Cable Options for Eucard 2

Eucard'13, CERN

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CERN, TE-MSC-SCD

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Cables for accelerator magnets

High Jc conductor

High **I** cables

High **Je**

Field quality

- precise and controlled **dimensions** of cables
- controlled **inter-strand resistance** (coupling currents)
- low **magnetization** – also at low field (injection current)
- **twisted** filaments and strands
- **transposed** cable configuration

Mechanical strength, mechanical stability, windability (bending radius)

Stability

Protection

Radiation resistance characteristics

Cost (conductor + cabling (yield, assembly, stabilization,…))

Specification derived experience with LTS cables

Nb-Ti Main Dipole Inner Cable

STRAND	Type 01
Diameter (mm)	1.065
Cu/NbTi ratio	1.6-1.7 ± 0.03
Filament diameter (μm)	7
Number of filaments	8800
Jc (A/mm^2) @1.9 K	1530 @ 10 T
μ_0M (mT) @1.9 K, 0.5 T	30 ±4.5
CABLE	**Type 01**
Number of strands	28
Width (mm)	15.1
Mid-thickness (mm)	1.900 ±0.006
Keystone angle (degrees)	1.25 ±0.05
Cable Ic (A) @ 1.9 K	13750 @ 10T
Interstrand resistance (μΩ)	10-50

Number of Nb-Ti strands=28

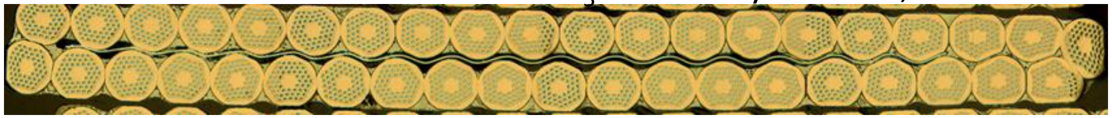
Cable transposition pitch =115 mm

Packing factor = 90%

Je(10 T,1.9 K) ~ 480 A/mm^2

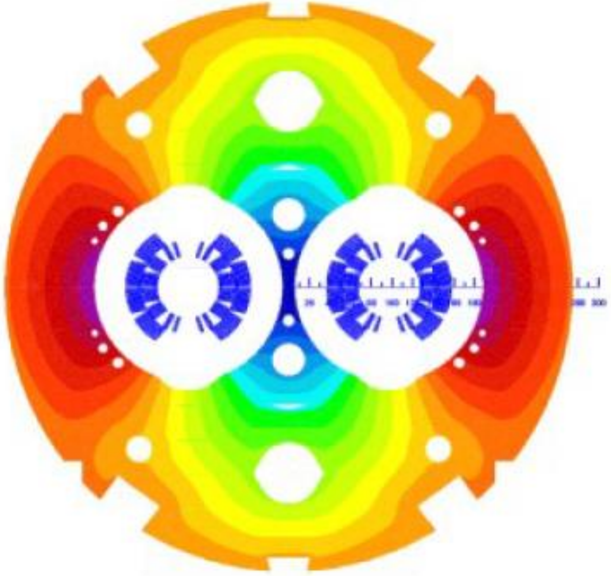
Higher field magnets – Nb_3Sn for LHC

Nb_3Sn cable by L. Oberli, A. Bonasia



11 T Dipole Magnet LHC Nb_3Sn Rutherford Cable

Nb_3Sn Keystoned Cored Cable
Diameter of strands = 0.7 mm
Number of strands = 40
Width = 14.7 mm
Mid-thickness = 1.269
Packing factor = 86 %
Transposition pitch = 100 mm
Inom = 11850 A
Jen ~ 640 A/mm²



CERN Eucard 2 Program

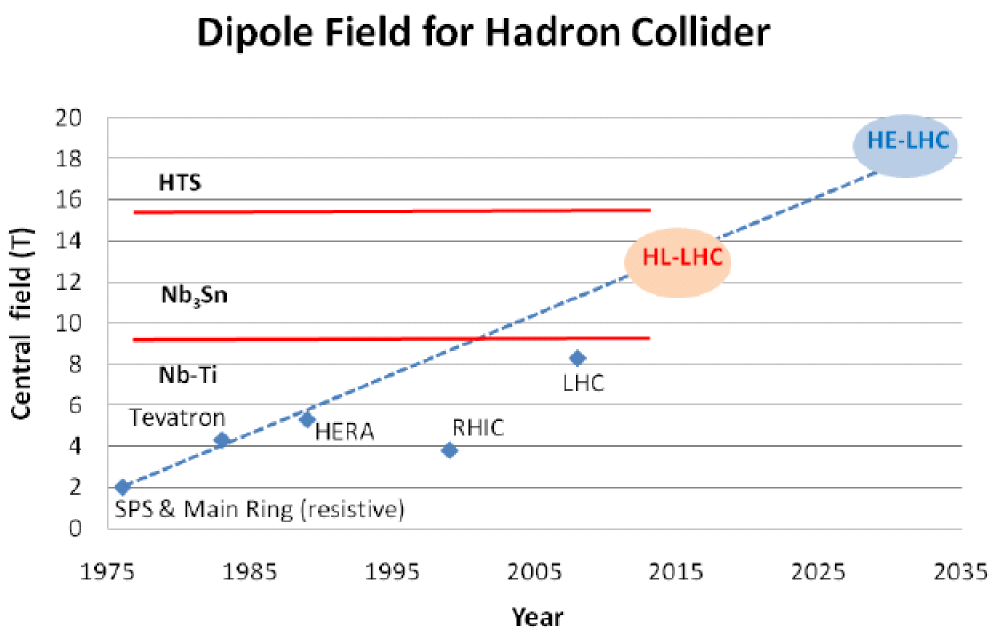
Target performance for HTS cables

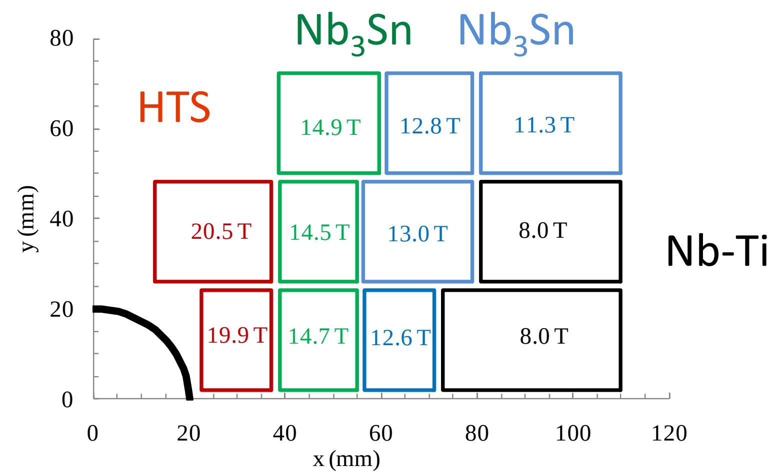
parameter	units	targets
J_E (20 T, 4.2 K)	(A/mm^2)	600
J_E (15 T, 4.2 K)	(A/mm^2)	675
J_E (12 T, 4.2 K)	(A/mm^2)	800
σ (I_C) within a unit length	(%)	10
M(1.5 T, 10 mT/s)	(mT)	300
Range of $\sigma_{transverse}$	(MPa)	100
Range of $\varepsilon_{longitudinal}$	(%)	±0.3
Unit length	(m)	100

5 T Dipole Insert (40 mm bore)
in a 15 T dipole magnet

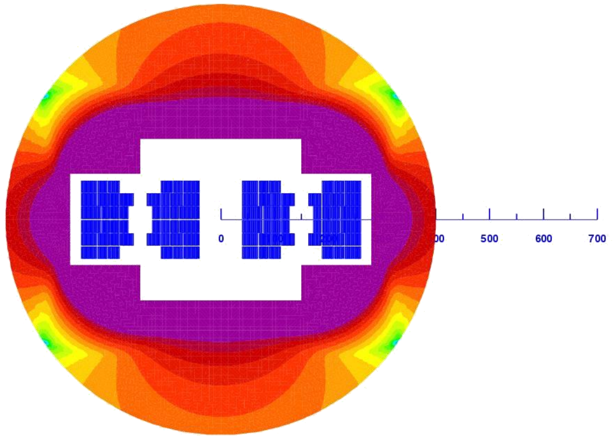
Higher energy accelerators

Eucard 2 (Lucio Rossi, CERN Edms No. 1152224)





$J_{overall\_HTS}$ = 400 A/mm^2 @ 20 T



High Energy LHC: 2×16.5 TeV beams

Twin aperture dipole, **20 T**, 15 m long, bore spacing 300 mm, iron diameter 800 mm

L. Rossi and E. Todesco.

HTS Cables

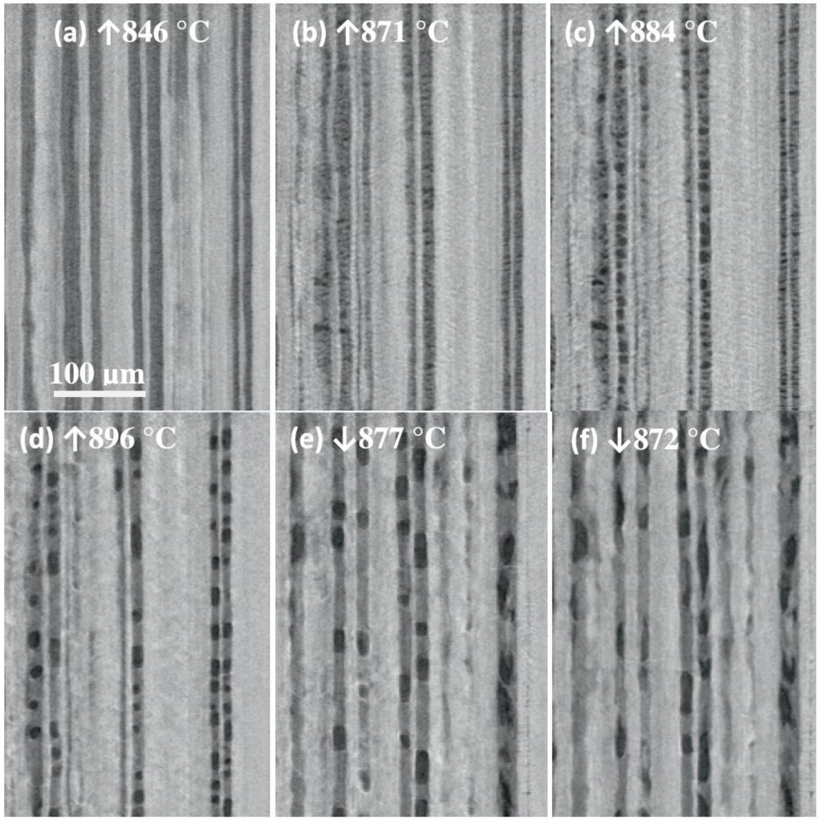
- **HTS** Conductors are different from **LTS** Conductors
  → Possibly required new approaches to magnet design

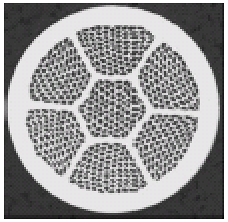
- **Bi-2212** conductor is different from **YBCO**
  →Cables will/must be different

- **Conductor's characteristics** are strongly dependent on state of the adevelopment (OP Processing for Bi-2212, doping for in field performance and reduction of anisotropy,…)
  → They should be known before starting a cable design

- **Long lengths** (100 m) of accelerator type cables today are not available (this is certainly in the case for YBCO)

BSCCO 2212





250 filament Bi-2212 wire ~ 0.8 mm dia.

Isotropic Conductor Round Wire

Jc(20 T) ~ 2400 A/mm^2

Je(20 T) ~ 500 A/mm^2

D. Larbalestier et al.

Bi-2212 Rutherford Cables

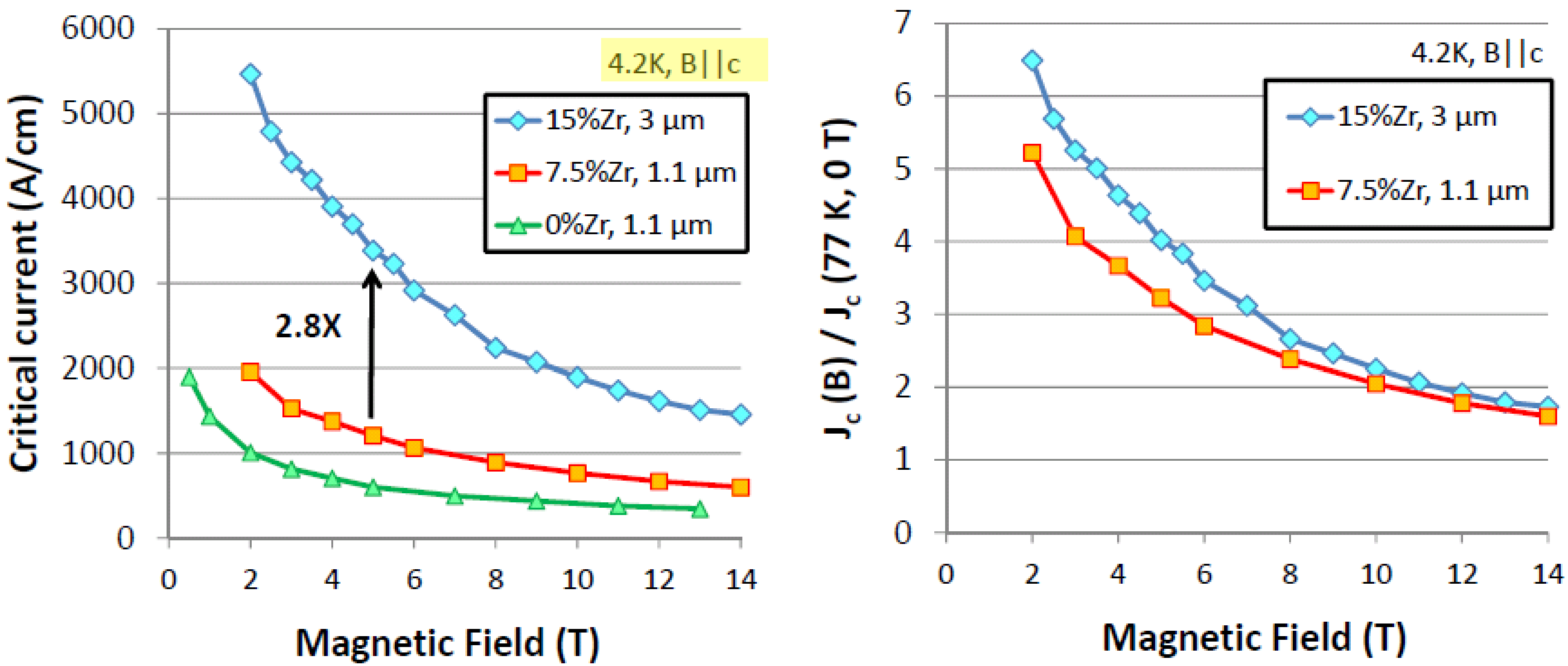
D. Dietderich et al., ASC-2000

The most suitable conductor for making a cable for accelerator magnets

See next presentation by D. Larbalestier

J. Jang, W. Starch, M. Hannion, F. Kametani, U. Trociewitz, E. Hellstrom and and D. Larbalestier, "Doubled critical Current Density in Bi-2212 Round Wires by Reduction of the Residual Bubble Density", 2011 Superconductor Science and Technology

YBCO Conductor



Measurements by J. Jaroszynski, D. Abraimov, X. Hu and D. Larbalestier, NHMFL

Je(4.2 H, 20 T) ~ 1000 A/mm²

Data courtesy of SuperPower

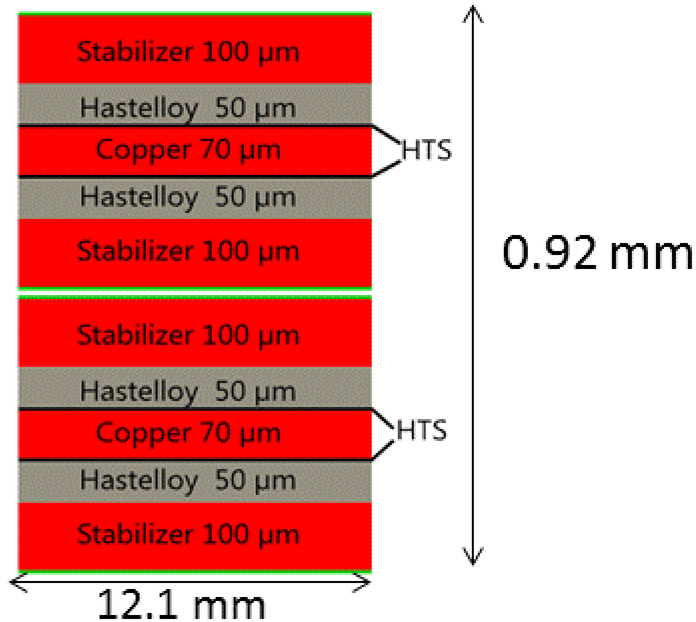
HTS Cables developed for High Field magnets

A

Strands wrapped around a core to make a multi-layer cable

D. Van der Laan et al.

B



Stacked-tape conductor

Eucard stack-cable
(Race-track HTS Insert-Fresca 2
6 T in a 13 T dipole field)

C

Twisted-stacked tape conductor

Takayasu, Chiesa, Minervini et al.

HTS Cables developed for High Field magnets

C

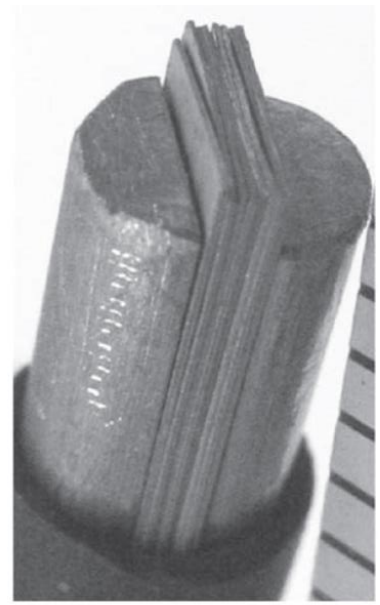
12 mm x 12 mm CICC
(copper diameter 9.5 mm)

40 YBCO tapes in a copper diameter 9.5 mm.

20 YBCO tapes in each helical groove in a copper diameter 9.5 mm.

Takayasu, Chiesa, Minervini et al.

C



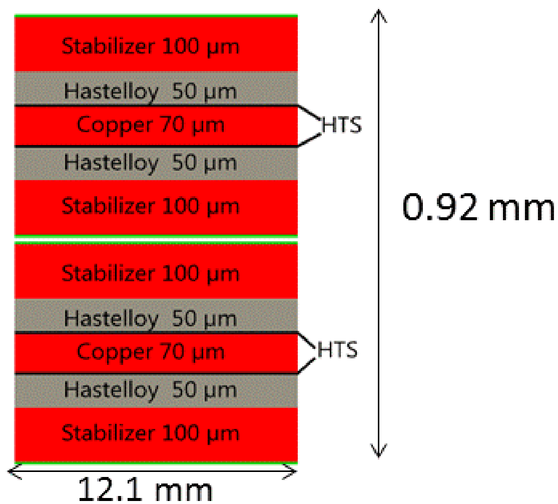
Uglietti, Bruzzone, et al.

All not fully-transposed Cables

72 Tapes, 4 mm width
17 Layers
Φ = 7.5 mm
Je (4.2 K, 19 T)= 114 A/mm²
Bending radius > 8 cm
Requires dog-bone ends
Not practical for accelerator magnets

D. Van der Laan et al.

B



4 Tapes, 12 mm width
Je-op(4.2 K, 19 T)= 250 A/mm²
Can/will be wound

Eucard stack-cable
(HTS Insert-Fresca 2)

C

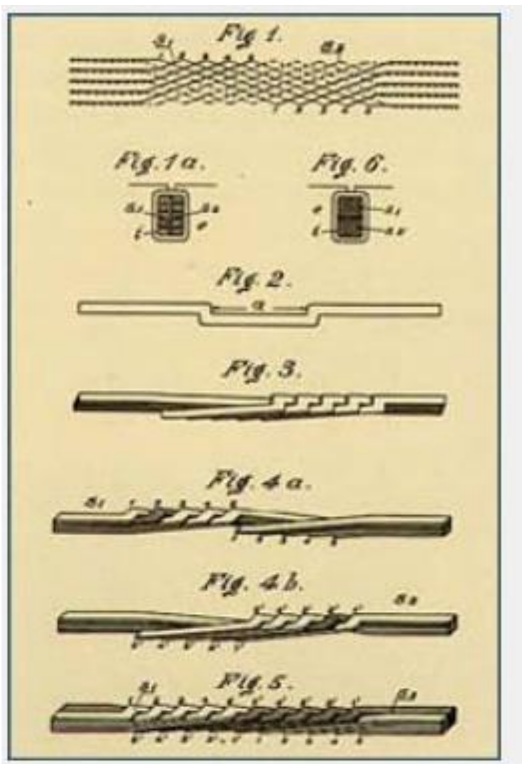
40 Tapes, 4 mm width
Φ=7 mm
Je (4.2 K, 15 T)= 160 A/mm²
Requires dog-bone ends
Not practical for accelerator magnets

Takayasu, Chiesa, Minervini et al.

CERN cabling machine for producing cables made stacks of 4-mm wide tapes and for electrically insulating the assembled stacks (Kapton®). Up to 8 tapes. Developed for producing Twisted-Pair cables for electrical transmission (SC Link Project)

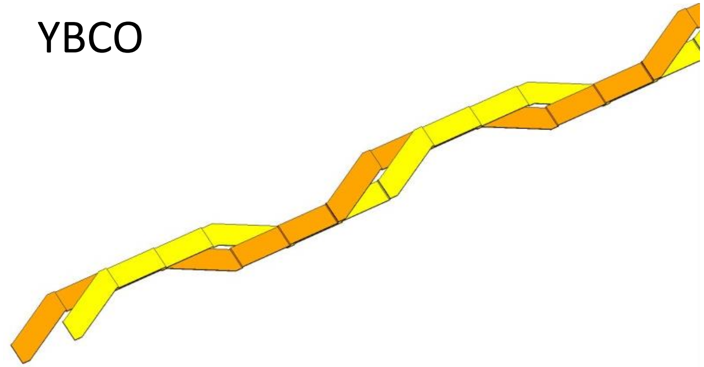
Roebel Cable

- Fully Transposed Cable
- High Compaction factor
- High Je

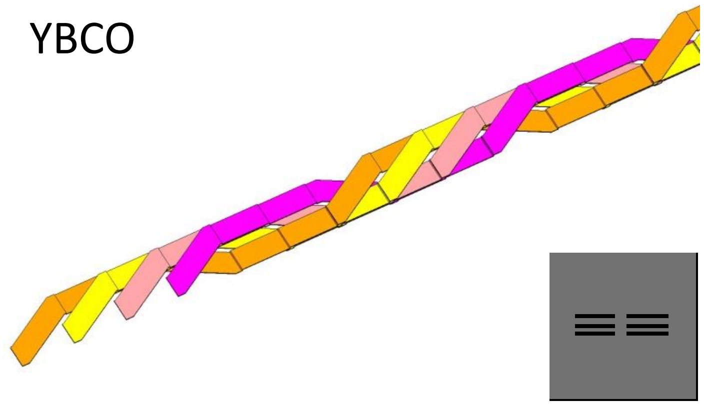


Patent (**1912**) of Ludwig Roebel (BBC)
Low-loss Cu cables for power generators

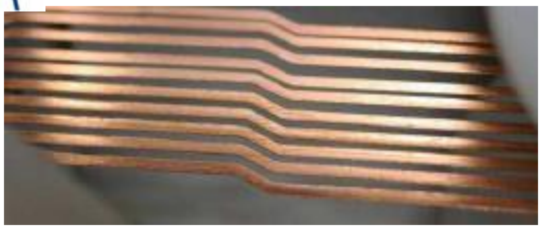
YBCO



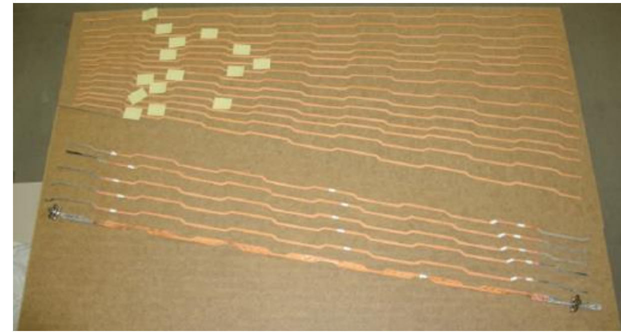
YBCO

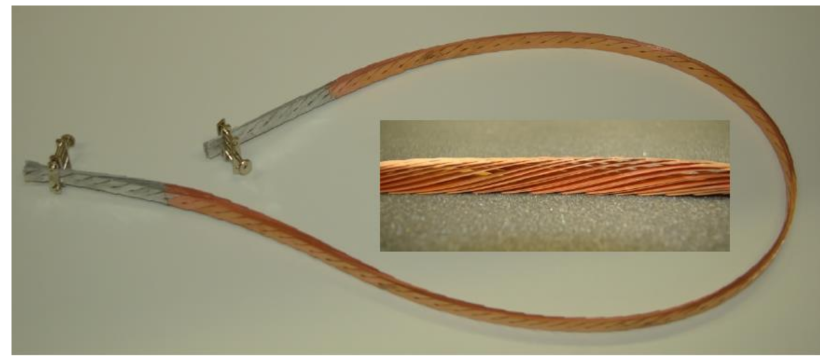


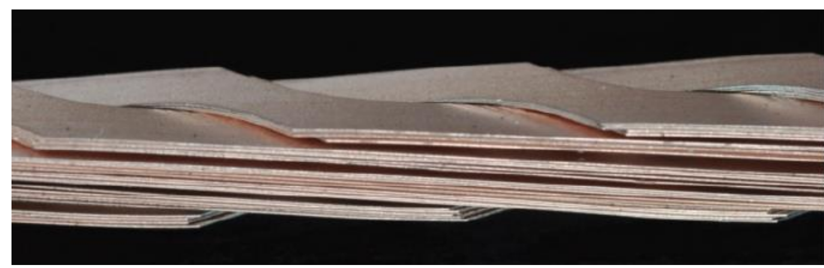
Roebel Cable



General Cable Superconductors
N. Long, A. Priest et al.
Cabling machine for long cable lengths

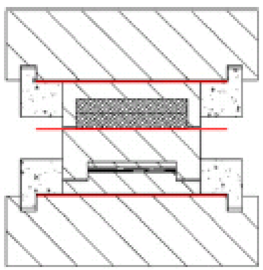




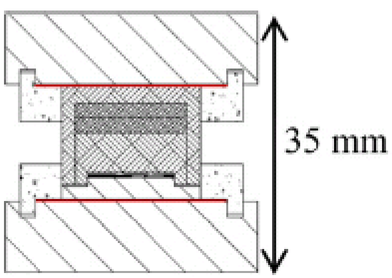


KIT
W. Goldacker, A. Kario, S. Schlachter, F. Grilli et al.

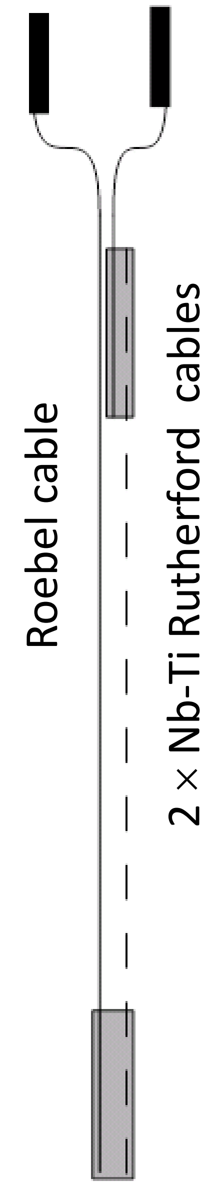
Roebel cables measured @ 4.2 K

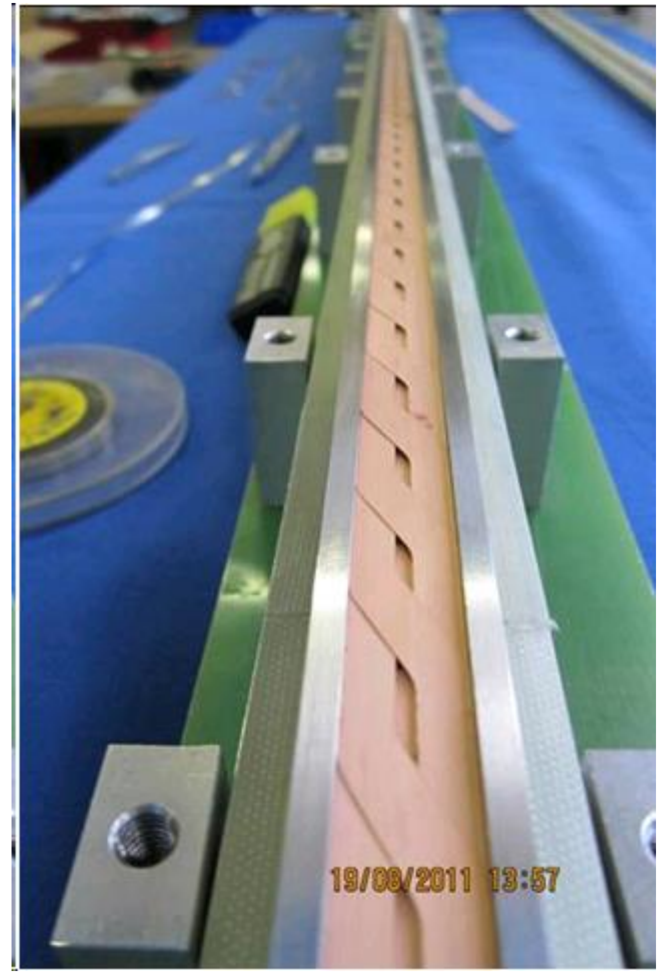


Main part



Bottom joint





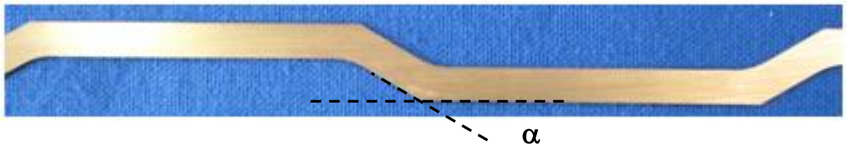
CERN, Superconducting Lab

J. Fleiter, PhD thesis, CERN and Univ. of Grenoble

Roebel cables measured @ 4.2 K

Measurements @ CERN in the FRESCA Test Station

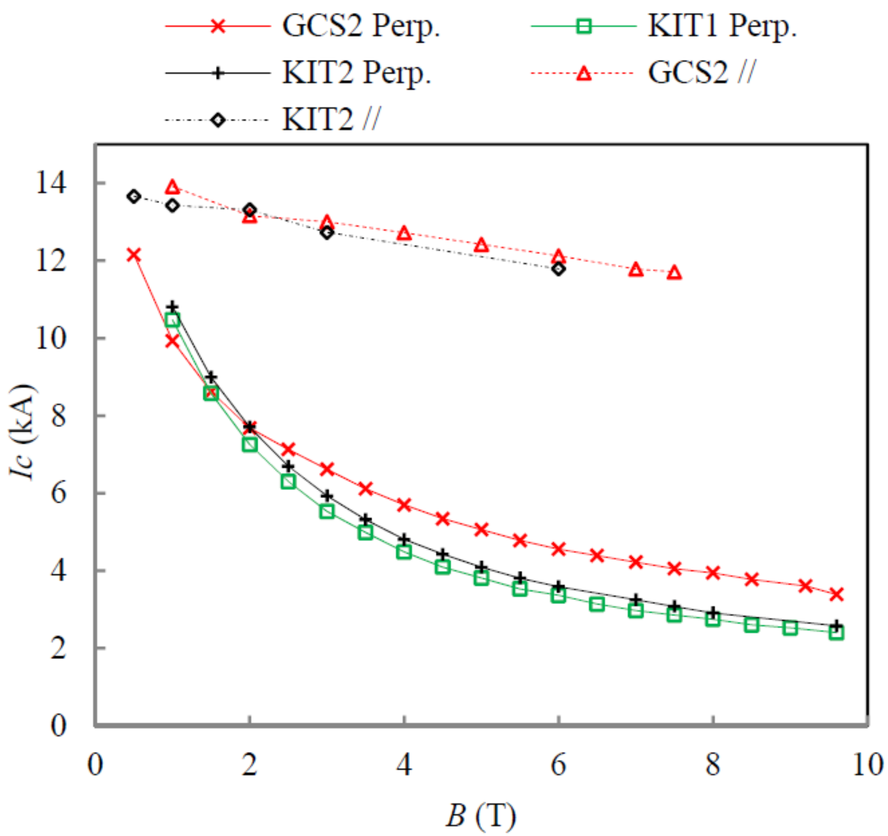
		Cable CGS	Cables KIT
Number of tapes	**-**	15	10
Transposition length	**mm**	300	126
Width	**mm**	12	12
Thickness	**mm**	0.85	0.79

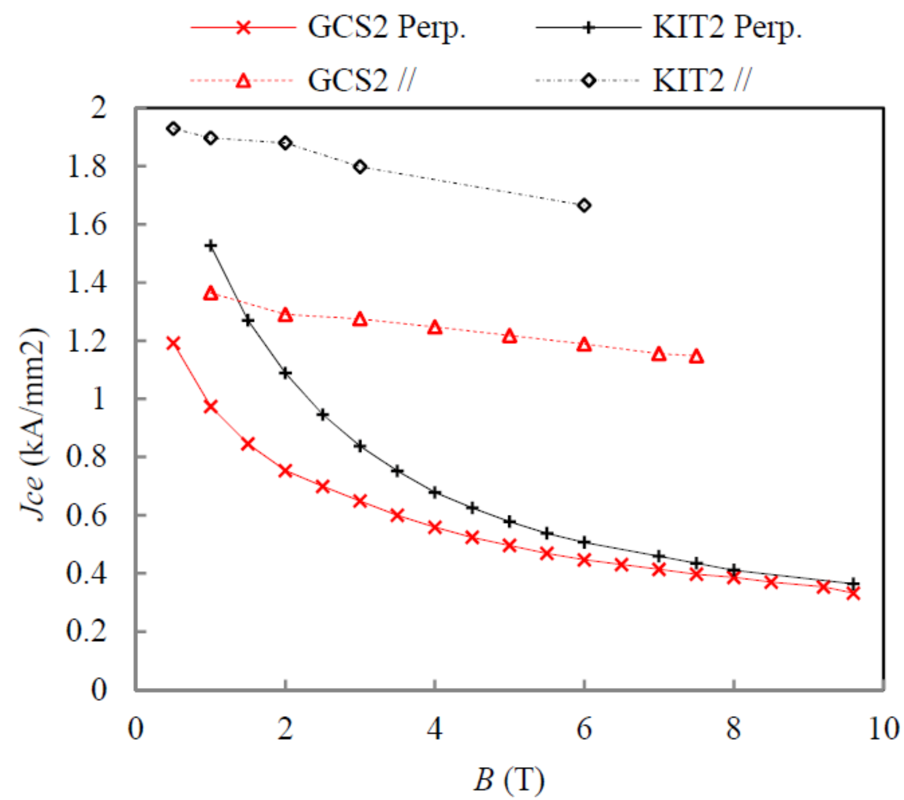


Width = 5 mm
Ic (77 K, s.f.) = 165 A

Roebel cables

Measurements @ CERN in FRESCA Test Station





Ic (B⊥=9.6 T, 4.2 K) = 3.4 kA

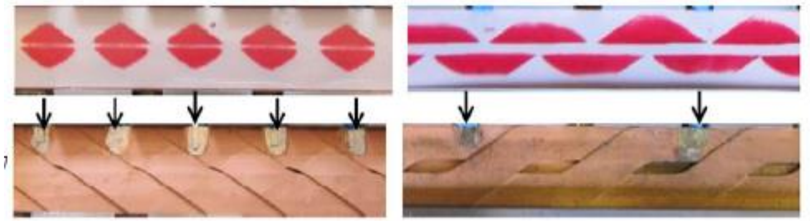
Je (B⊥=9.6 T, 4.2 K) = 400 A/mm²

CERN, Superconductors Laboratory

Supercond. Sci. Technol. 26 (2013) 065014 (5pp)

JFleiter, PhD thesis, CERN and Univ. of Grenoble

Roebel cables



J. Fleiter, CERN

- Non homogeneous stress distribution across the length and across the section
  Measured no Ic reduction up to 45 MPa of average transverse stress (188 MPa peak)

- Tensile axial strength of YBCO tape in a Roebel cable (~ 0.3 %) about half of that of a straight tape

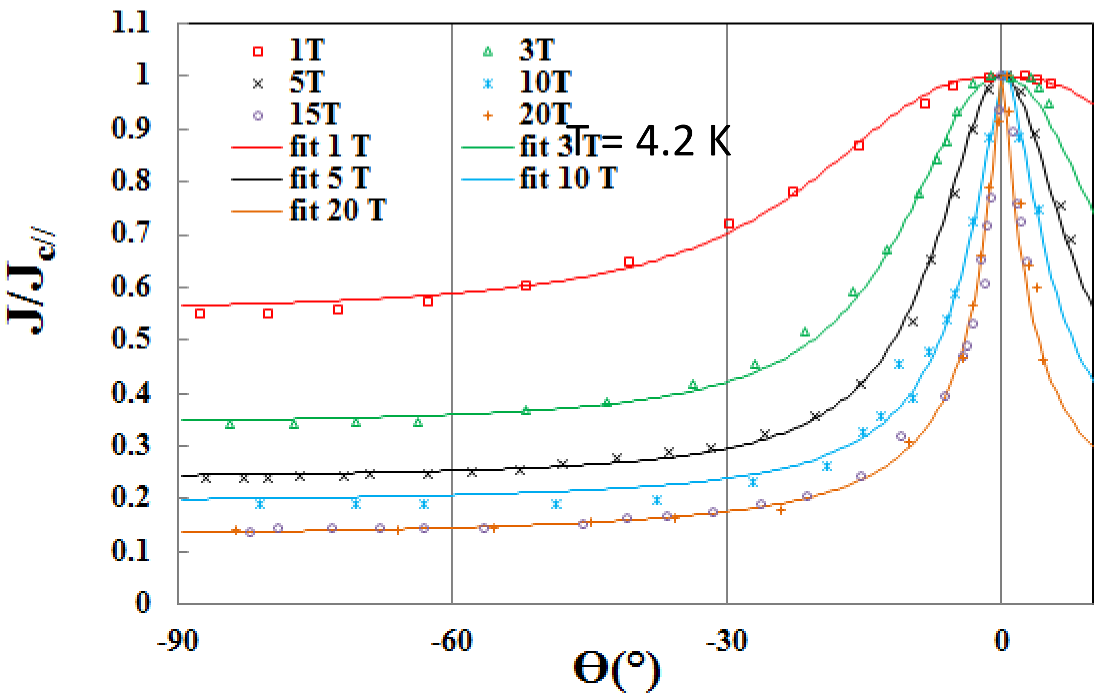
- Internal delamination is an issue that must be addressed, as well as possibility of doing impregnation

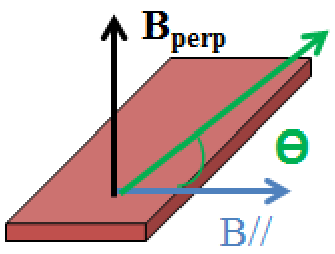
- Using tape conductor has an implication on field quality. Striation will help but the cable will not be fully transposed – it would be like a Rutherford cable with un-twisted filaments

- Unit length of cable that can be produced ?

YBCO Cables

YBCO is a **highly anisotropic conductor**. Orientation of external field in the magnet configuration shall be optimized from the very beginning for high Jc





$$J_c\left(B,T,\theta\right) = J_{c,perp} + \frac{J_{c,//} - J_{c,perp}}{1+\left(\frac{|\theta|}{c}\right)^{e}}$$

J. Fleiter, PhD thesis, CERN and Univ. of Grenoble

Conclusions

- For **Bi-2212** the **Rutherford cable** technology can be applied – **R&D** is required for optimization of cable parameters and full understanding/control of the heat treatment conditions

- For **YBCO**, among the cable geometries up to now proposed only the **Roebel cable** meets the requirements for Je and transposition, but the **possibility of achieving reasonable field quality should be addressed** – together with **protection** and **mechanical** requirements

- Roebel cables (KIT and GCS) at 4.2 K and in field were successfully **measured at CERN**. **Extrapolation will require more work**

- **Cabling machines** for **Rutherford** (CERN, Berkeley Lab and FermiLab), **stack-cables** (CERN) and **Roebel** (New Zeeland) exist

- There is plenty of room for proposals for **other cable topologies** !

Thanks for your attention !