

# WP-10

## Future magnets

### Some considerations about HTS conductors for high field inserts

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# Outline



- z Specifications of a conductor for dipole insert
- z HTS conductors: Bi-2212 and YBCO
- z Reinforcement of Bi-2212
- z YBCO high current cables

# Insert conductor specifications

- High current density
  - $J_e \geq 300 - 400 \text{ MA/m}^2$
- High mechanical strength
  - 600 MPa in EuCARD<sup>1</sup>
- High current
  - Protection
- Low AC losses
  - Field quality
- Possible current redistribution
  - Possible weak zones (YBCO)

# Insert conductor specifications

Protection: high current – hot spot temperature

Outsert and insert in series?

$$\int_{T_c}^{T_{\max}} \frac{c_p(q)}{r(q)} dq \gg J_o^2 \left( \frac{W_{mag}}{V_{\max} I_o} + t_{det} \right) \quad \begin{array}{l} \text{State between } T_{cs} \text{ and } T_c \\ \text{neglected (favorable } T_m \downarrow) \end{array}$$

$$T_{\max} = T_c + \left\langle \frac{r}{c_p} \right\rangle J_o^2 \left( \frac{W_{mag}}{V_{\max} I_o} + t_{det} \right)$$

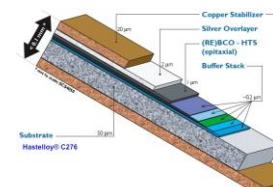
***What is the minimum current value  
New protection scenarii to be imagined?  
Is 10 kA really the minimum value?***

# HTS conductors

	<b>Bi-2212 (round wire)</b>	<b>YBCO (coated conductor)</b>
	<b>Round isotropic wire</b> ( $\varnothing = 0.8$ mm) High current cable (Rutherford) Bending radius (W & R)	Conductor of future with low cost <b>Performances</b> <b><math>J_c</math> &amp; mechanics (1000 MPa)</b>
	Defect free lengths Niche conductor	Thin tape ( $4 \times 0.1$ mm $^2$ ) Lengths & defect free lengths Large field anisotropy
	<b>Thermal treatment (<math>\Delta T \approx 2K</math>)</b> Mechanical performances (80 MPa) Cost	<b>High current cable</b> Cost, cost <b>Delamination of YBCO (trans.)</b>



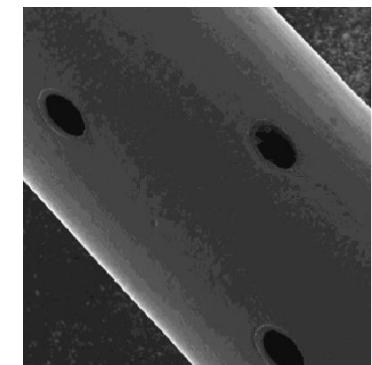
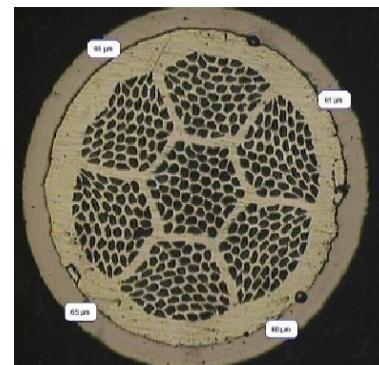
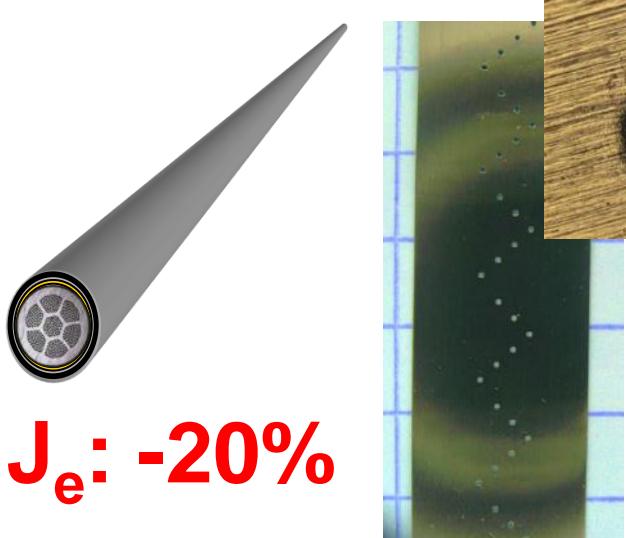
nexans



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Bi-2212 strand:  $\sigma_c \approx 80 \text{ MPa} \Rightarrow$  too low

Mechanical reinforcement by external sheath in Inconel 610  
(compatible with thermal reaction)



- Holes : 300  $\mu\text{m}$  ( $\text{O}_2$ )
- Sheath thickness : 50  $\mu\text{m}$

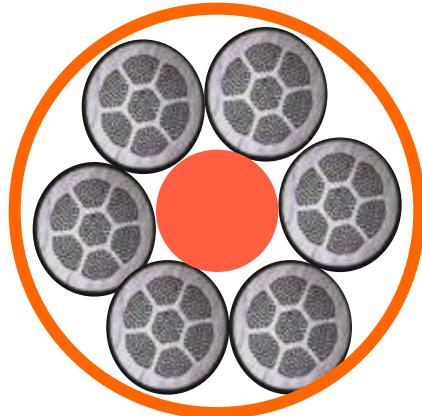
Reinforced conductor  $\sigma_c \approx 200 \text{ MPa}$  (Inconel: 540 MPa (0.2 %))

**No strong I<sub>c</sub> degradation after reinforcement**

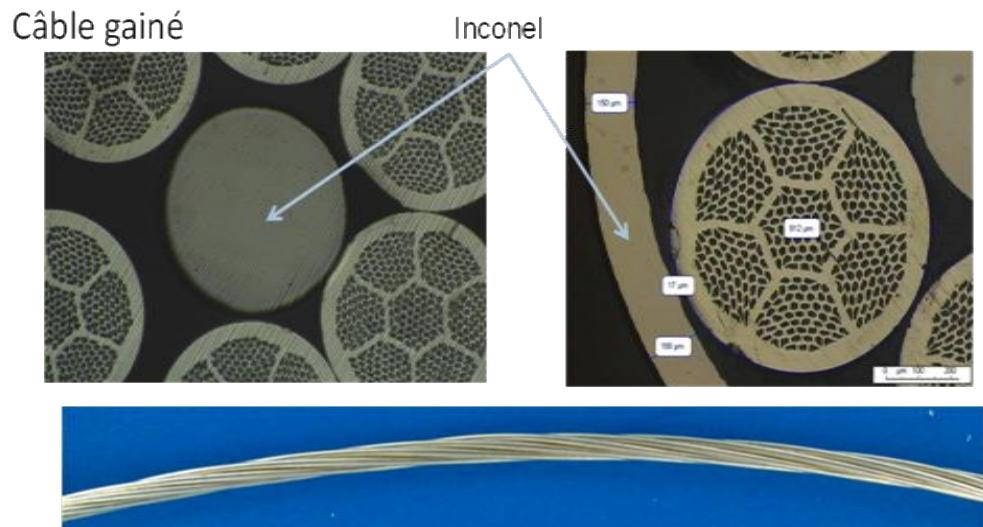
# Works on Bi-2212

Bi-2212 strand:  $\sigma_c \approx 80 \text{ MPa} \Rightarrow$  too low

Mechanical reinforcement by external sheath for 6+1 conductor



Inconel  
610  
(150  $\mu\text{m}$ )

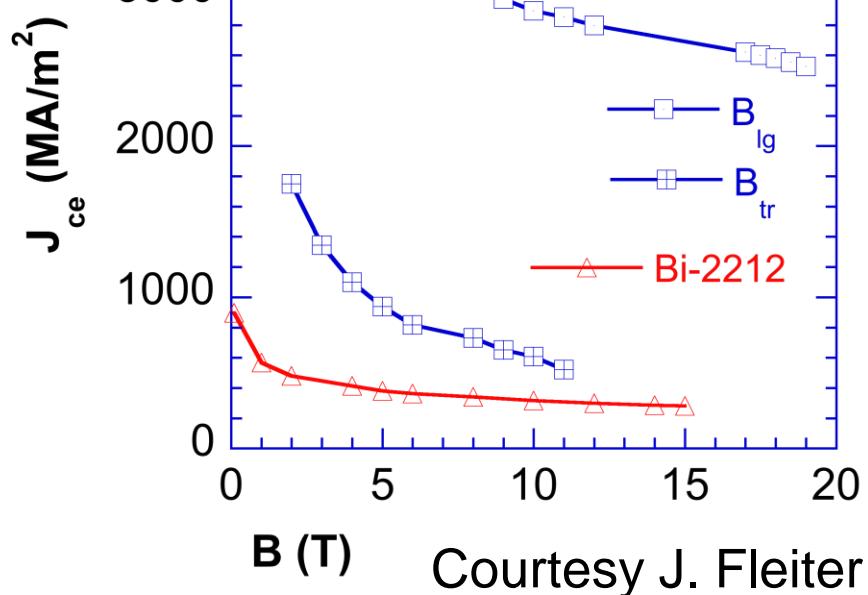


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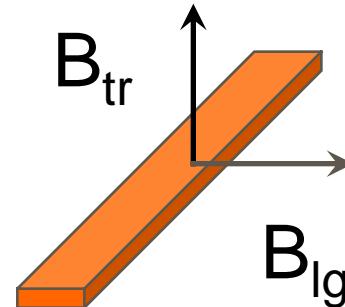
***No strong  $I_c$  degradation after reinforcement***

# HTS conductors

YBCO (SuperPower<sup>©</sup>) & Bi-2212  
4.2 K



Courtesy J. Fleiter

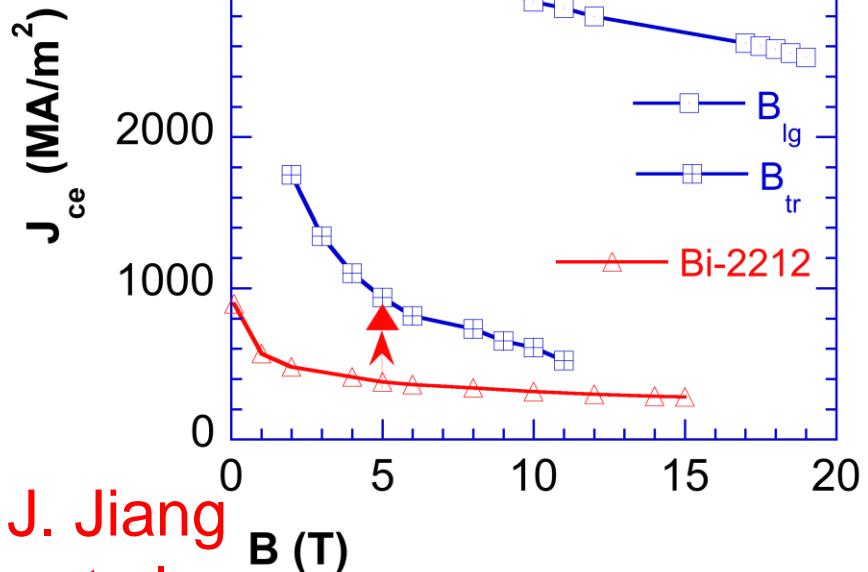


Consequence:  
Critical point localized  
=> Propagation not facilitated!

Parametrization:  $I_c(T, B, \theta)$

# HTS conductors

YBCO (SuperPower<sup>©</sup>) & Bi-2212  
4.2 K

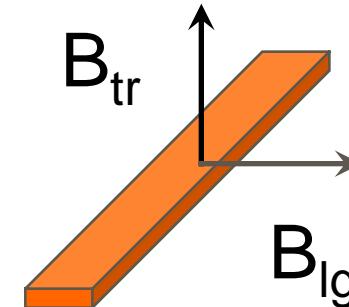


J. Jiang  
et al.

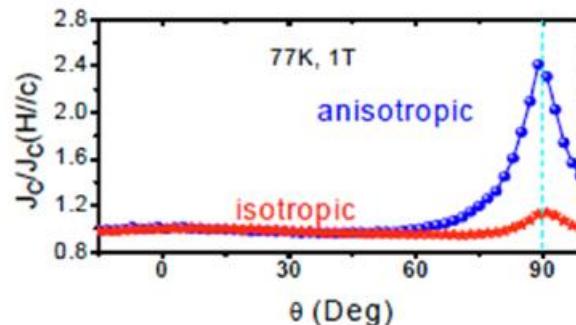
Parametrization:  $I_c$  (T, B,  $\theta$ )



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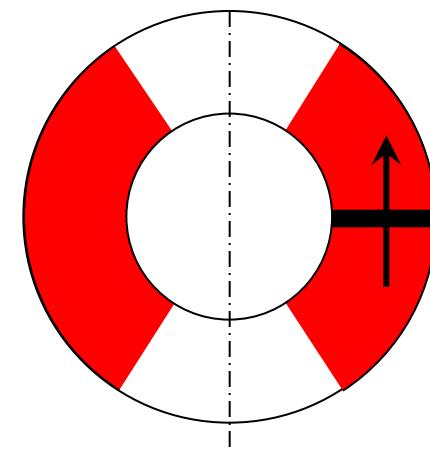
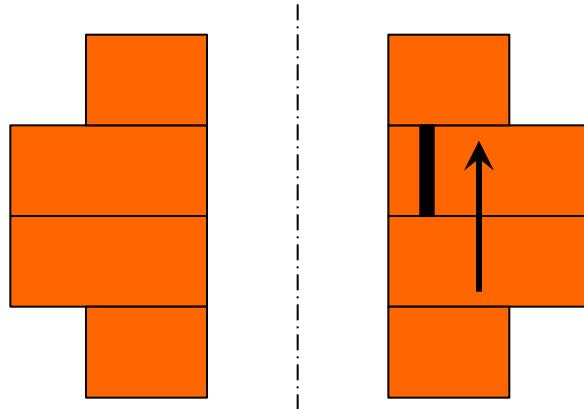
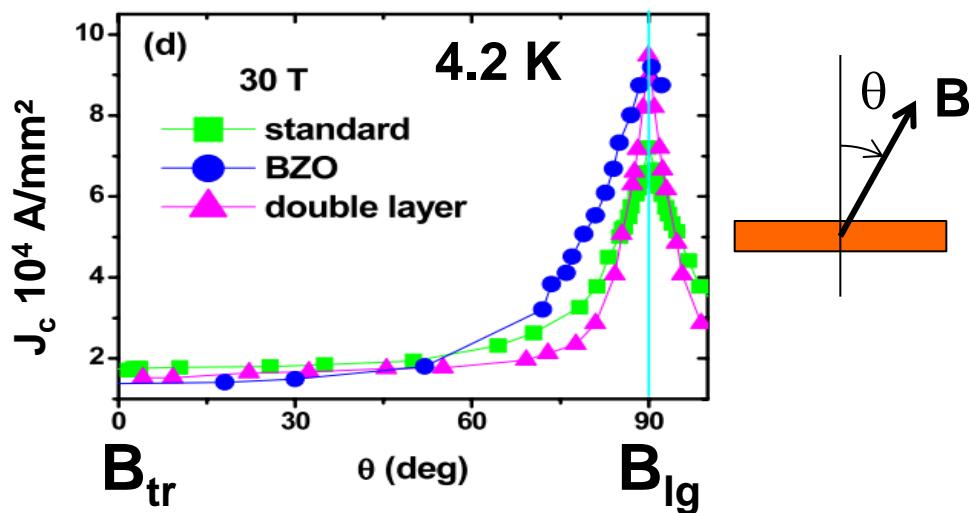
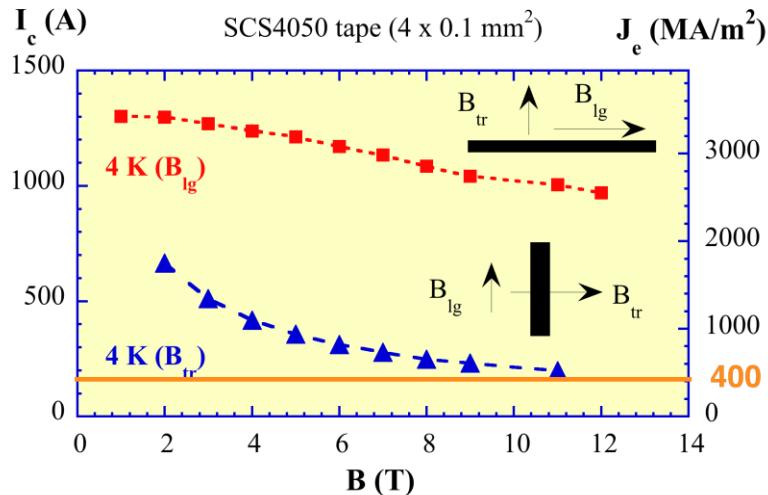


Consequence:  
Critical point localized  
=> Propagation not facilitated!



YBCO  
progresses  
too!

# YBCO insert



YBCO => Block coils

# YBCO high current cables: elect. mach.

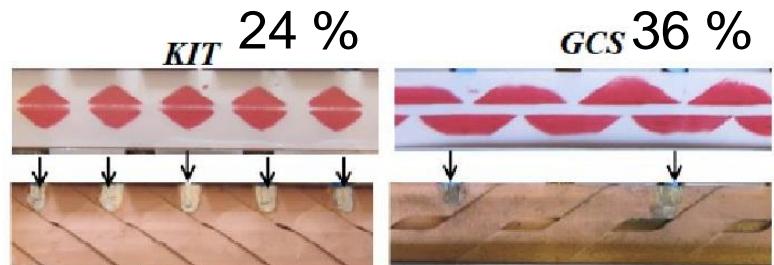
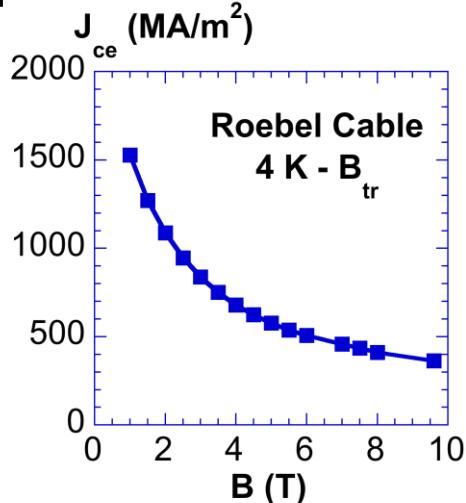


## Roebel cable

- Fully transposed
- Cost
- Delicate



Courtesy J. Fleiter



Courtesy J. Fleiter

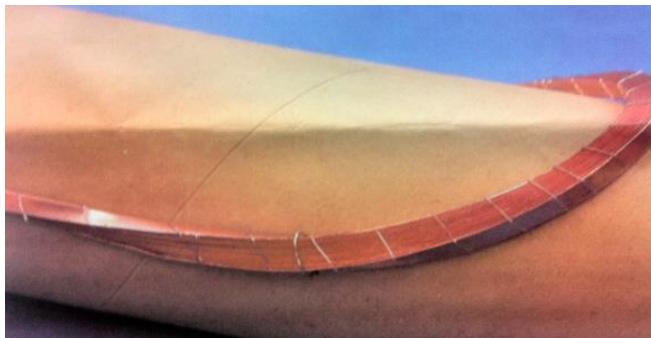
- Cost
- Mechanics
- Coil ends



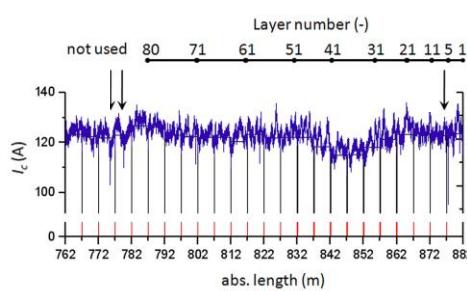
# YBCO high current cables: elect. machines

## Stack of tapes

Transposition in the coil head



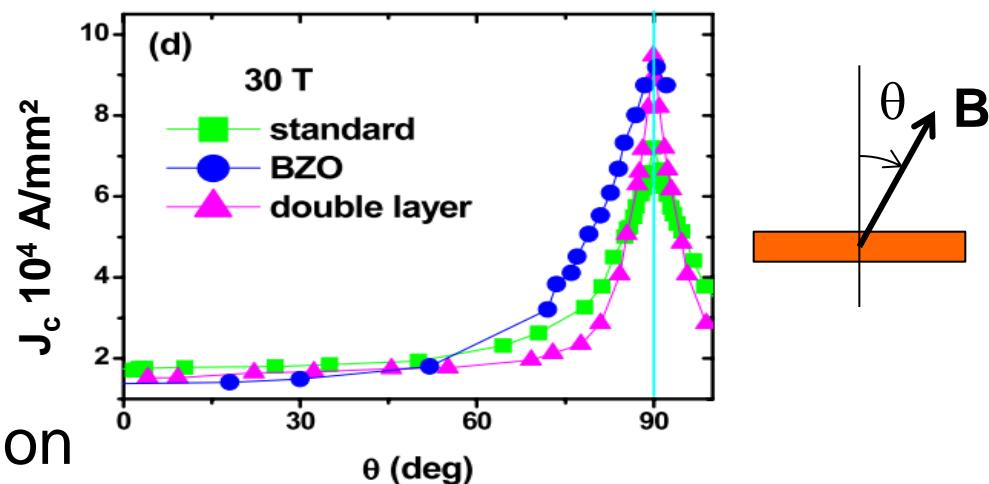
50 tapes IEEE ASC 2013 (4800104)  
(Cylinder  $\varnothing$  50 mm)



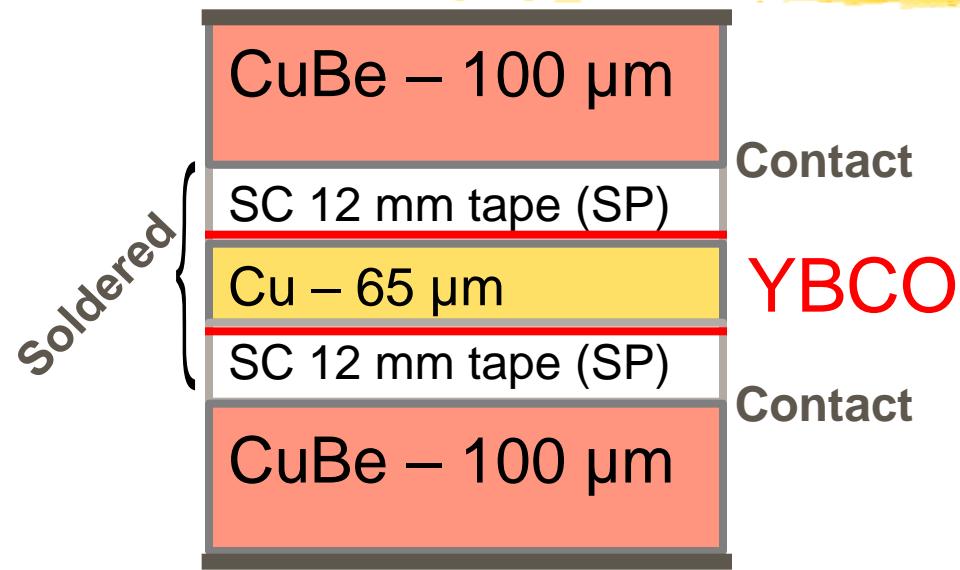
Stack: possible local redistribution

- Simple solution
- Cost effective
- High  $J_e$

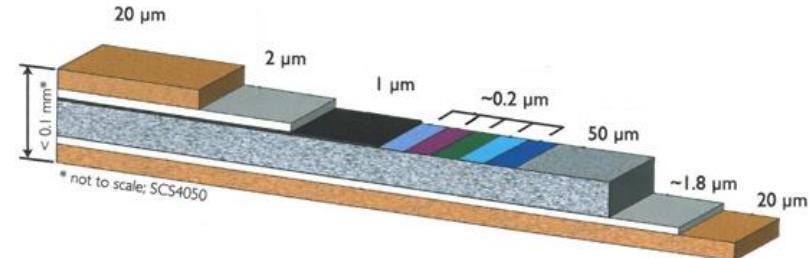
Transverse field issue  
in the coil heads



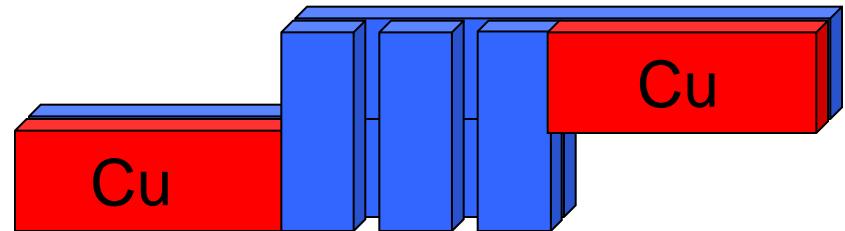
# EuCARD<sup>1</sup> Insert YBCO conductor



- Stabilization
- Easy connexions
  - within and between pancake
- YBCO close to neutral axis
- 600 MPa
- AC losses

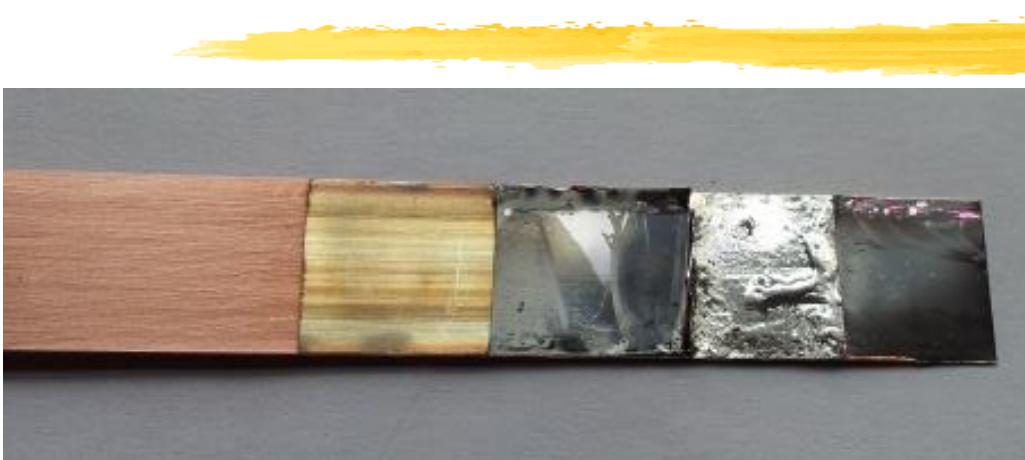


**Connexions within pancake**

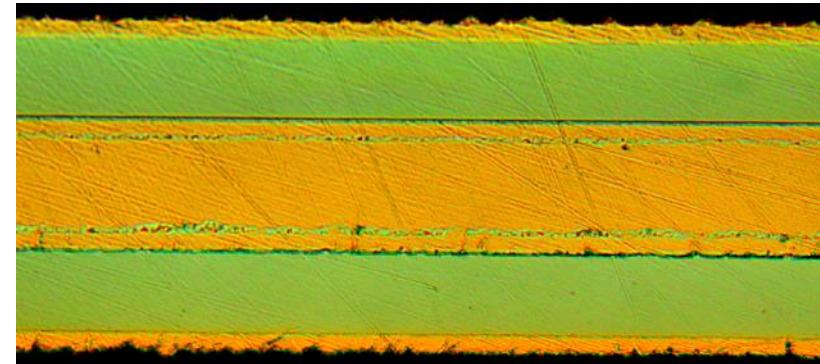


**Connexions between pancake**

# EuCARD insert YBCO conductor

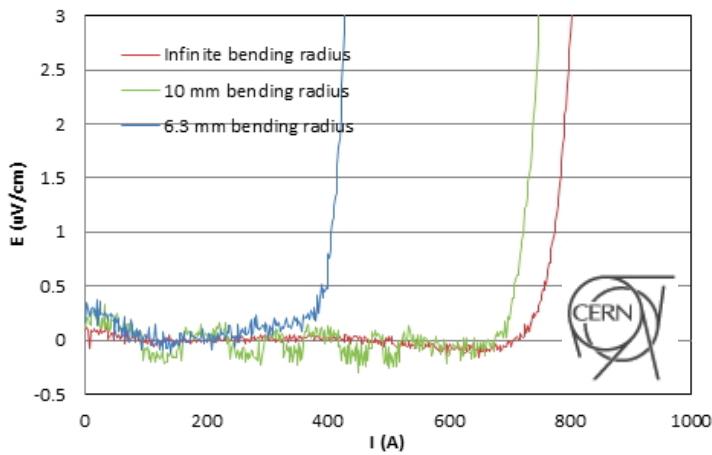


CNRS<sup>©</sup>



CERN<sup>©</sup>

EI plot EUCARD conductor 77 K self field



Courtesy J. Fleiter

Two such conductors wound in parallel  
 $\Rightarrow I = 2.8 \text{ kA}$  (700 A per tape)  
Transposition pole to pole  
Equilibrated current in the conductor  
(not equilibrated in the tapes)