

**Magnetization measurements as a tool for investigating the potential electrical transport properties of Nb<sub>3</sub>Sn superconducting wires.**

**Michela Greco, INFN-Genova**





is aimed at the development of a large-aperture high field (up to 15 T) superconducting dipole magnet that will serve as a technology test bed for LHC luminosity upgrade

Development of a high-performance Nb<sub>3</sub>Sn wire (aiming at a non-copper critical current density of 1500 A/mm<sup>2</sup> at 4.2 K and 15 T) is carried out.

A Working Group on Conductor Characterization (WGCC)

*CEA, CERN, INFN-Genova, INFN-Milano, University of Twente*

is aimed to define and carry out reliable, reproducible methods for the measurement of electromagnetic properties.

Intro

m(T, B)

m(B)

$\chi(B, T)$

samples

Nb?

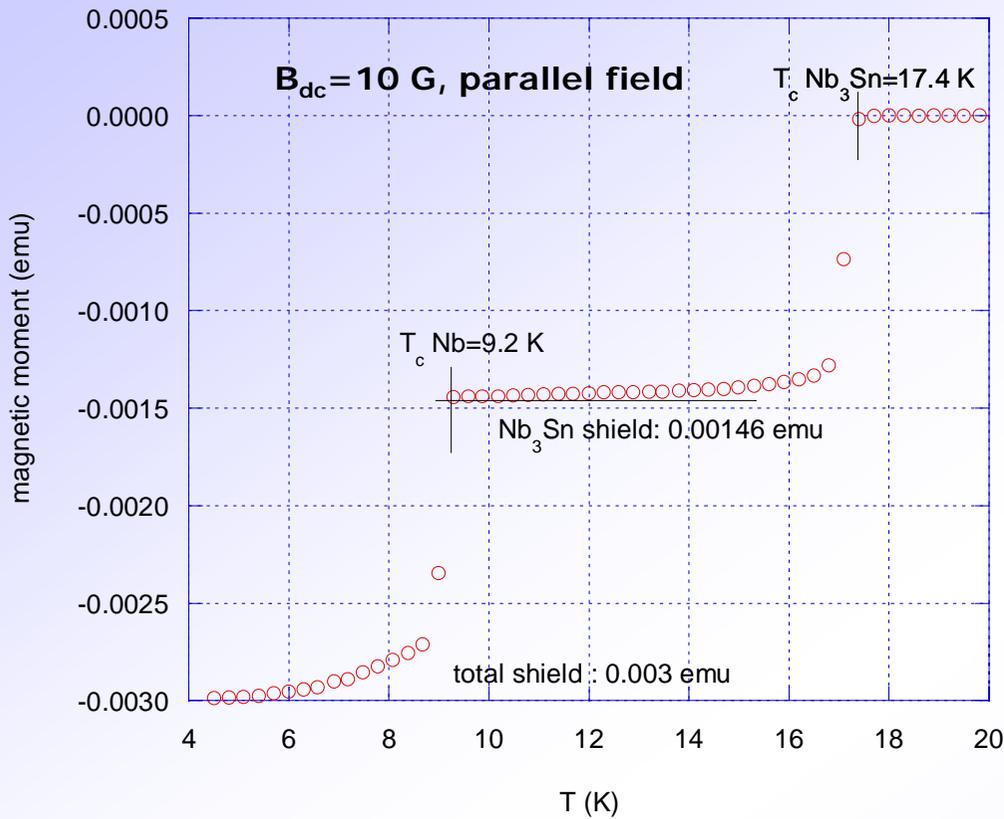
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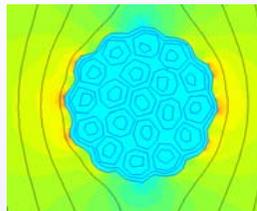
Genova coordinates three groups, having at disposal three facilities: a Vibrating Sample Magnetometer (VSM) in Frascati, a DC-SQUID magnetometer and an AC susceptibility apparatus in Genova.

<i>Field orientation</i>	<i>Meas type</i>	<i>Applied Field</i>	<i>Info</i>
<i>Parallel</i>	$m(T)$	$B_{dc} = 10 \text{ G},$ $B_{dc} = 100 \text{ G}$	$Nb_3Sn$ shielded volume $T_c(B)$
<i>Parallel</i>	$\chi(T)$		Sample geometry, $Nb_3Sn$ homogeneity
<i>Transverse</i>	$m(T)$	$B_{dc} = 10 \text{ G},$ $B_{dc} = 100 \text{ G}$	Demagnetizing factor evaluation
<i>Transverse</i>	$\chi(T)$		Sample geometry, $Nb_3Sn$ homogeneity
<i>Transverse</i>	$m(B)$	0-3T, 0-8T	Surface shielding, flux jumps, $J_c$

*Pasquale Fabricatore, INFN-Genova;*  
*Carlo Ferdeghini, CNR-INFM; Umberto Gambardella, INFN-Frascati*



From the comparison of measurements in parallel and transverse field it is possible to evaluate demagnetizing value  $N$  [ $B_{eff} = B / (1 - N)$ ] and compare with FEM calculation.



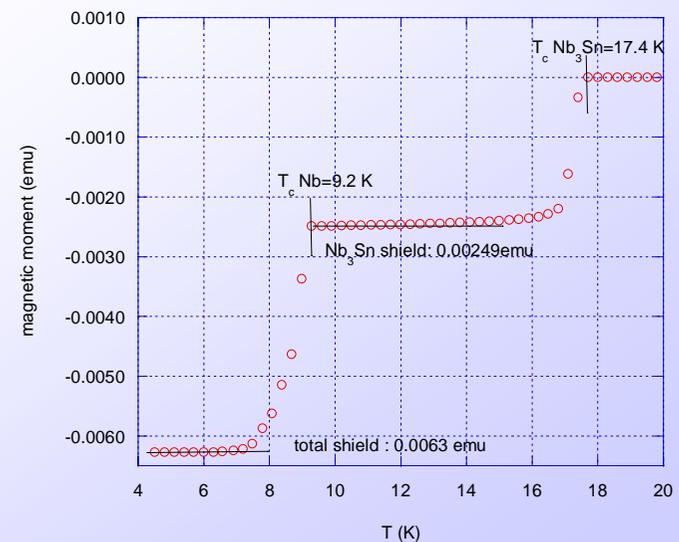
## $m(T)$

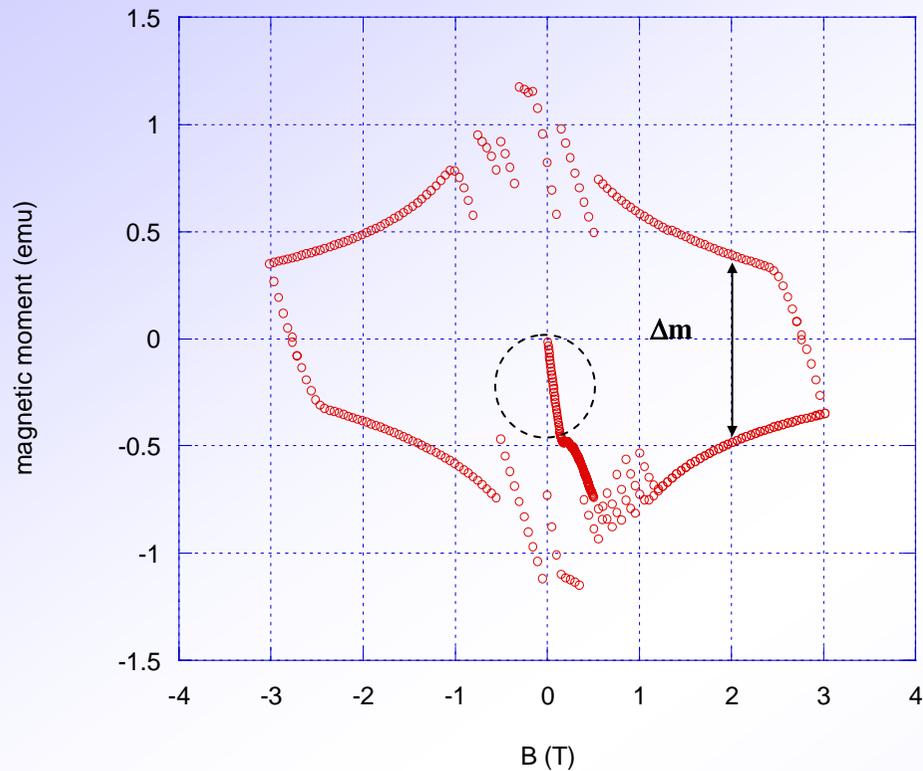
- $T_c(B)$
- Nb shielded volume
- $Nb_3Sn$  shielded volume

$m = \chi_0 \times \text{Applied Field} \times \text{Sample Volume}$  [Wb m]  
 Conversion from cgs to SI units  $1 \text{ emu} = 10^{-10} / 4\pi$  [Wb m]

**Susceptibility**  $\chi_0$  can be calculated using FEM. The samples measured can be assumed as cylinders

Parallel field,  $\chi_0 \sim 1$ ; Transverse field,  $\chi_0 \sim 2$





## $m(B)$

- Parallel and transverse field
- indication of shielding
- flux jumps at low fields
- Estimation of  $J_c(B)$  from  $\Delta m$  from meas in transverse field

$$\Delta m_{\text{wire}} = \frac{N_{\text{fil}}}{3} J_{c,\text{sc}}(B,T) \mu_0 l d^3 (1-\eta^3)$$

$$J_{c,\text{sc}}(B,T) = \frac{3\Delta m_{\text{wire}}}{N_{\text{fil}} \mu_0 l d^3 (1-\eta^3)}$$

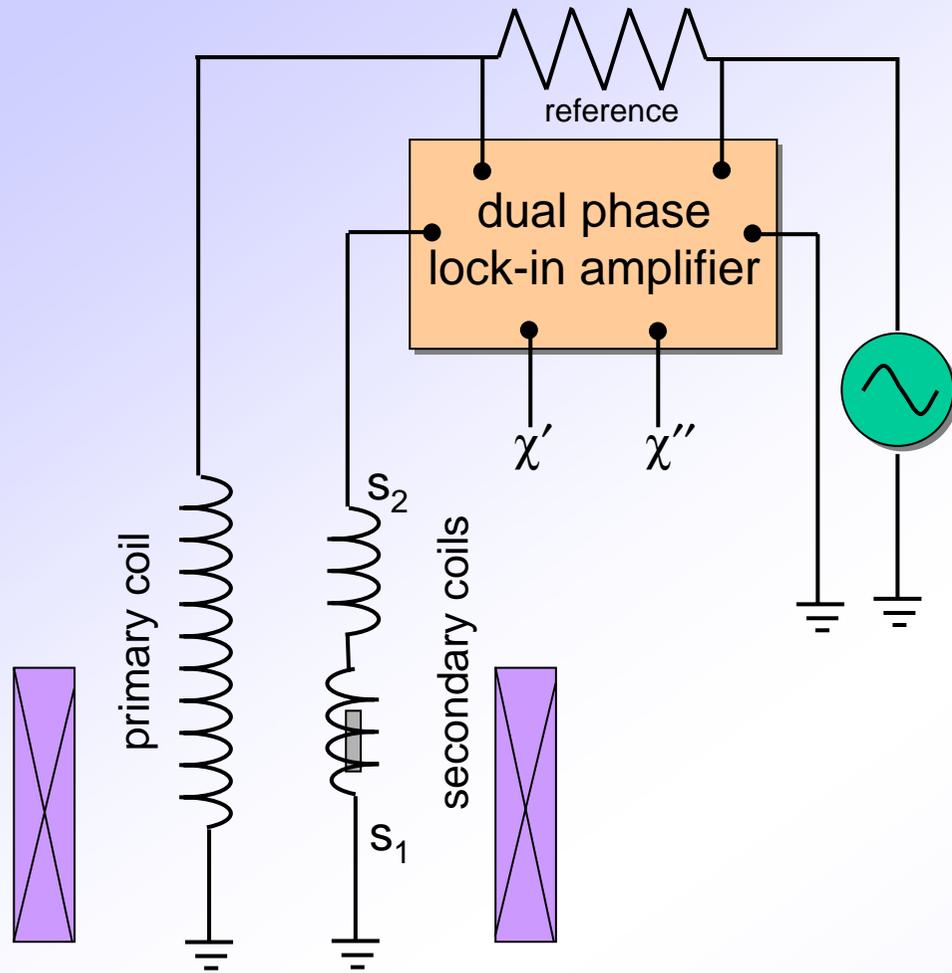
$$\eta = r_{\text{Sn}} / r_{\text{Nb}_3\text{Sn}}$$

$$d = 2r_{\text{Nb}_3\text{Sn}}$$

$$S = \pi(r_{\text{Nb}_3\text{Sn}}^2 - r_{\text{Sn}}^2)$$

$$I_c = N_{\text{fil}} J_{c,\text{sc}}(B,T) S$$

→comparison with  $I_c$  results←



The signal  $U$  at the pick-up coils  $s_1$  and  $s_2$  gives relevant information:

$$\Delta U = U_{s_1} - U_{s_2} = N2\pi v / G m$$

$N$  = Turns in the pick-up coils,

$v$  = frequency

$G$  = geometrical factor

$m$  = magnetic moment

$\chi(B, T)$

$$B_{ext} = B_0 e^{i\omega t}$$

$$B = \sum_{n=1}^{\infty} (A_n - iB_n) e^{in\omega t}$$

$$\chi = \frac{dB / dt}{dB_{ext} / dt} - 1 = \chi_0 (\chi' - i\chi'')$$

$\chi_0$  → external susceptibility under conditions of perfect screening (Meissner state)

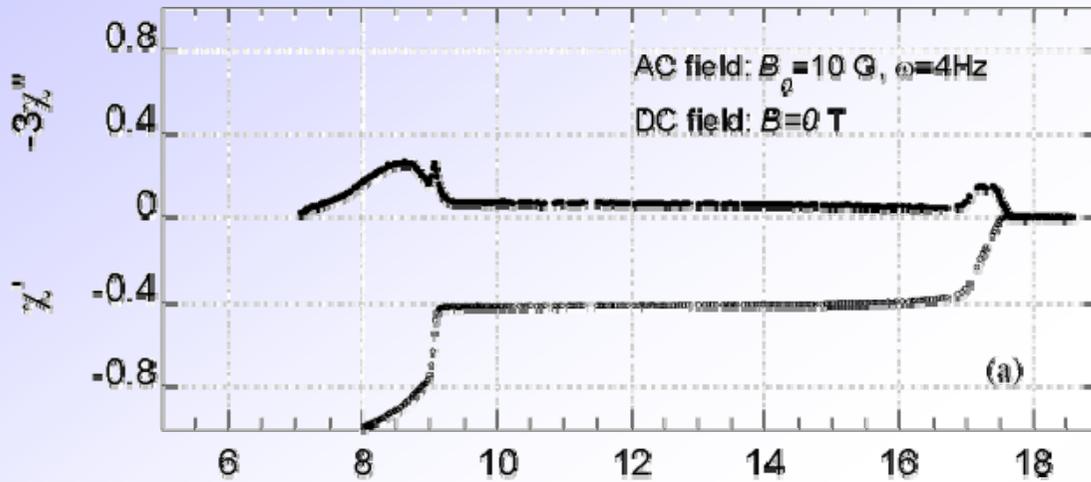
$\chi'$  → stored energy

$\chi''$  → dissipated energy

normal state →  $B = \mu_0 H$ , so  $\chi' = \chi'' = 0$

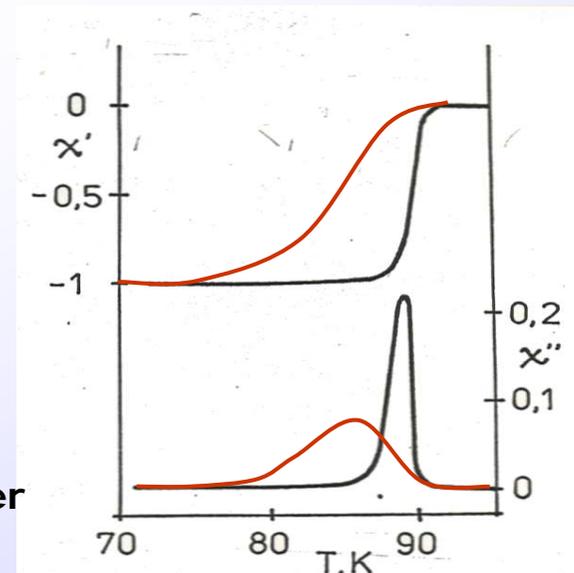
perfect screening →  $\chi'' = 0$ ,  $\chi_0 = -M / B_0$

# $\chi(B, T)$



- Sharp transition → homogeneous material
- Smooth transition → key of dishomogeneity

The peak becomes lower and smoother



- $T_c(B)$
- Nb shielding volume
- $\text{Nb}_3\text{Sn}$  shielded volume



*First phase:*

- *Preliminary measurements on Internal TIN and “old” PIT samples*
- *Calibrated the  $DC_{\text{squid}}$  /VSM/AC apparatus and understand “different” results, if any*
- *Verified the info that can be derived from different meas*

Intro

m(T)

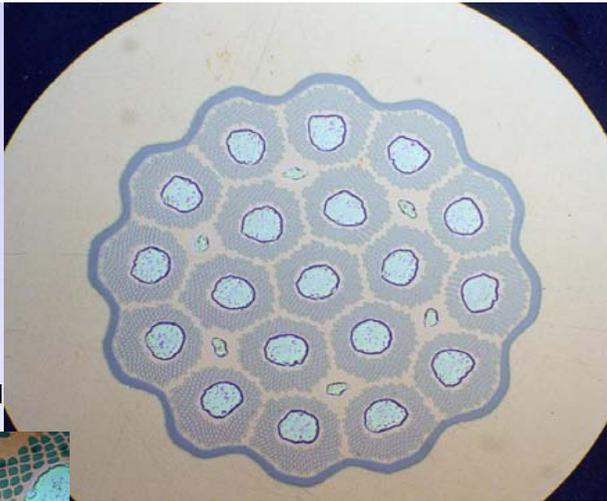
m(B)

$\chi(B,T)$

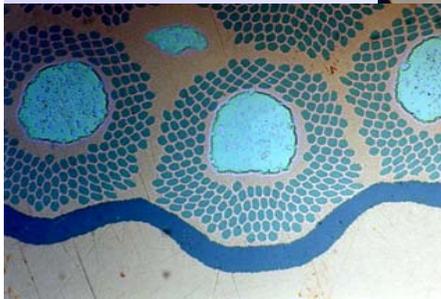
samples

Nb?

...

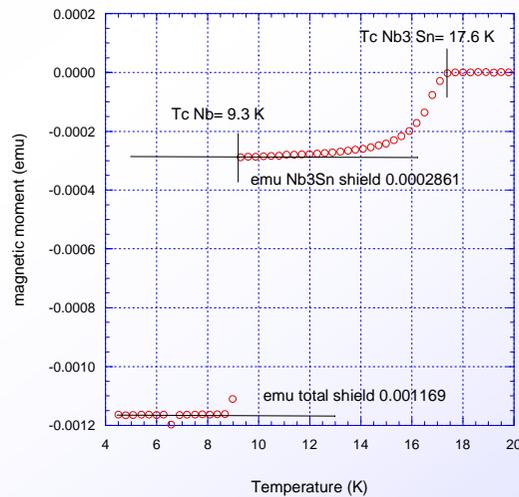
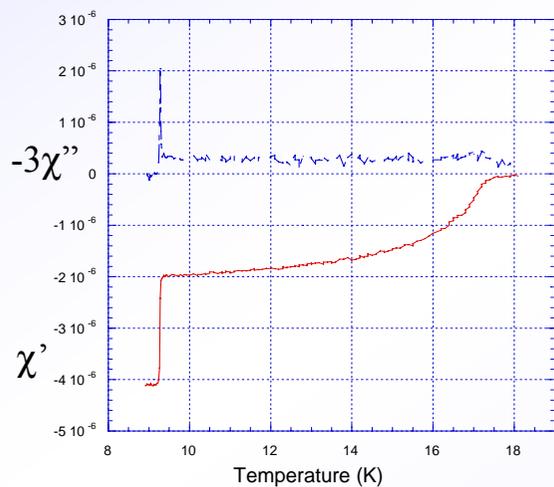


Courtesy  
A. Devred, CEA/CERN

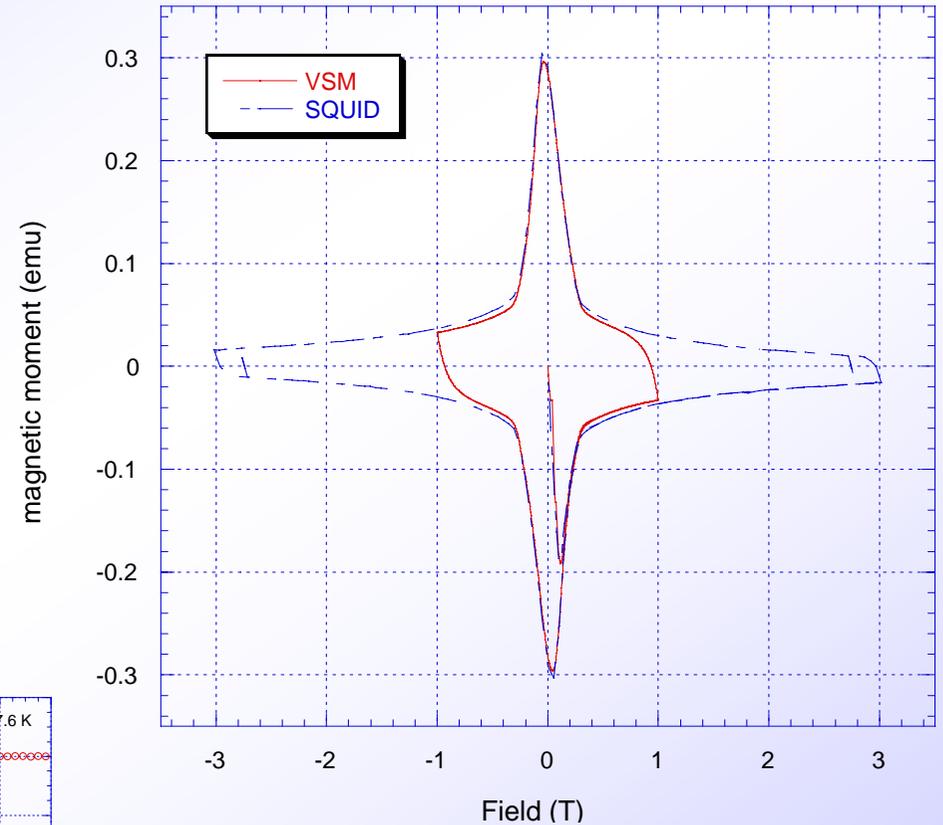


## INTERNAL TIN sample

Extremely smooth  $Nb_3Sn$  transition  
presence of several phases.



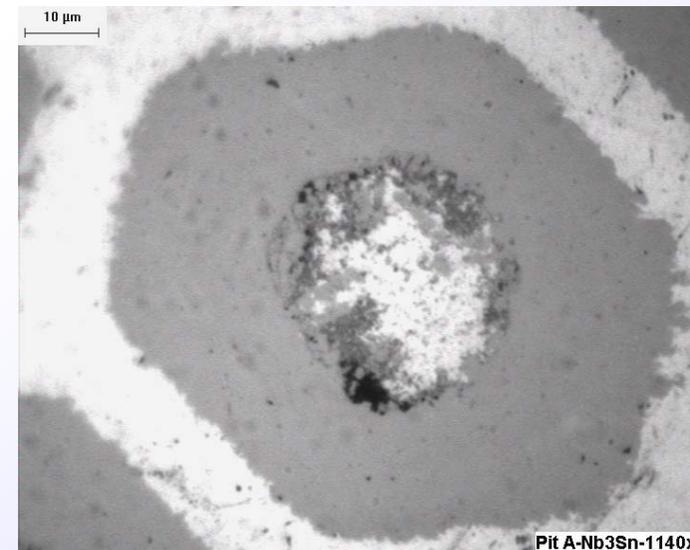
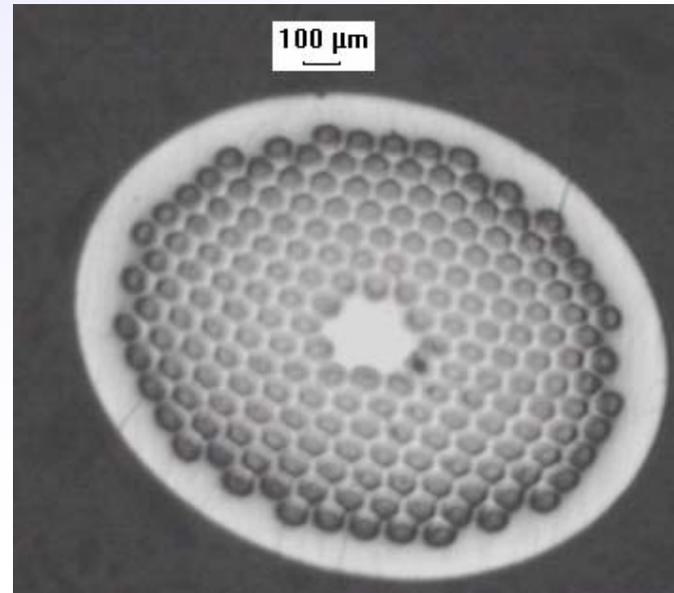
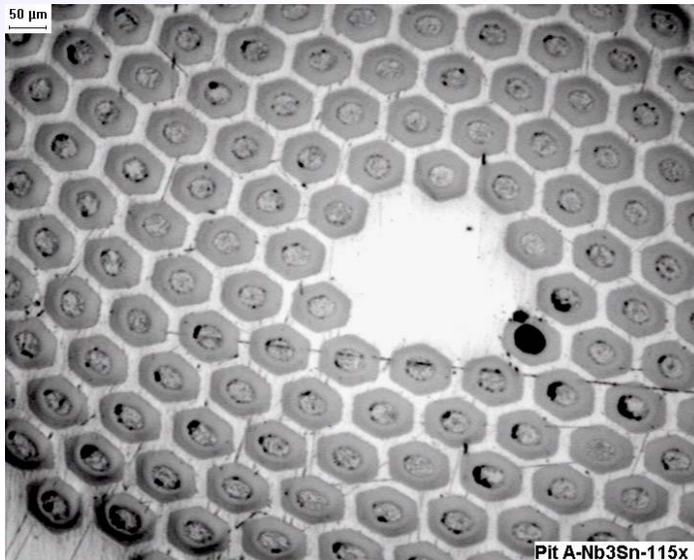
Comparison of m-B measurements at 4.2 K  
with SQUID and VSM on two different  
samples differing by 7.5% in length



- Absence of flux-jumps at low field
- 20% difference between  $Nb_3Sn$  geometrical and shielded volume values..hint of filament interconnection?

Critical current measurements show high values of  $J_c$  for this kind of  $Nb_3Sn$  wires..but, unfortunately, all the samples measured up-to-now show instabilities at low fields.

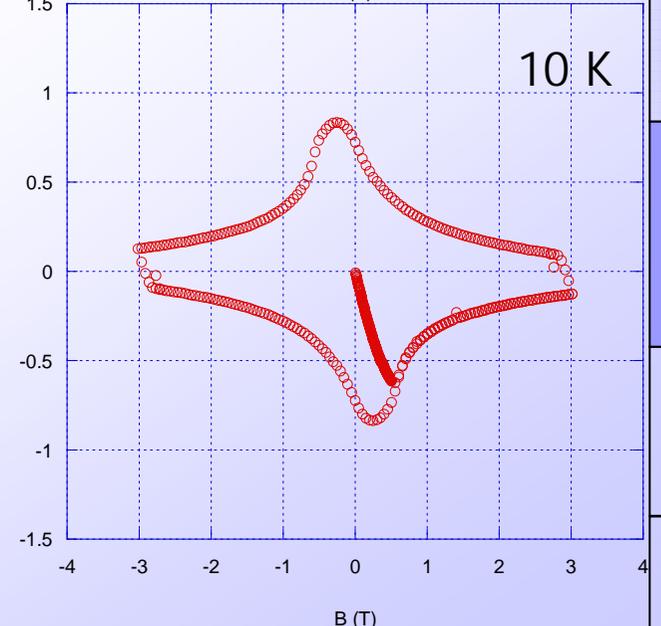
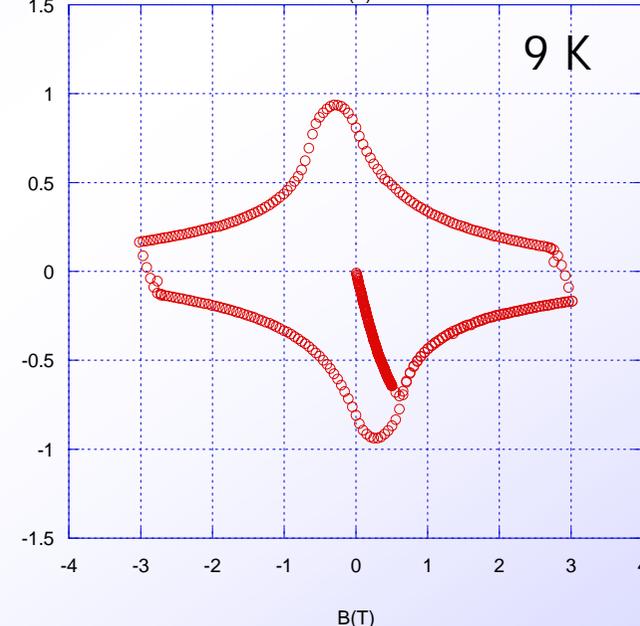
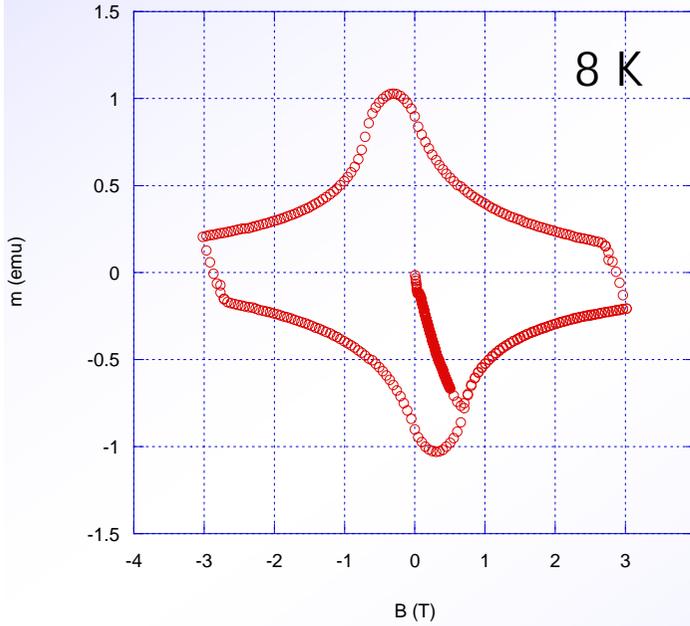
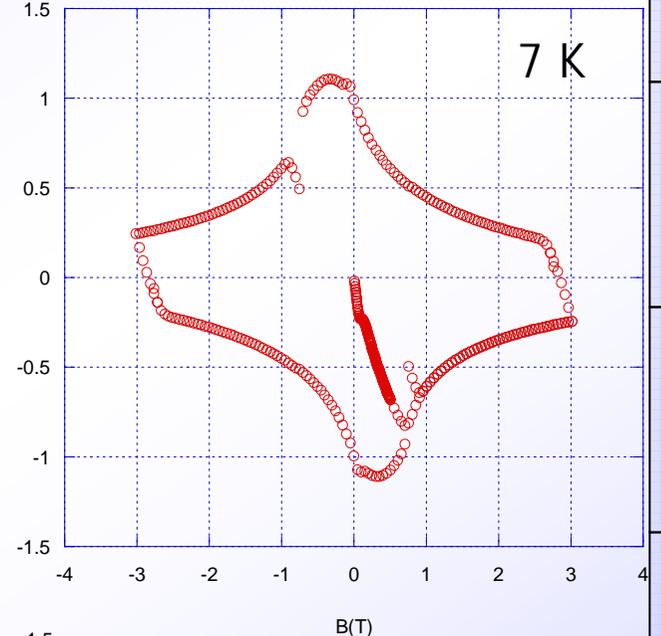
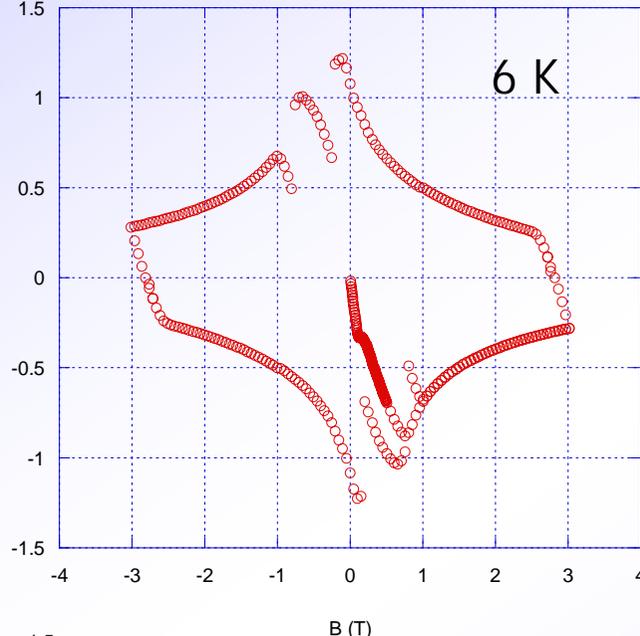
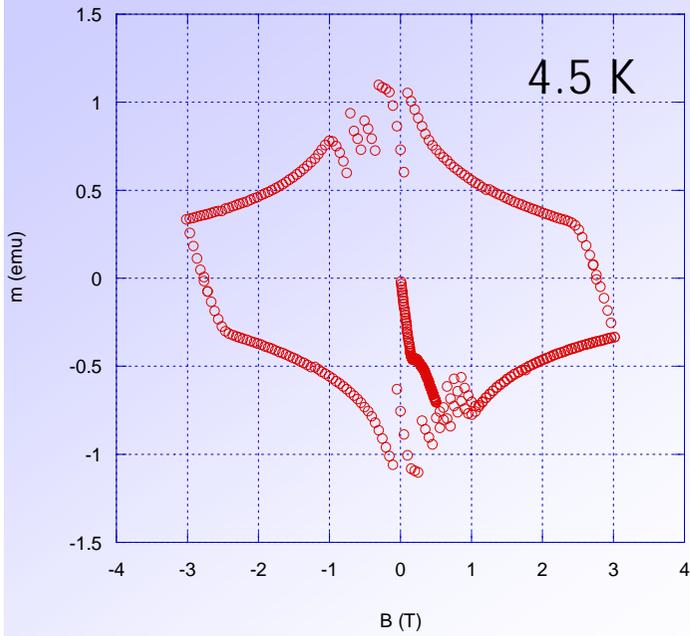
## POWDER-in-TUBE samples



Samples: courtesy of A. Den Ouden & S. Wessel, UTwente  
Micrograph: courtesy of Carlo Ferdeghini, CNR-INFN LAMIA



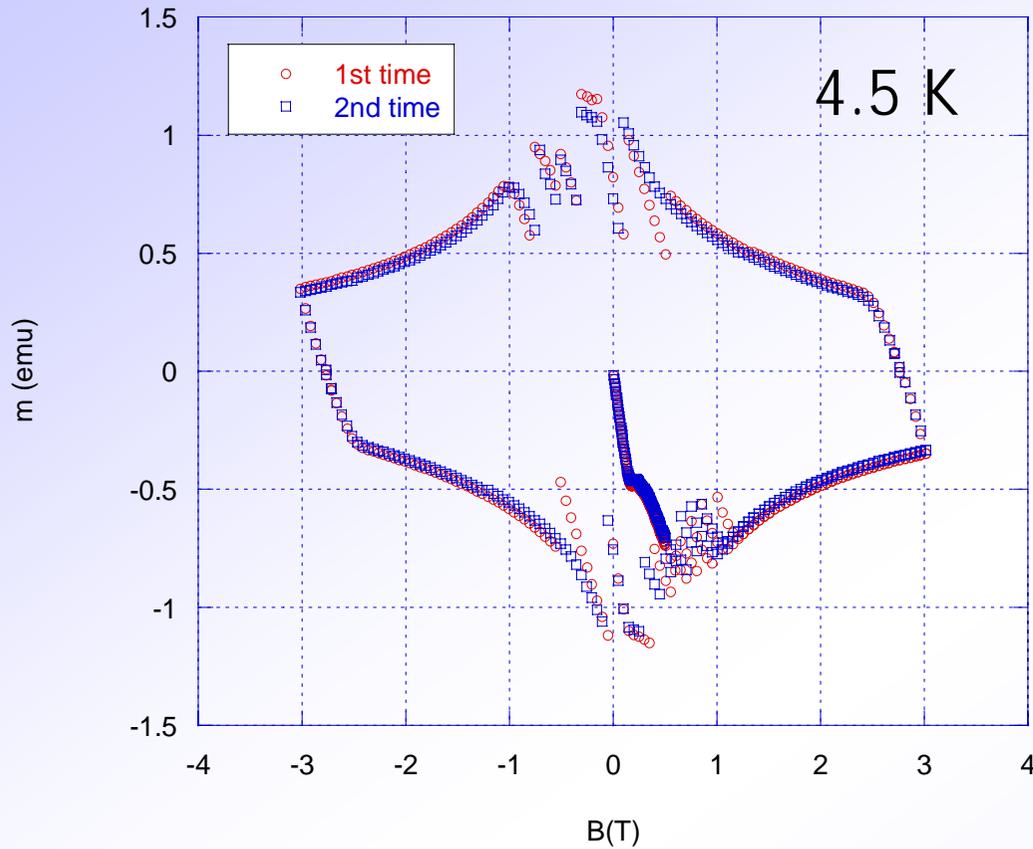
# Powder-in-Tube sample



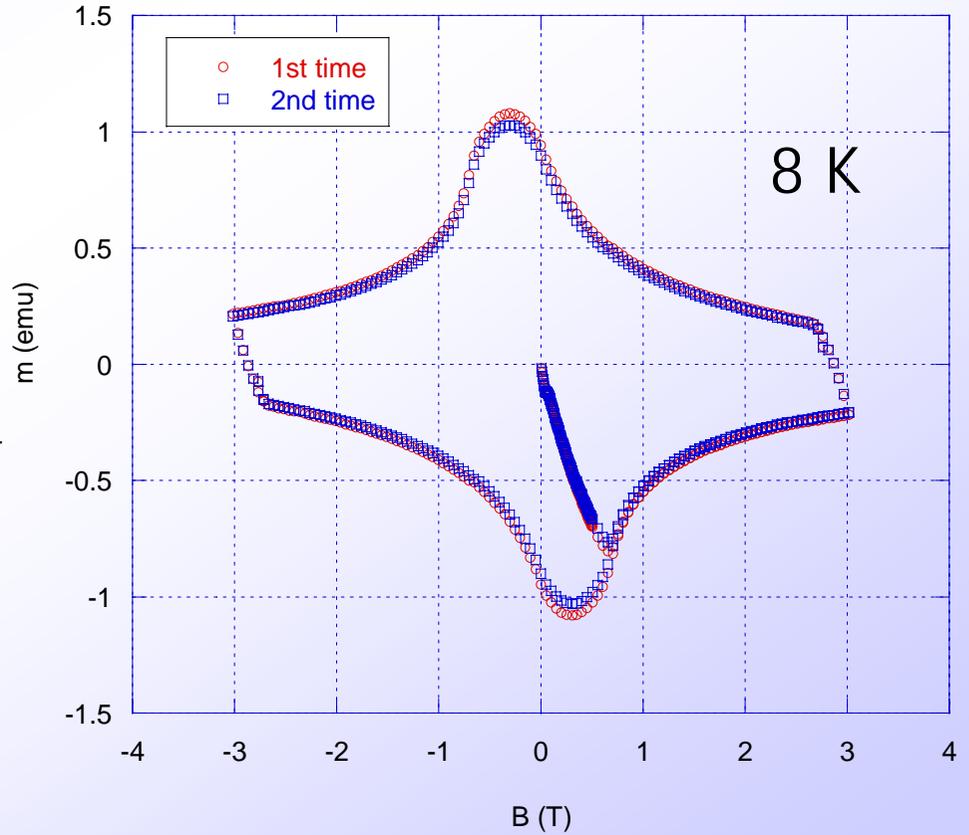
Intro
m(T)
m(B)
$\chi(B,T)$
PIT
Nb?
...



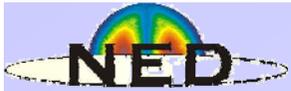
# POWDER-in-TUBE sample



Reliability of repeated measurements in parallel field with SQUID



Intro
m(T)
m(B)
$\chi(B,T)$
PIT
Nb?
...



## *Second phase:*

- *Measurements in parallel to the critical current cross-check program:*
  - *cross-check "different" results, if any of CEA, TWENTE and INFN-Milano*
  - *evaluation of wire degradation*
  - *why flux jumps?*

...

Nb?

samples

$\chi(B,T)$

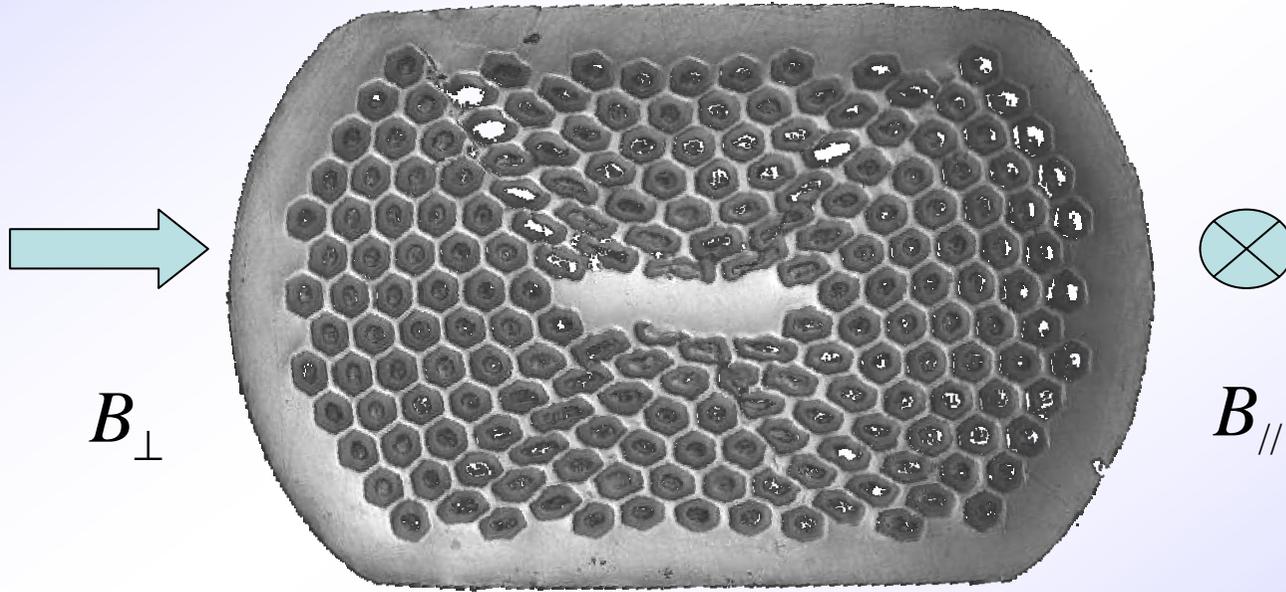
m(B)

m(T)

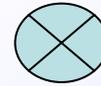
Intro



Courtesy of Thierry Boutboul, CERN



$B_{\perp}$

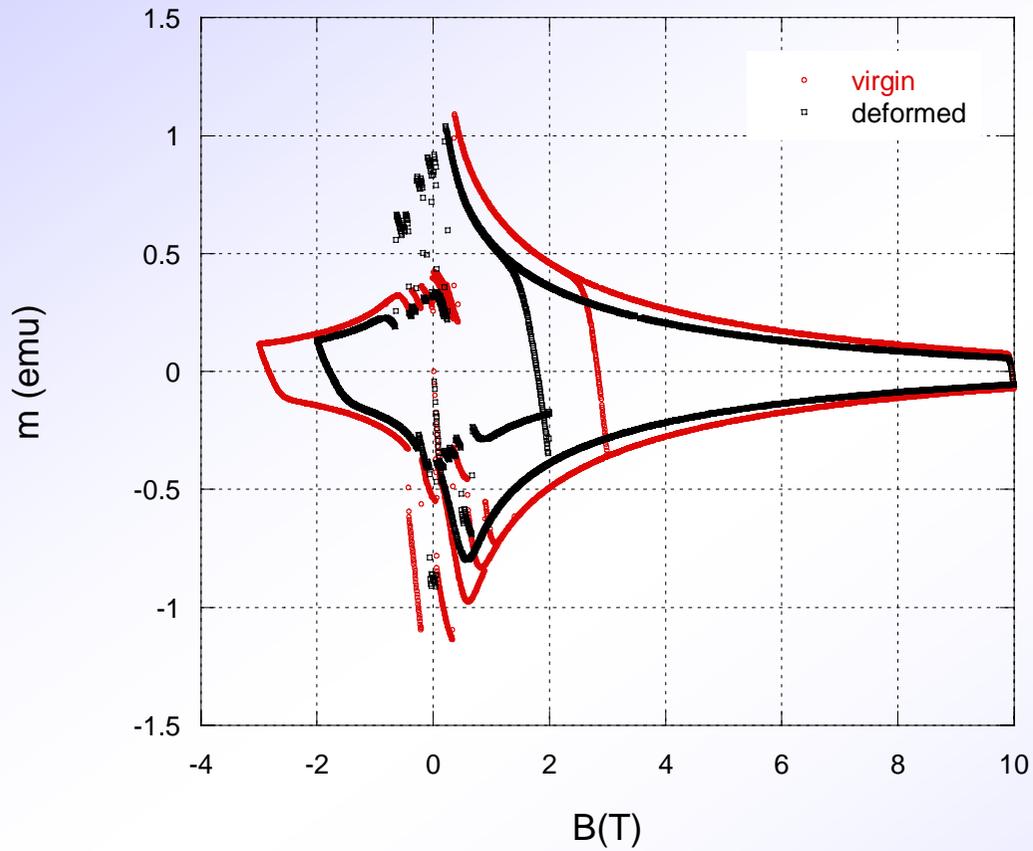


$B_{\parallel}$

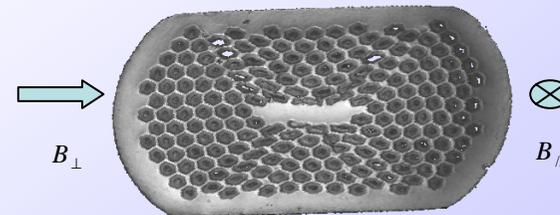
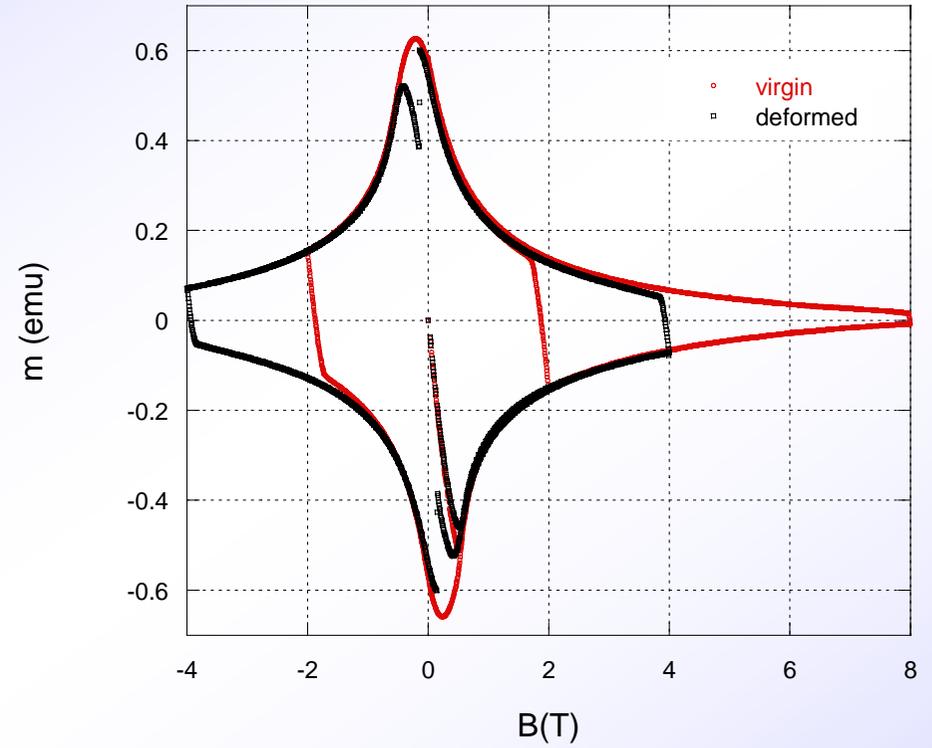
...	Nb?	wire degr	$\chi(B,T)$	$m(B)$	$m(T)$	Intro
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# First results..

4.5 K, transverse field



10 K, parallel field



Intro

m(T)

m(B)

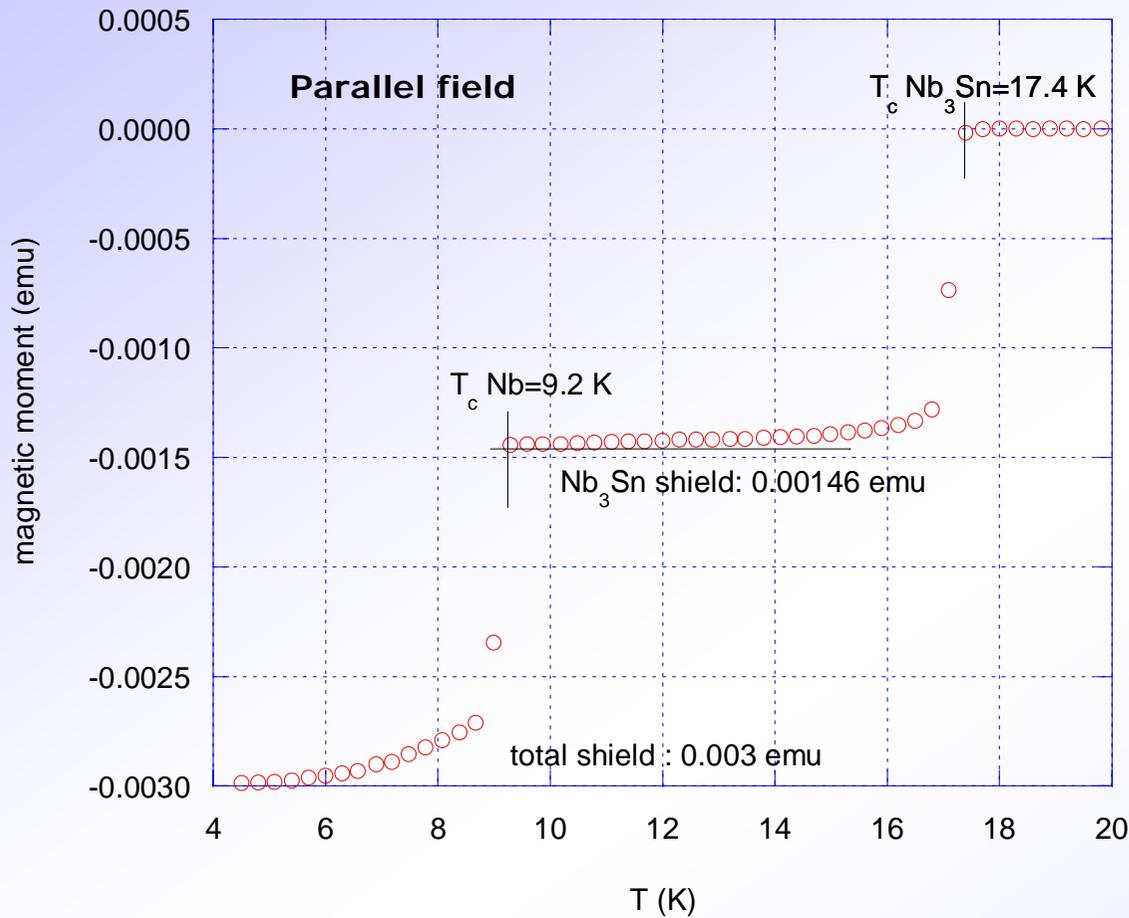
$\chi(B,T)$

wire degr.

Nb?

...

There is a large amount of Nb in the conductor



Why flux-jumps?

$$m = \chi_0 B_a V$$

$$m = 3 \cdot 10^{-3} \text{ emu} = 3.77 \cdot 10^{-12} \text{ Wb m}$$

$$1 \text{ emu} = 4\pi \cdot 10^{-10} \text{ Wb m}$$

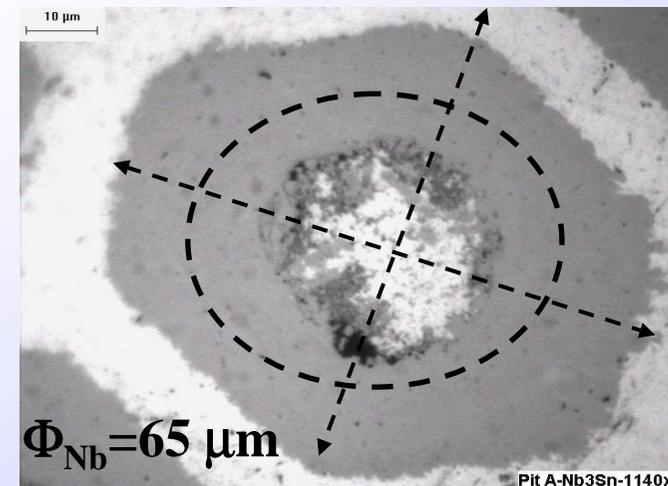
$$B_a = 10 \text{ G}$$

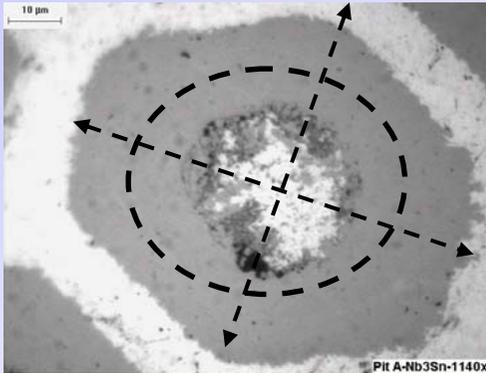
$$V_{\text{shielded Nb}} = 3.77 \text{ mm}^3$$

$$V_{\text{shielded Nb}_3\text{Sn}} = 1.83 \text{ mm}^3$$

$$\rightarrow \Phi_{\text{Nb}_3\text{Sn}} = 44 \mu\text{m}$$

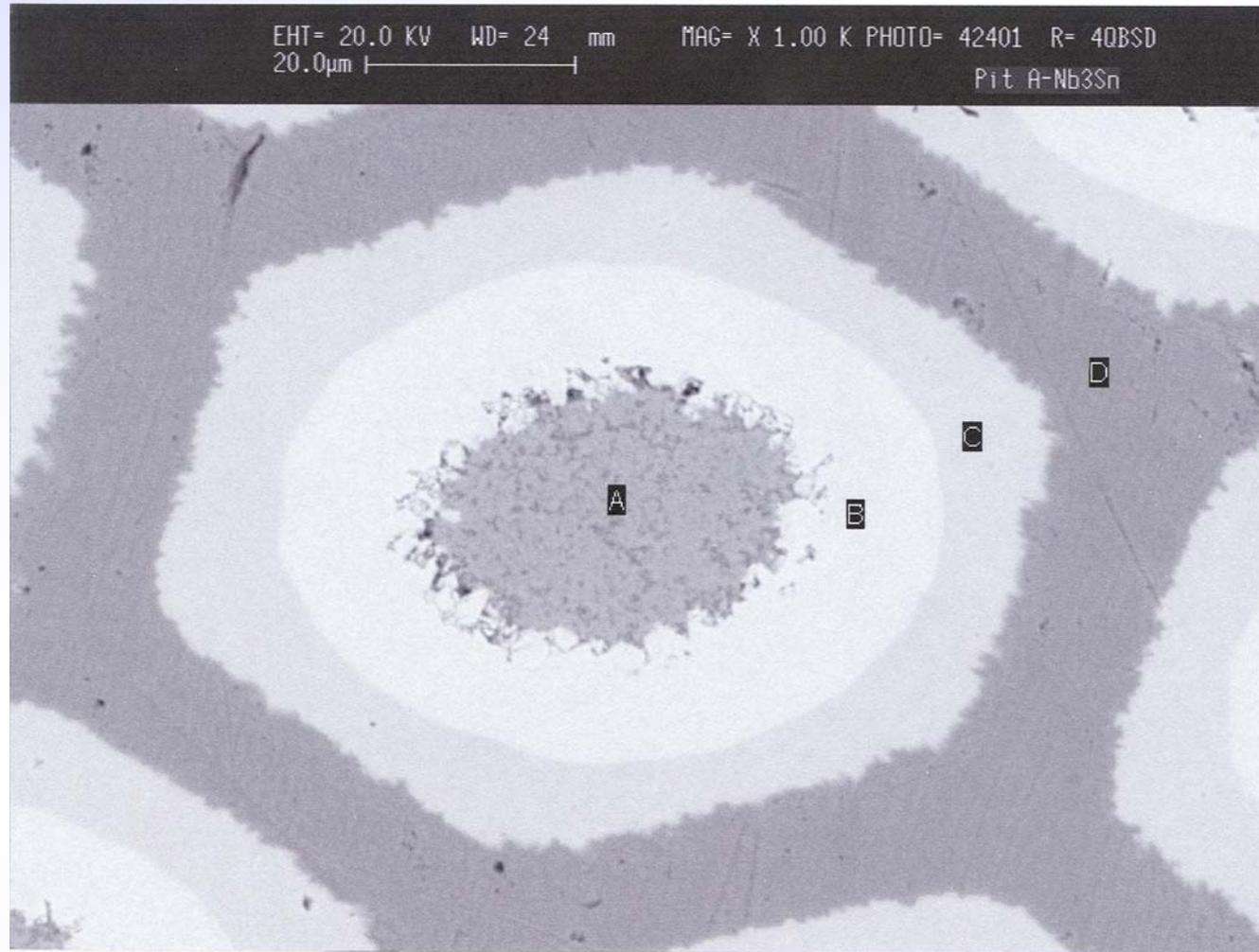
$$\rightarrow V_{\text{Nb}_3\text{Sn}} = 0.98 \text{ mm}^3$$





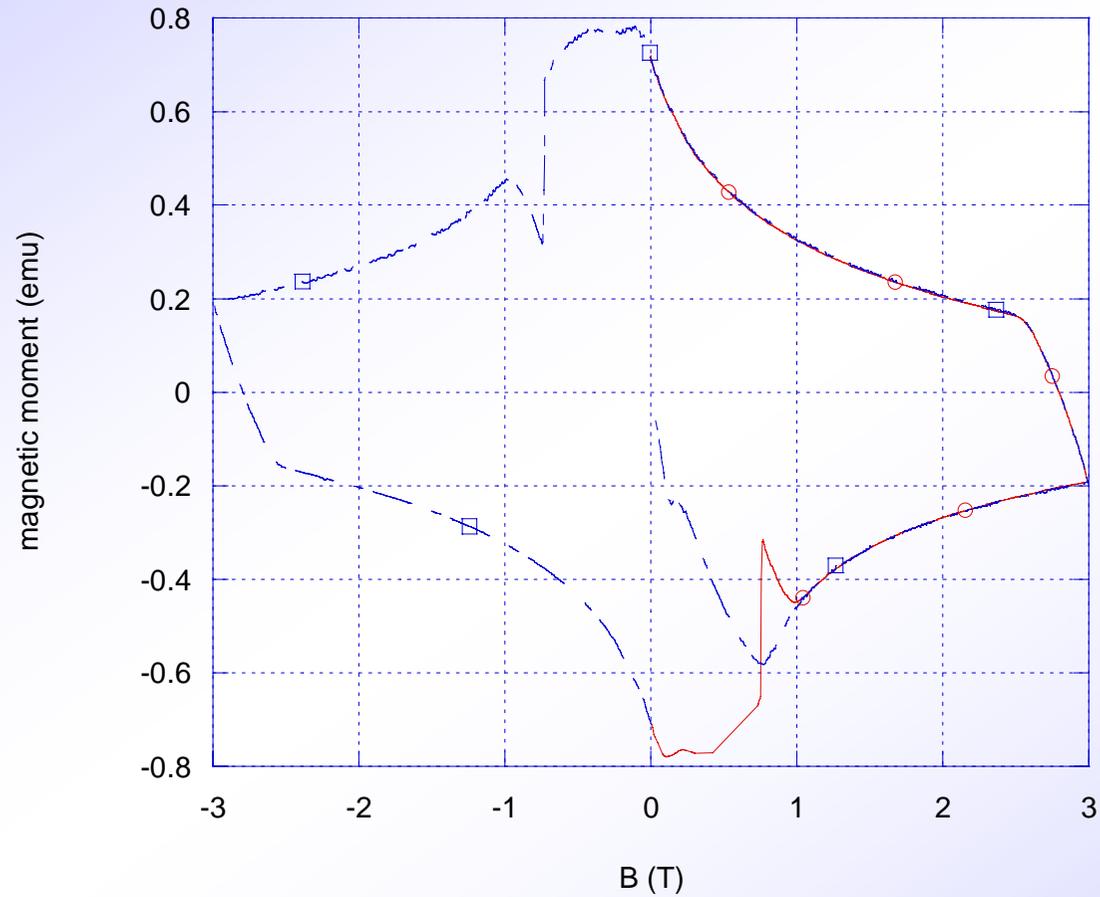
$\Phi_{\text{Nb}} = 65 \mu\text{m}$ ,  
 $\Phi_{\text{Nb}_3\text{Sn}} = 44 \mu\text{m}$

## Enquire the role of Nb in the conductor

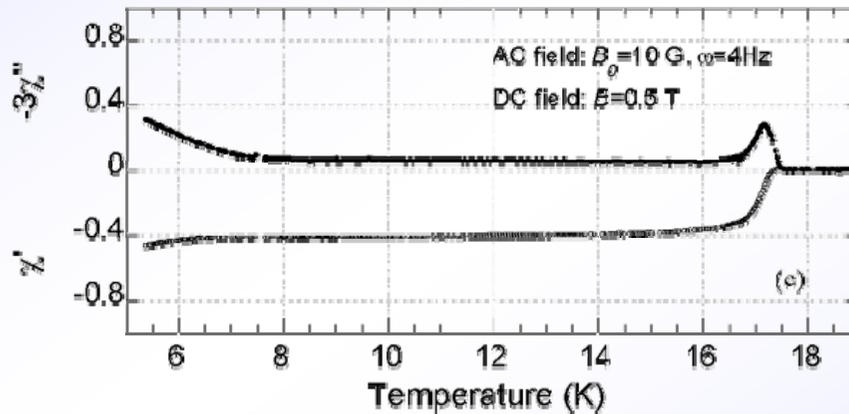
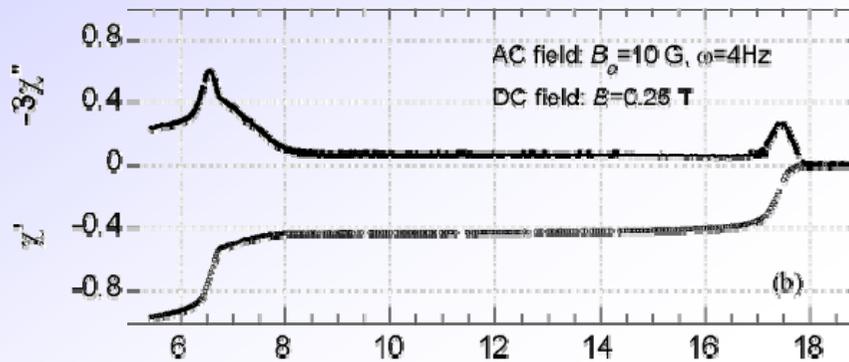
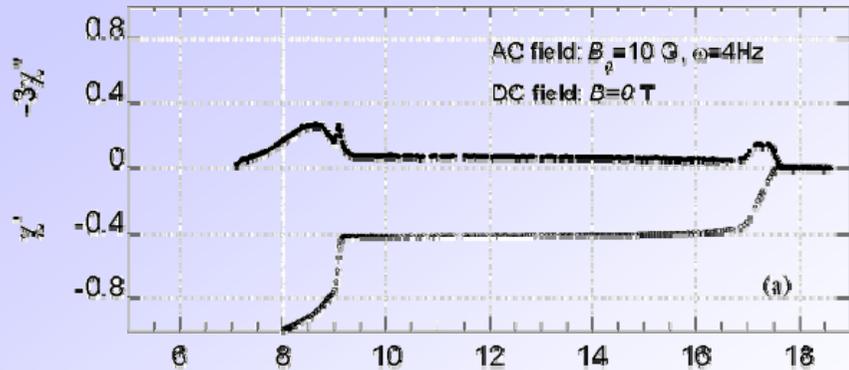


B is the  $\text{Nb}_3\text{Sn}$  area, corresponding to  $\Phi = 50 \mu\text{m}$

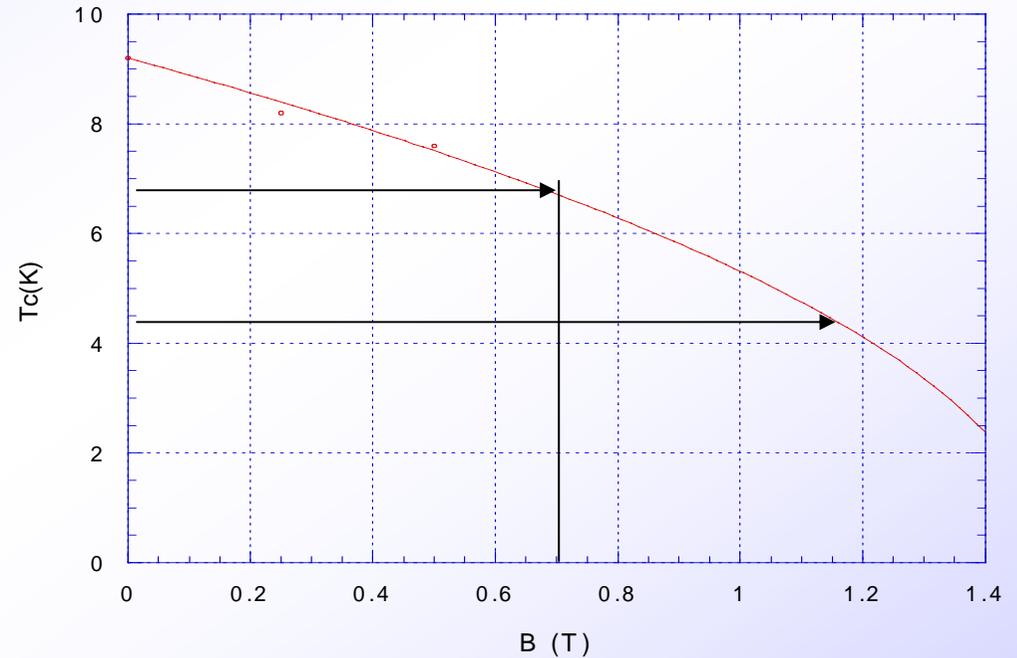
VSM meas at 6.6 K



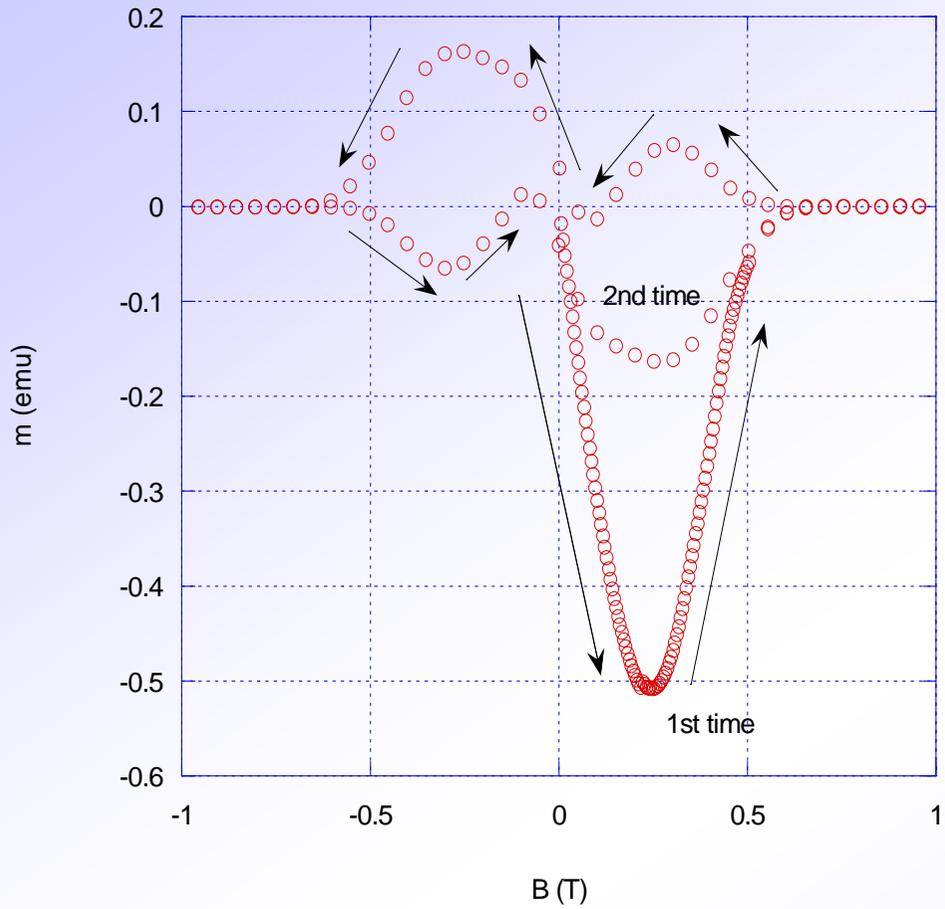
Is this a single flux-jump or rather the transition of the pure Nb phase? May this phase quench at 0.7 T?



## ac measurements in normal field

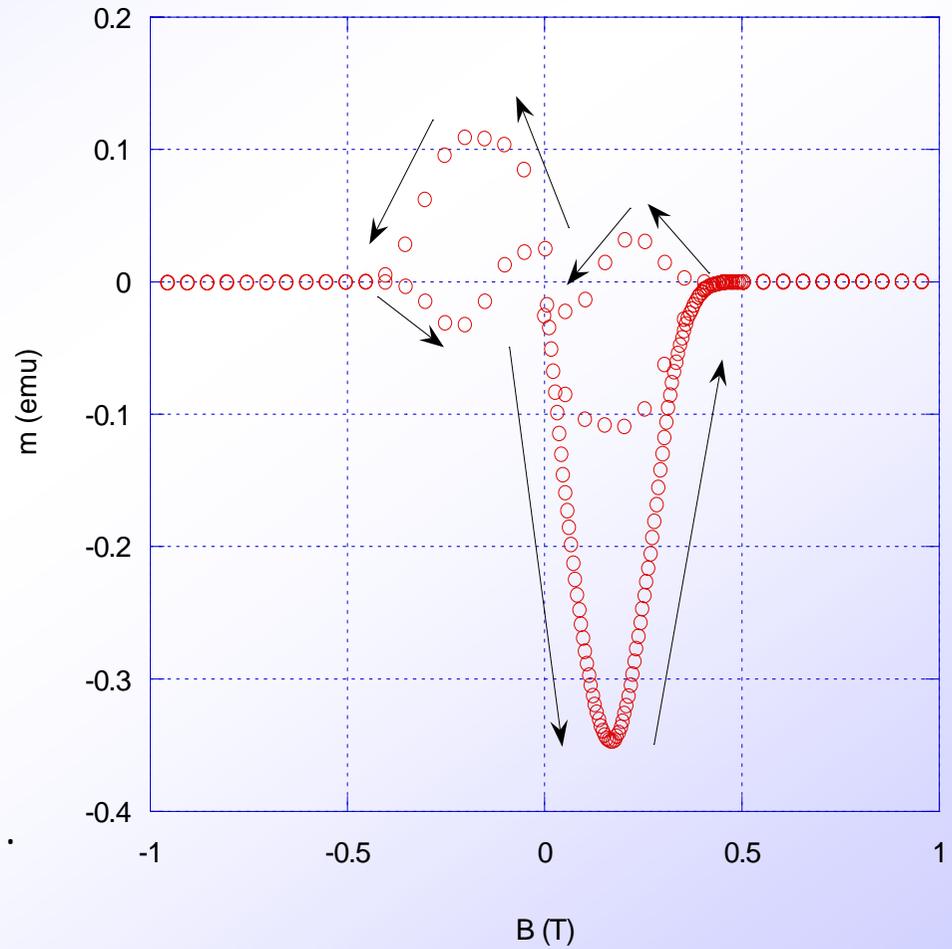


According to this extrapolation, at 4.2 K we can have strong effects on magnetization due to this dirty Nb phase

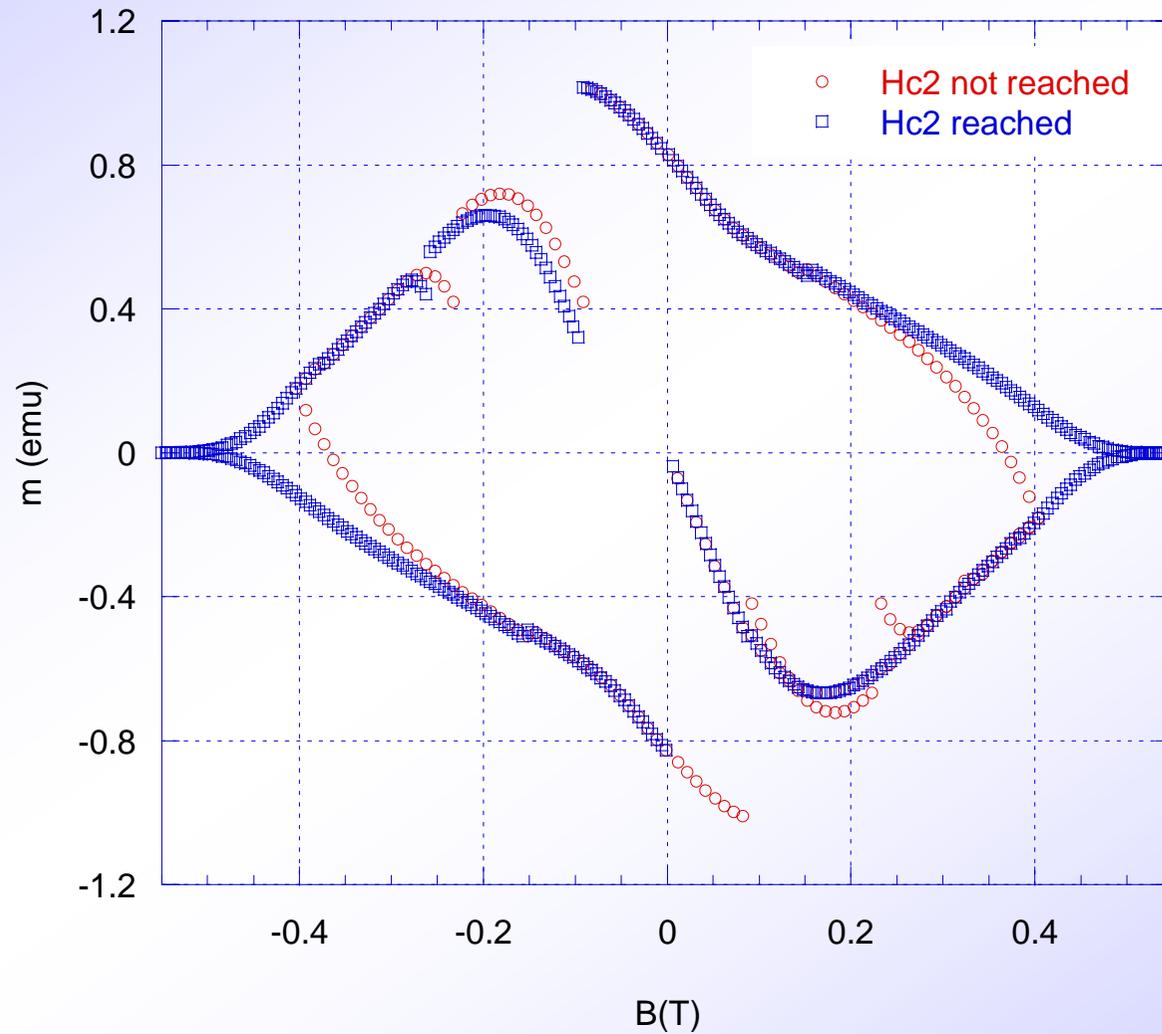


Apparently strange behaviour..

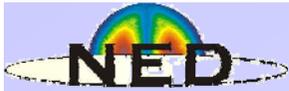
M(B) on a not-reacted PIT sample in parallel field



### M(B) on a not-reacted PIT sample in transverse field



Flux jumps...



**Magnetization measurements are a powerful tool**

**→ correlation with  $J_c$  meas**

**→ study of degradation**

**→ flux jumps**

**[..the presence of instabilities at low field is a strong limitation of application of  $Nb_3Sn$ ..]**

**Modelization with FEM is in progress**

**No concluding word, for sure, but a warning on the importance of Nb in PIT  $Nb_3Sn$  wires.]**

Intro

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m(B)

$\chi(B,T)$

PIT

Nb?

...