



WAM



New Flat Cable Beyond Roebel

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WAMHTS -4

**4th Workshop in Accelerator Magnets in HTS
Barcelona, 15-17 February 2017**

Outline

- Superconducting cables
 - Requirements for use in accelerator magnets
- REBCO Roebel cable
- RERC cable
- Other flat cable geometries
- Conclusions

Cable(s) for accelerator magnets

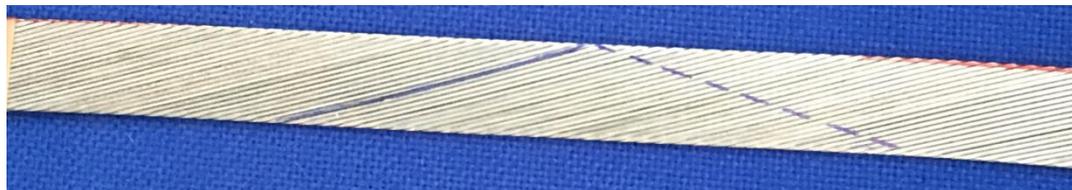
- **High J_e**
- **Field quality** both at steady and varying currents:
 - Magnetization (low at low - injection - field);
 - Intra-strand eddy currents (among filaments);
 - Inter-strand eddy currents (among strands in a cable)

Correction of multipoles is possible – provided the effects are reproducible and predictable

Cable(s) for accelerator magnets

- **Small and twisted filaments** ($\leq 10 \mu\text{m}$) – to minimize magnetization at low (injection) field
- **Twisting** of **strands** in cables
- **Transposition** of **strands** in cables
- **Sharing of current among strands** for stability and protection
- **Mechanical properties** for enabling winding and withstanding forces in the coil configuration (flat cable, transverse stresses $\geq 150 \text{ MPa}$)
- Accuracy of **geometrical dimensions** ($\sim 0.01 \text{ mm} - 0.05 \text{ mm}$)

Rutherford Cable

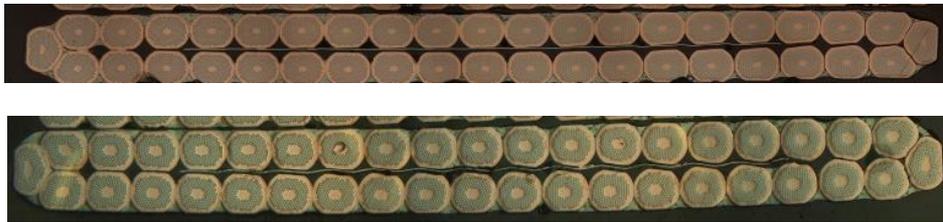


LTS Cables for LHC Magnets

Nb-Ti LHC Main Dipole Rutherford cable – 36 strands

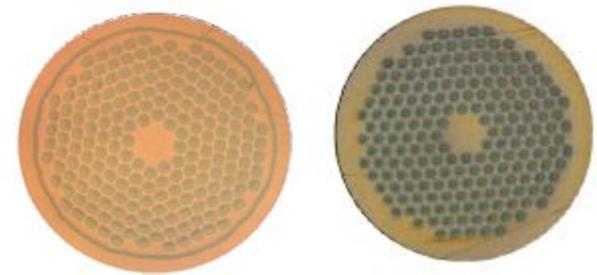


Nb₃Sn Rutherford cable for HL-LHC – 40 strands



J. Fleiter et al., 4LPo2B-06

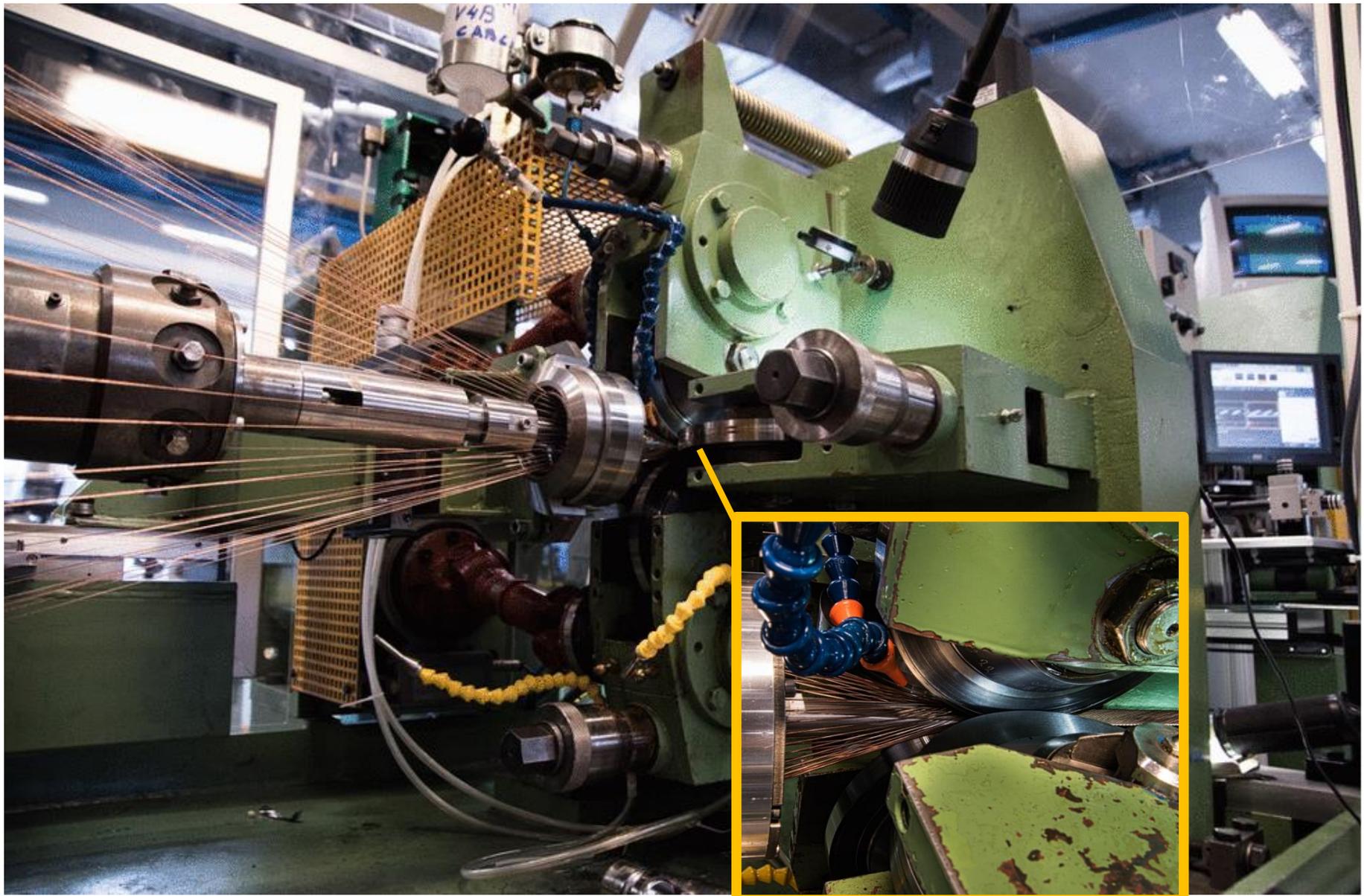
Nb₃Sn wire for HL-LHC



B. Bordini et al., ASC 2016

Cable compaction ~ 90 %

$J_e \sim 400\text{-}500 \text{ A/mm}^2$ at the operational temperature and field



Rutherford cabling machine at CERN

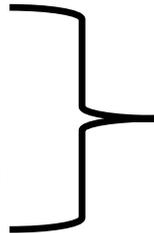
REBCO Tape

- Very high J_c (and J_e)
- **Reacted** conductor

But

- Tape geometry
 - ~~Small and twisted filaments~~

- Quench detection
- Quench protection

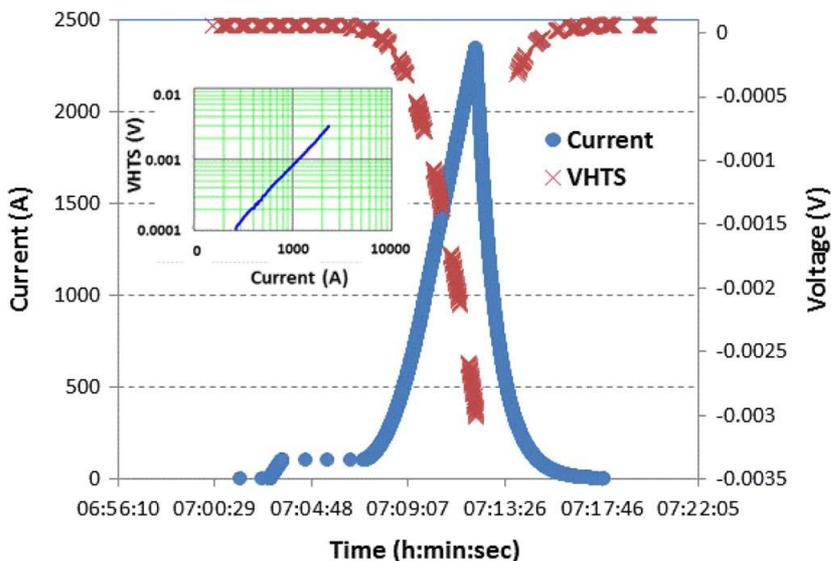


**Related to the geometry
of the cable**

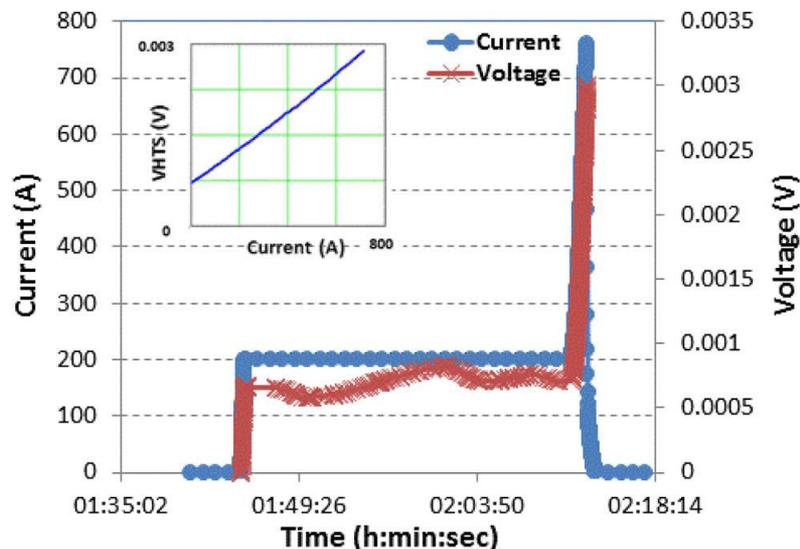
Protection of HTS in LHC

Stacks of (Bi-2223) tapes in LHC HTS current leads operational in the LHC accelerator – 1074 components

Noisy electro-magnetic environment
3 mV detection threshold
Dedicated electronics



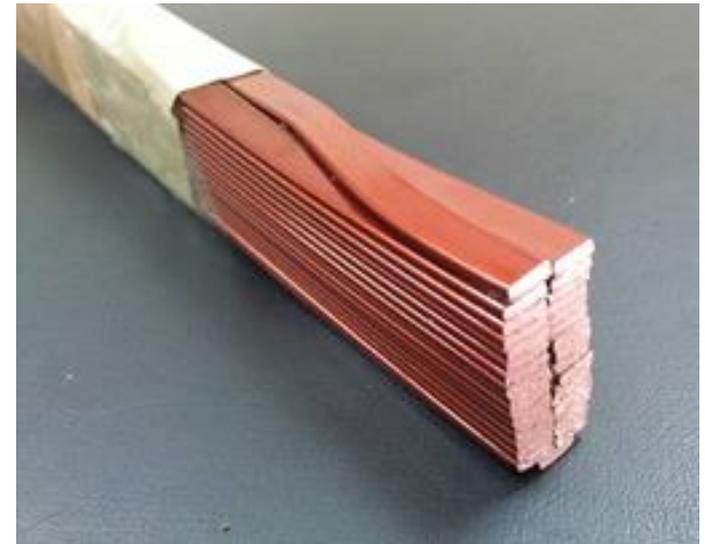
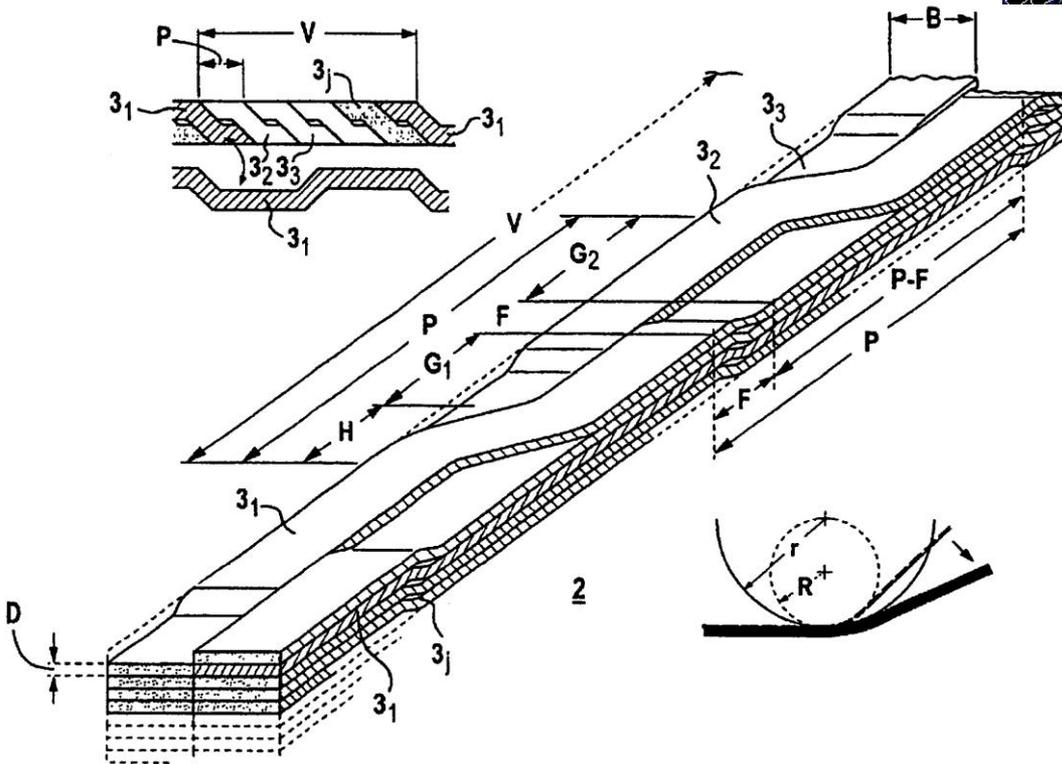
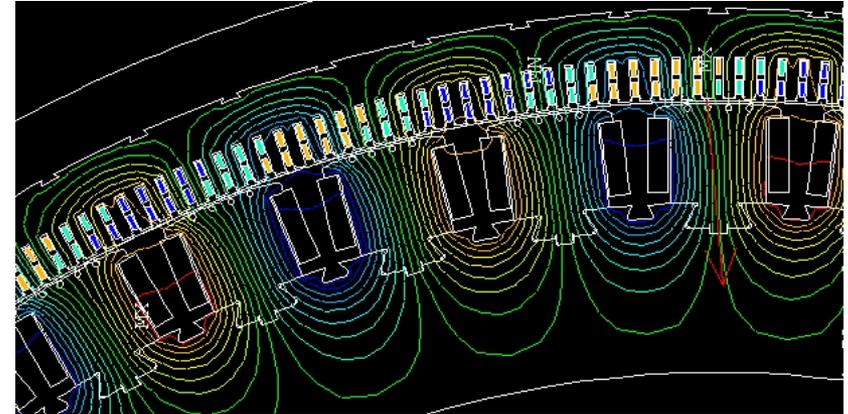
Quench in HTS lead for Main Dipole



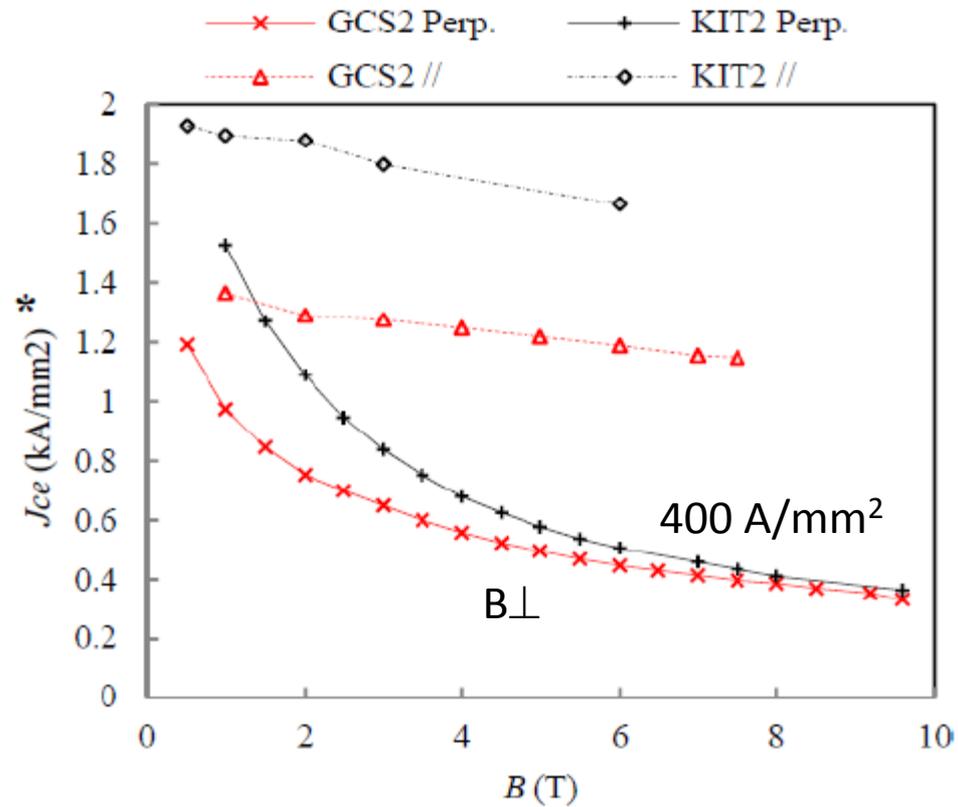
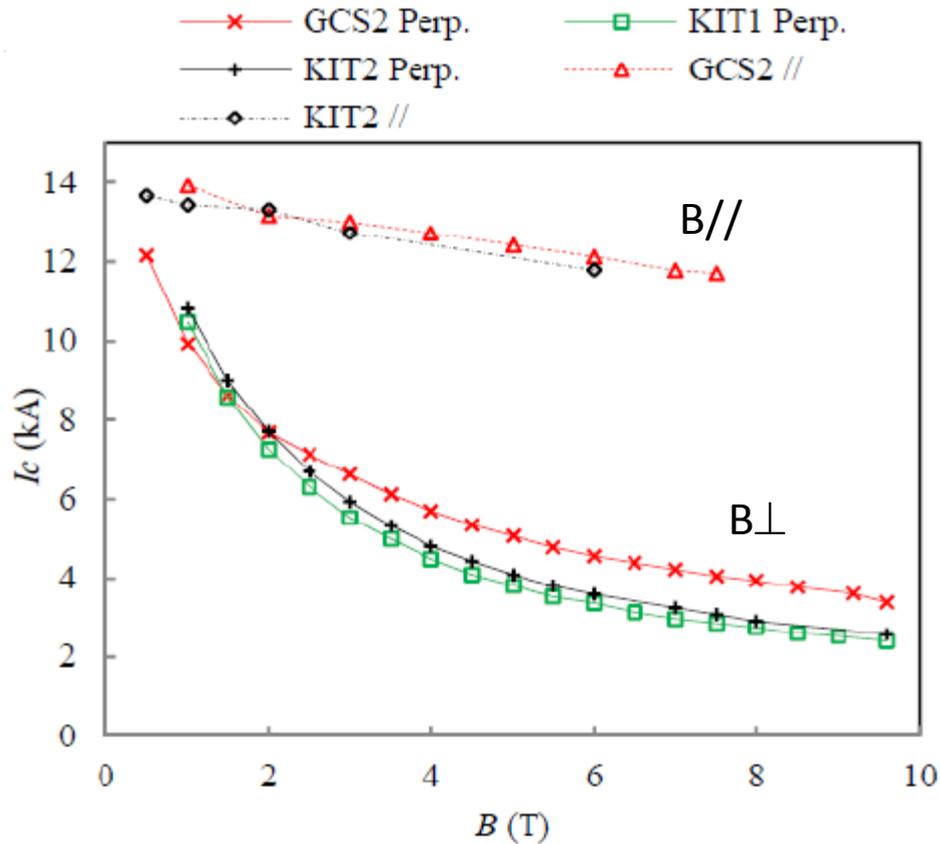
Quench in HTS lead for Separation Dipole

Roebel Bar

As developed for generators



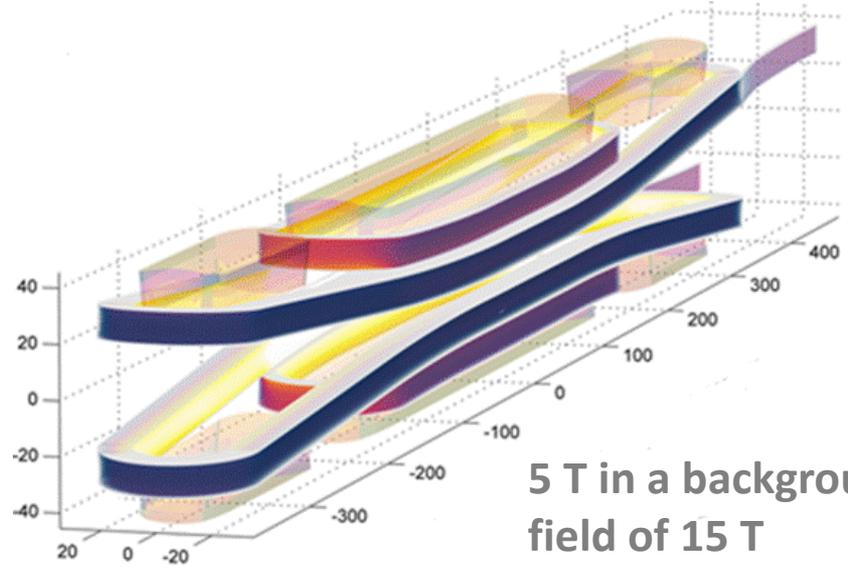
Measurement of Roebel Cables



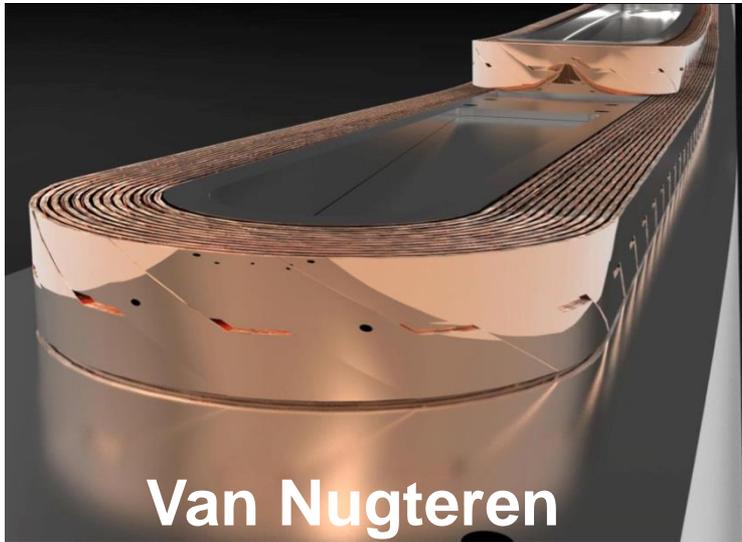
J. Fleiter et al, Supercond. Sci. Technol. 26 (2013) 065014

REBCO Roebel Cable

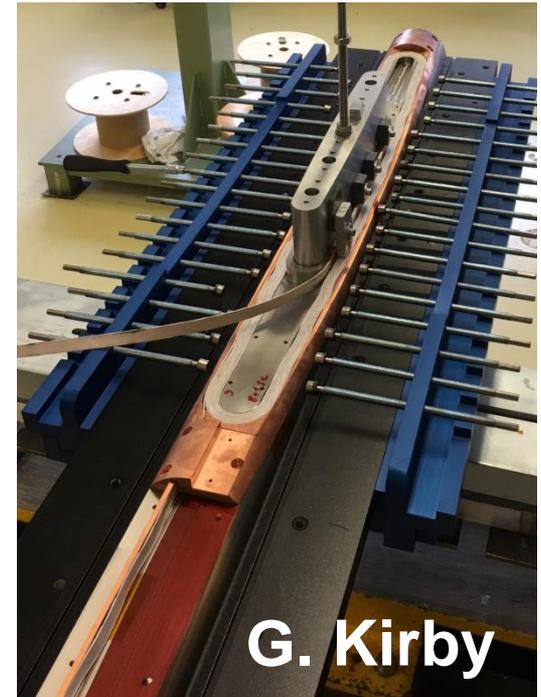
Eucard 2



5 T in a background field of 15 T



Van Nugteren

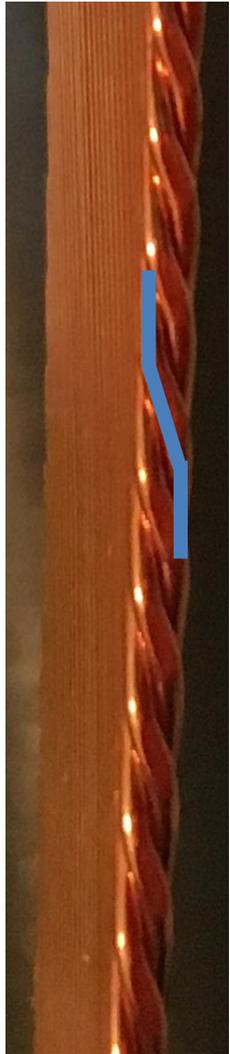


G. Kirby

Cables assembled by KIT, Tape produced by Bruker

Roebel: topological transformation of Rutherford

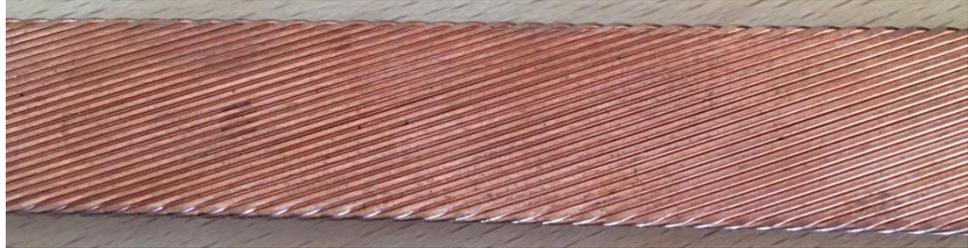
Thickness
Rutherford



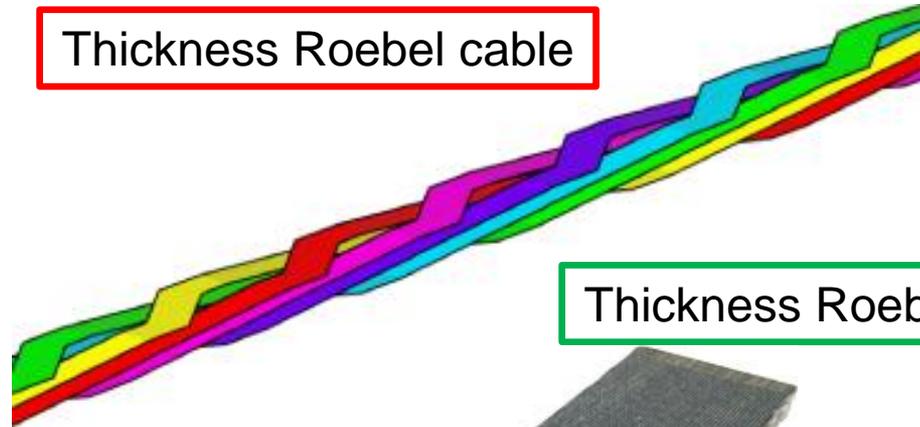
Width
Roebel



Width
Rutherford



Thickness
Roebel cable

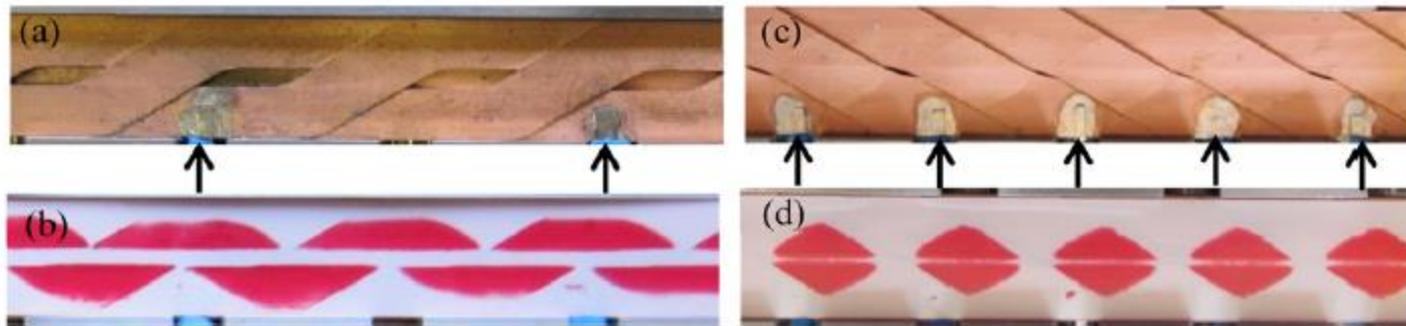


Thickness
Roebel bar



REBCO Roebel Cable

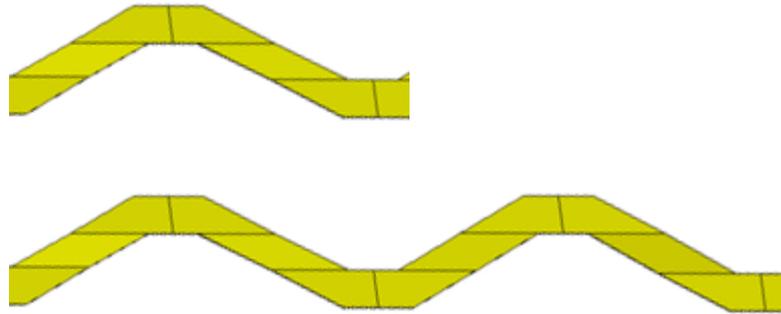
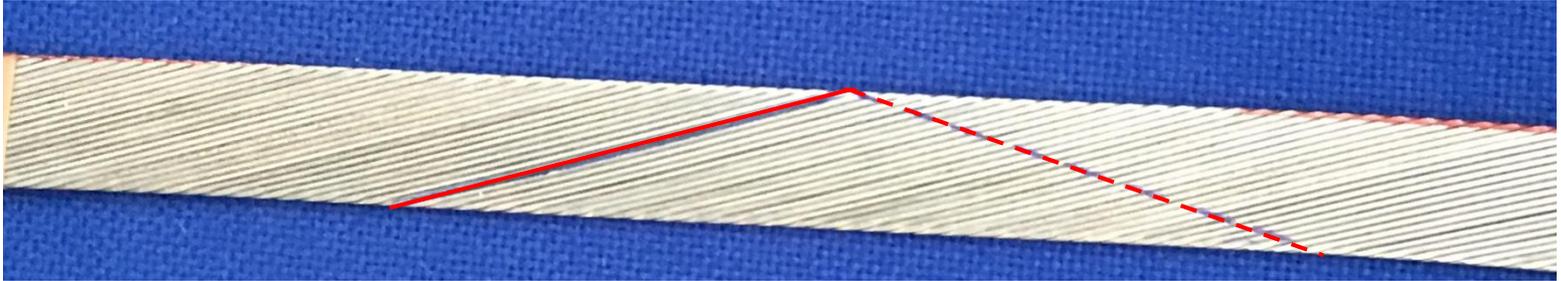
- **Long twist pitches** (200 mm-300 mm in Roebel vs 60 mm–100 mm in Rutherford)
- **Non-homogeneous cross section** (→ impregnation)



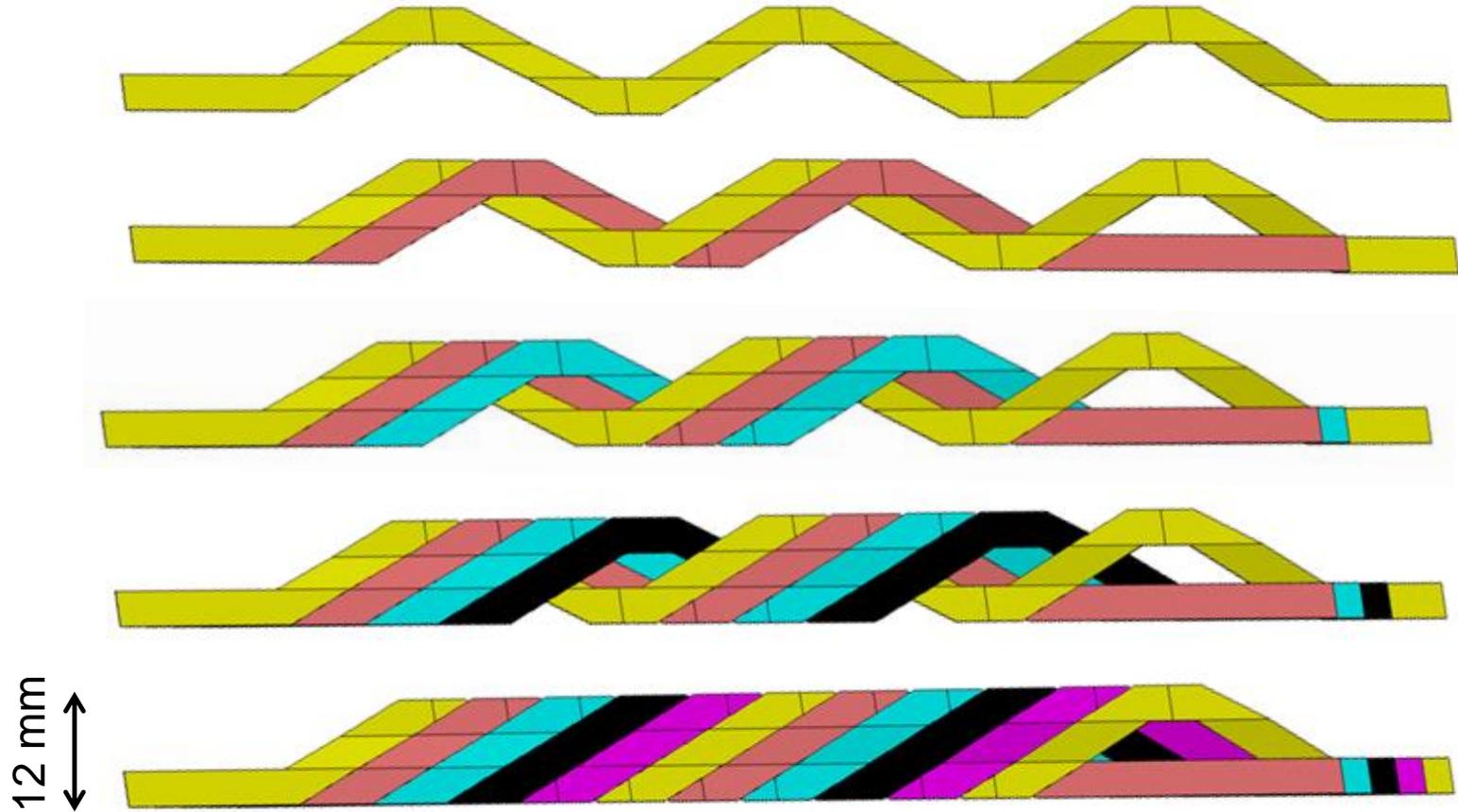
J. Fleiter et al, Supercond. Sci. Technol. 26 (2013) 065014 (5pp)

- **No current sharing among tapes:**
 - presence of resistive substrates;
 - each tape constrained between the same two tapes while moving along the pitch

Rutherford Cable

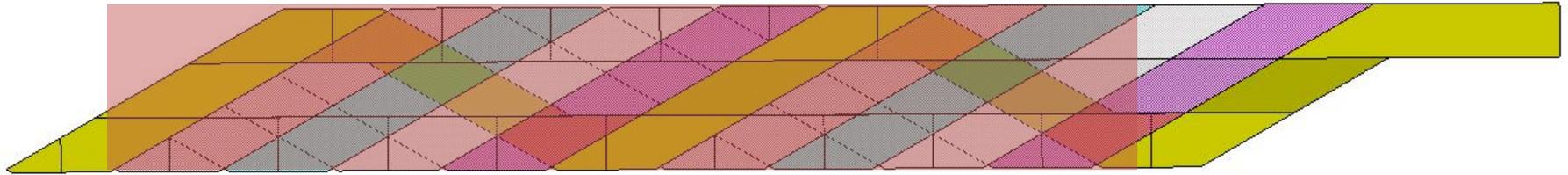


REBCO Rutherford Cable (RERC)



REBCO Rutherford Cable (Five tapes, each tape 4 mm wide)

REBCO Rutherford Cable (RERC)

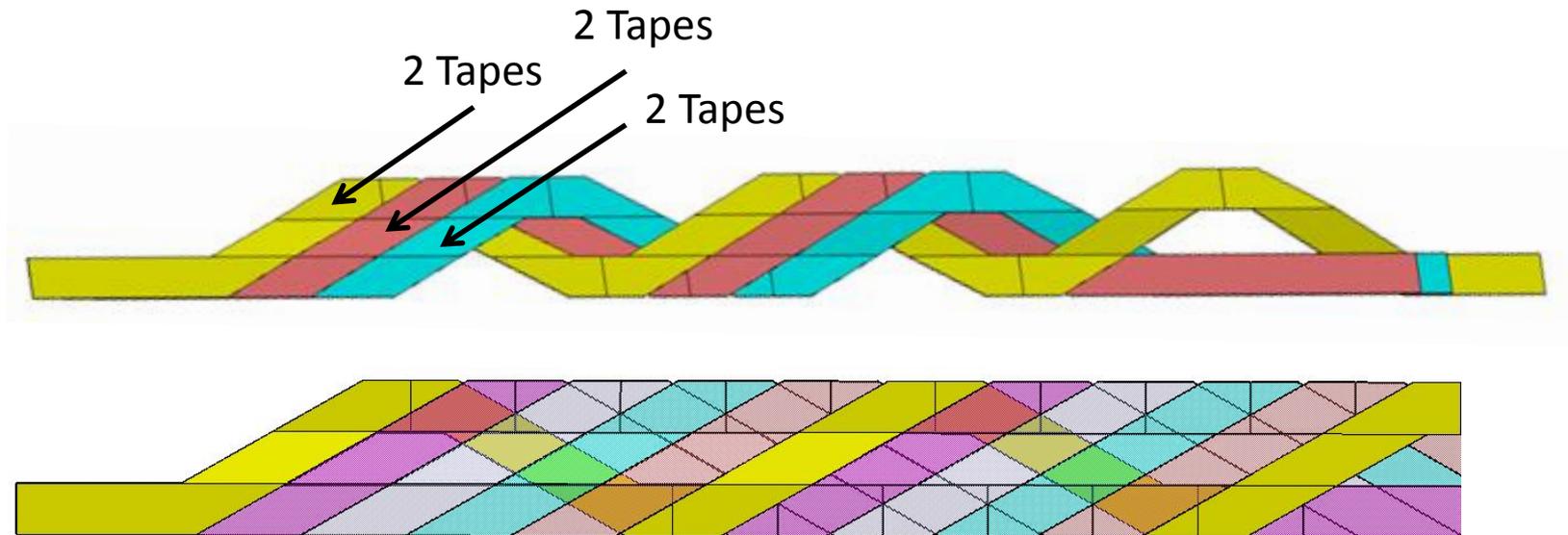


REBCO Rutherford Cable (Five tapes, each tape 4 mm wide)

- In-plane **twisting** of tapes
- Full **transposition** of tapes along cable twist pitch
- **Crossing** of each tape with any other tape in the cable (current sharing among conductors)
- Possibility of adding **stabilizer, in contact with all tapes**, on the two faces of the cable
- Where the sides of the tapes with the superconductor are facing each other: **controlled inter-strand resistance** via optimized coating
- Homogeneous **geometry** (homogeneous distribution of transverse pressure)

Increasing Ic in RERC

- Use of wider (> 12 mm) “base” tape to enable crossing of more tapes along the cable width
- Grouping tapes during cabling



REBCO Rutherford Cable (Ten tapes, each tape 4 mm wide)

REBCO Rutherford Cable (RERC)



REBCO Rutherford Cable (Five tapes, each tape 4 mm wide)

$$I_{c_tape}(18\text{ T}, 4.2\text{ K}) = 1200\text{ A/cm}$$

For 4 mm wide tapes:

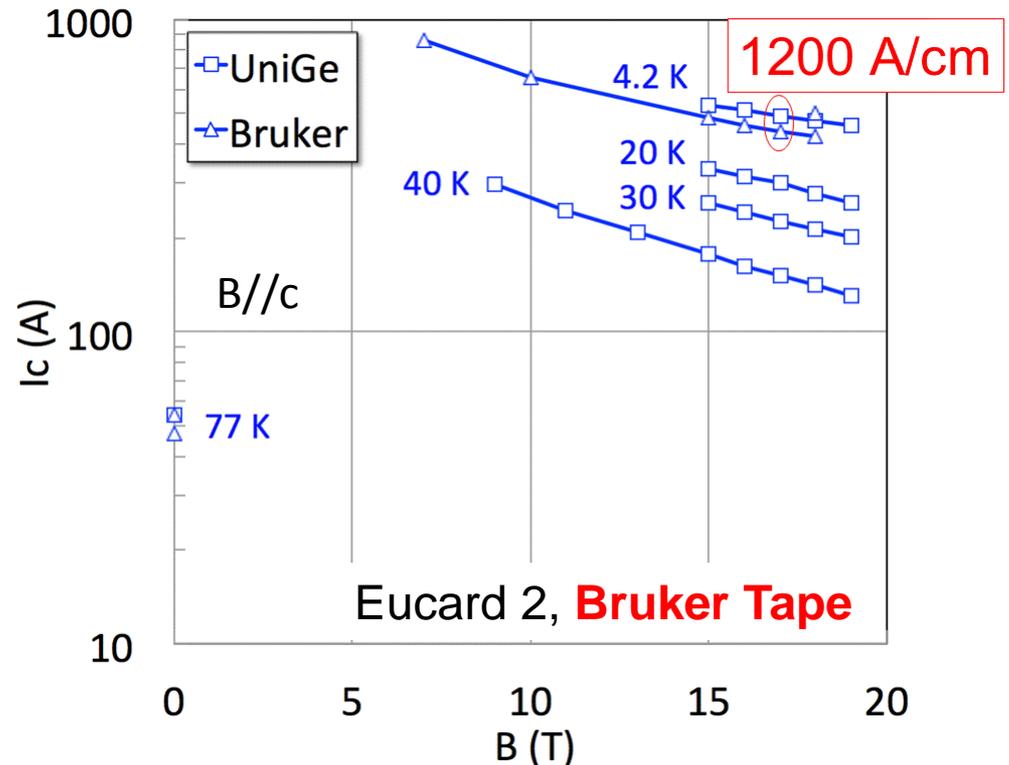
$$W_{cable} = 12\text{ mm}$$

$$Th_{cable} = 0.2\text{ mm}$$

$$L_{twist} = 20\text{ mm}$$

$$J_{e_cable}(18\text{ T}, 4.2\text{ K}) \sim 1000\text{ A/mm}^2$$

$$I_c(18\text{ T}, 4.2\text{ K}) \sim 2400\text{ A}$$



REBCO Rutherford Cable (RERC)



REBCO Rutherford Cable (Five tapes, each tape 4 mm wide)

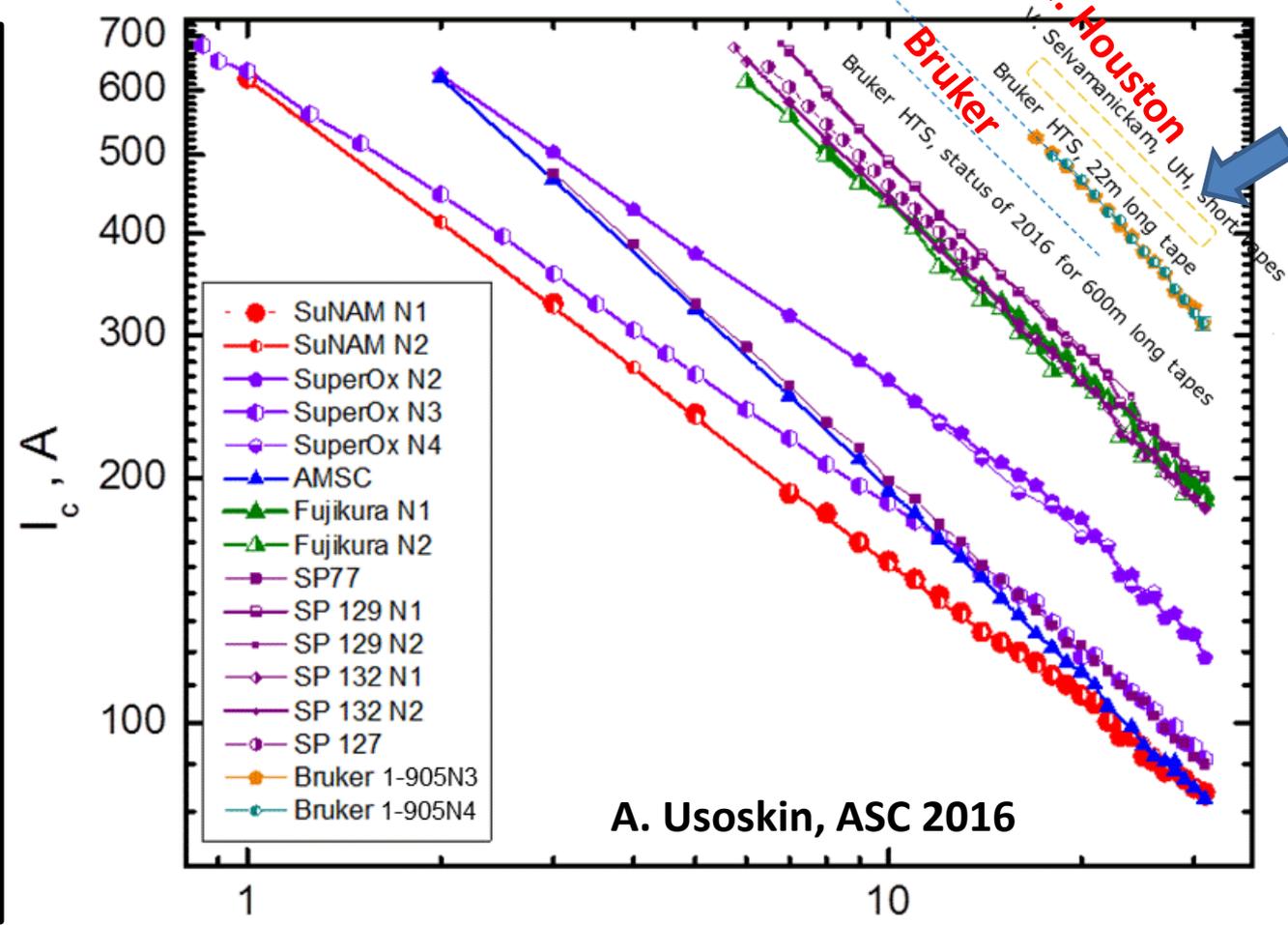
For 4 mm wide tapes:

W_cable = 12 mm
 Th_cable = 0.2 mm
 L_twist = 20 mm

Je_cable(18 T, 4.2 K)
 ~ **1400 A/mm²**

I_c (18 T, 4.2 K)
 ~ 3350 A

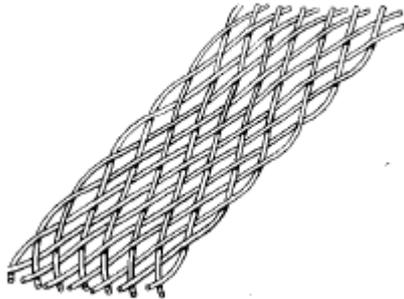
I_c (10 T, 4.2 K)
 > 4000 A



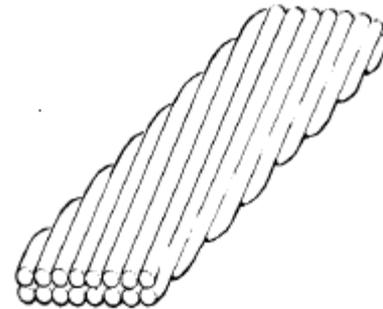
Flat Cable Cables

- Use of tapes (2 mm - 4 mm width) with small bending radius (≤ 2 mm)
- Assemble from these tapes high Je:

Braided cables



Rutherford cables



Conclusions

- **Roebel cable** is interesting for accelerator technology. The on-going EUCARD 2 activity studies pro and cons of REBCO Roebel cables in a coil configuration
- Besides **J_e** , other characteristics are important in a cable - among them **quench performance** and **current sharing**. The desired performance shall be taken into account in the definition of the cable geometry
- Other geometries of cables made from REBCO tapes can be studied. If we like the **Rutherford**, we can....
- To make these Roebel/RERC **cables affordable**: could REBCO deposition be done on pre-cut substrates?
- Tapes **< 4 mm wide** with thinner substrate (small bending radius) open the way to **new accelerator-type cable geometries**

Thanks for your attention !