Interplay between two type II superconductors at the nanoscale

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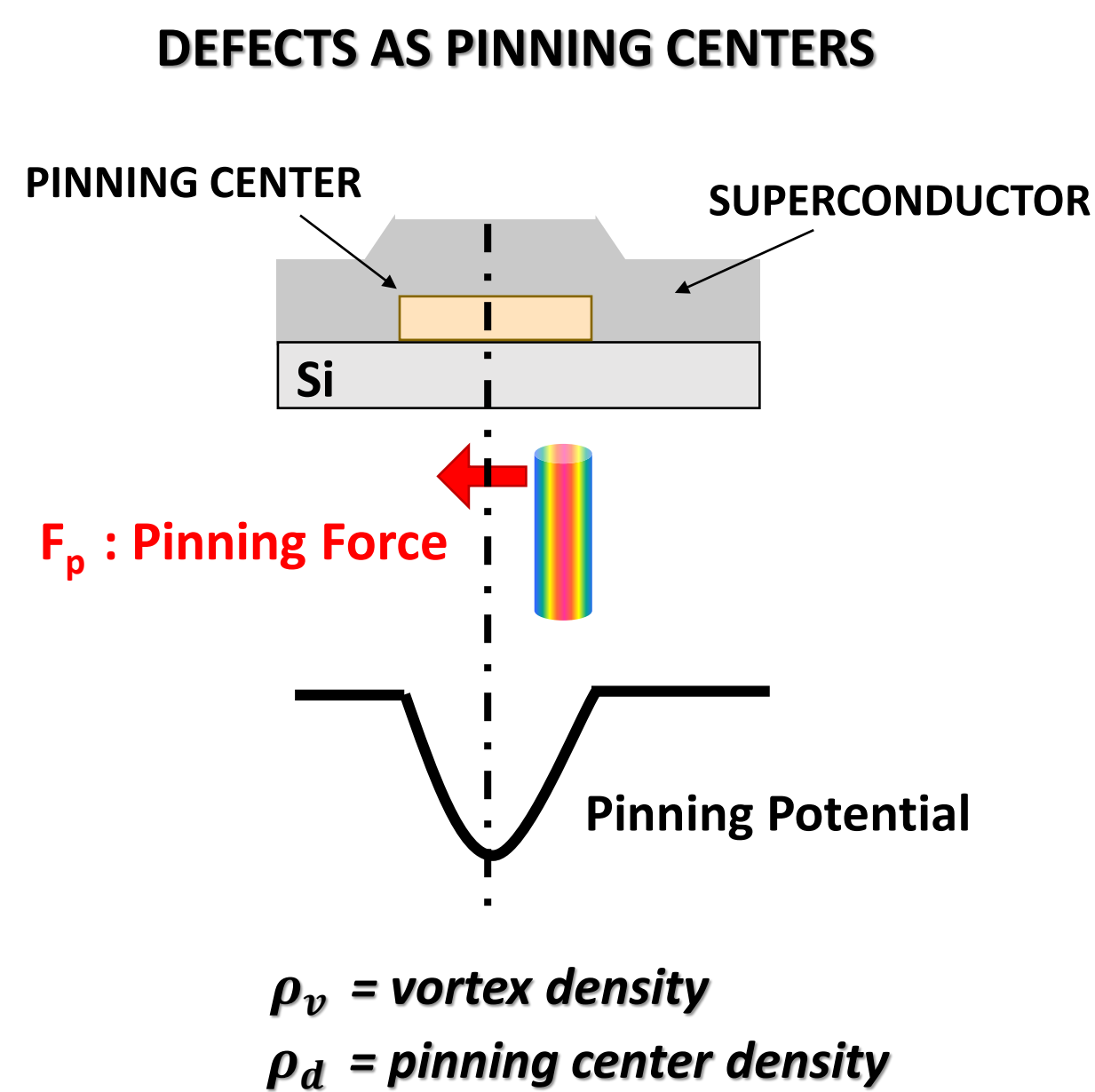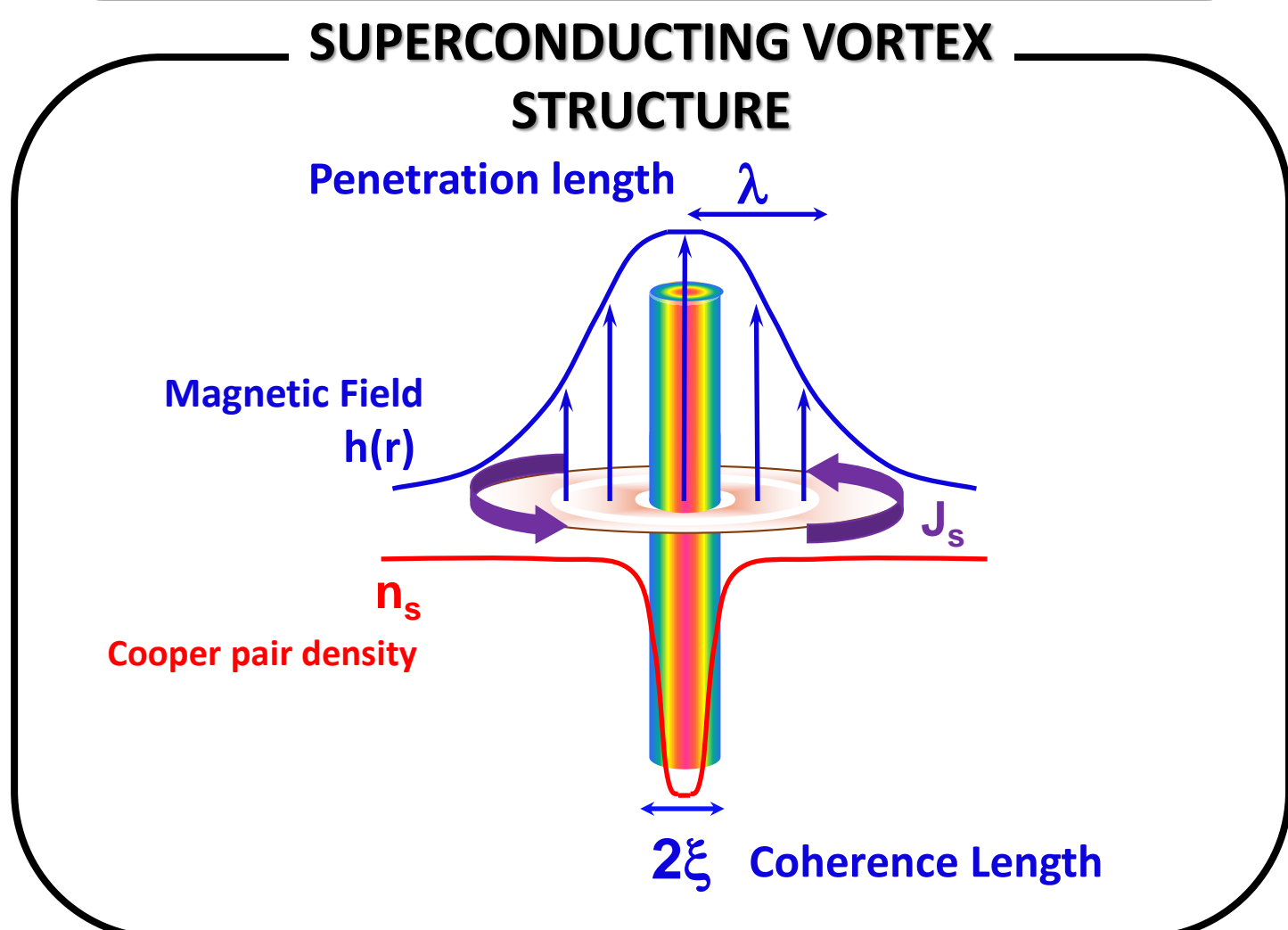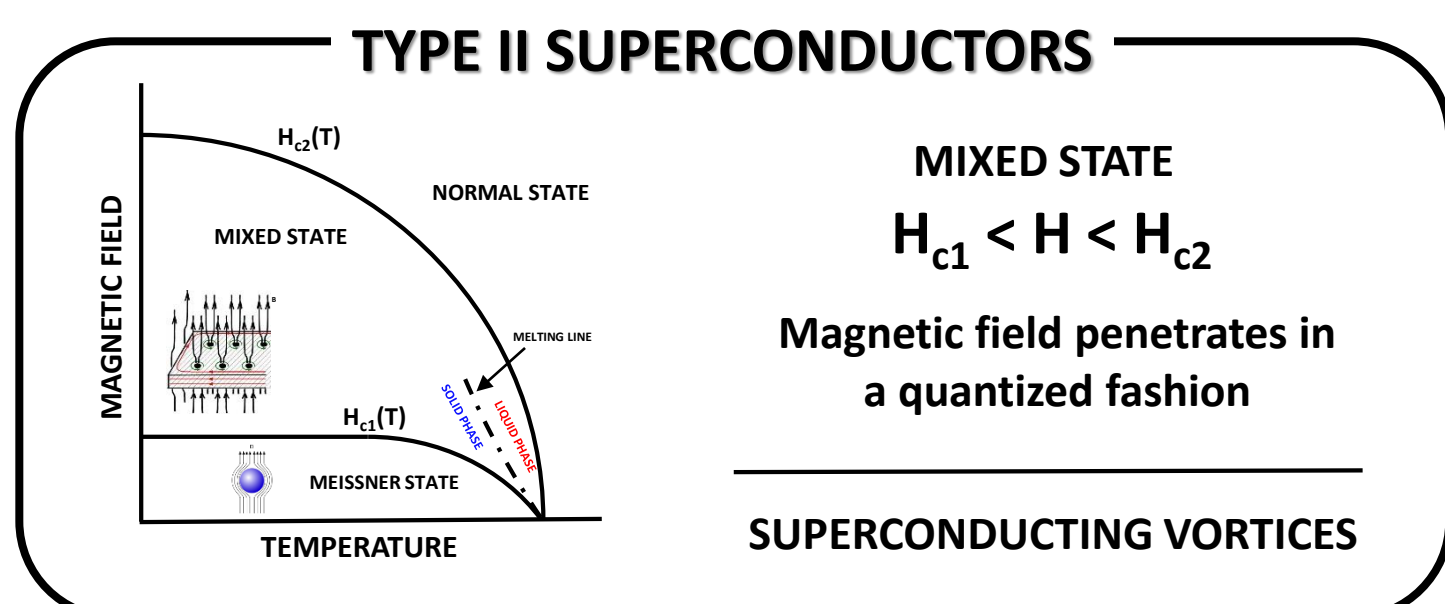[3] Centro de Astrobiología (CSIC-INTA), Torrejón de Ardoz, 28850 Madrid, Spain.
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TYPE II SUPERCONDUCTORS: COMMENSURABILITY EFFECT

TYPE II SUPERCONDUCTORS

MIXED STATE
$H_{c1} < H < H_{c2}$

Magnetic field penetrates in a quantized fashion

SUPERCONDUCTING VORTICES

SUPERCONDUCTING VORTEX STRUCTURE

Penetration length λ
Magnetic Field $h(r)$
J_s
n_s Cooper pair density
2ξ Coherence Length

DEFECTS AS PINNING CENTERS

PINNING CENTER — SUPERCONDUCTOR — Si

F_p : Pinning Force

Pinning Potential

ρ_v = vortex density
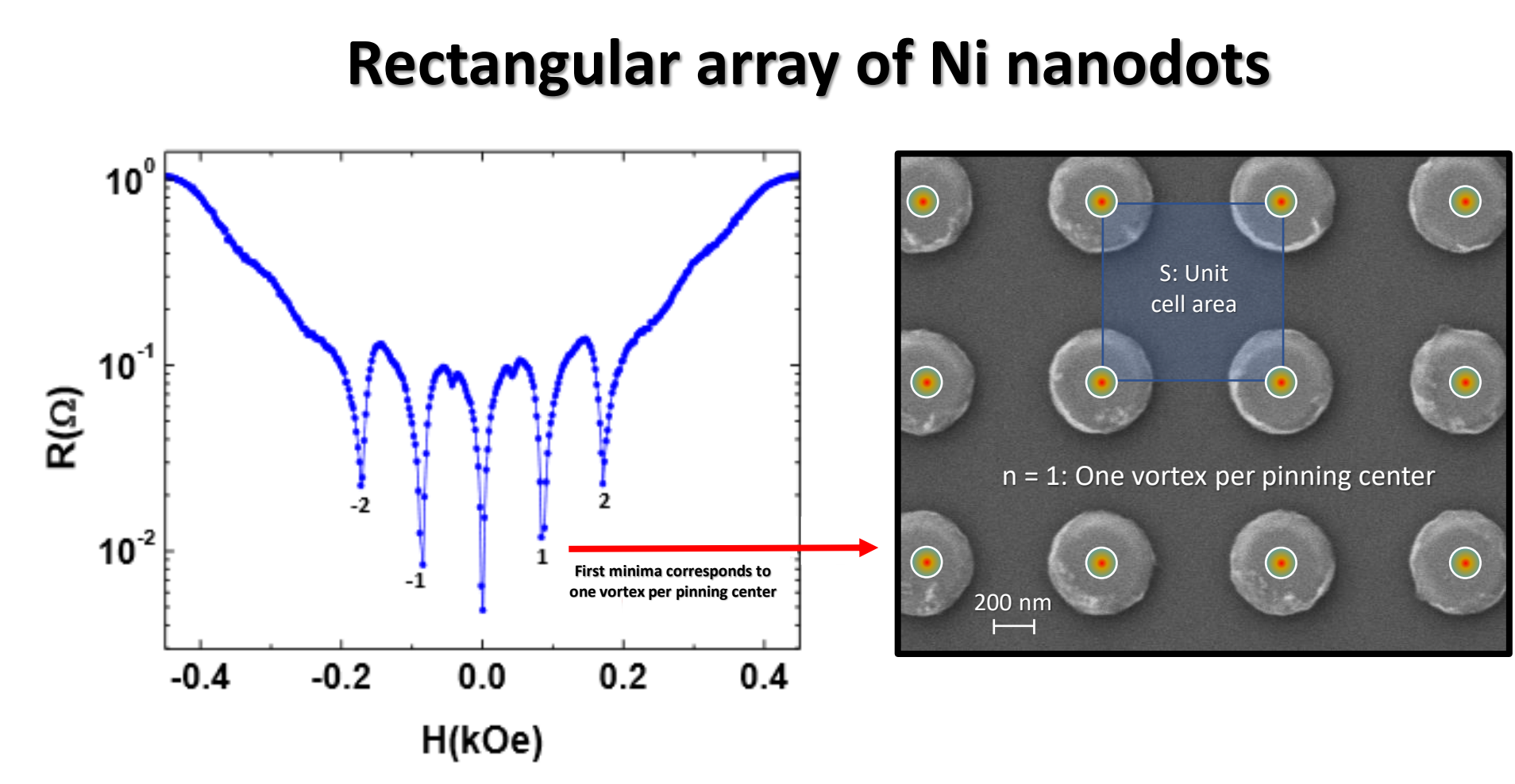ρ_d = pinning center density

MATCHING CONDITION [1]

$$\rho_v = m \cdot \rho_d \qquad m \in \mathbb{Z}$$

SHARP MINIMA IN MAGNETORESISTANCE CURVES

MATCHING FIELDS $\quad H_m = m\frac{\Phi_0}{S}$

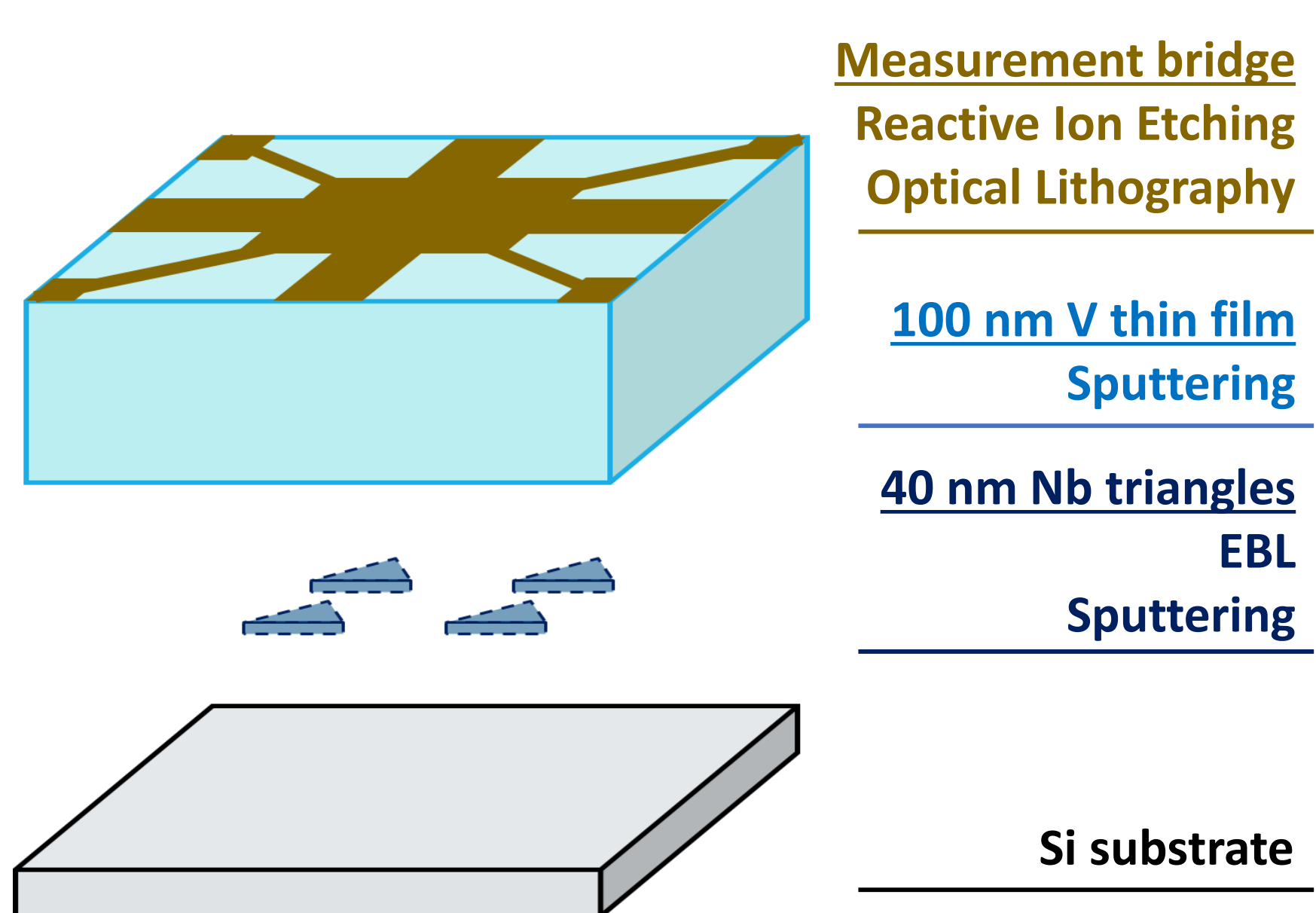S: Pinning centers array unit cell area

Rectangular array of Ni nanodots

First minima corresponds to one vortex per pinning center

n = 1: One vortex per pinning center
200 nm
S: Unit cell area

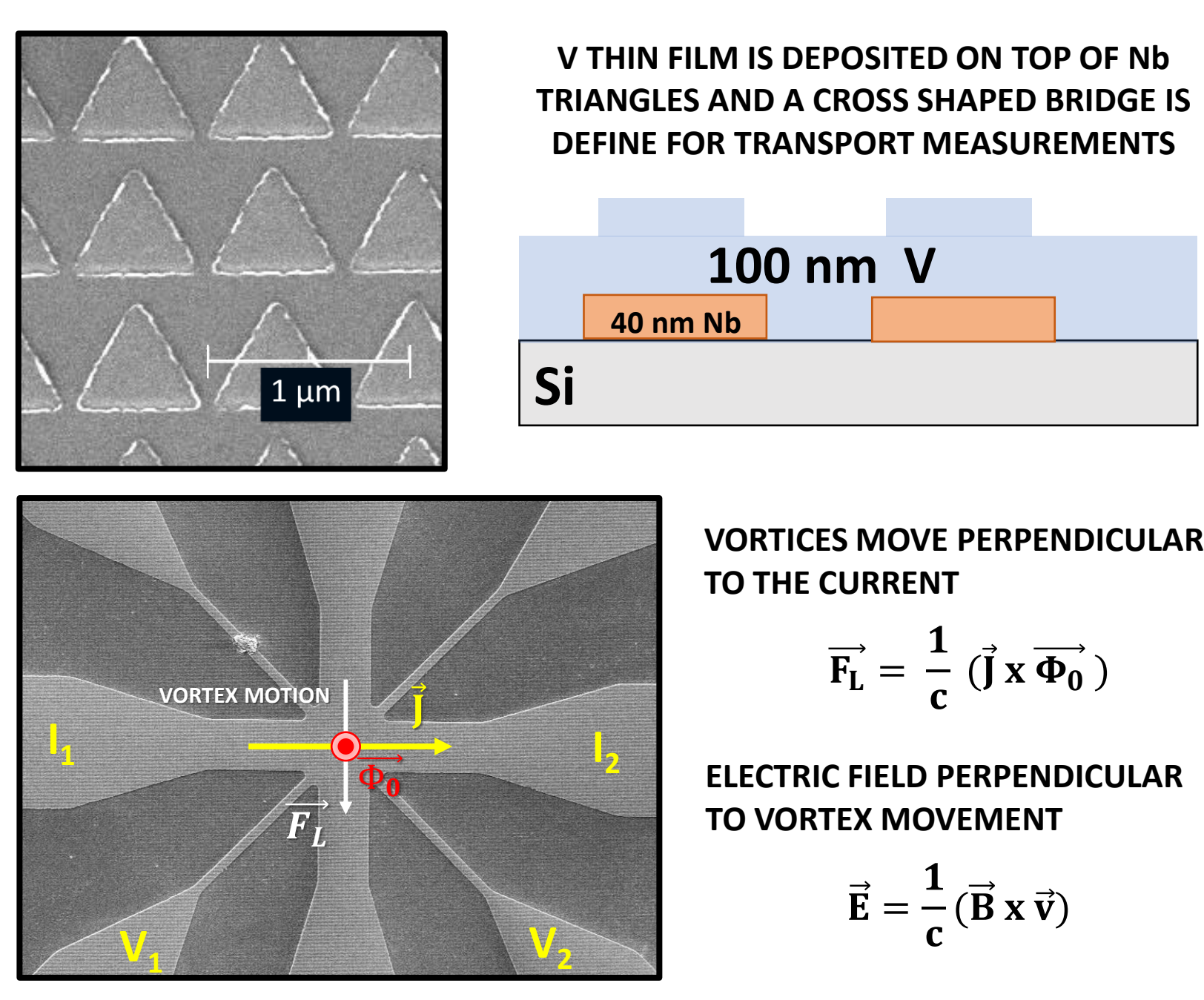VORTEX MOTION SLOWS DOWN

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RESISTANCE DROPS

DEFECTS MADE OF SUPERCONDUCTING MATERIAL
INTERPLAY BETWEEN TWO DIFFERENT SUPERCONDUCTORS [2]
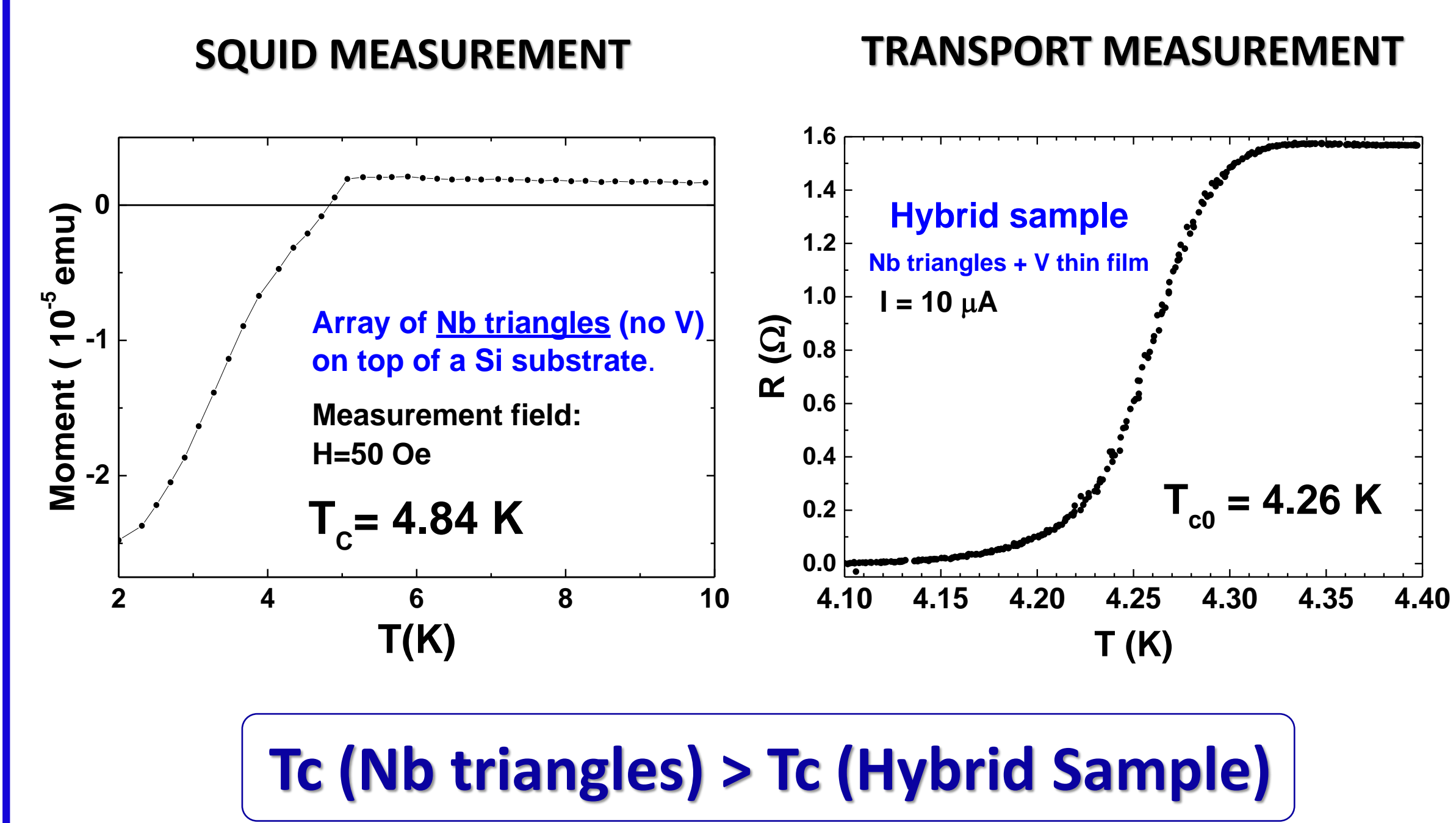
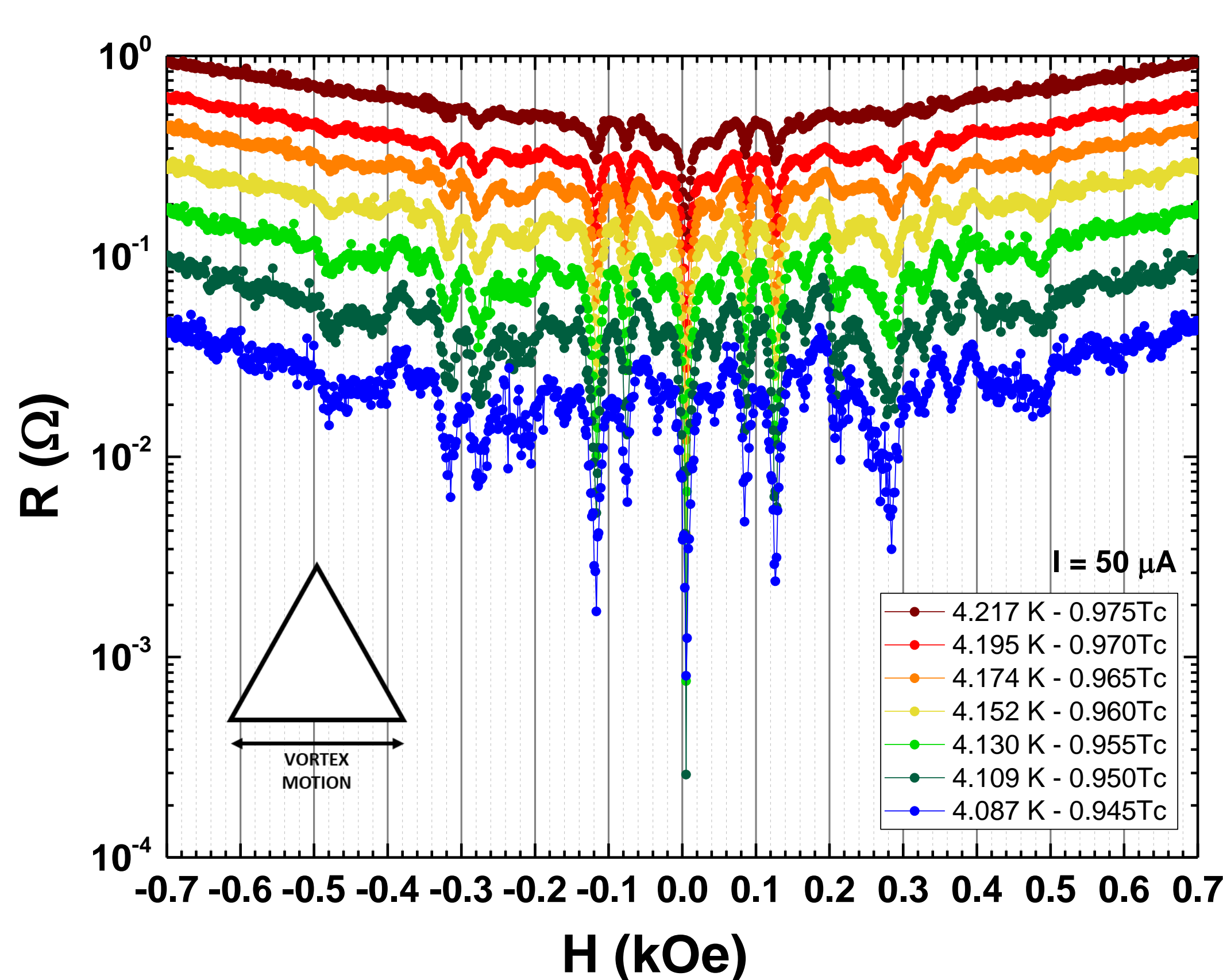## SAMPLE DESCRIPTION AND CHARACTERIZATION

FABRICATION PROCESS

Measurement bridge
Reactive Ion Etching
Optical Lithography

100 nm V thin film
Sputtering

40 nm Nb triangles
EBL
Sputtering

Si substrate

FABRICATED HYBRID SAMPLE

V THIN FILM IS DEPOSITED ON TOP OF Nb TRIANGLES AND A CROSS SHAPED BRIDGE IS DEFINE FOR TRANSPORT MEASUREMENTS

100 nm V
40 nm Nb
Si

1 µm

VORTICES MOVE PERPENDICULAR TO THE CURRENT

$$\vec{F_L} = \frac{1}{c}(\vec{J} \times \vec{\Phi_0})$$

ELECTRIC FIELD PERPENDICULAR TO VORTEX MOVEMENT

$$\vec{E} = \frac{1}{c}(\vec{B} \times \vec{v})$$

SUPERCONDUCTING CRITCAL TEMPERATURE

SQUID MEASUREMENT

Array of Nb triangles (no V) on top of a Si substrate.
Measurement field: H=50 Oe
$T_c = 4.84$ K

TRANSPORT MEASUREMENT

Hybrid sample
Nb triangles + V thin film
I = 10 µA
$T_{c0} = 4.26$ K

Tc (Nb triangles) > Tc (Hybrid Sample)

TRANSPORT MEASUREMENTS

MATCHING EFFECT

I = 50 µA

VORTEX MOTION

- 4.217 K - 0.975Tc
- 4.195 K - 0.970Tc
- 4.174 K - 0.965Tc
- 4.152 K - 0.960Tc
- 4.130 K - 0.955Tc
- 4.109 K - 0.950Tc
- 4.087 K - 0.945Tc

ANOMALOUS MATCHING EFFECT IN THE LIQUID PHASE

VORTEX LIQUID PHASE ENHANCEMENT [3]

PURE V

LIQUID PHASE
SOLID PHASE

V on Nb TRIANGLES

LIQUID PHASE
SOLID PHASE
(5/2)H_1
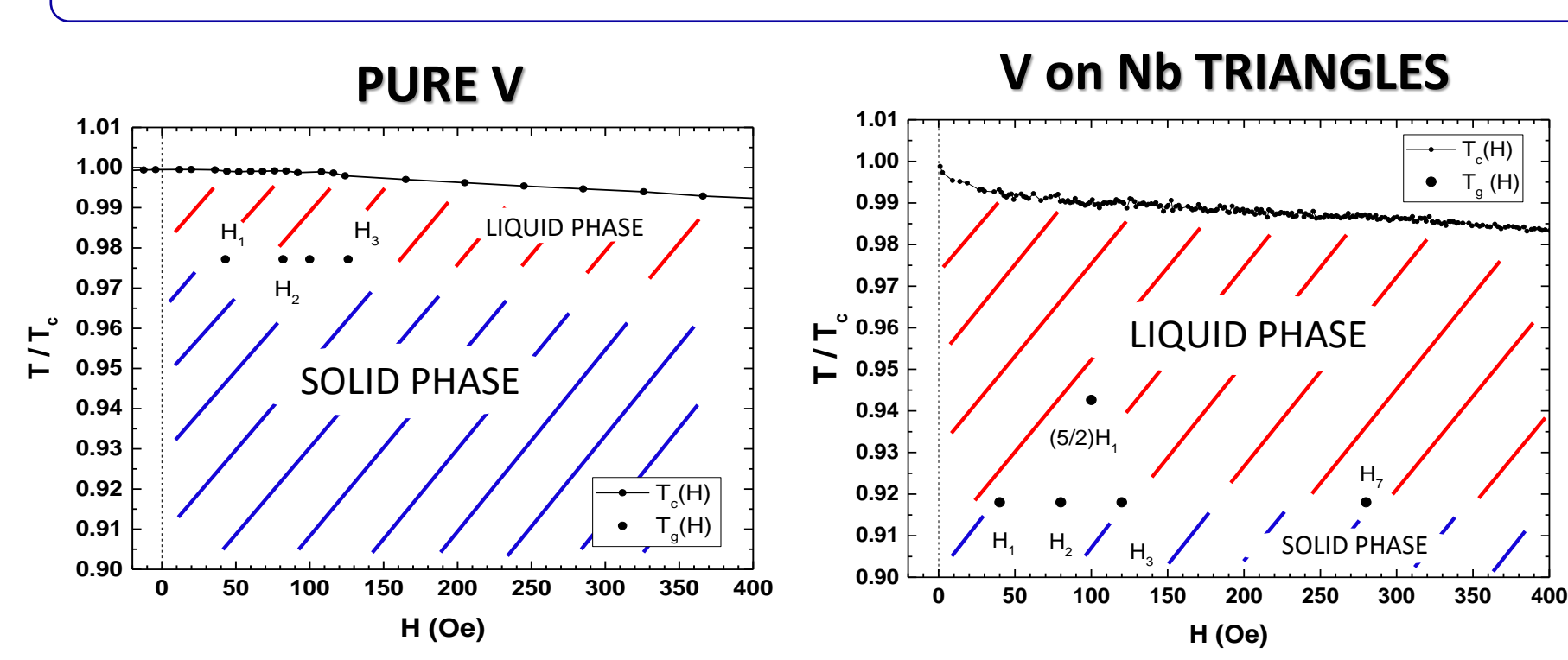
ANGLE DEPENDENT MEASUREMENTS

- 5°
- 25°
- 59.5°
- 71°
- 85°

$H_m(\theta) = \frac{H_m(0)}{\cos\theta}$

θ H

- Usual minima periodicity angle dependence $H_m \sim 1/\cos(\theta)$ [2]
- Normal commensurability effect is recovered at θ > 70°
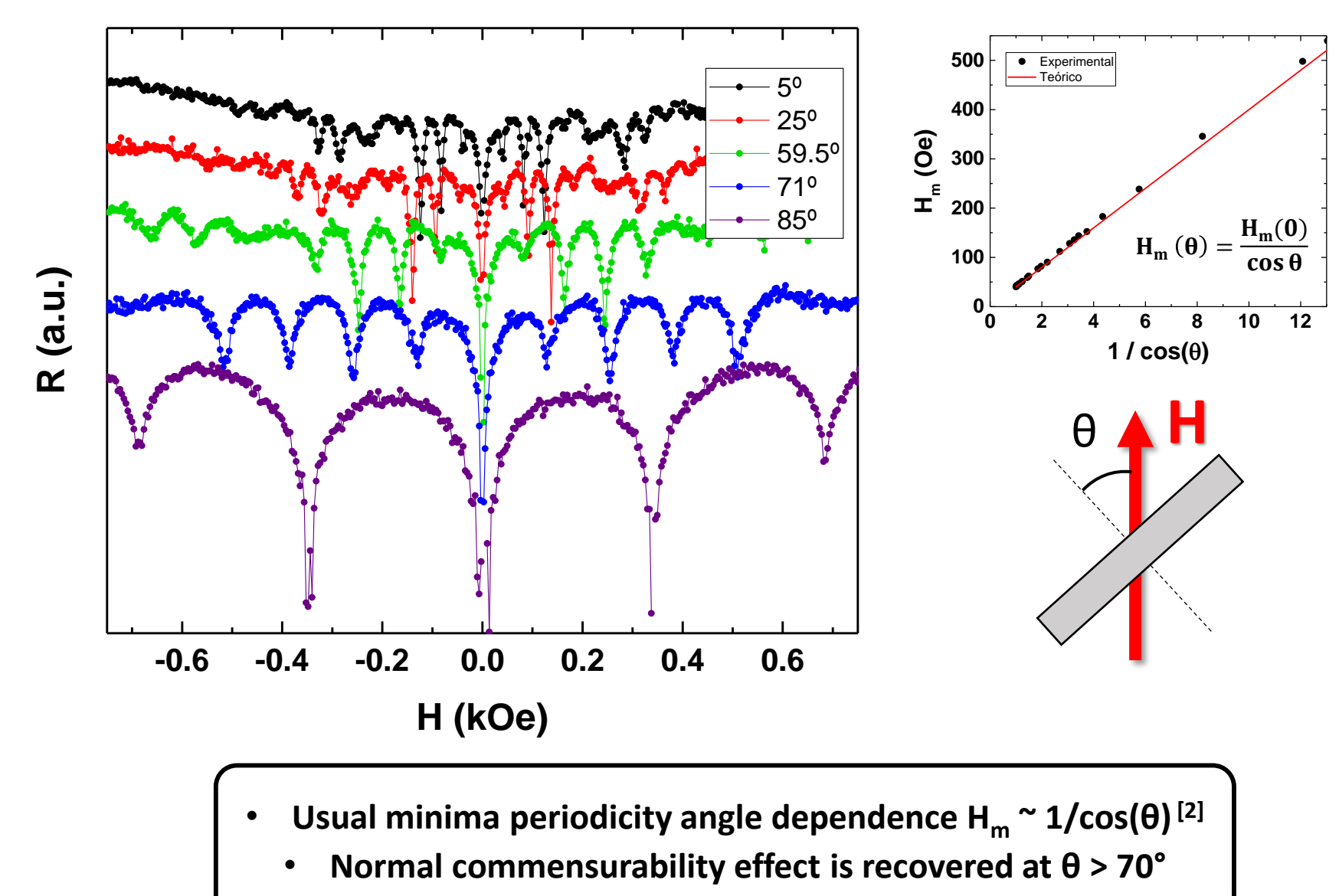
MINIMA VANISH AT SOLID PHASE

- 0.975Tc = 4.15 K - 50 µA
- 0.805Tc = 3.43 K - 5.05 mA

RESISTANCE OSCILATIONS AT LOW TEMPERATURE

USUAL BEHAVIOUR WITH NON-SUPERCONDUCTING TRIANGLES
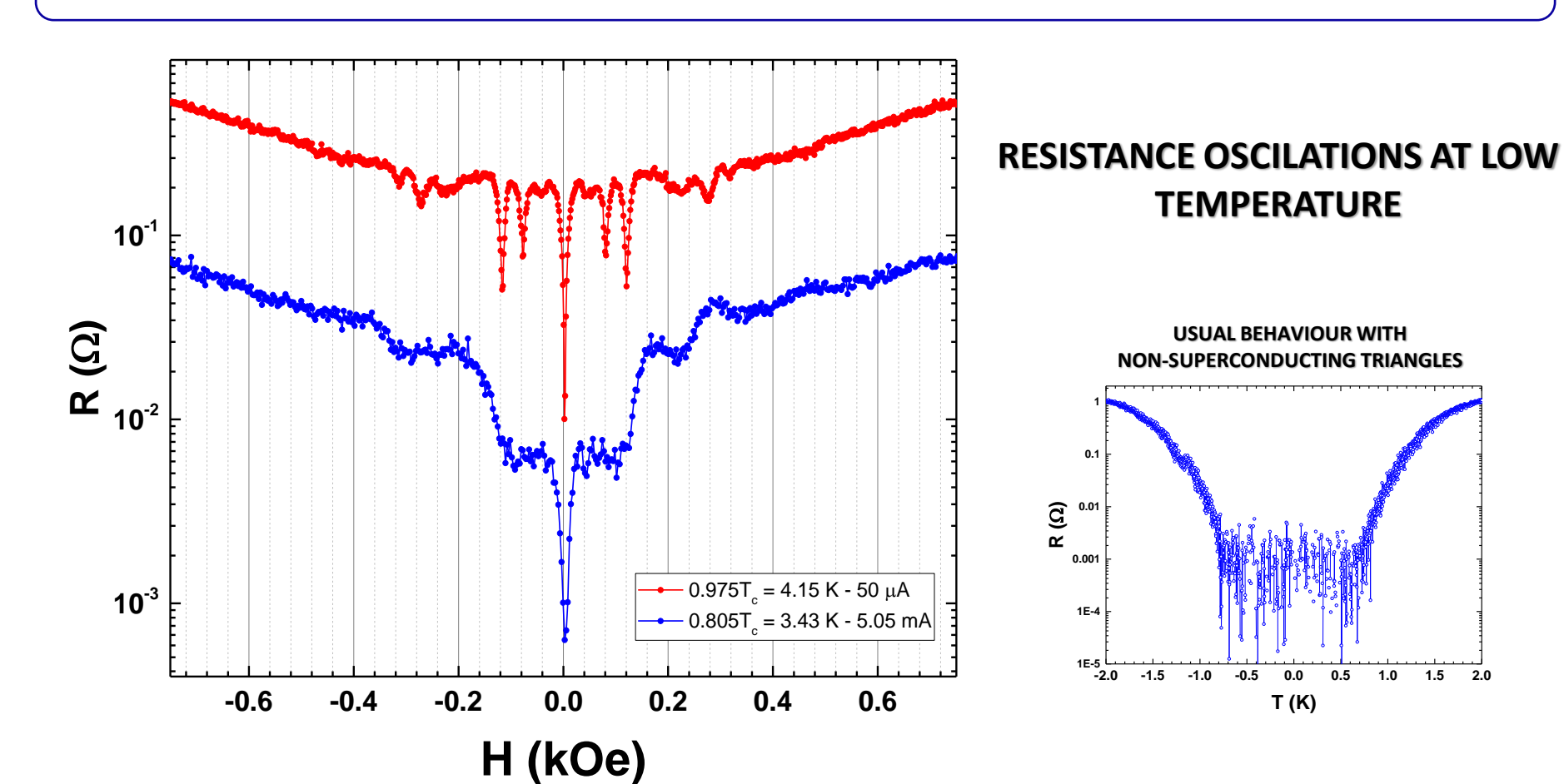
HYSTERETIC BEHAVIOUR AT SOLID PHASE

- Increasing magnetic field
- Decreasing magnetic field

$T = 0.805Tc - 3.43$ K
I = 5.05 mA

ADDING VORTICES (increasing field)
≠
REMOVING VORTICES (decreasing field)

⬇

HYSTERESIS

CONCLUSIONS

- SUPERCONDUCTING PINNING SITES
- ANOMALOUS MATCHING EFFECT
- MINIMA VANISH AT LOW TEMPERATURES
- LIQUID PHASE BROADENING
- MAGNETIC FIELD – SAMPLE ANGLE MODIFIES COMMENSURABILITY

REFERENCES

[1] J. I. Martin et al. Phys. Rev. Lett. 79, 10 (1997)

[2] E. Navarro et al. Phys. Rev. B 92, 144512 (2015)

[3] J. del Valle et al. New J. Phys. 17 093022 (2015)