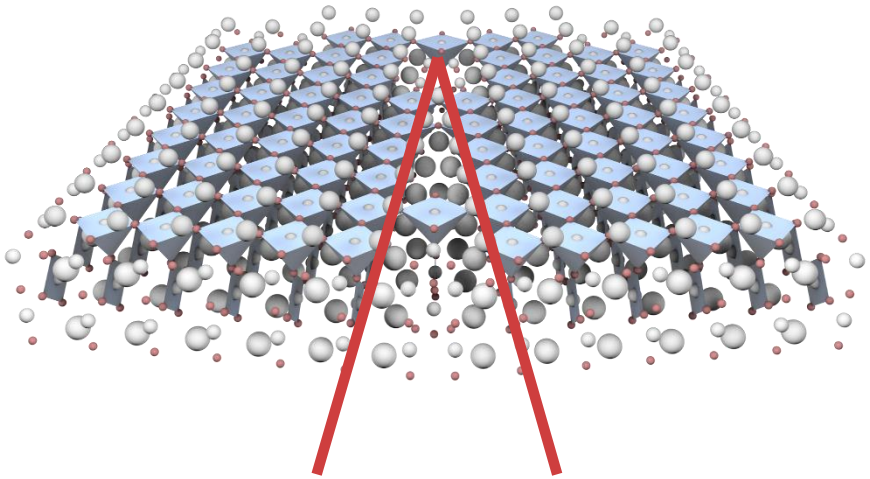
MS42 → appointing IAB - M12
MS43 → 1st academia meets industry – M24
MS44 → 2nd academia meets industry – M36
MS45 → 1st HTS short length **M8**
MS46 → characterization of 1st long length **M18**
MS47 → review requirements doc – M12
MS42 → review design and conf doc– M21

$YBa_2Cu_3O_{7-x}$ (YBCO) coated conductors

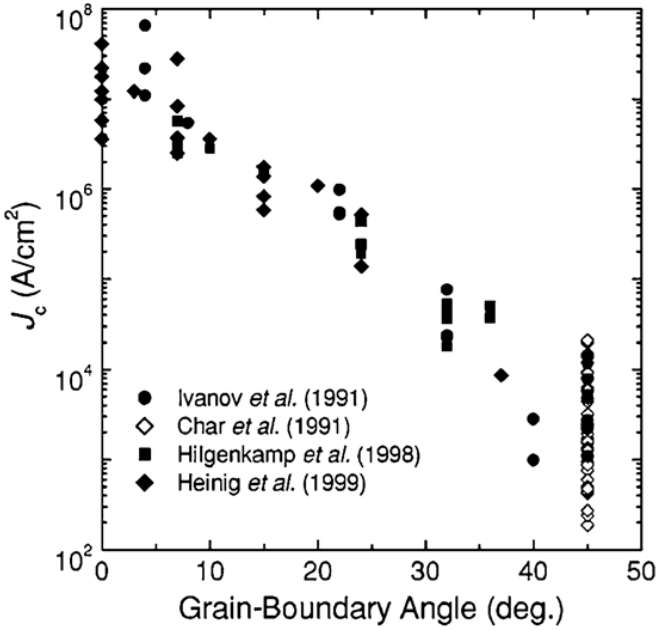




~1 µm of YBCO in a ~100 µm thick tape

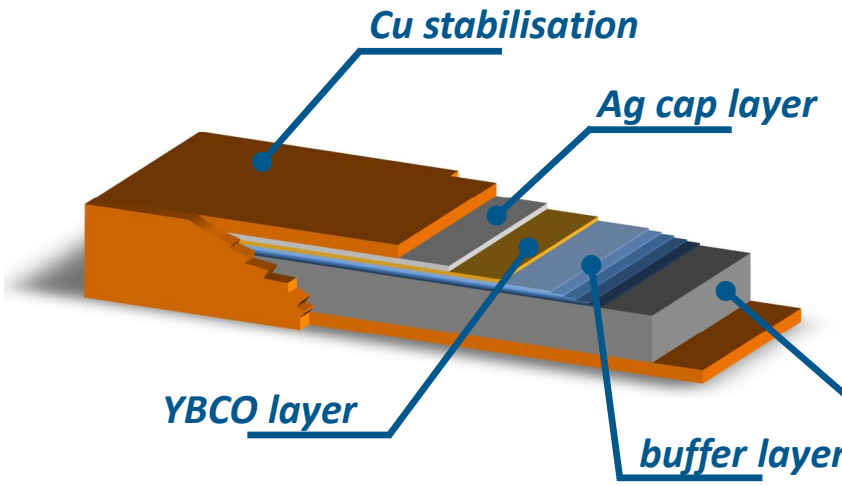


[001] tilt grain boundary

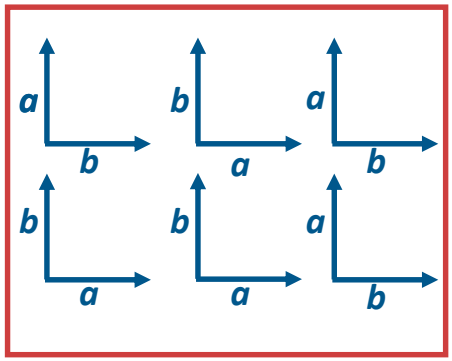


H. Hilgenkamp and J. Mannhart, RMP 74 (2002) 485

$YBa_2Cu_3O_{7-x}$ (YBCO) coated conductors



~1 µm of YBCO in a ~100 µm thick tape



Top view

The template is a metallic substrate coated with a multifunctional oxide barrier

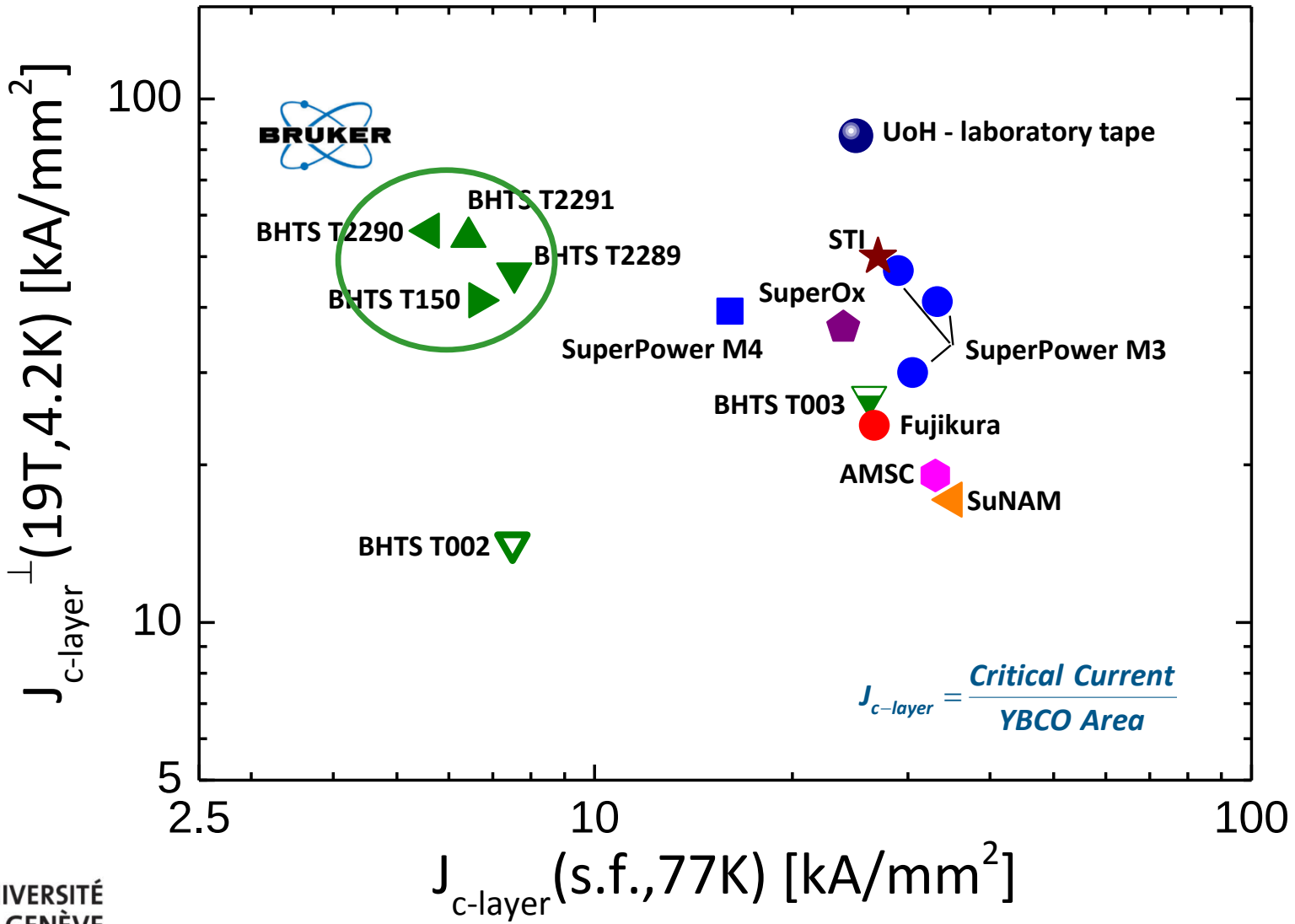
Biaxial texturing – within < 3° – is obtained

but with some also drawbacks:

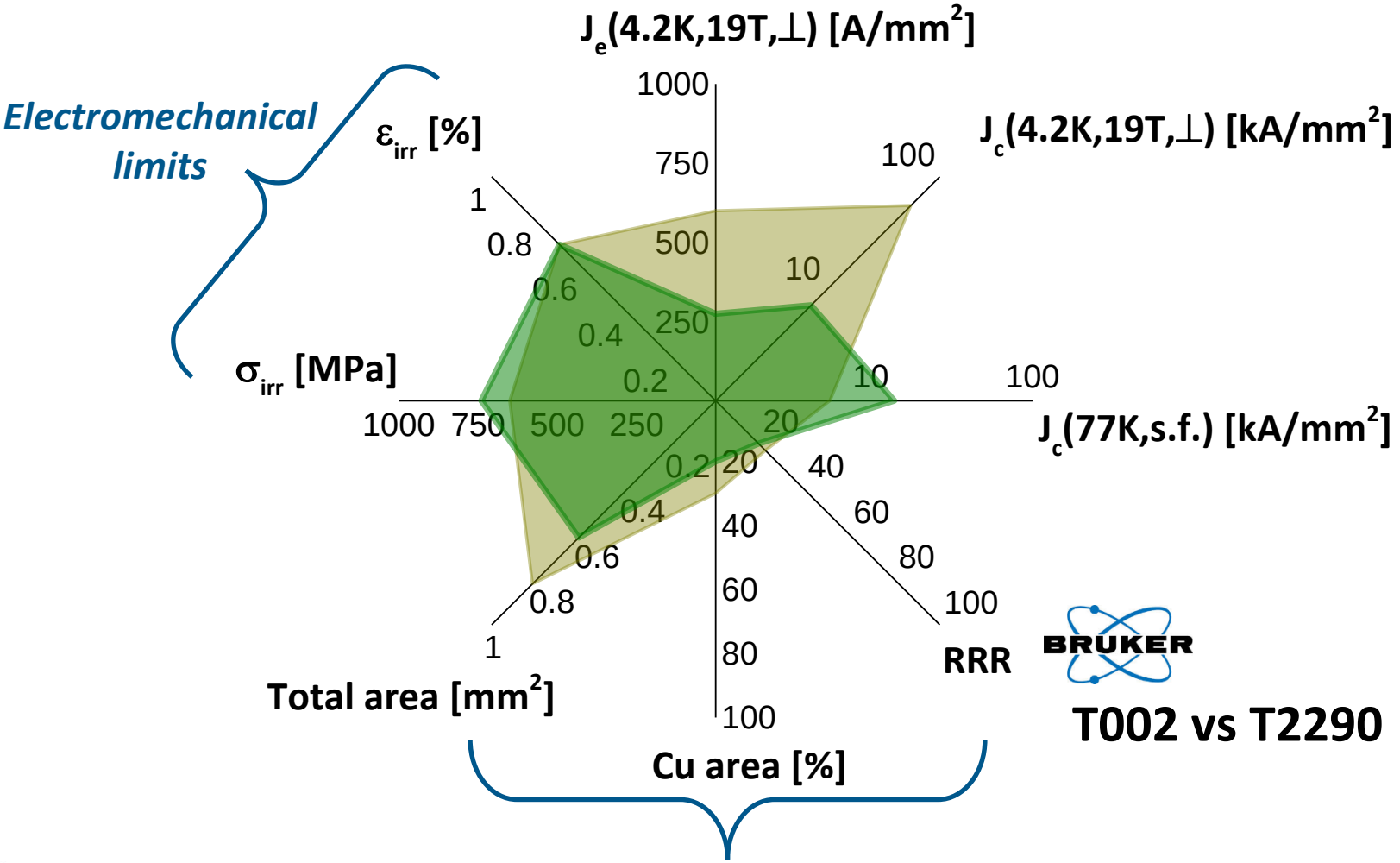
- *pronounced anisotropic behaviour*
- *complex and expensive manufacturing process*

Presently produced by American Superconductor, BRUKER, Fujikura, SuNAM, SuperOx, SuperPower Inc. A Furukawa Company, STI, THEVA, Shanghai, 上海超导, OXOLUTIA, deutsche nanoschicht, MetOx

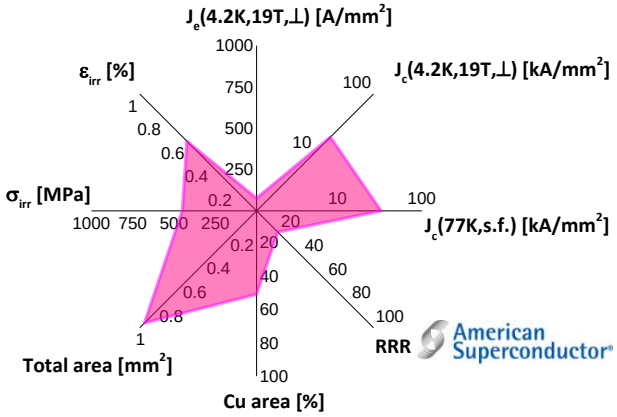
Performance overview: J_c(s.f.,77K) vs. $J_c^{\perp}$(19T,4.2K)

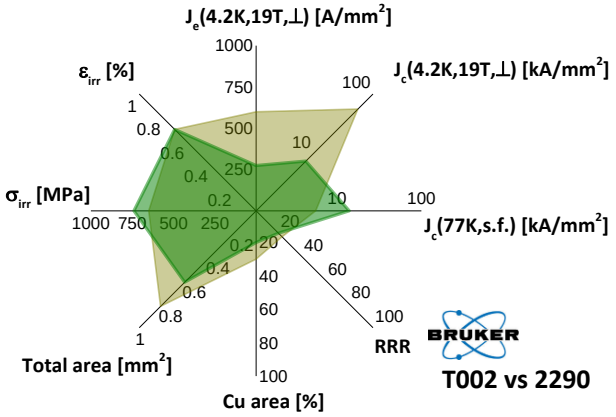


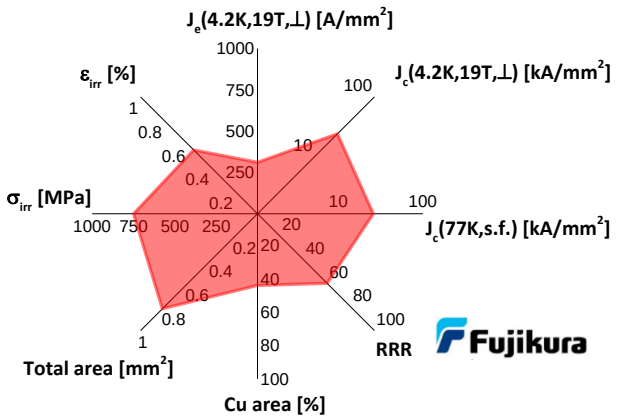
Is high J_c all you need ?

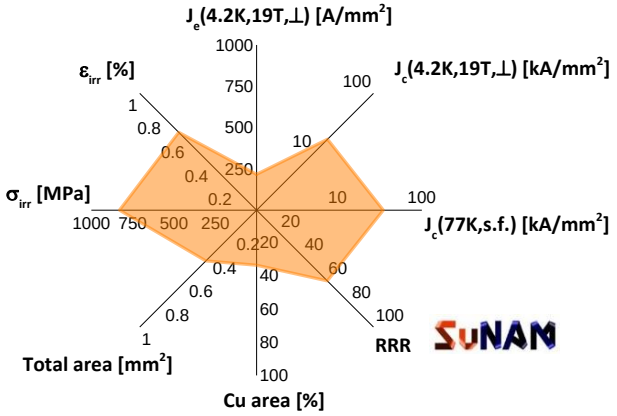


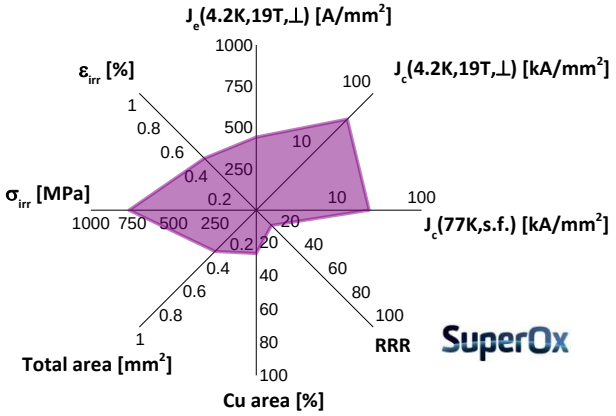
Main parameters at a glance

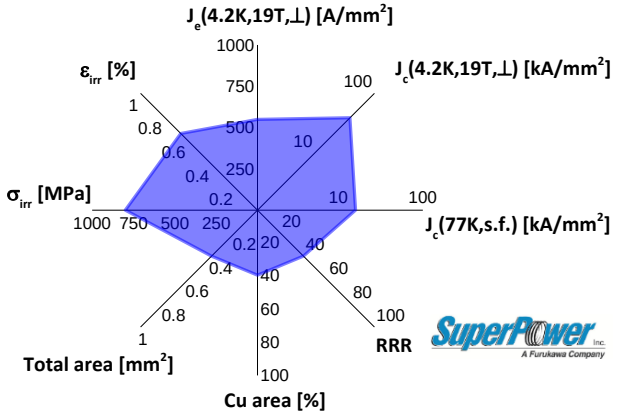










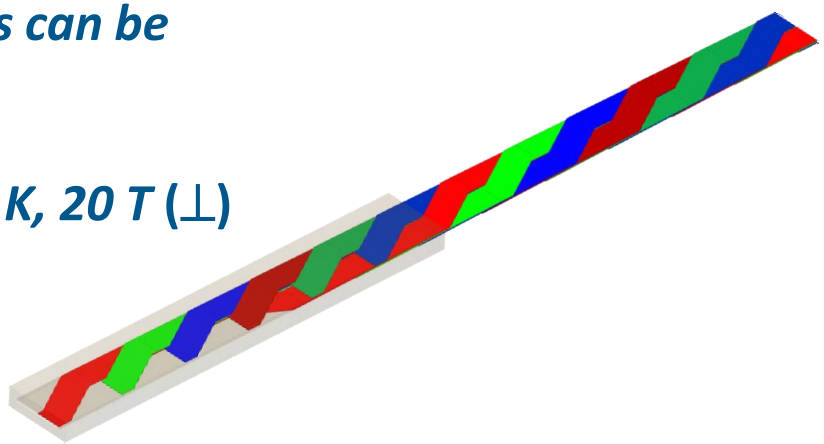


HTS cable technology: the Roebel cable

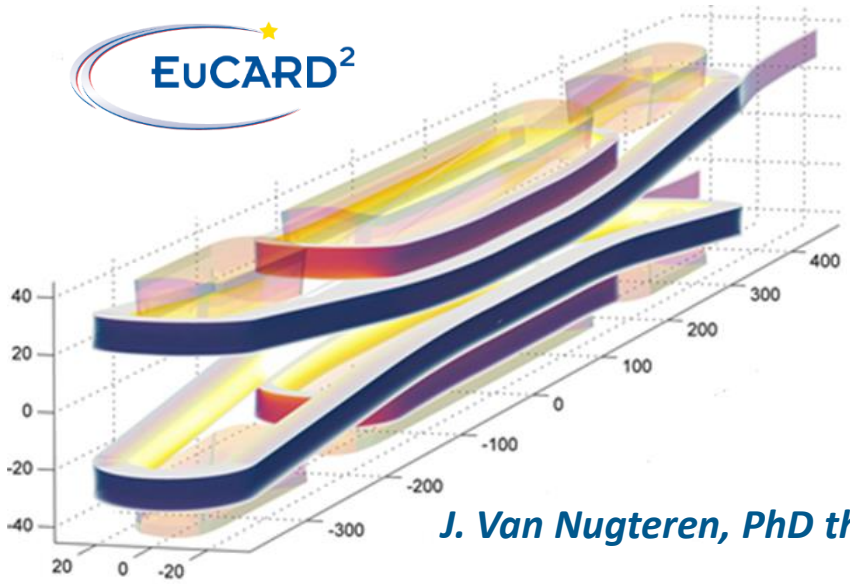
The Roebel cable

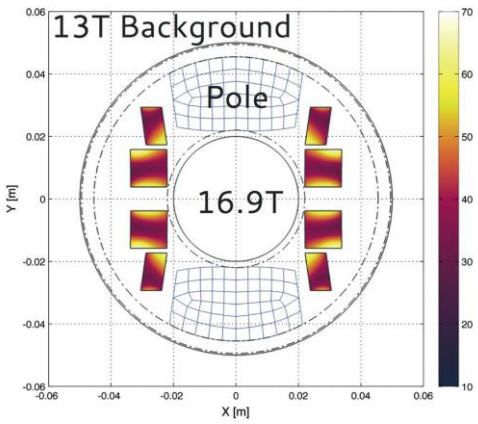
Accelerator magnets require large operating currents ~ 10 kA

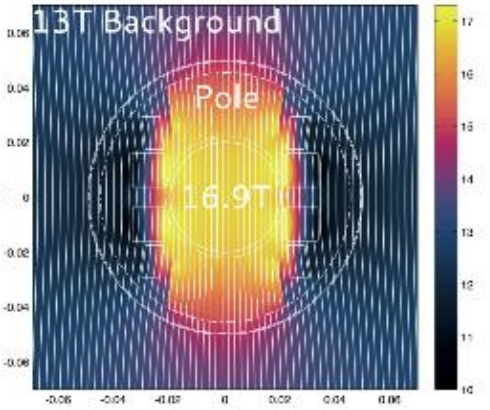
- *Roebel cables are assembled starting from meandered tapes*
- *Meandering obtained by punching – Recently introduced Cu plating after punching to prevent tape delamination*
- *Fully transposed*
- *Transposition length and number of tapes can be adapted to the needs of the application*
- *High current density, > 600 A/mm² @ 4.2 K, 20 T (⊥)*



A coil of Roebel cable: a Short Dipole Demonstrator

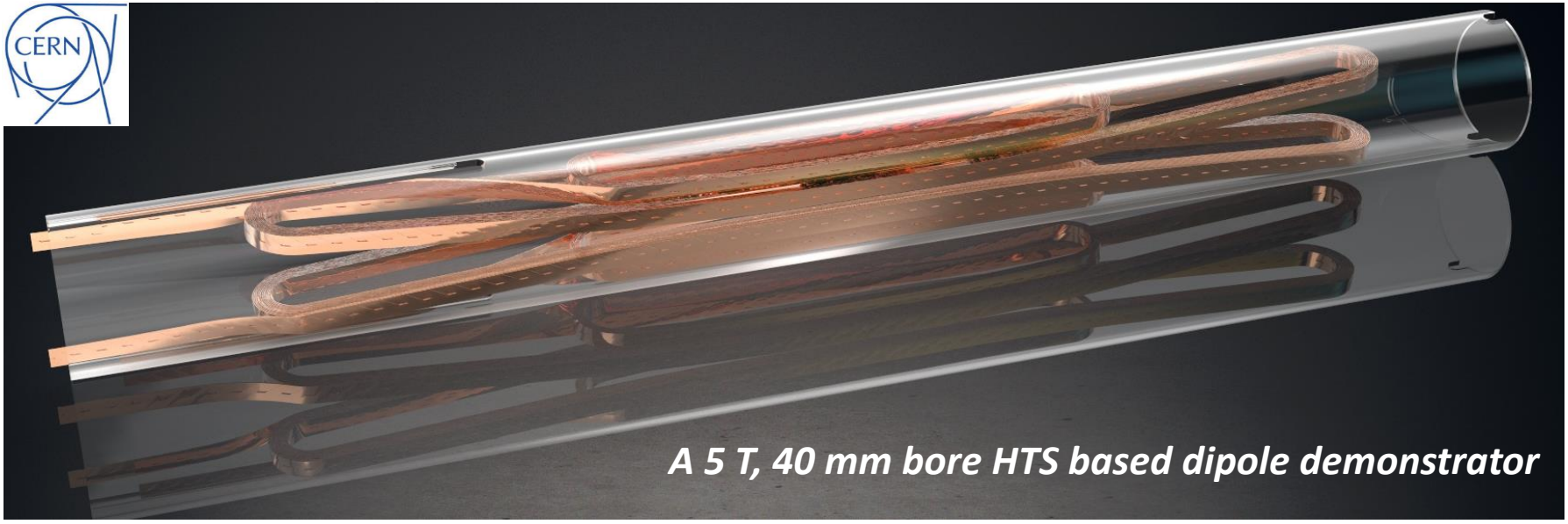






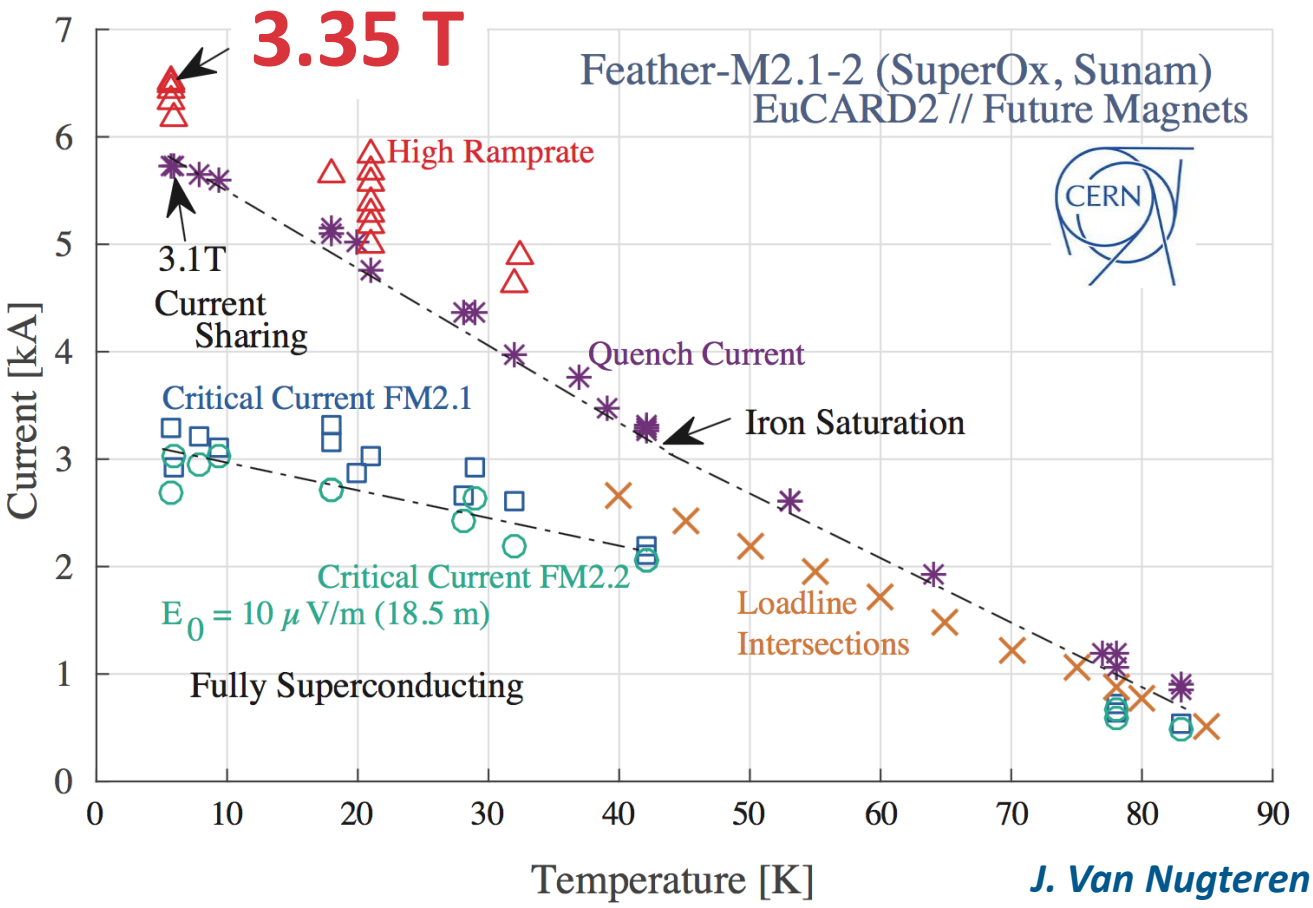
J. Van Nugteren, PhD thesis, 2016

CERN



Short Dipole Demonstrator results

1st coil wound with moderate I_c SuNAM cable (~40% of the Bruker cable)

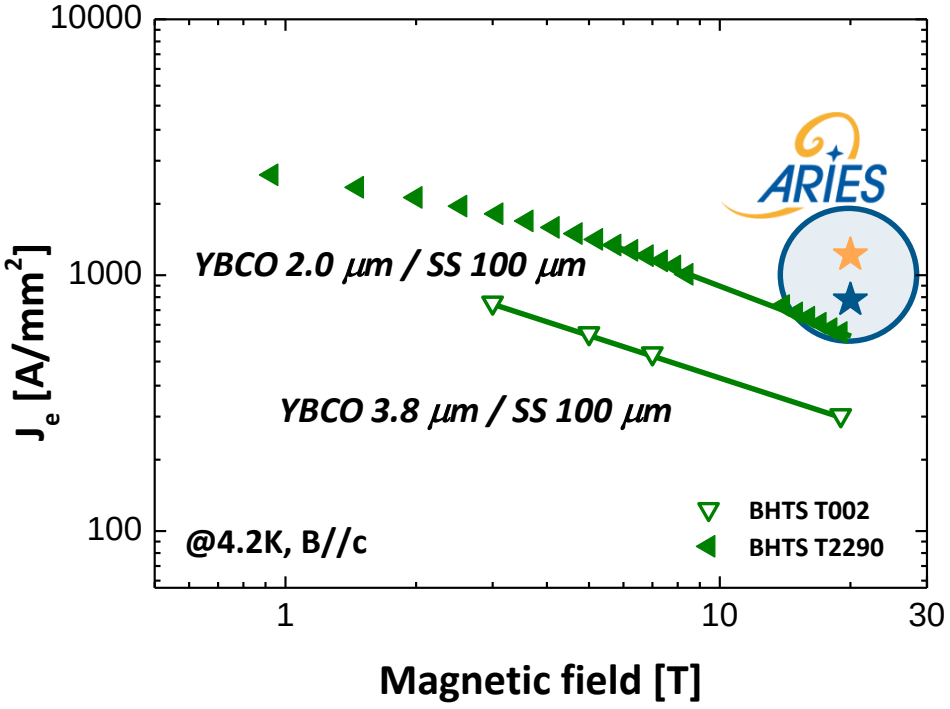


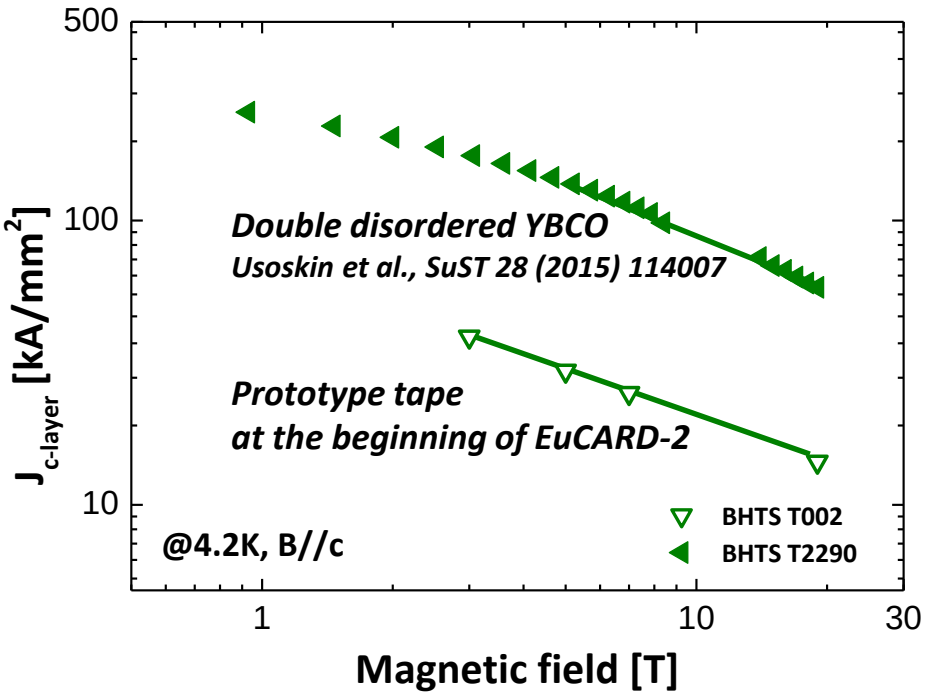
J. Van Nugteren @ EUCAS2017

New coil with ultra-high I_c cable from Bruker already wound

Expected field in stand-alone test ~7T

Performance target for ARIES

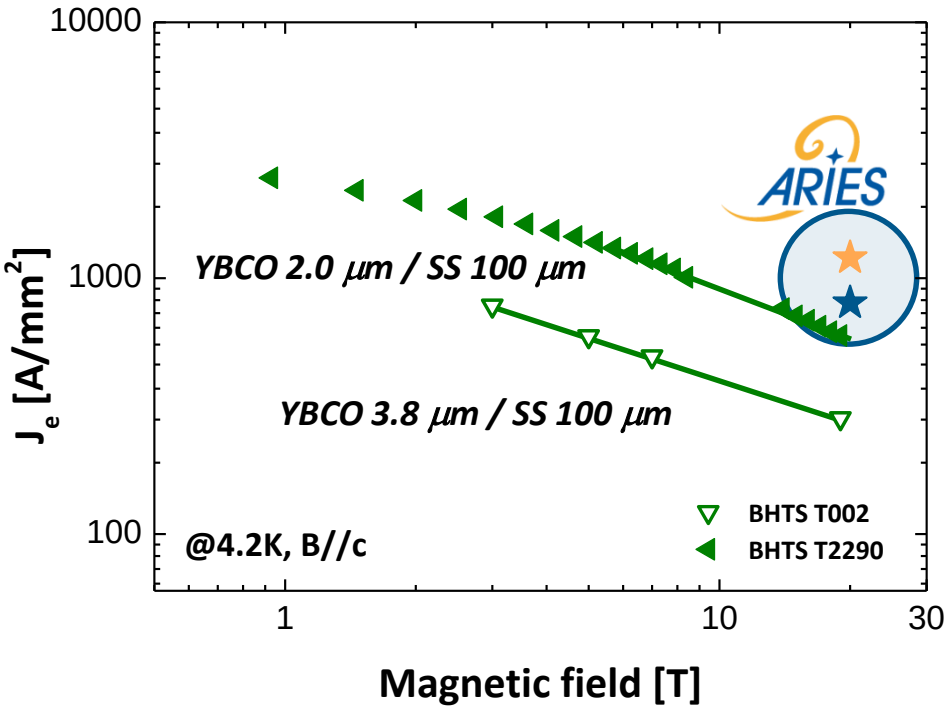




$$J_e = \frac{Critical\ Current}{Total\ Area}$$

$$J_{c-layer} = \frac{Critical\ Current}{YBCO\ Area}$$

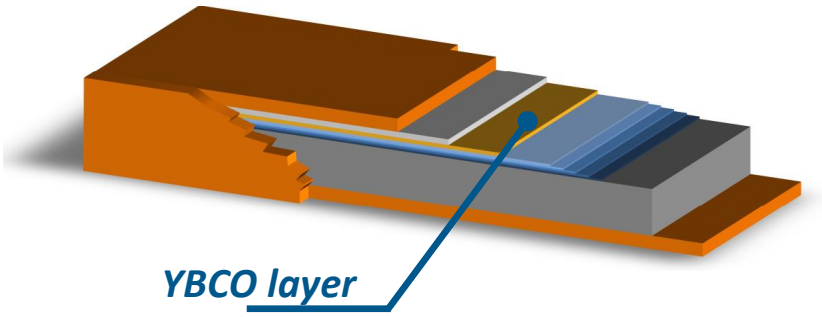
Performance target for ARIES



How to get there?

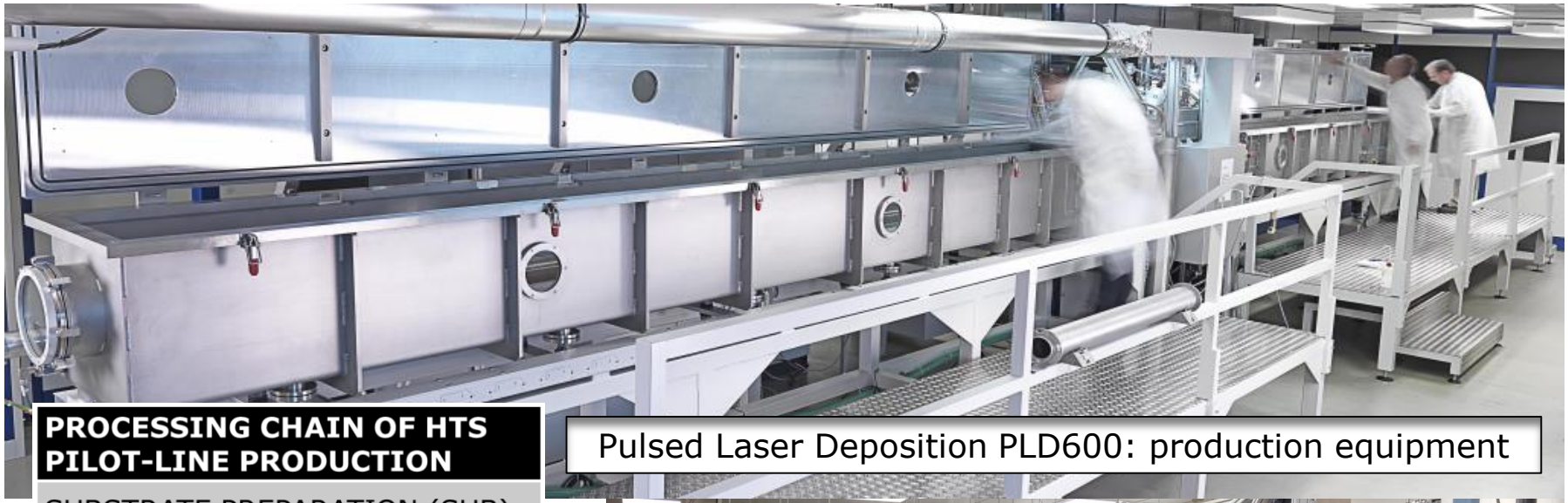
- Increase the layer J_c of YBCO
- Increase the thickness of YBCO
- Reduce the thickness of the substrate 100 μm SS → 50 μm SS

$$J_e = \frac{\text{Critical Current}}{\text{Total Area}}$$



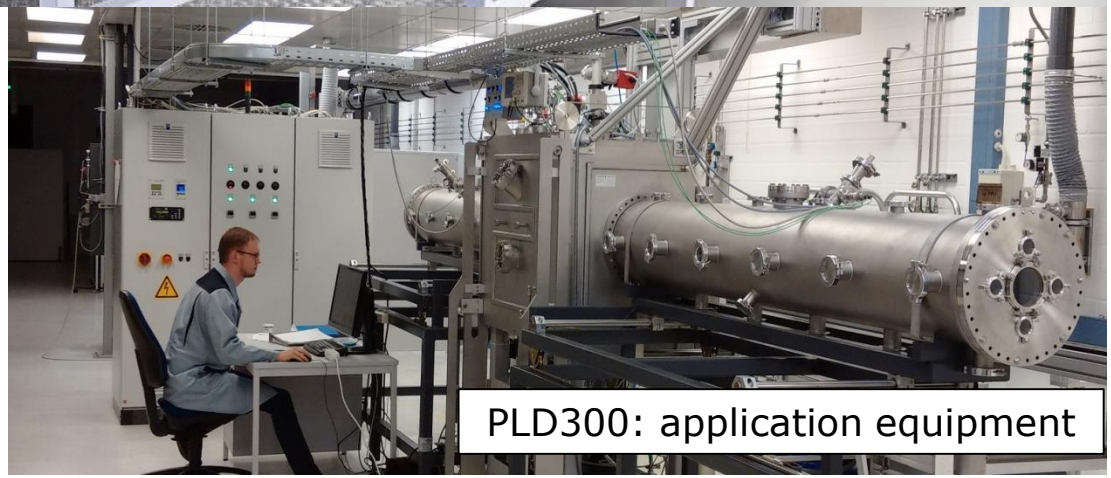
ARIES project @ Bruker HTS

The PLD300 system, used for ARIES, is co-owned by BHTS and CERN



Pulsed Laser Deposition PLD600: production equipment

PROCESSING CHAIN OF HTS PILOT-LINE PRODUCTION
SUBSTRATE PREPARATION (SUB)
BUFFER LAYER COATING (ABAD)
HTS LAYER COATING (PLD)
METAL COATING (MET)
COPPER PLATING (PLA)
FINAL TAPE INSPECTION (INS)



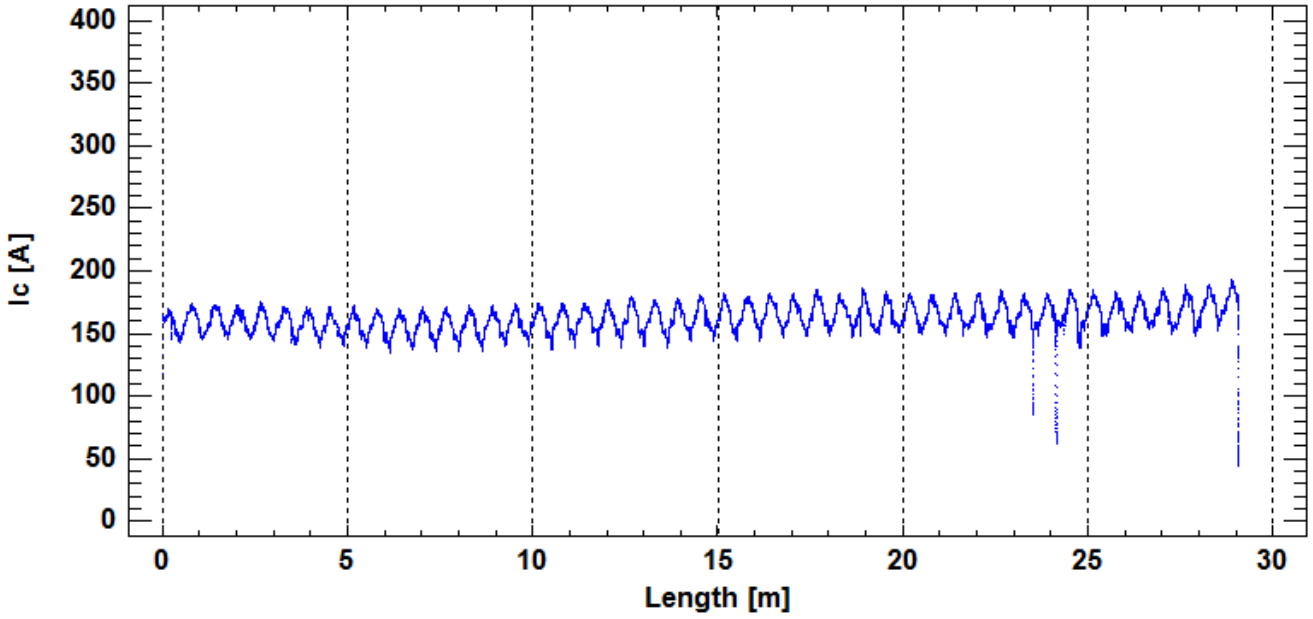
PLD300: application equipment

Courtesy of A. Usoskin, BHTS

ARIES project @ Bruker HTS

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*



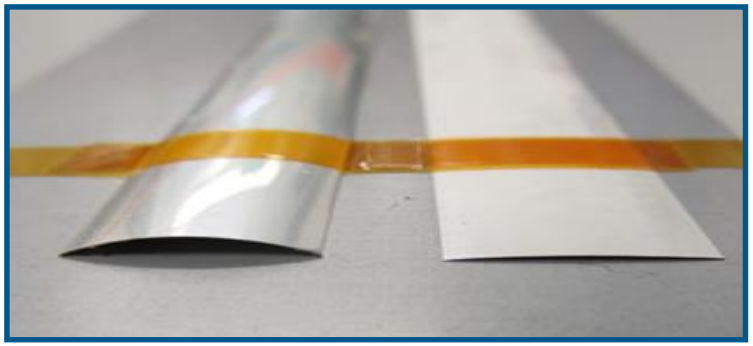
Courtesy of A. Usoskin, BHTS

ARIES project @ Bruker HTS

General appearance of HTS tapes with 50 µm SS substrates

The new tapes reveal a strong tape curvature (tape bow) due to intrinsic film stresses of the coatings

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

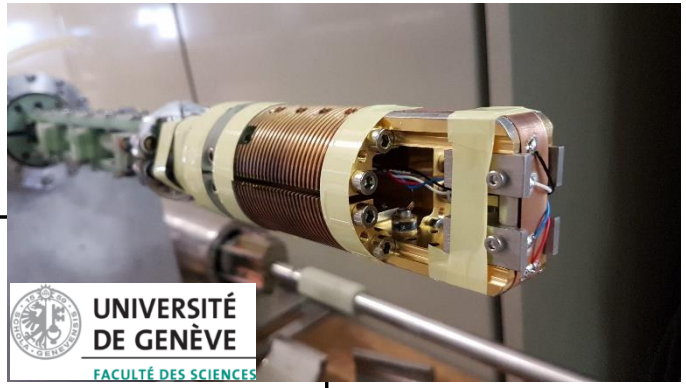


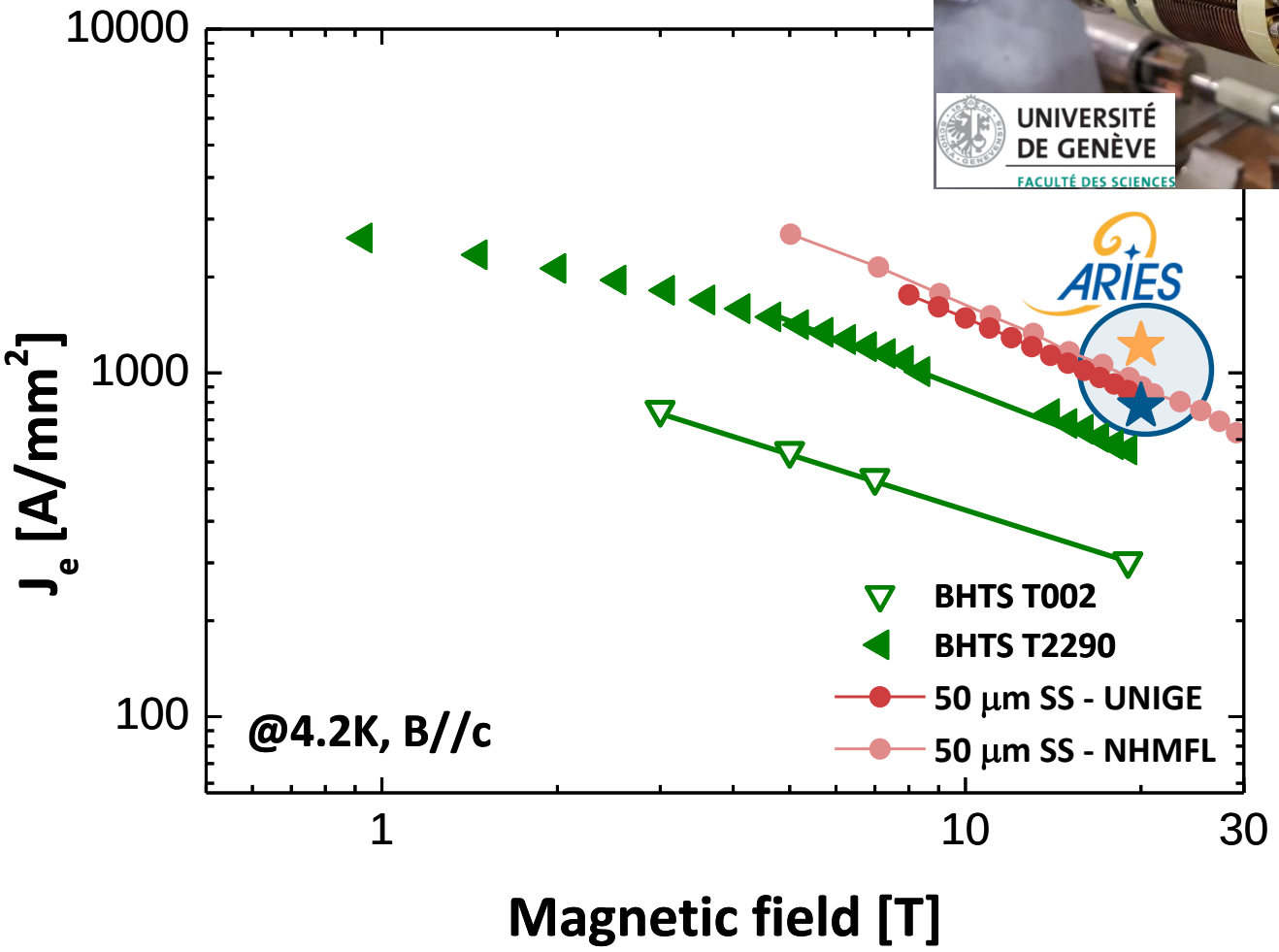
Optimization of the coating process is ongoing

First results show a large reduction of the tape bow

Courtesy of A. Usoskin, BHTS

First I_c measurements: where do





MS45 is successfully achieved !!

Summary

- *The program had a very good start, on the shoulder of EuCARD-2*
- *The first short lengths of tape with thinner substrate (50 μm stainless steel) were produced*
- *Deposition parameters still need to be optimized*
- *In spite of that, we got already a record $J_e \approx 900$ A/mm² @ 4.2 K, 19 T*

Thank you for the attention !

Carmine SENATORE

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The technology of REBCO coated conductors

Alternative approaches for growing epitaxial REBCO on flexible metallic substrates in km-lengths

- **Substrate texturing**
  - **RABiTS** : Rolling-Assisted, Biaxially Textured Substrates
    - Texture is created in NiW by a rolling-and-recrystallization process
  - **IBAD** : Ion Beam Assisted Deposition
    - A biaxially textured MgO layer is grown on polycrystalline Hastelloy
- **REBCO layer deposition**
  - Physical routes
    - **PLD** Pulsed Laser Deposition
    - **RCE** Reactive Co-Evaporation
  - Chemical routes
    - **MOD** Metal-Organic Deposition
    - **MOCVD** Metal-Organic Chemical Vapor Dep.

Layer J_c: where do we stand ?