



Italian National Agency for New Technologies,  
Energy and Sustainable Economic Development

# EUCAS 2017



## Effective vortex-pinning features of pulsed laser deposited $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ films with self-assembled mixed $\text{Ba}_2\text{YTaO}_6/\text{Ba}_2\text{YNbO}_6$ columnar defects, grown on ABAD-based metallic templates



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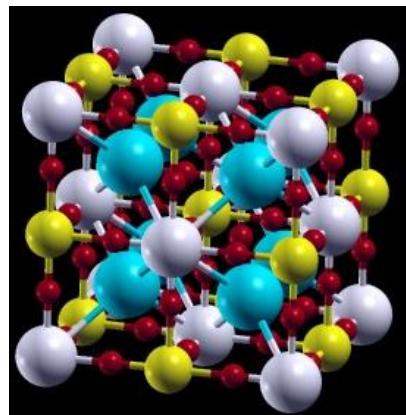
Genève, September 21<sup>st</sup>



# Outline

- Motivations
- Growth of  $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$  (YBCO) thin film with  $\text{Ba}_2\text{YTaO}_6$  +  $\text{Ba}_2\text{YNbO}_6$  (BYNTO) columnar nano-inclusions on ABAD template
  - Failure of the direct growth (YBCO-BYNTO/ABAD template)
  - Successful introduction of YBCO seed layers  
(YBCO-BYNTO/**YBCO**/ABAD template)
- Morphological and structural characterization
- D.C. transport properties measurements ( $B$ ,  $T$ ,  $\theta$ ) and analyses
- Conclusions and perspectives

# Motivation: Nb and Ta based effective APCs



Ba  
O  
Y  
Ta/Nb



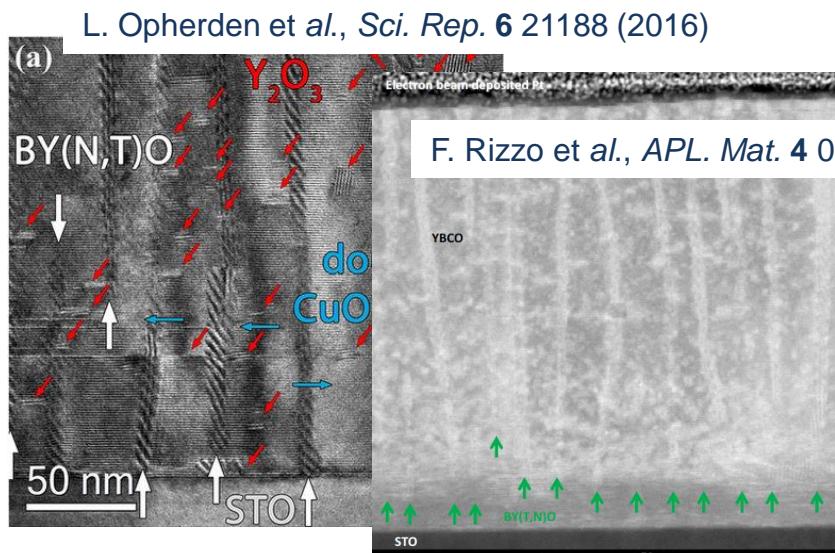
## YBCO-Ba<sub>2</sub>Y(Nb/Ta)O<sub>6</sub>/SrTiO<sub>3</sub> sc

Remarkable transport properties:

- High  $J_c$  self-field values
- $\mu_0 H_{\text{irr}} @ 77 \text{ K} \geq 11 \text{ T}$
- $F_p^{\text{Max}} @ 77 \text{ K} \geq 20 \text{ GN/m}^3$

**Ba<sub>2</sub>YTaO<sub>6</sub>/Ba<sub>2</sub>YNbO<sub>6</sub>**

- Double perovskite structure (0.85 nm)
- In plane lattice mismatch (~ 9.4%) > c-axis lattice mismatch (~ 8.3%) → promote c-axis nanocolumns development
- Nb/Ta atoms do not substitute Cu in YBCO, preventing poisoning effects



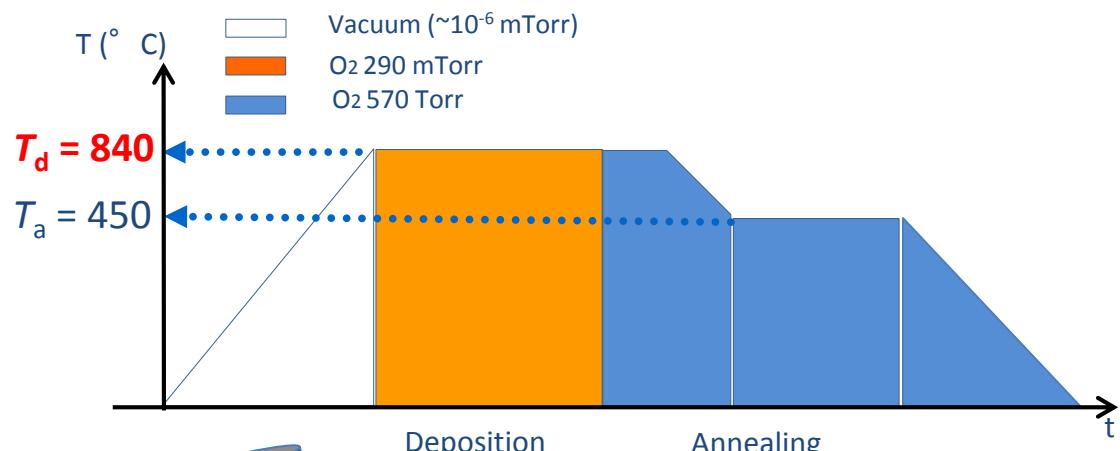
# PLD growth of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ + BYNTO

## PLD setup

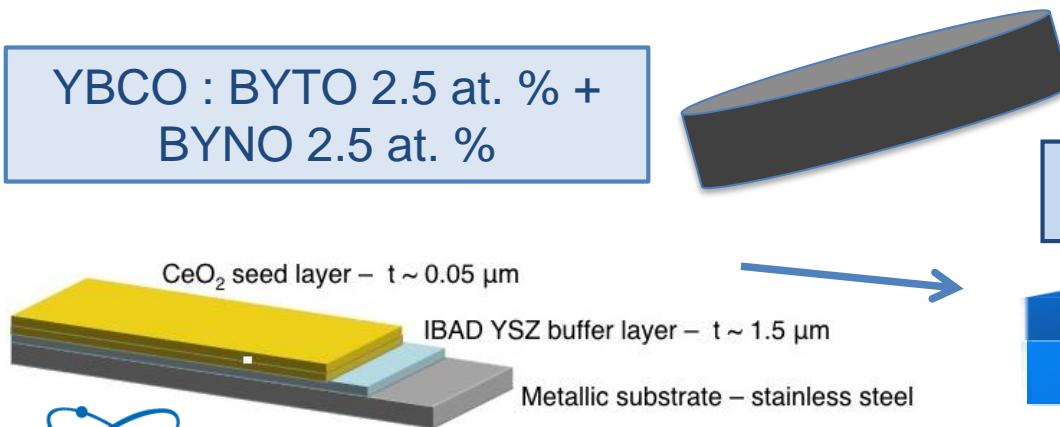
KrF and XeCl Excimer Lasers

$\lambda = (248, 308) \text{ nm}$

$\tau = 18 \text{ ns pulse} / f_L = 10 \text{ Hz}$   
fluence  $\sim 1.5 - 2 \text{ J/cm}^2$



YBCO : BYTO 2.5 at. % +  
BYNO 2.5 at. %

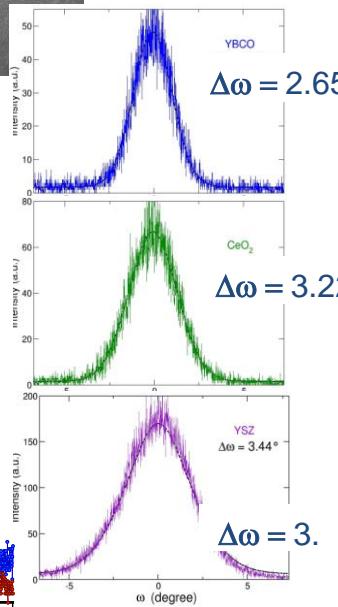
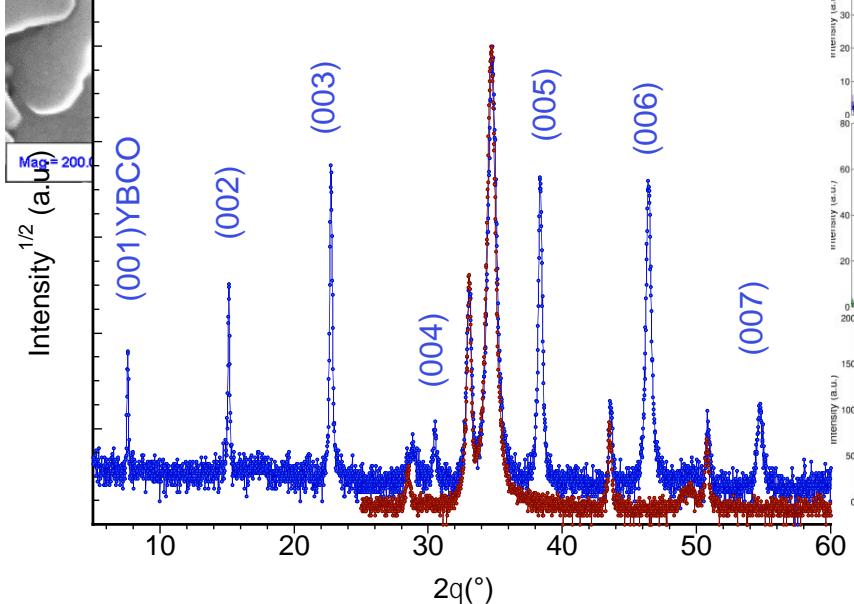
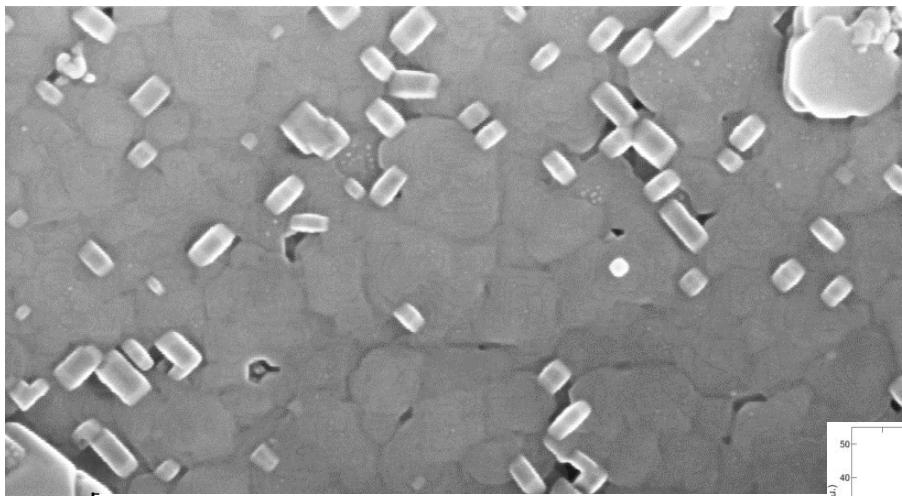


**YBCO-BYNTO/ABAD**



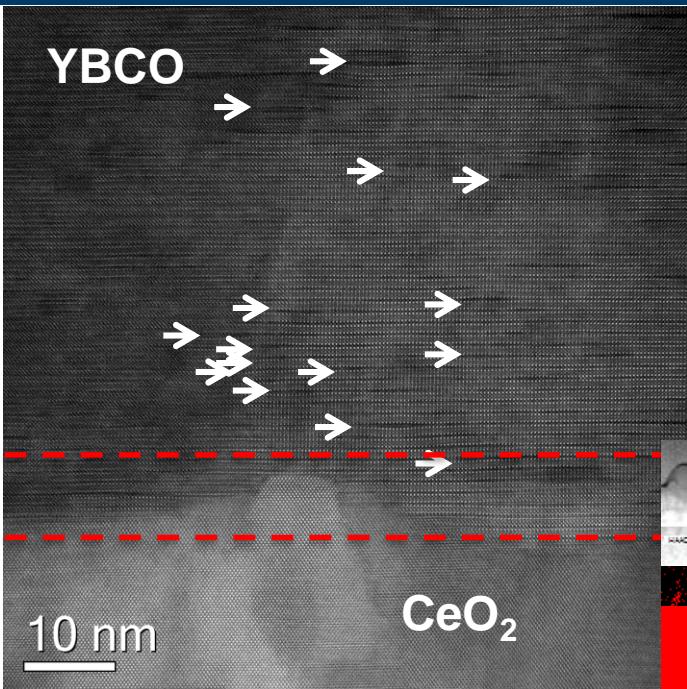
$t = [100 - 250] \text{ nm}$   
 $T_c = [85 - 87] \text{ K}$

# Morphological (SEM) and structural (XRD) properties

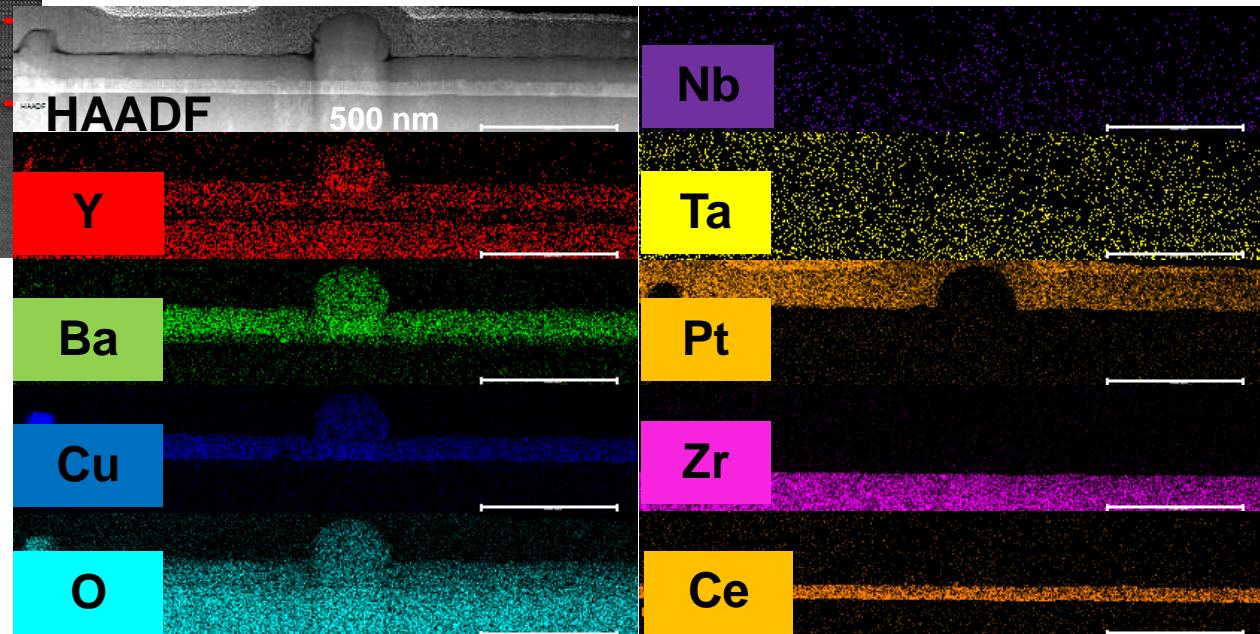


- Smooth and cracks-free surface
- Poor YBCO grains coalescence
- Good (00l) epitaxial growth
- Sharp out-of-plane YBCO texture ( FWHM (005)  $\omega$ -scan =  $2.65^\circ$  )
- No evidence of BYNTO reflections

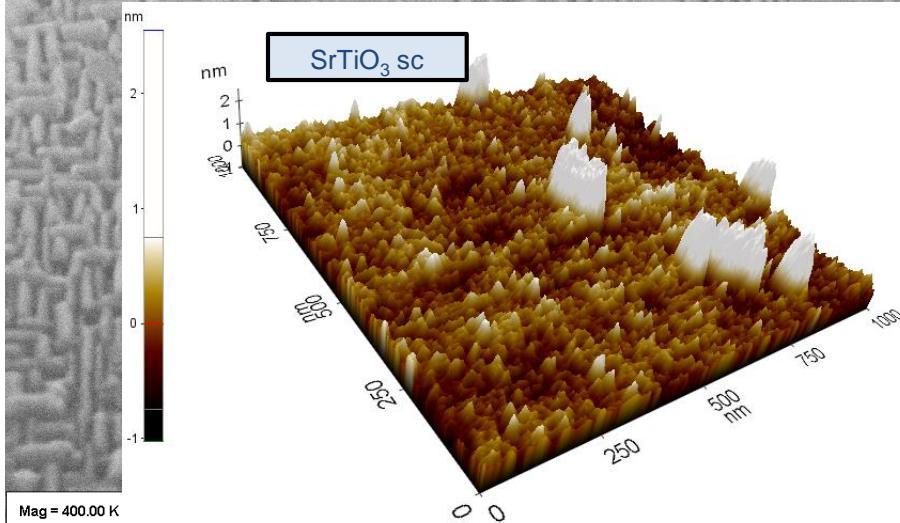
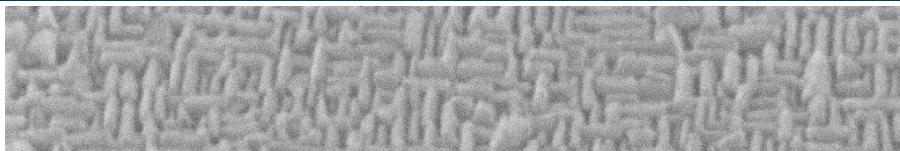
# Structural properties (TEM)



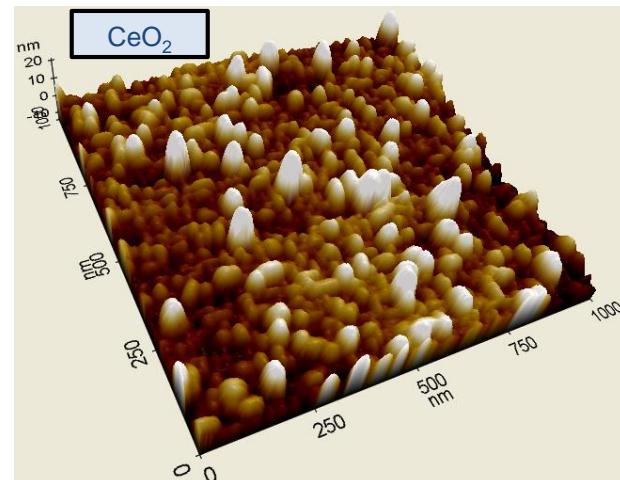
- No evidence of BYNTO columns in the YBCO layer
- Ba and penetrates into the  $\text{CeO}_2$  layer but no  $\text{BaCeO}_3$



# CeO<sub>2</sub> seed layer surface analysis (SEM, AFM)



- Elongated (00l)-oriented grains with poor coalescence (SEM)



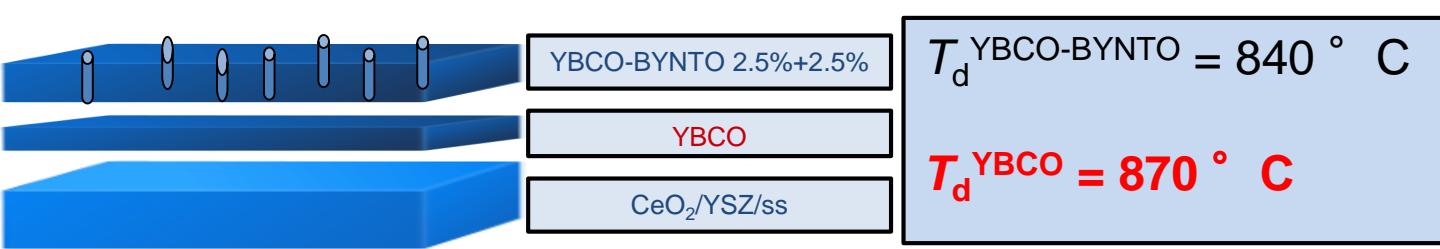
- Grains length ~ 50 nm (SEM/AFM)
- Surface roughness  $\sigma_{\text{RMS}} \sim 4 \text{ nm}$  ( $\sigma_{\text{STO RMS}} \sim 0.3 \text{ nm}$ ) (AFM) limiting Nb/Ta ion mobility???

Need of a flattening layer?

Chemical compatibility issue? → surface passivation

# Multi-layers approach

Homo-epitaxial YBCO growth →  
**YBCO-BYNTO/YBCO/ABAD**



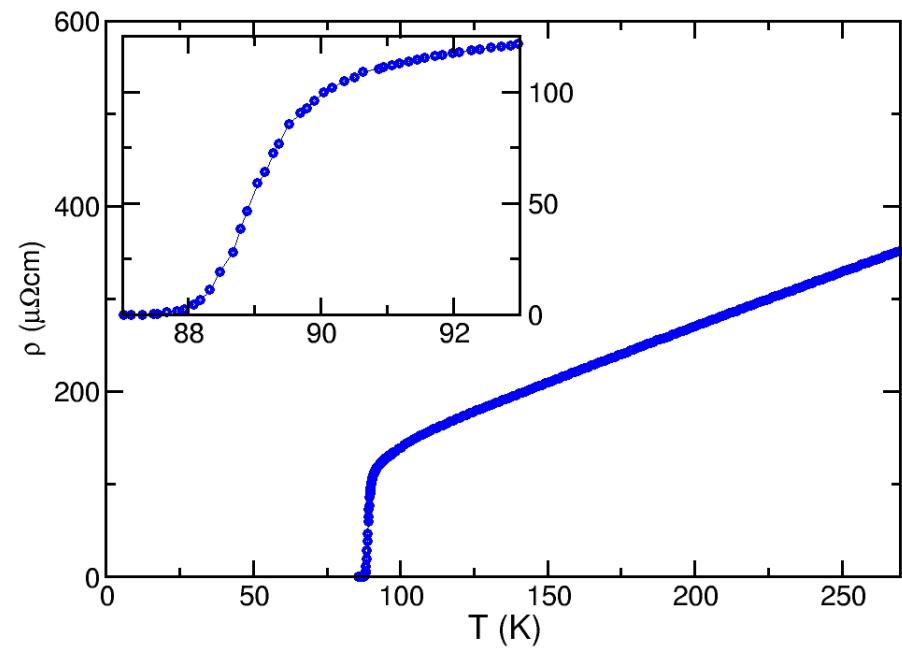
$$T_d^{\text{YBCO-BYNTO}} = 840 \text{ } ^\circ \text{C}$$

$$T_d^{\text{YBCO}} = 870 \text{ } ^\circ \text{C}$$

$$t = (150 - 200) \text{ nm}$$

$$t_{\text{YBCO}} \sim (10 - 60) \text{ nm}$$

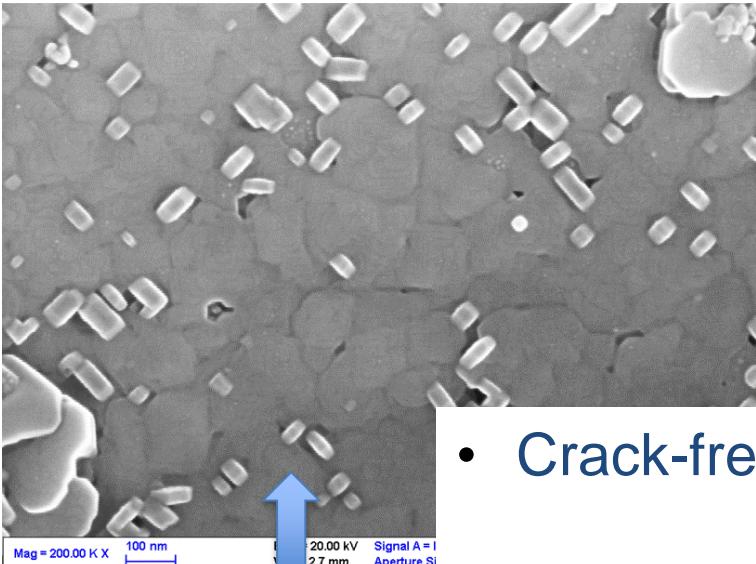
$$\rho = (0.2 - 0.3) \text{ nm/s}$$



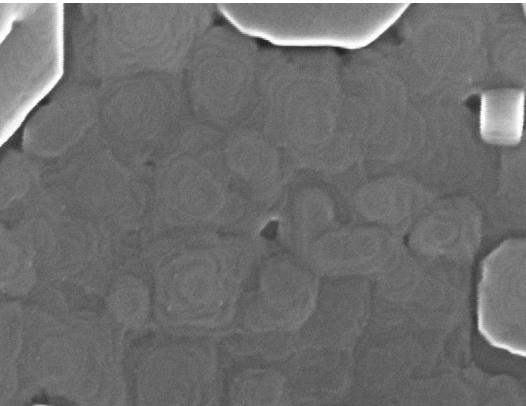
- Sharp electrical transition
- Room temperature resistivity  $\sim 350 \mu\Omega\text{cm}$
- $T_c$  in the range (86.8 – 88.2) K

# Morphological analysis

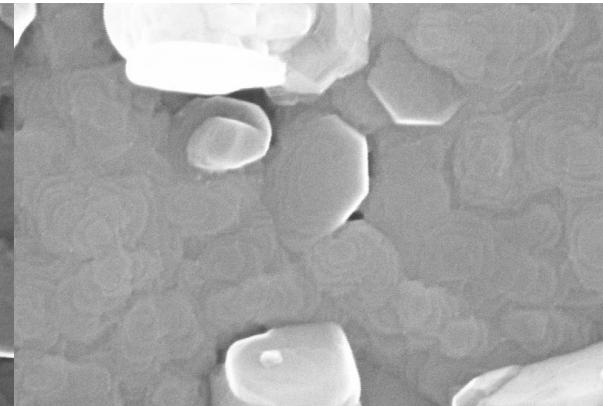
No seed layer



$t^{\text{YBCO}} \sim 60 \text{ nm}$



$t^{\text{YBCO}} \sim 15 \text{ nm}$

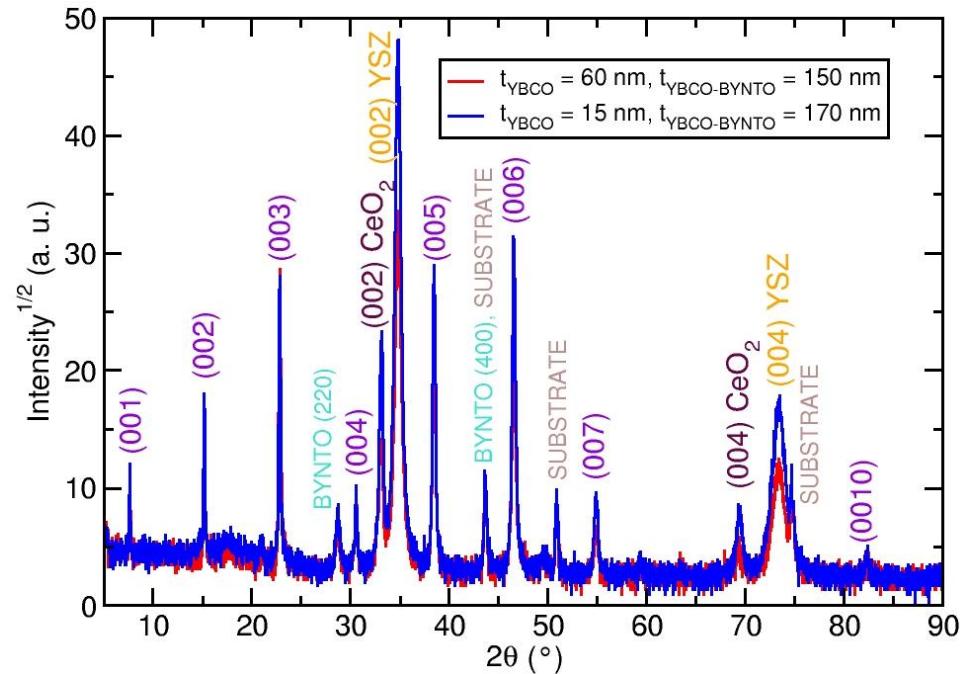


- Crack-free surface
- Rich presence of inter-growths
- Evident islands growth
- Improved grains coalescence (seed layer)

$T_c \sim 88 \text{ K}$

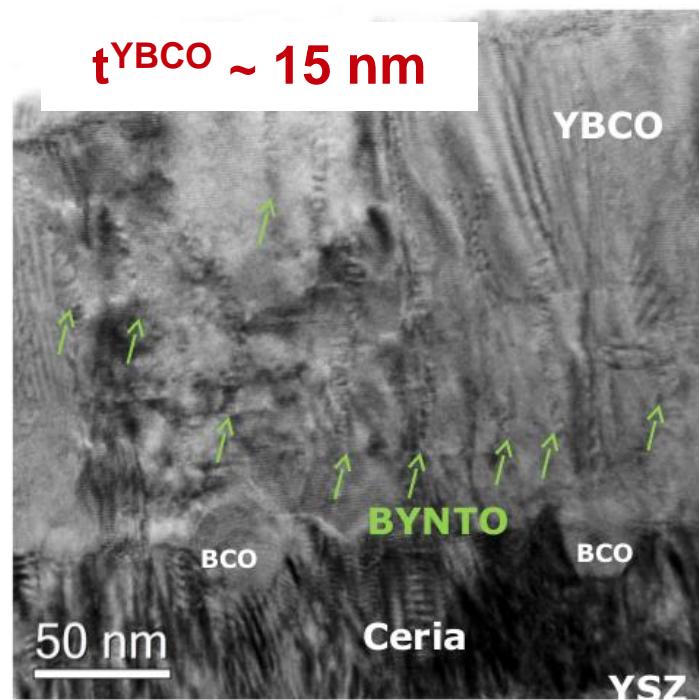
7.4 K

# Structural properties (XRD - TEM)

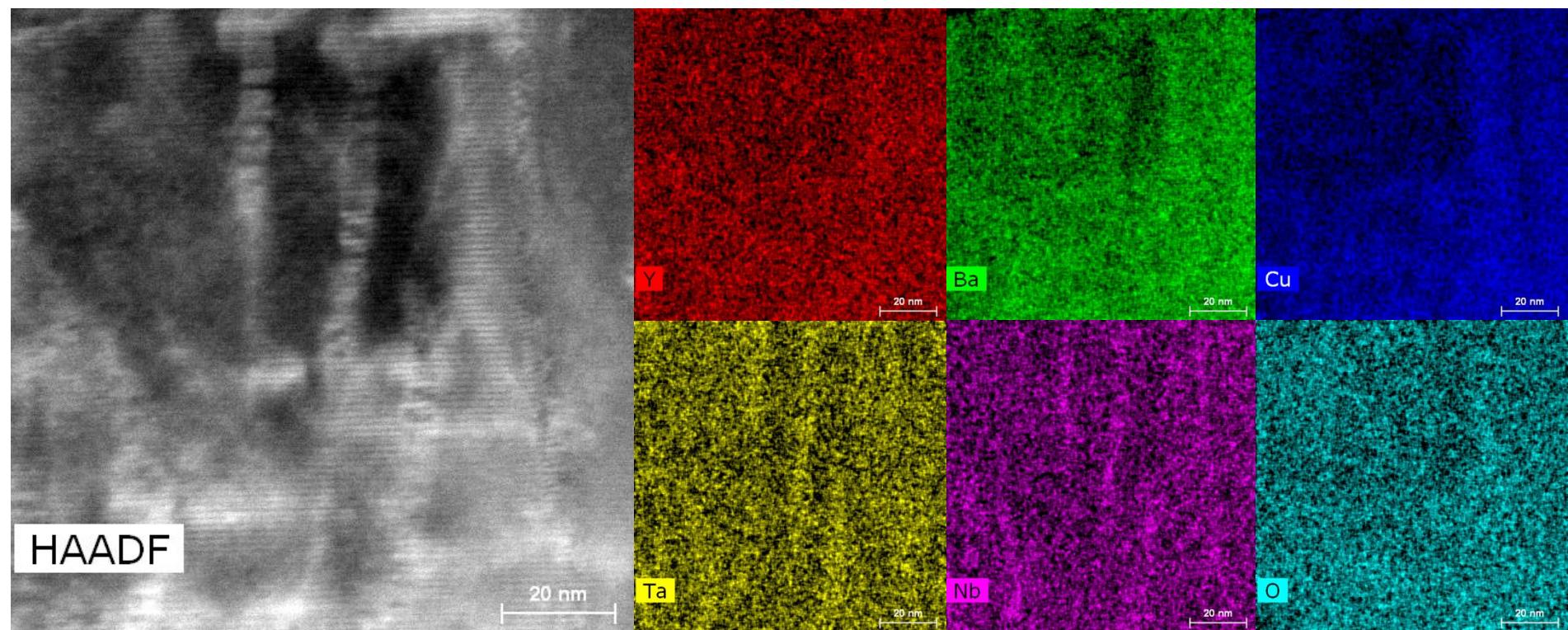


- Evidence of the BYNTO nanocolumns
- Splayed and partially interrupted columns ( $d \sim 8$  nm)
- BaCeO<sub>3</sub> at the CeO<sub>2</sub>/YBCO interface

- Very good (00l) YBCO epitaxial growth
- Evidence of BYNTO epitaxial growth

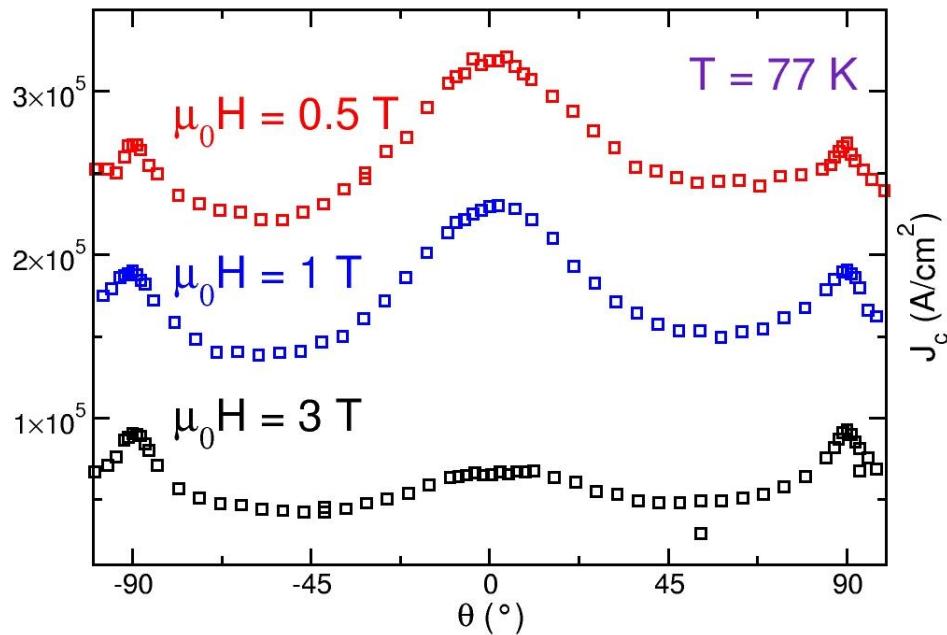


# Structural properties (EDX)

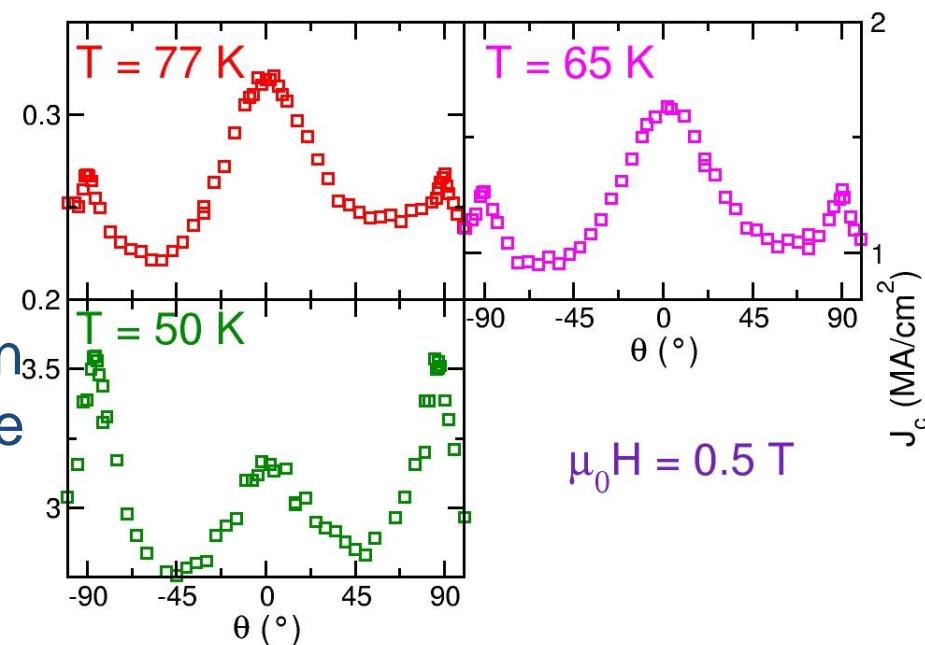


- Nb and Ta observed in the nanocolumns

# Transport properties – Angular behaviour



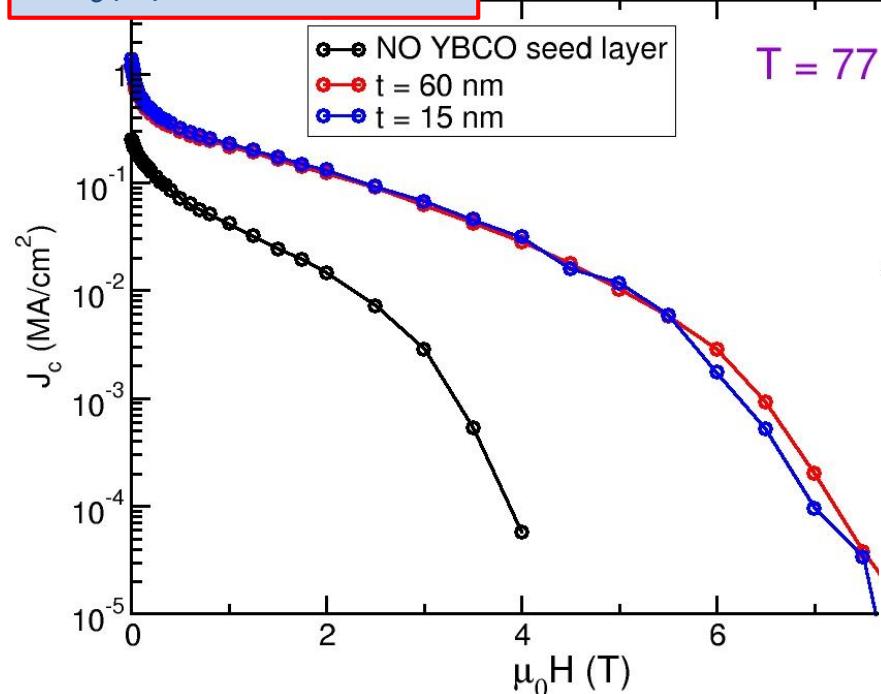
- Evident correlated contribution in the layered film, active in the low-to-mid field range (0.5 – 3) T
- $J_c^{\min} \sim 60\% J_c^{\max}$  (@ 1T), reduced anisotropy



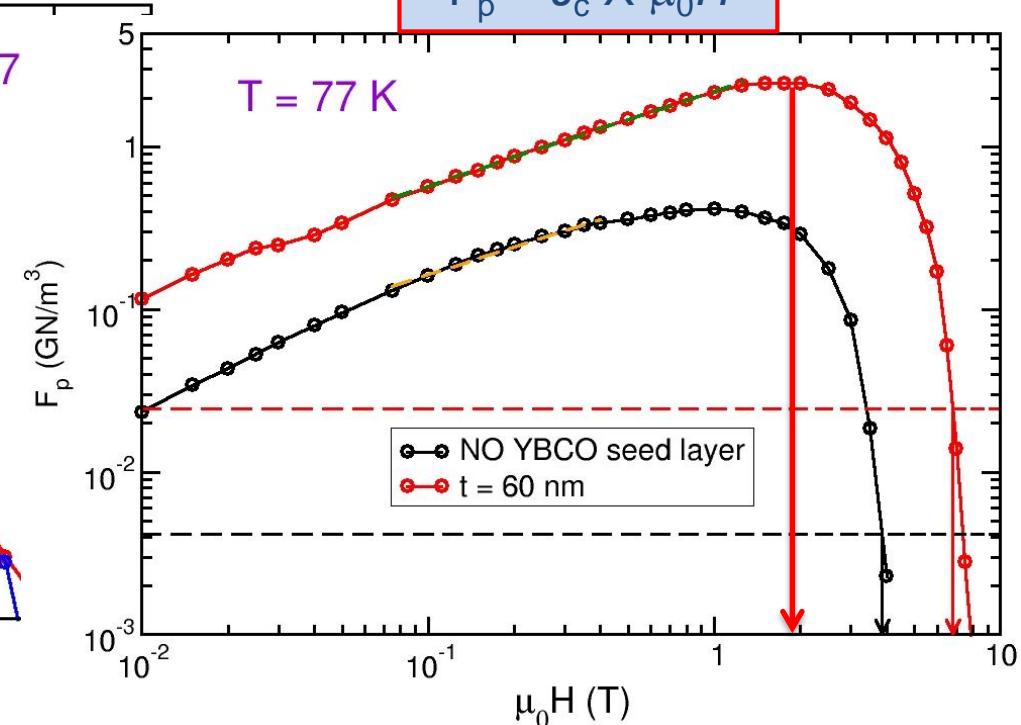
- Correlated contribution effective in the mid-to-high temperature range [77- 50] K

# Transport properties – in-field behaviour @ 77 K

$J_c(B)$  -  $B \parallel c\text{-axis}$

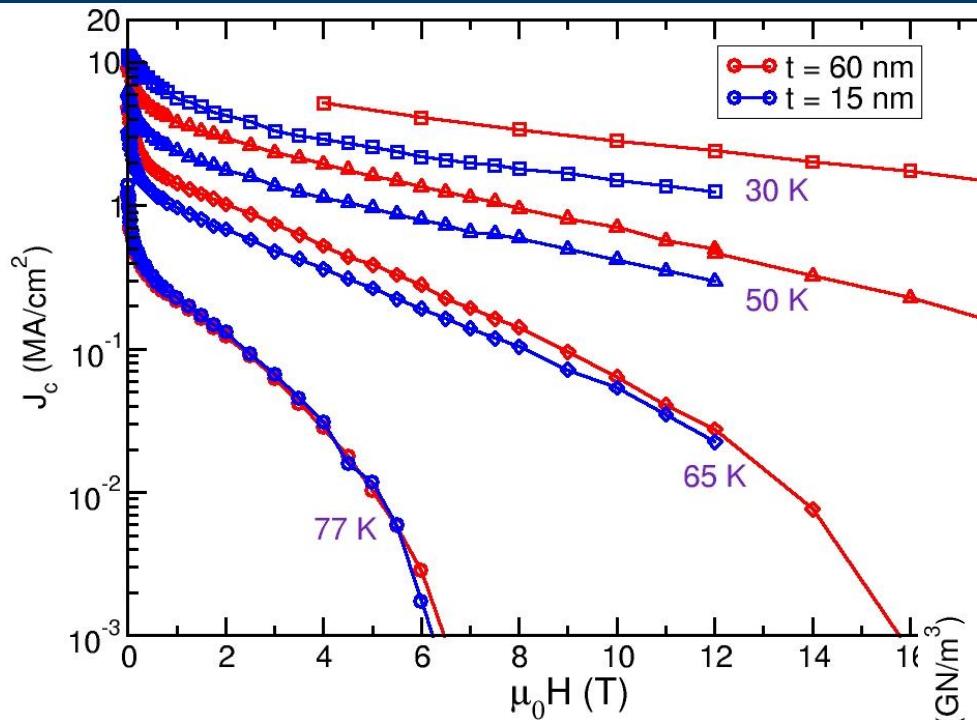


$F_p = J_c \times \mu_0 H$

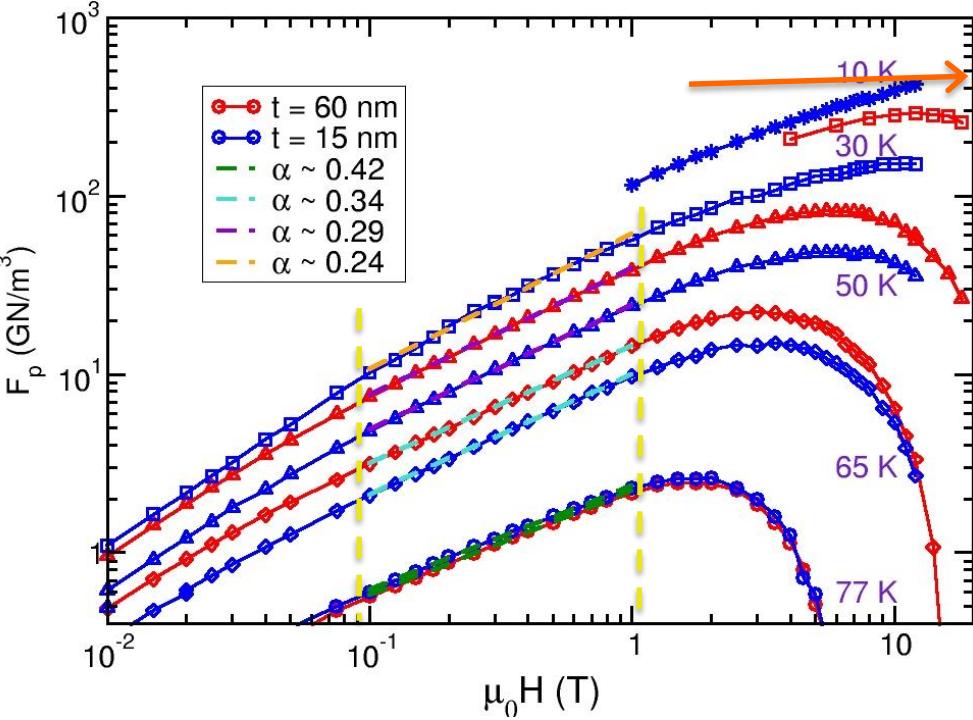


$T = 77 \text{ K}$	$J_c(0) (\text{MA}/\text{cm}^2)$	$F_{\text{pin}}^{\text{Max}} (\text{GN}/\text{m}^3)$	$\mu_0 H^{\text{Max}} (\text{T})$	$\mu_0 H^{\text{irr}} (\text{T})$
$t = 60 \text{ nm}$	1.15	2.5	1.8	6.8
$t = 15 \text{ nm}$	1.40	2.6	2	6.6
NO seed	0.25	0.4	1	3.9

# Transport properties – temperature behaviour



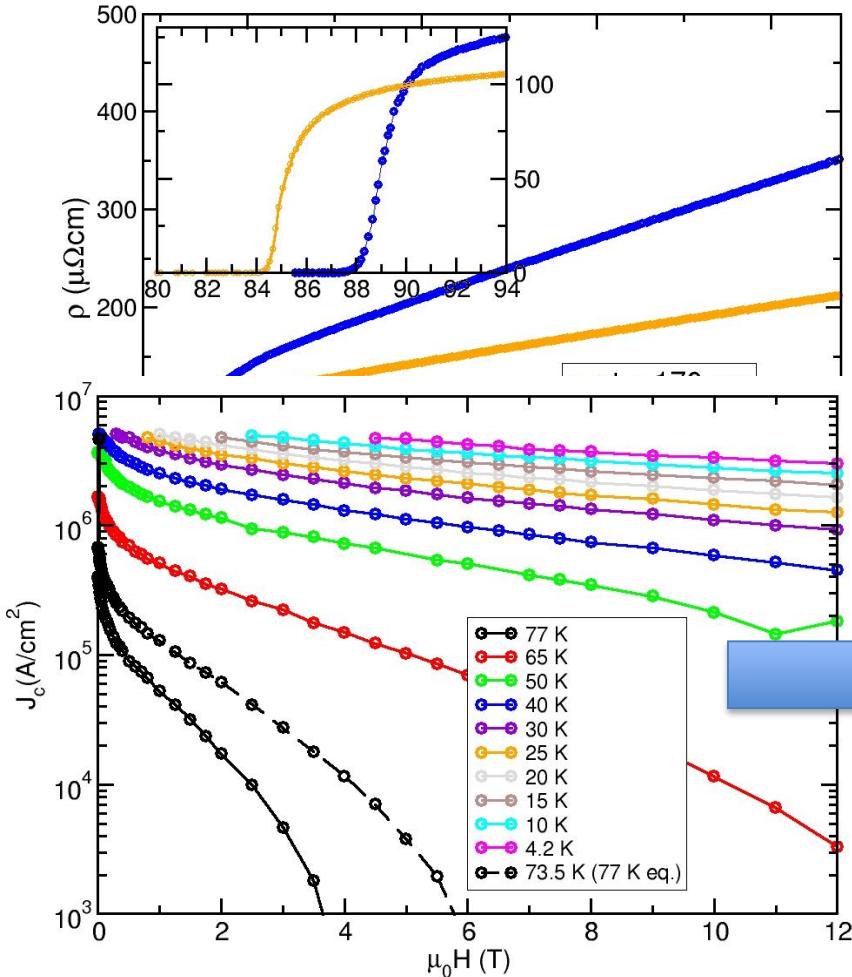
- Very good  $J_c$  in field behaviour, in particular in the low  $T$ -high field regime



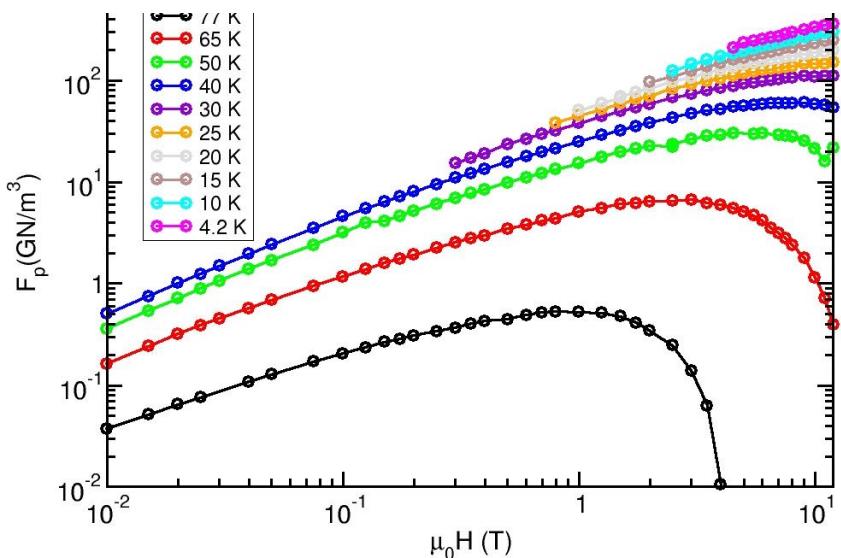
- Low field regime  $J_c \sim H^{-\alpha}$ :  $\alpha(T) < 0.5 \Rightarrow$  correlated pinning contribution effective also at low  $T$
- Good low temperature in-field behaviour  $F_p \sim 500$  GN/m<sup>3</sup> @ (10 K, 12 T)

# Towards practical applications

Thicker films: 170 nm → > 500 nm



- Better performances @  $T = 77 \text{ K}$  equivalent ( $\mu_0 H^{\text{irr}} (\text{T}) \sim 6 \text{ T}$ )
- Very good  $J_c$  in field behaviour, especially decreasing  $T$
- $F_p \sim 300 \text{ GN/m}^3$  @ (10 K, 12 T)



# Conclusions and perspectives

- First successful growth of YBCO-BYNTO with partially interrupted self-assembled nanocolumns on the technical Bruker ABAD template (through the introduction of a **YBCO seed layer**)
- Evident strong correlated pinning contribution in the  $J_c$  angular behaviour, active in the low-to-mid magnetic field regime
- Promising in-field and in temperature  $J_c$  performances:
  - Correlated pinning contribution effective till low  $T$
  - $F_p \sim 500 \text{ GN/m}^3$  @10K

Room for improvement by enhancing the quality of  
the columnar growth

thank you