DDF 2015

Reorganización dinámica en vórtices superconductores.

Gabriela Pasquini

Área de Materia Condensada
Laboratorio de Bajas Temperaturas

En colaboración con:

- **Mariano Marziali Bermúdez**
  (DF, FCEyN, UBA; IFIBA, CONICET)

- **Morten Eskildsen**
  (Notre Dame, USA)

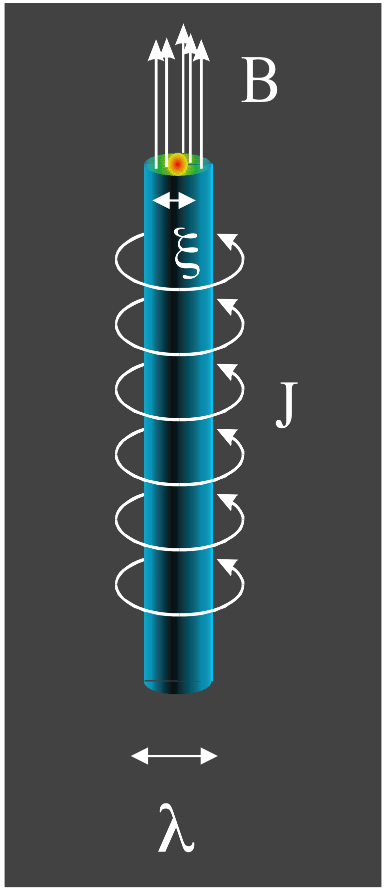
- **Victoria Bekeris**
  (DF, FCEyN, UBA; IFIBA, CONICET)

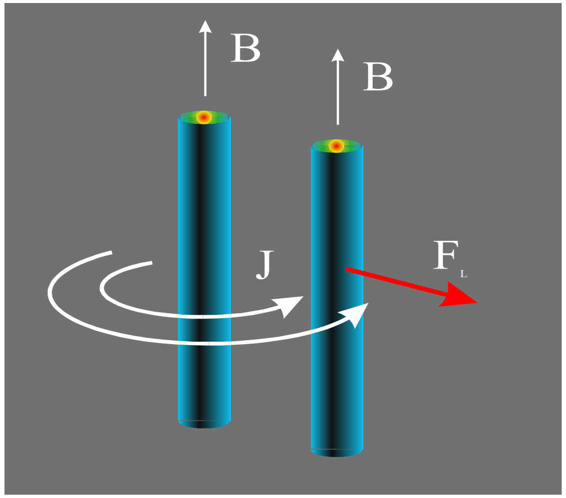
- **Gergeley Nagy** (PSI, Suiza)
- **Marek Bartkoviak** (PSI, Suiza)

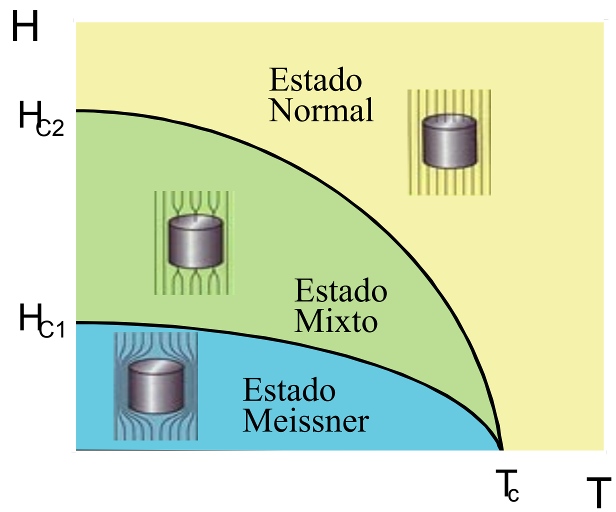
Experimentos previos y simulaciones:

- **Diego Pérez Daroca** (CNEA, CONICET)
- **Gustavo Lozano** (DF, FCEyN, UBA; IFIBA, CONICET)

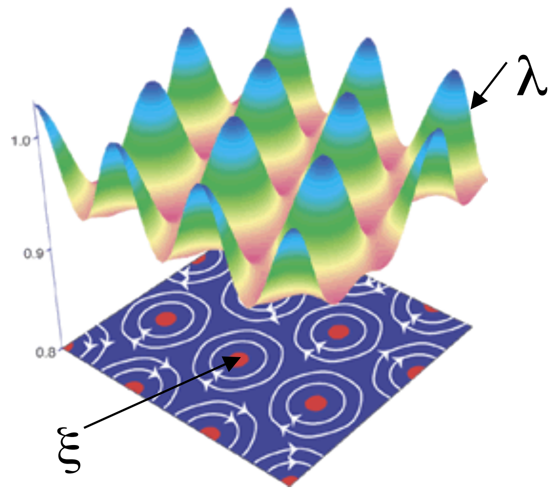
Vórtices en Superconductores





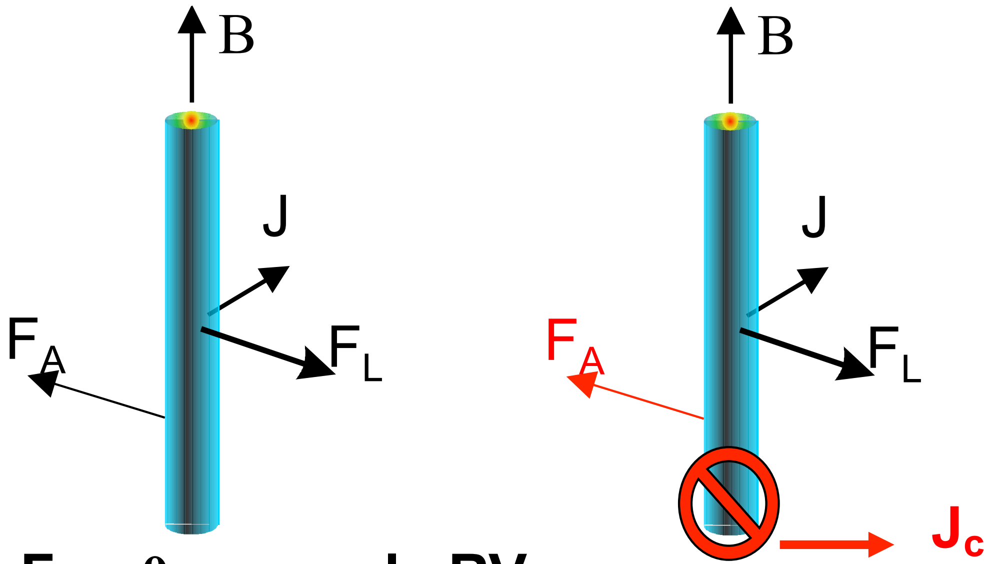


Interacción repulsiva



Se organizan en una Red de vórtices (RV)

Vórtices en Superconductores
El rol de los defectos estructurales



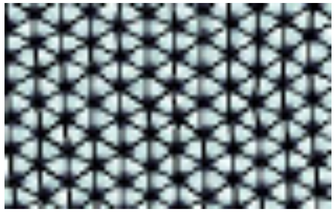
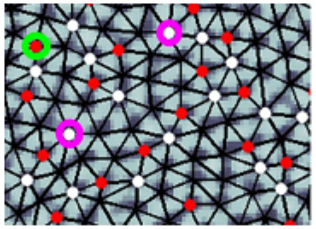
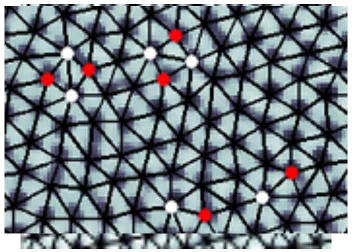
$F_L \neq 0$ mueve la RV

- Aparecen dislocaciones
- No hay orden de largo alcance
- El sistema se desordena

•Los defectos rompen la simetría de traslación!

•Hay sitios energéticamente favorables (centros de anclaje). Si $F_L < F_C$ no se mueven. F_C determina J_C.

La “materia de vórtices” es un sistema complejo: Interacciones competitivas

Interacción dominante	Configuración espacial	Anclaje
Vortice-vórtice	Bragg glass (BG) “sin dislocaciones”. 	débil
Vórtice defecto	Vidrio desordenado 	fuerte
Compiten	**Dislocaciones (desorden intermedio)** 	**intermedio**

Imágenes de experimentos de STM, S. Ganbuli et al. Scientific Report 5,10613, 2015

La materia de vórtices: un sistema complejo modelo

Envejecimiento

PRL 96, 217203 (2006) PHYSICAL REVIEW LETTERS week ending 2 JUNE 2006

Dynamic Compressibility and Aging in Wigner Crystals and Quantum Glasses

Leticia F. Cugliandolo,[1,2] Thierry Giamarchi,[3] and Pierre Le Doussal[2]
[1]Laboratoire de Physique Théorique et Hautes Energies, 4 Place Jussieu, 75252 Paris Cedex 05, France
[2]LPTENS CNRS UMR, 8549 24, Rue Lhomond 75231 Paris Cedex 05, France
[3]University of Geneva, DPMC, 24 Quai Ernest Ansermet, CH-1211 Geneva 4, Switzerland
(Received 19 November 2005; published 1 June 2006)

We study the nonequilibrium linear response of quantum elastic systems pinned by quenched diso
with Schwinger-Keldysh real-time techniques complemented by a mean-field variational approach.
find (i) a quasiequilibrium regime in which the analytic continuation from the imaginary-time rep
results holds provided the marginality condition is enforced, and (ii) an aging regime. The conducti
and compressibility are computed. The latter is found to cross over from its dynamic to static value
scale set by the waiting time after a quench, an effect which can be probed in experiments in, e.g., Wi
glasses.

DOI: 10.1103/PhysRevLett.96.217203 PACS numbers: 75.10.Nr, 71.55.Jv, 72.20.–i

Anclaje

Ruptura de Simetría

Cristales de Wigner

nature physics LETTERS
PUBLISHED ONLINE: 26 OCTOBER 2014 | DOI: 10.1038/NPHYS3132

Enhancement of long-range correlations in a 2D vortex lattice by an incommensurate 1D disorder potential

I. Guillamón[1,2,3]*, R. Córdoba[4,5†], J. Sesé[4,5], J. M. De Teresa[4,5,6], M. R. I
and H. Suderow[1,2]

Vórtices

Long-range correlations in two-dimensional (2D) systems are significantly altered by disorder potentials. Theory has predicted the existence of disorder-induced phenomena, such as Anderson localization[1] or the emergence of a Bose glass[2]. More recently, it has been shown that when disorder breaks 2D continuous symmetry, long-range correlations can be Thouless–Halperin–Nelson–Young (BKTHNY) theory through the two-stage proliferation and unbinding of topological defects[9,10,16,17]. Quenched disorder, on the other hand, is expected to suppress long-range correlations more effectively than temperature[18]. It can be classified as pinning with identifiable length scales, such as impurities or defects in 2D crystals, or as scale-invariant (random)

ARTICLES

Random organization in periodically driven systems

LAURENT CORTÉ[1], P. M. CHAIKIN[1], J. P. GOLLUB[2] AND D. J. PINE[1]*
[1]Department of Physics, New York University, 4 Washington Place, New York, New York 10003, USA
[2]Department of Physics, Haverford College, Haverford, Pennsylvania 19041, USA
*e-mail: pine@nyu.edu

Reordenamiento dinámico

Coloides

Published online: 16 March 2008; doi:10.1038/nphys891

Understanding self-organization is one of the key tasks for controlling and manipulating the structure of materials at the micro- and nanoscale. In general, self-organization is driven by interparticle potentials and is opposed by the chaotic dynamics characteristic of many driven non-equilibrium systems. Here we introduce a new model that shows how the irreversible collisions that generally produce diffusive chaotic dynamics can also cause a system to self-organize to avoid future collisions. This can lead to a self-organized non-fluctuating quiescent state, with a dynamical phase transition separating it from fluctuating diffusing states. We apply the model to recent experiments on periodically sheared particle suspensions where a transition from reversible to irreversible behaviour was observed. New experiments presented here exhibit remarkable agreement with this simple model. More generally, the model and experiments provide new insights into how driven systems can self-organize.

Elasticidad y plasticidad

VOLUME 93, NUMBER 6 PHYSICAL REVIEW LETTERS week ending 6 AUGUST 2004

Measurement of the Shear Strength of a Charge Density Wave

K. O'Neill, K. Cicak, and R. E. Thorne
Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, New York 14853-2501, USA
(Received 3 December 2003; published 6 August 2004)

We have explored the shear plasticity of charge density waves (CDWs) in $NbSe_3$ samples with cross sections having a single microfabricated thickness step. Shear stresses along the step result from thickness-dependent CDW pinning. For small thickness differences the CDW depins elastically at the volume average depinning field. For large thickness differences the thicker, more weakly pinned side depins first via plastic shear, and shear plasticity contributes substantial dissipation well above the depinning field. A simple model describes the qualitative features of our data and yields a value for the CDW's shear strength of approximately 9.5×10^3 Nm^{-2}. This value is orders of magnitude smaller than the CDW's longitudinal modulus but much larger than corresponding values for flux line lattices, and in part explains the relative coherence of the CDW response.

DOI: 10.1103/PhysRevLett.93.066601 PACS numbers: 72.15.Nj, 71.45.Lr, 73.23.–b, 74.25.Qt

The elastic and plastic properties of driven periodic media including charge/spin density waves (CDWs/ ... $NbSe_3$ and related quasi-one-dimensional CDW materials grow as long thin ribbons. Shear usually results from ... (b) axis, which

Ondas de densidad de carga

Paredes de domino

jamming

desorden intermedio

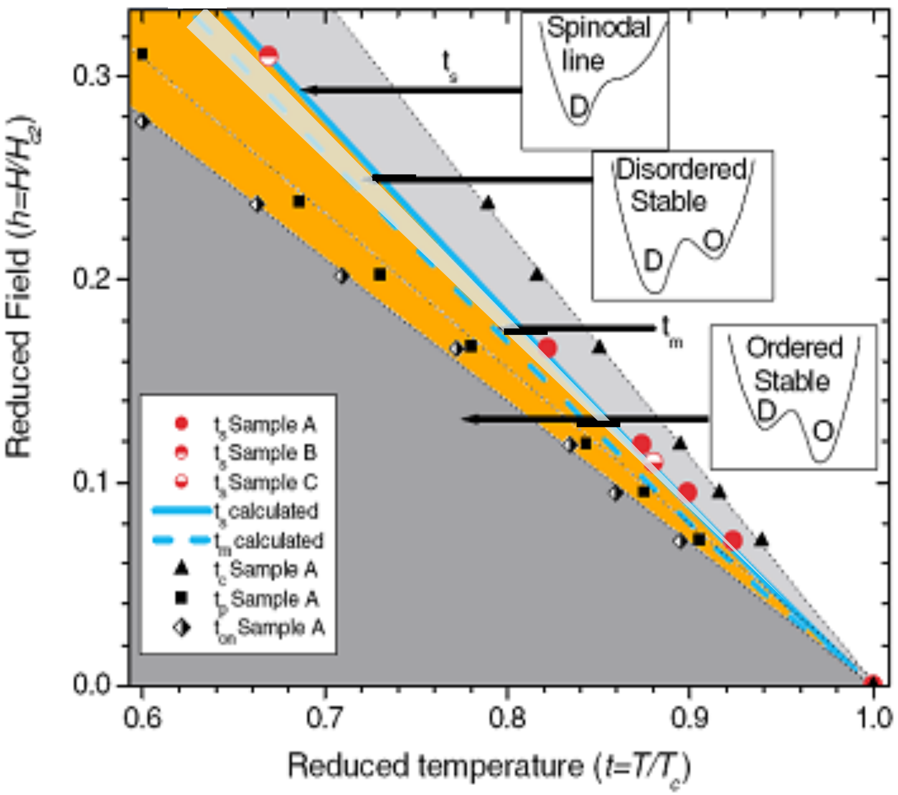
LETTERS nature physics
PUBLISHED ONLINE: 6 JULY 2014 | DOI: 10.1038/NPHYS3006

Solids between the mechanical extremes of order and disorder

Carl P. Goodrich[1]*, Andrea J. Liu[1] and Sidn

Packing de esferas

Transición Orden-Desorden (TOD) y Efecto Pico (EP)



Monocristales limpios de $NbSe_2$

Z. Xiao et al; PRL. **85**,3265 (2004)

Vidrio de Bragg (Bragg Glass: BG)

Longitud de correlación $\zeta >> a_0$

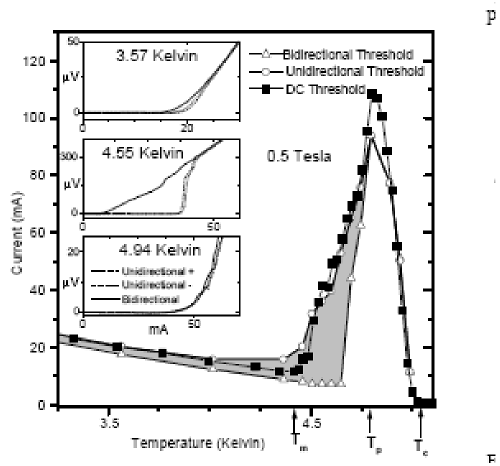
Sin dislocaciones

bajo anclaje, baja J_c

Región de transición

TOD

J_c ↑



Amorfo

Longitud de correlación $\zeta \sim a_0$

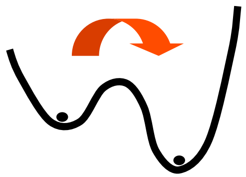
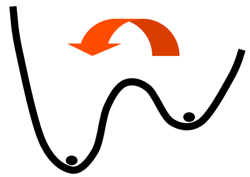
Dislocaciones

Efectos de historia dinámica

Después de mover los vórtices

- Con una corriente
- Variando H
- Con un campo alterno

En una fase metaestable

En el BG H y T bajos	H y T altos
Domina $F_{V\text{-}V}$ Se ordena la RV Anclaje (J_c) disminuye 	Domina F_{anc} Se desordena la RV Anclaje (J_c) aumenta 

Qué pasa en la región de transición?

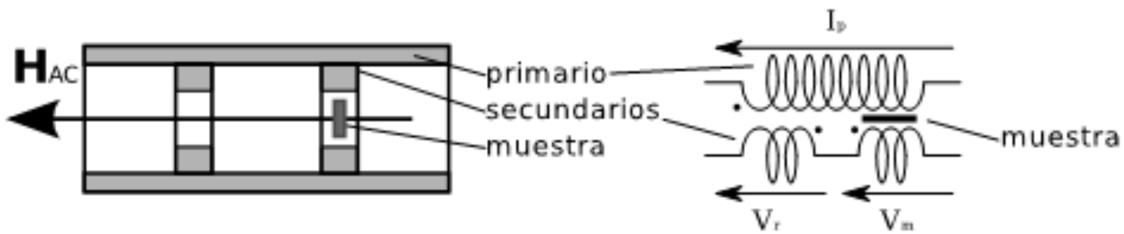
Susceptibilidad alterna en BT

La muestra se monta en un pequeño transformador a temperatura criogénica , con un campo aplicado H.
El primario modula H . Dos secundarios en contrafase miden la variación de flujo en la muestra.

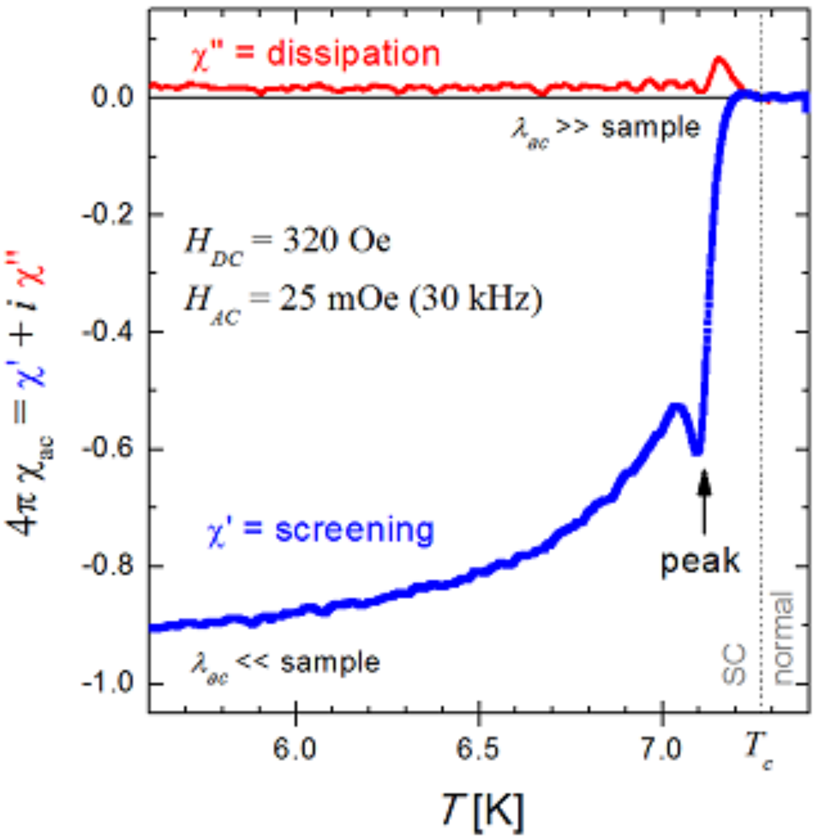
Mediciones no invasivas

- h_{ac} muy chico ($h_{ac} \sim H/10^5$).

Transformador diferencial



Susceptibilidad alterna lineal χac(t) : una forma no invasiva de medir el anclaje de los vórtices



Recuerden

$\uparrow$ χ' $\uparrow$ λ_{ac} $\downarrow$ anclaje

Qué pasa en la región de transición?

PRL **100**, 247003 (2008) PHYSICAL REVIEW LETTERS week endir 20 JUNE 2(

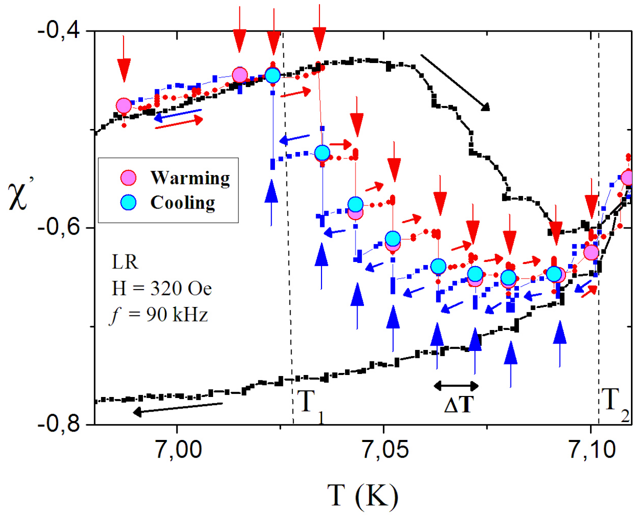
Ordered, Disordered, and Coexistent Stable Vortex Lattices in $NbSe_2$ Single Crystals

G. Pasquini,* D. Pérez Daroca, C. Chiliotte, G. S. Lozano, and V. Bekeris
Departamento de Física, FCEyN, Universidad de Buenos Aires, Pabellon 1, Ciudad Universitaria, Buenos Aires, Argentina
(Received 28 December 2007; published 16 June 2008)

PHYSICAL REVIEW B **84**, 012508 (2011)

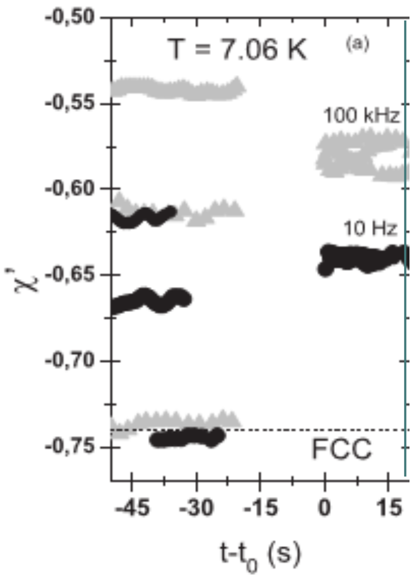
Dynamics of superconducting vortices driven by oscillatory forces in the plastic-flow regime

D. Pérez Daroca,* G. Pasquini, G. S. Lozano, and V. Bekeris
Departamento de Física, FCEyN, Universidad de Buenos Aires and IFIBA, CONICET; Pabellon 1, Ciudad Universitaria, 1428 Buenos Aires, Argentina
(Received 15 April 2011; revised manuscript received 20 May 2011; published 29 July 2011)



Después de agitar los vórtices: Respuestas intermedias independientes de condición inicial

La respuesta final depende de la frecuencia de agitado!



Modelo + simulaciones

Propusimos reorganización dinámica.

Nuestra propuesta

χ' intermedia → Orden Intermedio

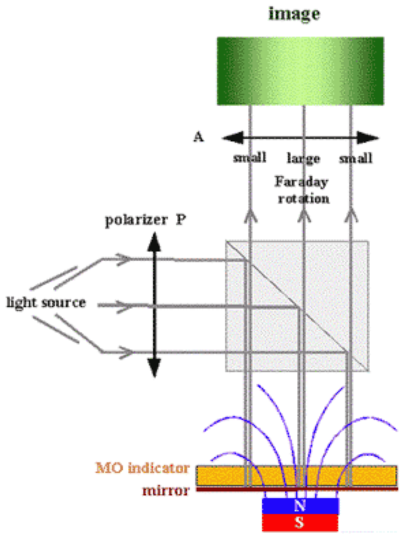
Dependencia en frecuencia y simulaciones numéricas sugieren una reorganización dinámica

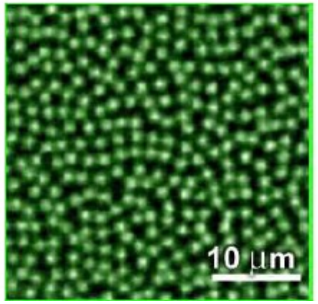
G. Pasquini, D. Perez Daroca, C. Chiliotte, G. Lozano y V. Bekeris; Phys.Rev.Lett. **100**, 247003 (2008).

D. Pérez Daroca, G. Pasquini, G.Lozano and V. Bekeris, Phys. Rev. B **84**, 012508 (2011) .

Vamos por evidencia directa

(bajos B)

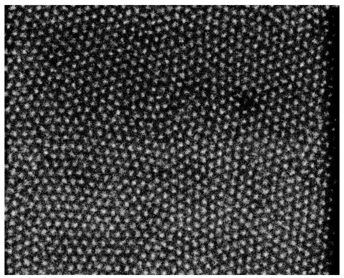


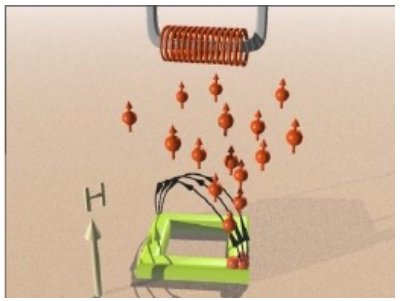


MO

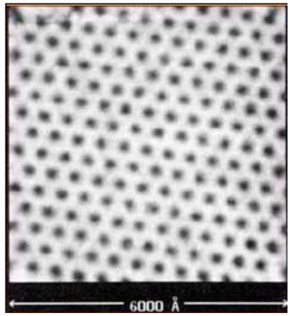
Decoración de Bitter

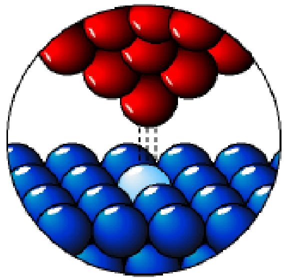
(bajos B)



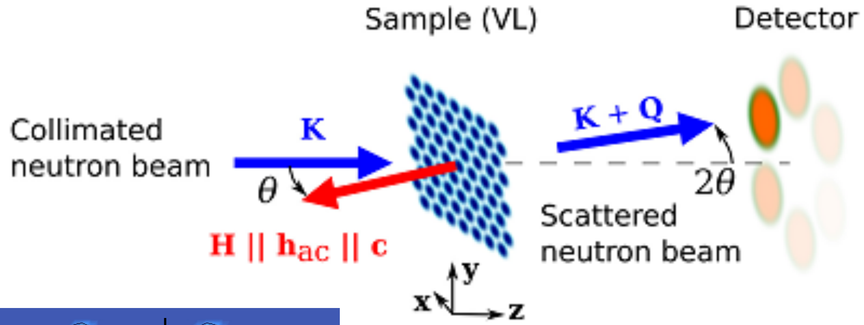


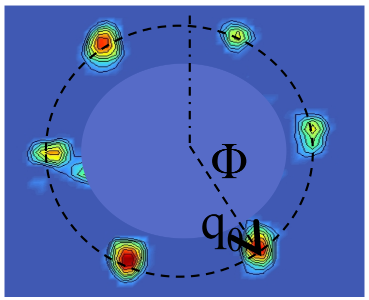
(areas chicas)





STM

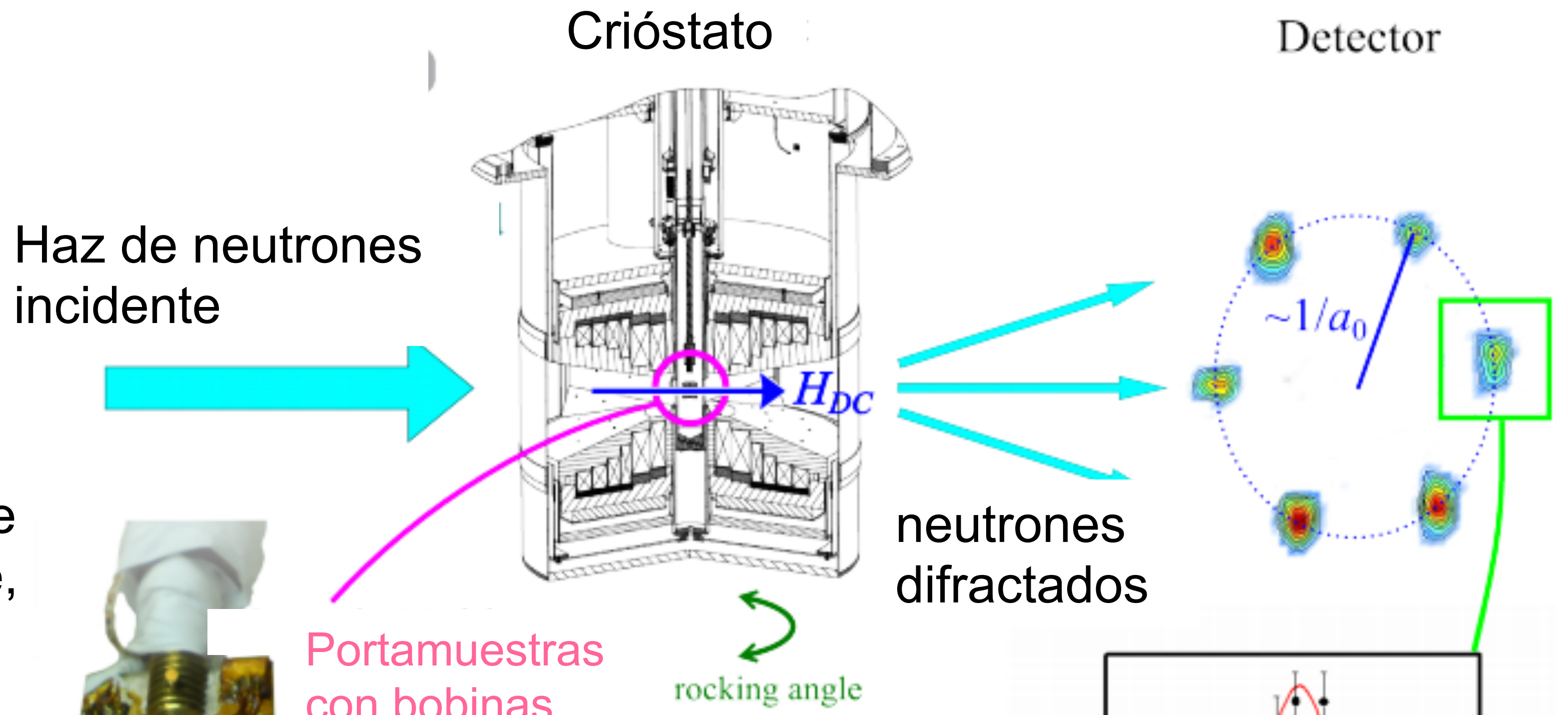




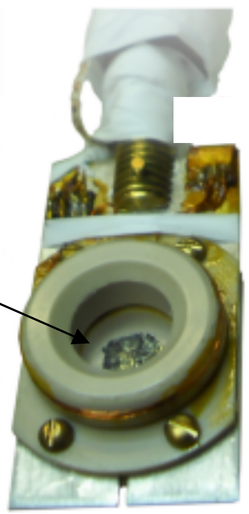
Neutrones: SANS

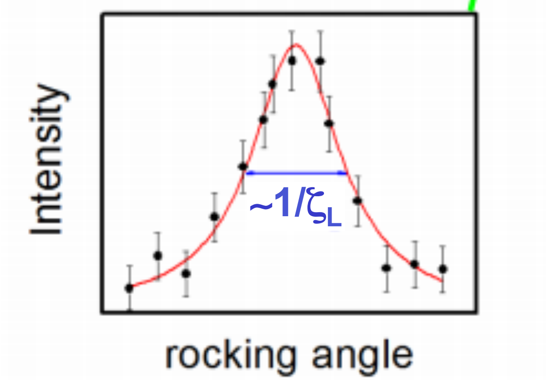
Toda la muestra.
B altos

Vamos por evidencia directa
Difracción de neutrones (SANS)



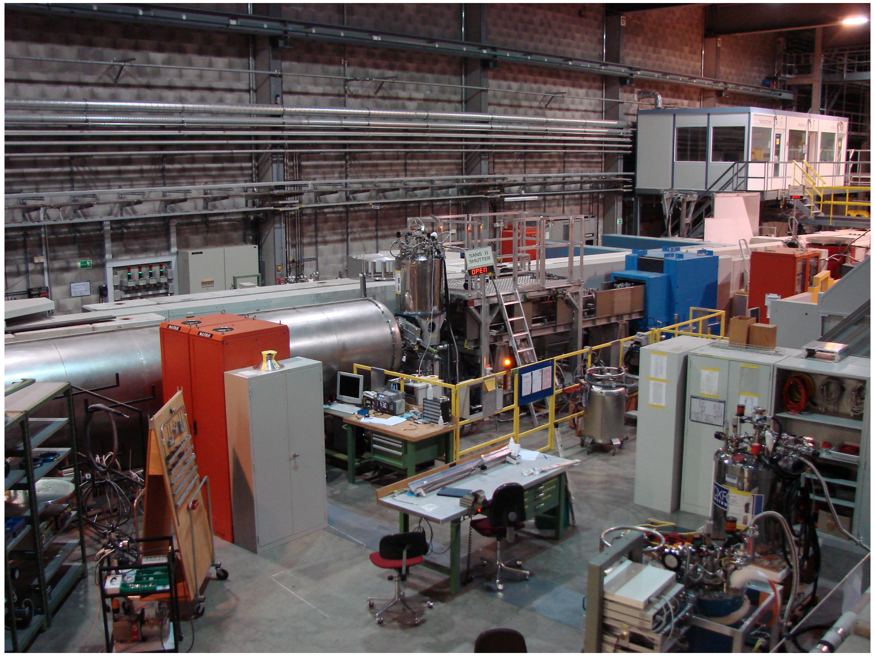
Monocristal de $NbSe_2$ grande, fabricado en Bell Labs



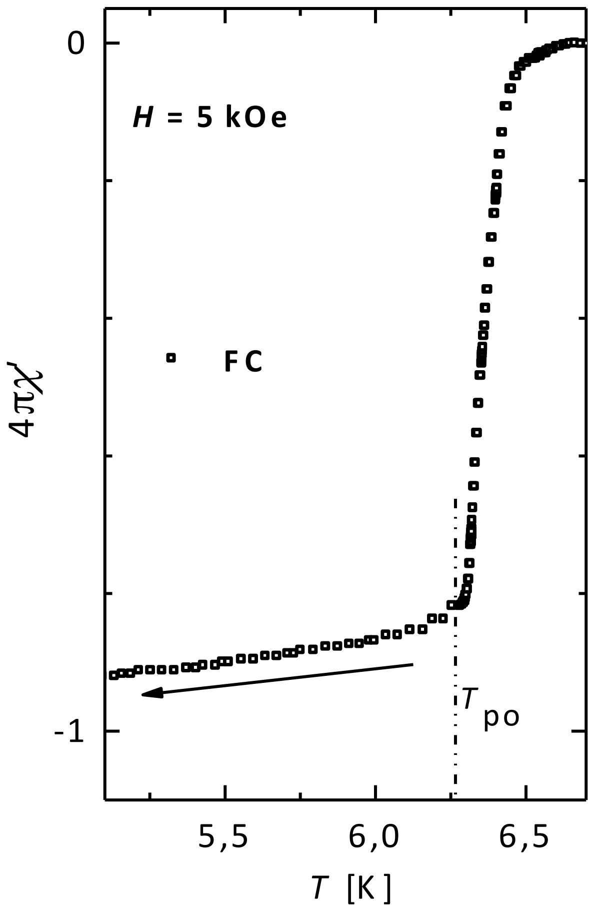


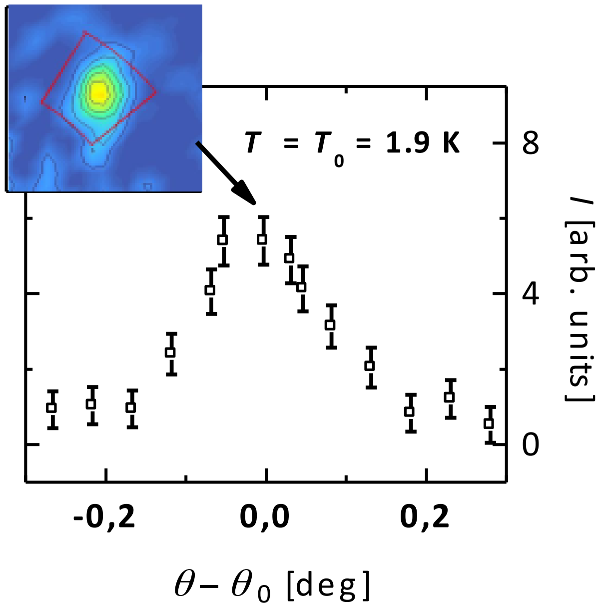
Vórtices en el espacio recíproco

PSI SANS-II/ MA11

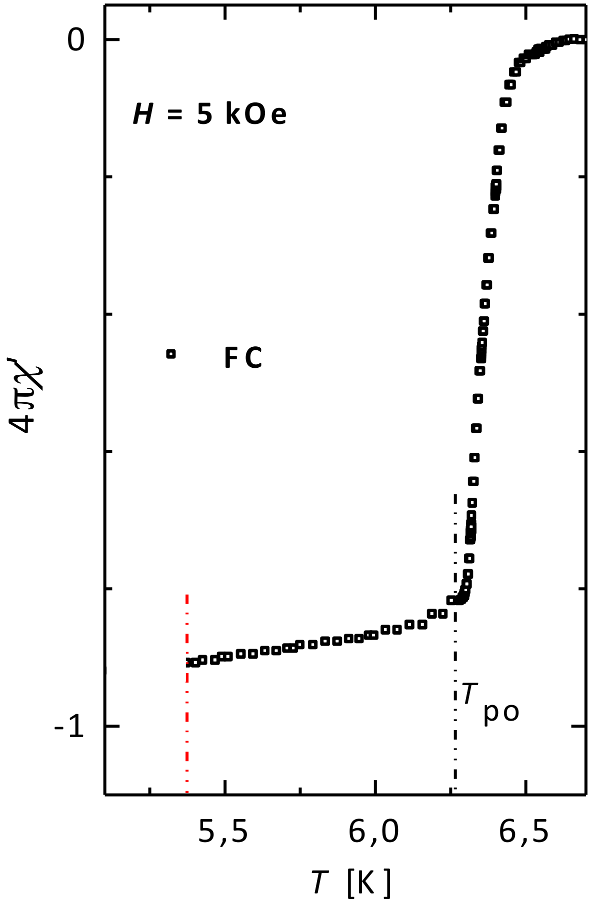


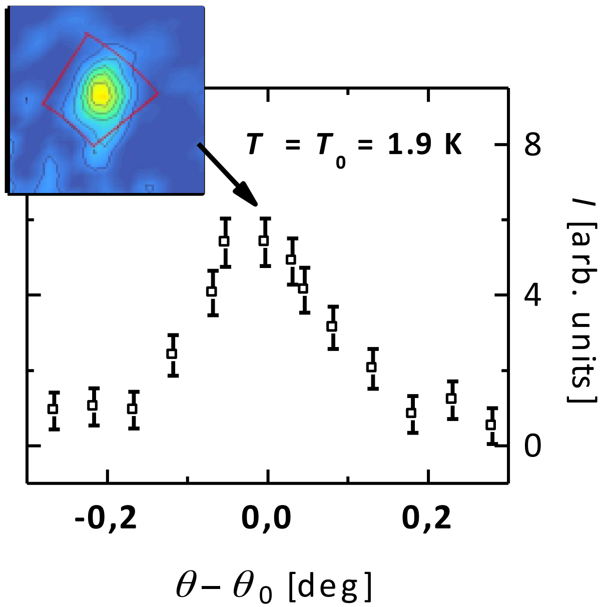
Agitando vórtices en el BG



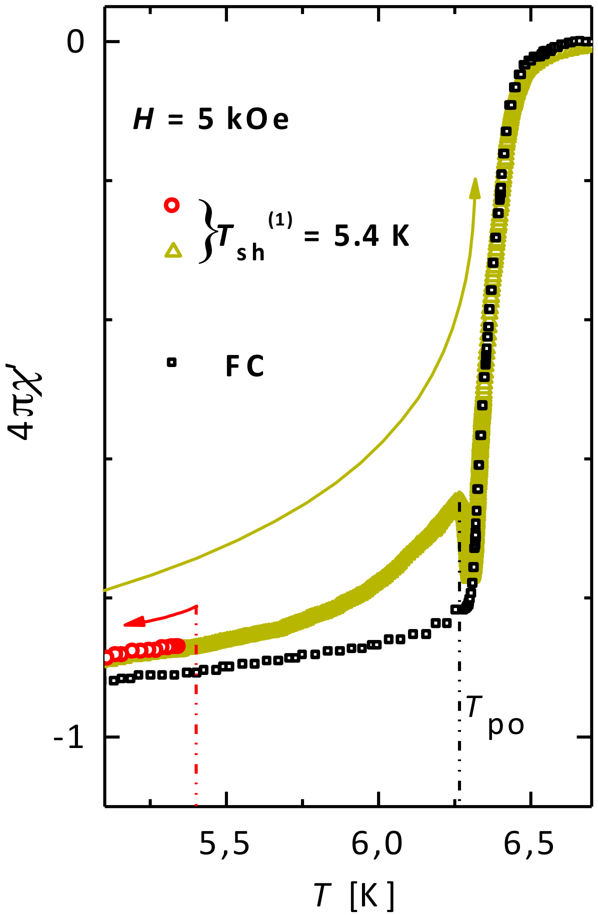


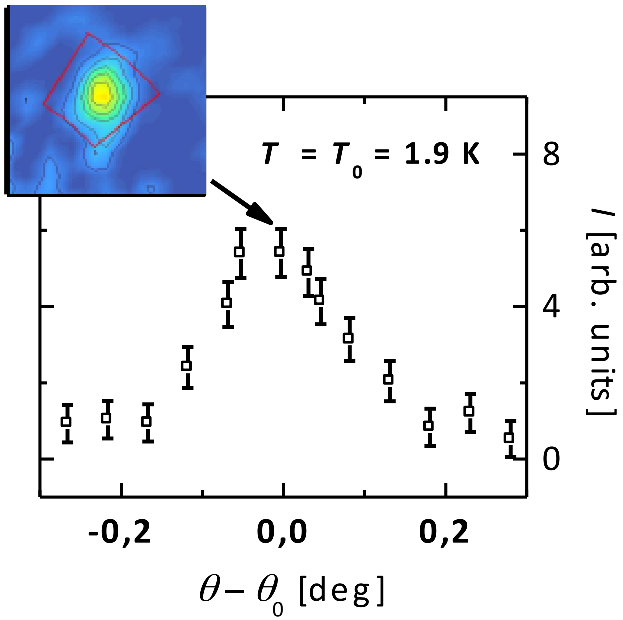
Agitando vórtices en el BG



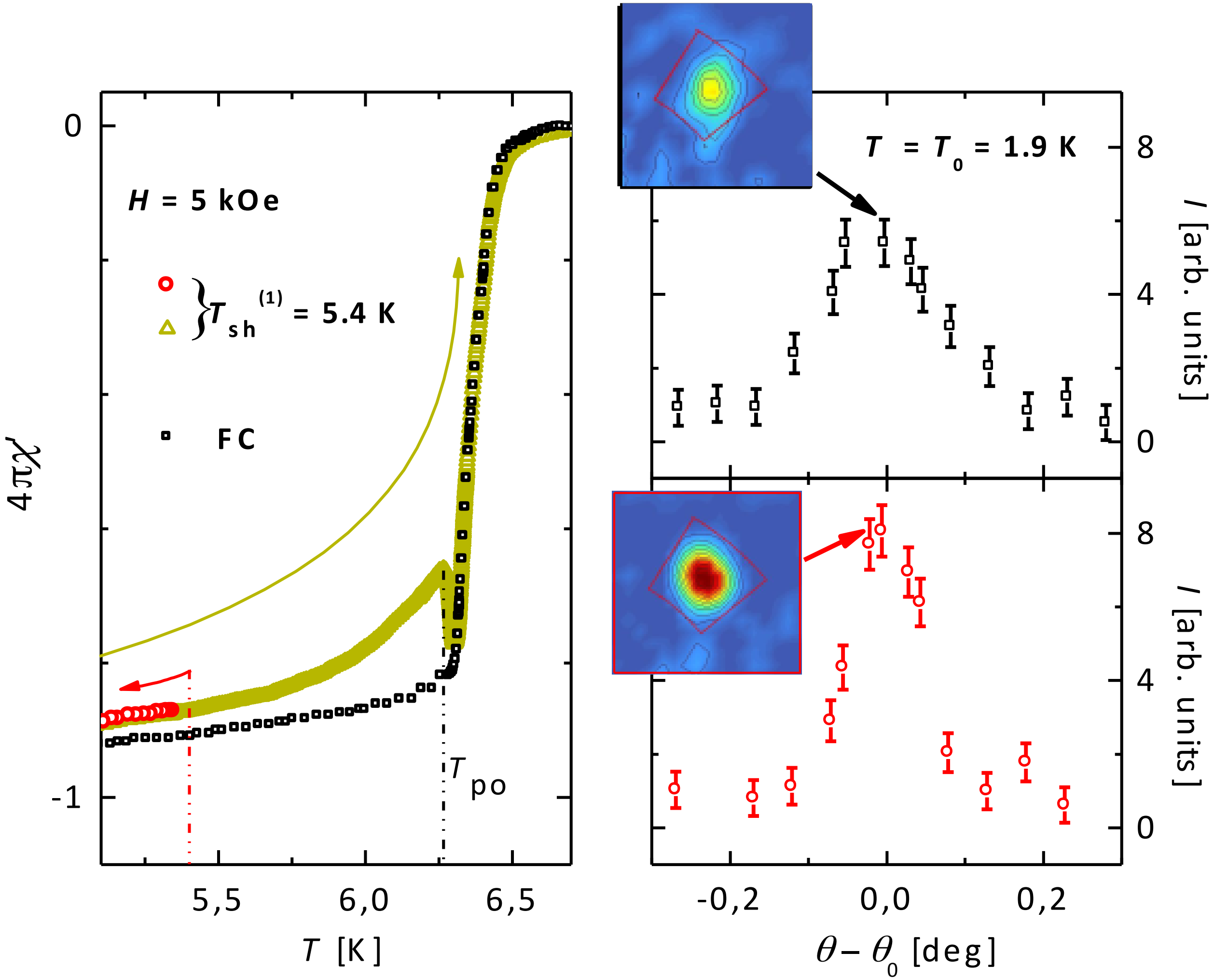


Agitando vórtices en el BG

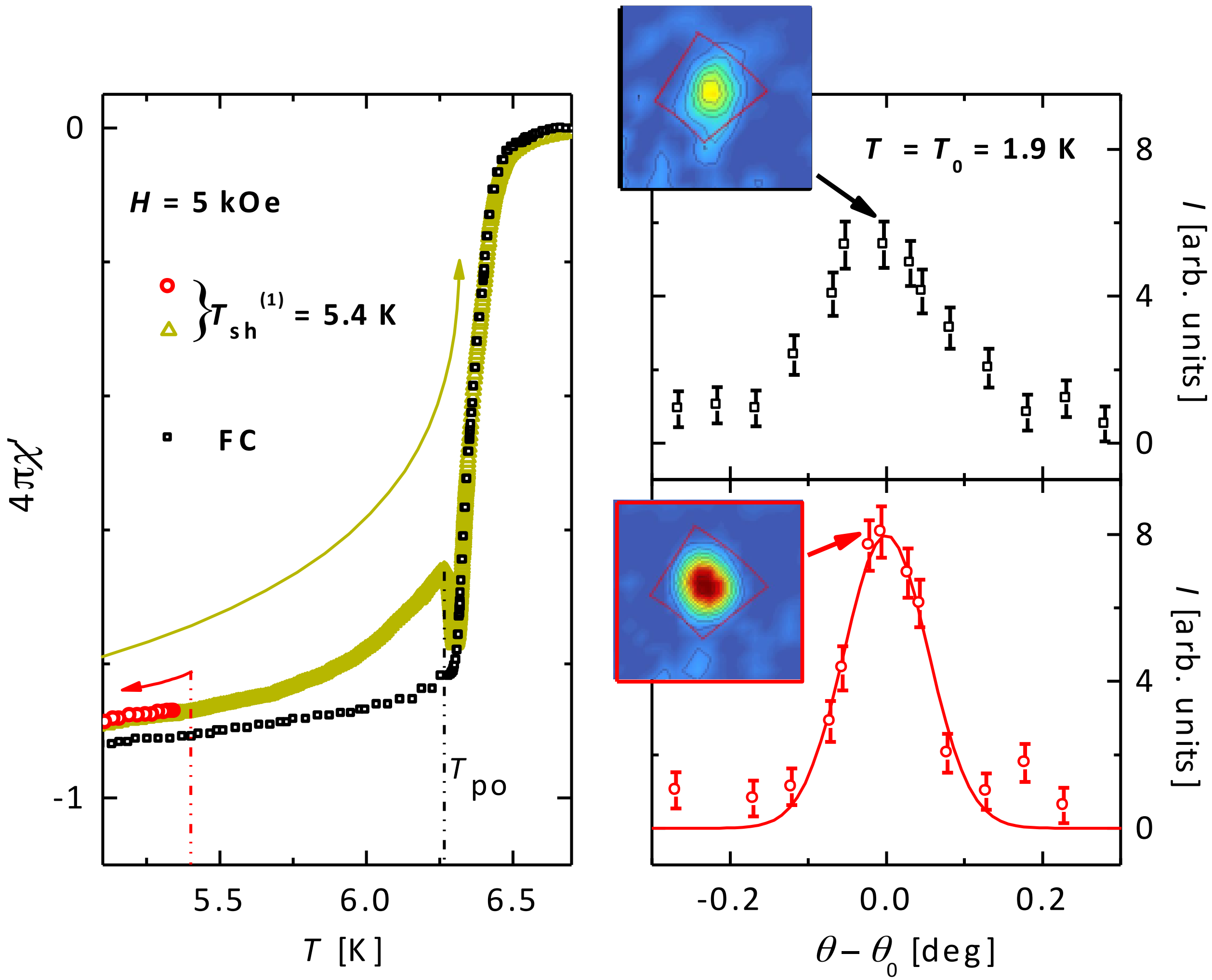




Agitando vórtices en el BG



Agitando vórtices en el BG

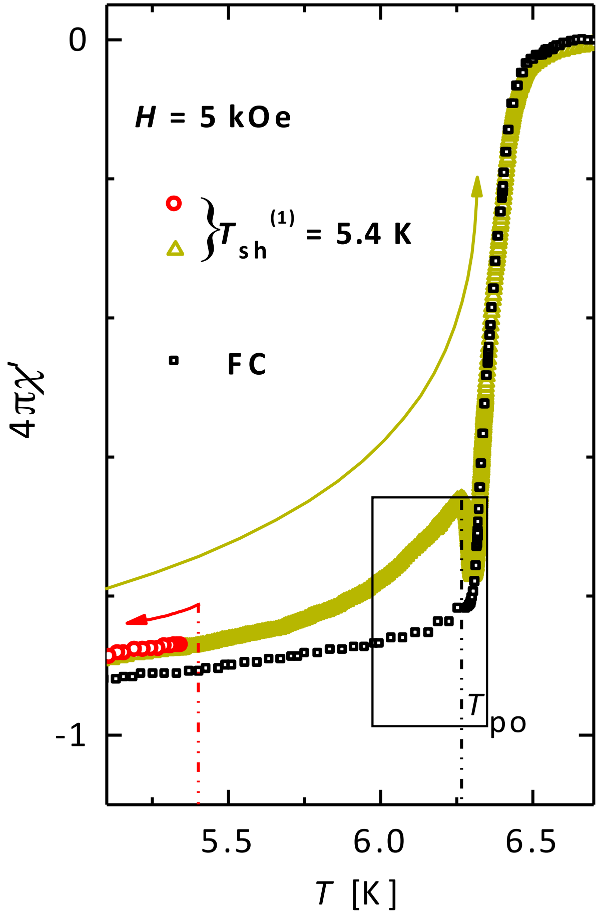


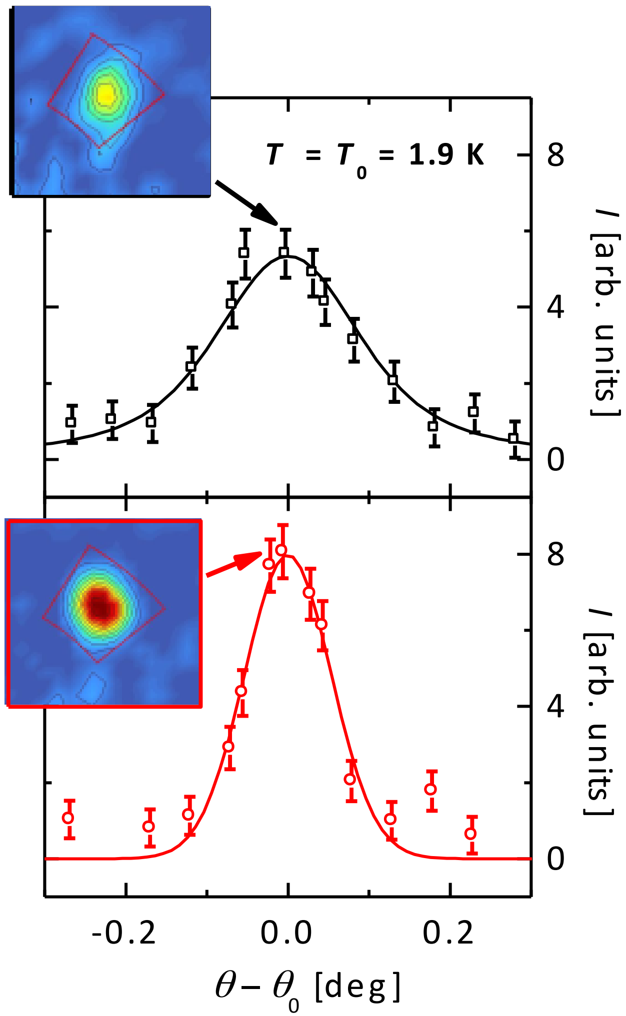
Resolución experimental

$$I(\theta) \approx \frac{2I_0}{\sqrt{2\pi}w_{res}} \exp\left[2\left(\frac{\theta-\theta_0}{w_{res}}\right)^2\right]$$

$\zeta_L >> 1/\omega_{res}$

Agitando vórtices en el BG





Podemos medirlo

$$I(\theta) = \int_{-\infty}^{\infty} \frac{I_0}{\pi} \frac{\gamma}{\gamma^2 + (\theta' - \theta_0)^2}$$

$$\frac{2}{\sqrt{2\pi} w_{res}} \exp\left[2\left(\frac{\theta' - \theta}{w_{res}}\right)^2\right] d\theta'.$$

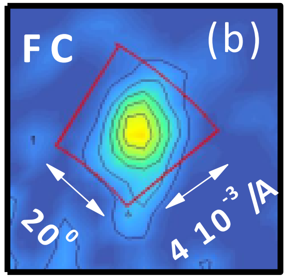
$\zeta_L = \gamma\, Q_0$

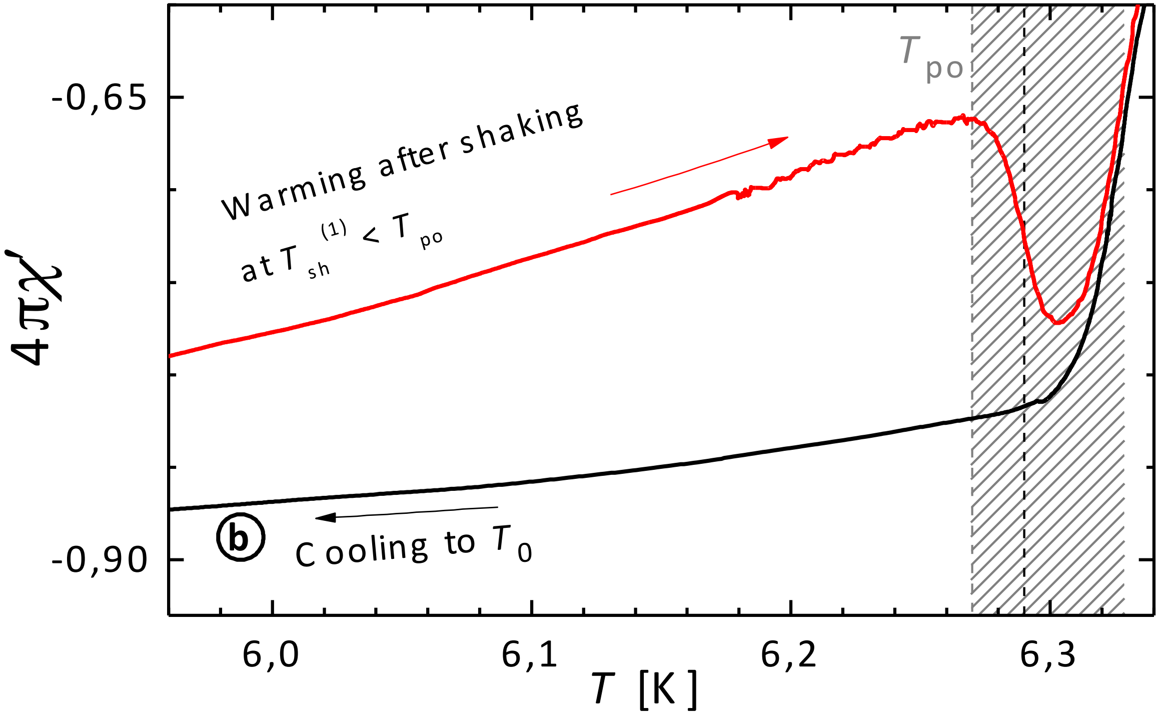
Resolución experimental

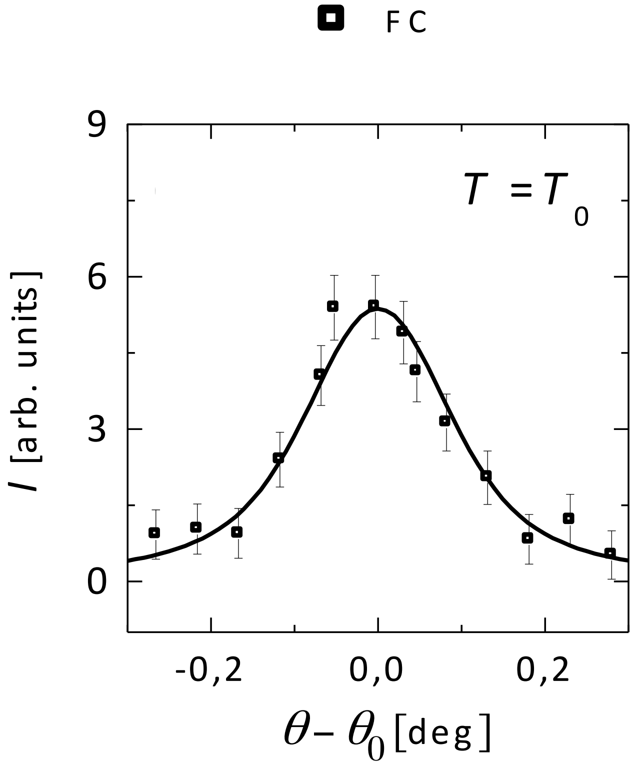
$$I(\theta) \approx \frac{2I_0}{\sqrt{2\pi} w_{res}} \exp\left[2\left(\frac{\theta - \theta_0}{w_{res}}\right)^2\right]$$

$\zeta_L >> 1/\omega_{res}$

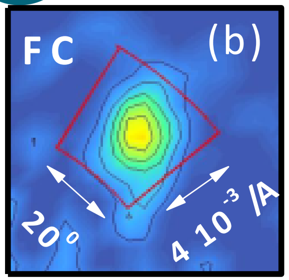
Agitando en la región de transición

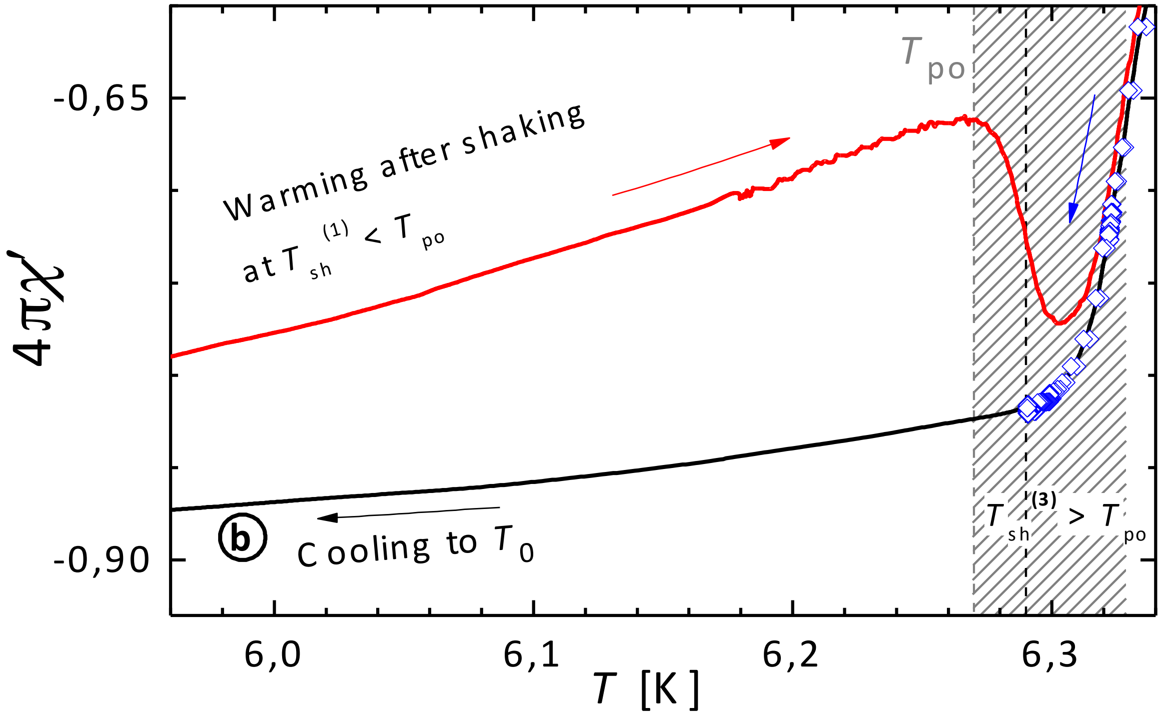


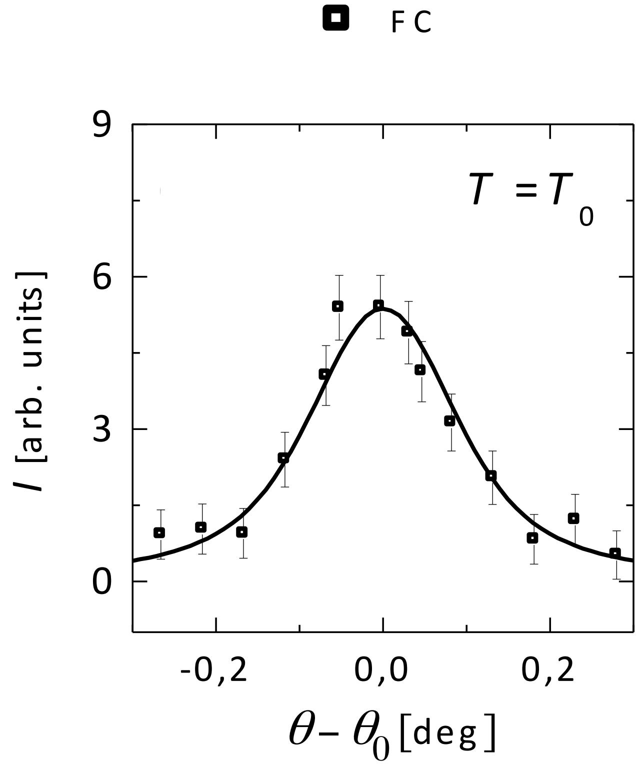




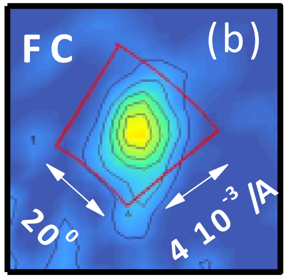
Agitando en la región de transición

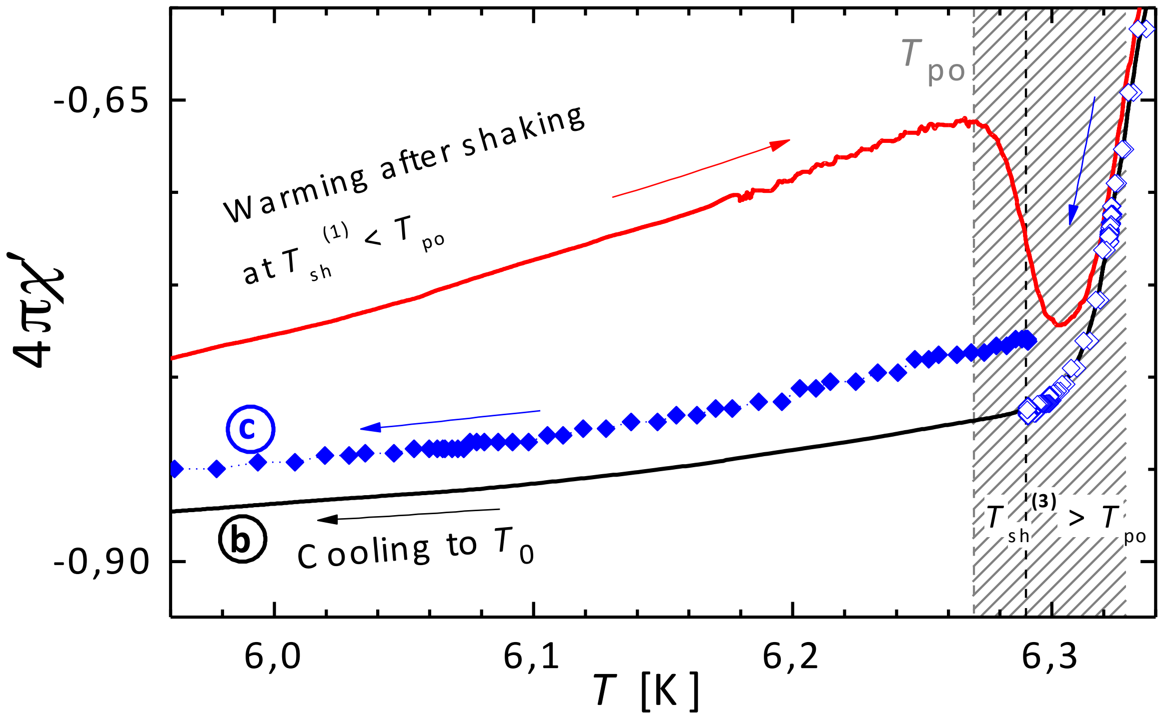


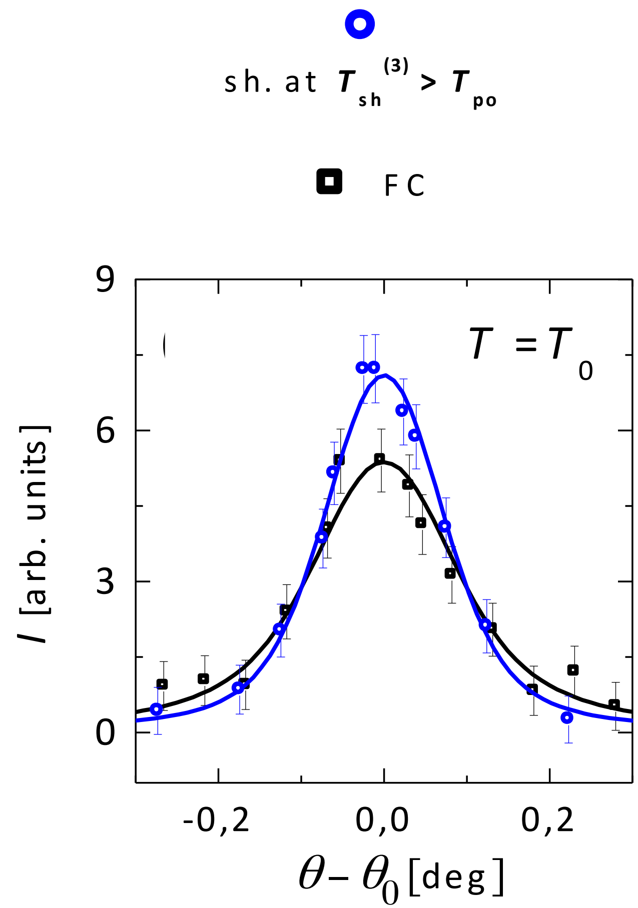




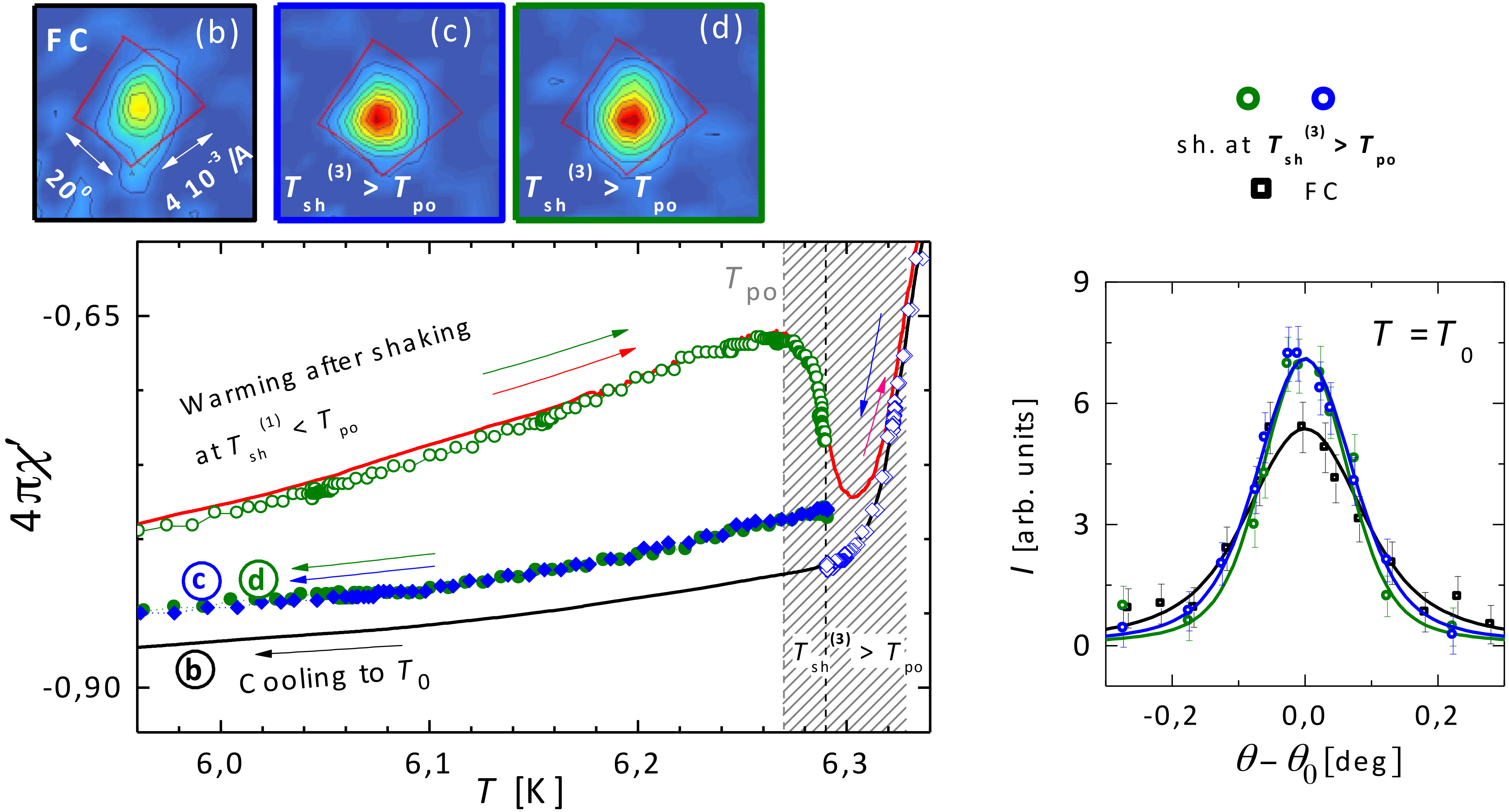
Agitando en la región de transición



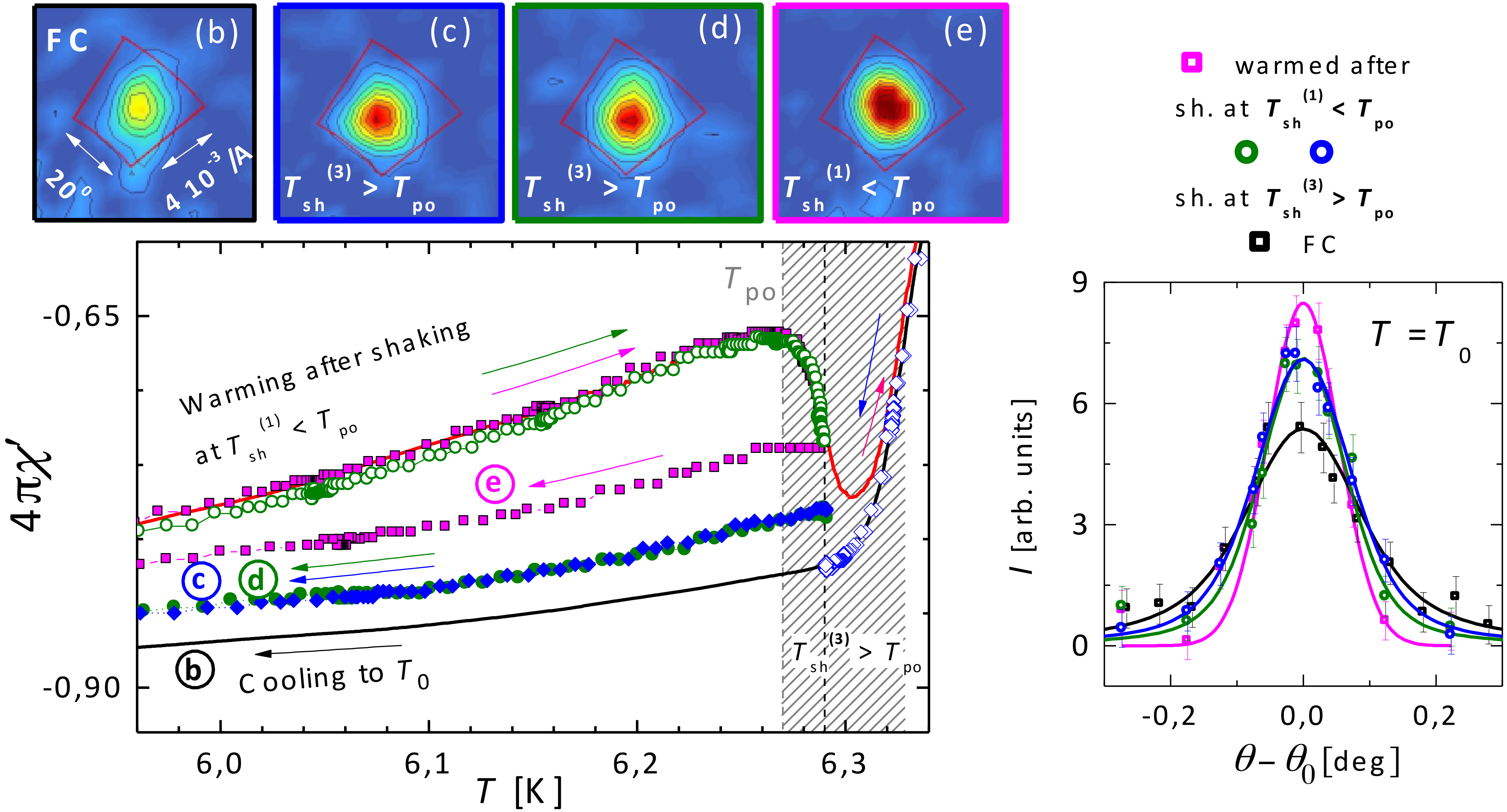




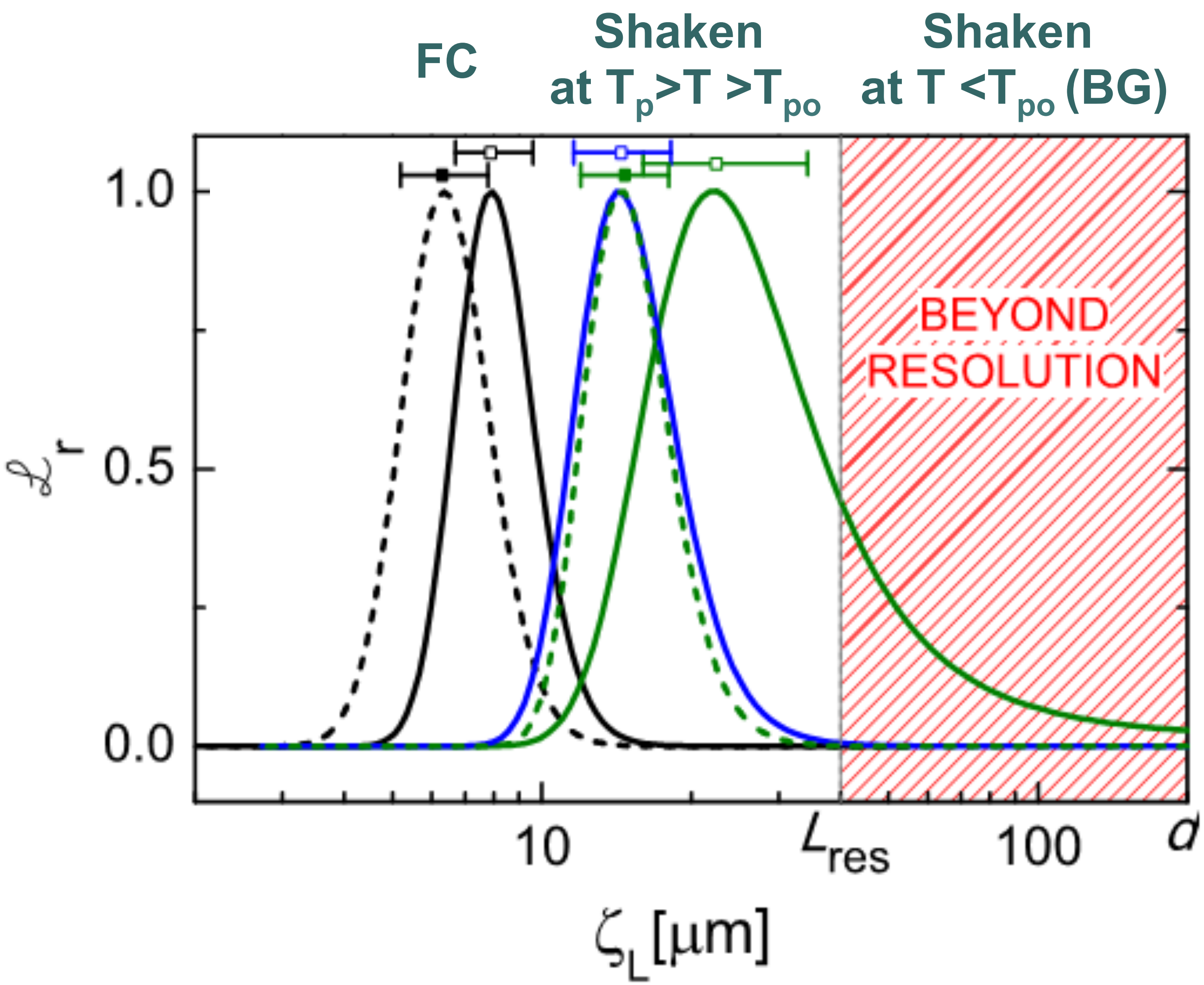
Agitando en la región de transición



Agitando en la región de transición



Desorden intermedio



$\zeta_\perp > a_0$

$\zeta_\perp$ **(BG) > L_{res}/14 ~ 35 a_0**

Estimaciones:

$\zeta_\perp$ **(FC) ~ 9 a_0** (5 a_0)

$\zeta_\perp$ **(int) ~ 18 a_0** (12 a_0)

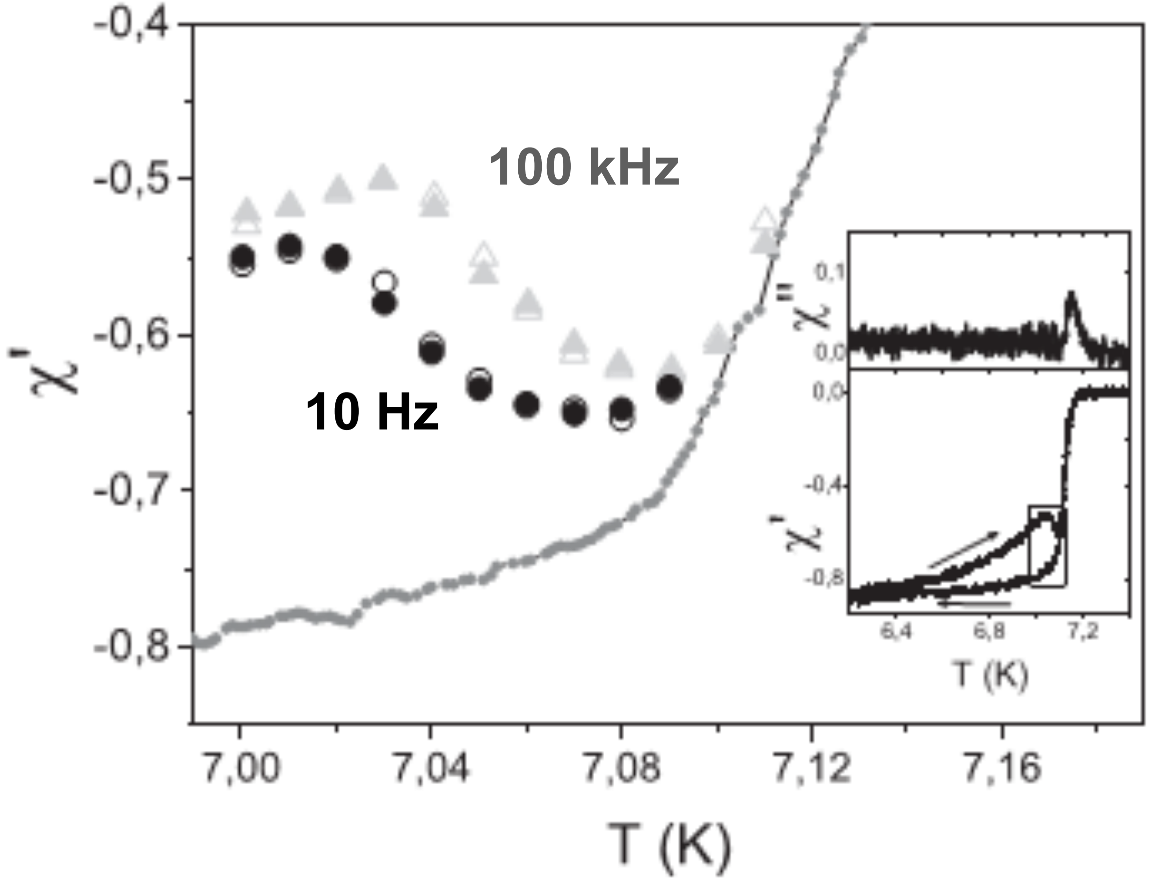
Conclusiones

- La dinámica oscilatoria (agitado) en la región de transición lleva al sistema de vórtices a configuraciones con desorden intermedio:
  - En toda la muestra (bulk)
  - Independientes de la configuración inicial
    - ⇒ Agitar puede ordenar o desordenar la RV
  - Correlacionado con respuestas intermedias
    - ⇒ $\zeta \gg a_0$ pero suficientemente chicas como para modificar la respuesta global.
  - La respuesta depende de la frecuencia del agitado

EVIDENCIA DIRECTA DE REORGANIZACIÓN DINÁMICA

Gracias por la atención!

Intermediate responses in the transitional region



- *D. Pérez Daroca et al., PRB* ***84****, 012508 (2011).*

2D numerical simulations

the shaking force. At very low frequencies, the system reaches

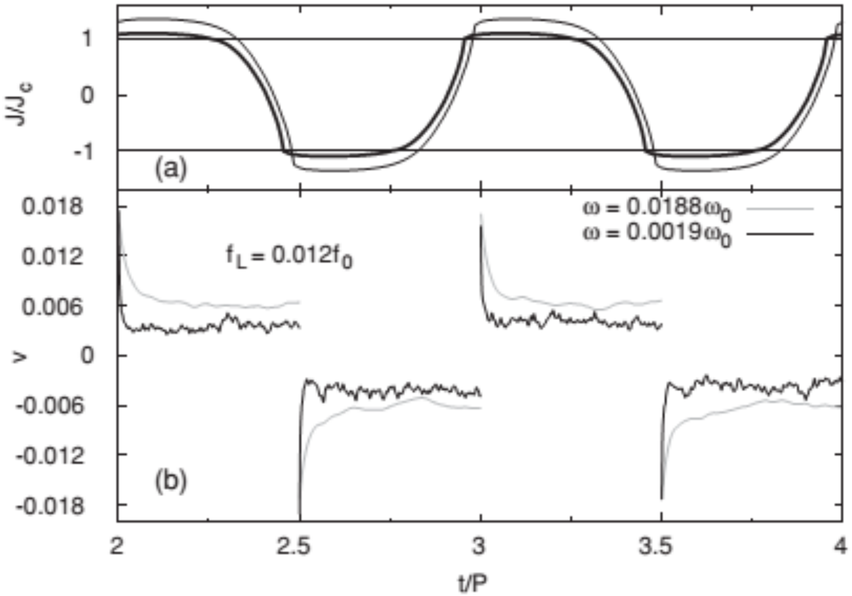


FIG. 3. (a) Theoretical current density J/J_c at a fixed position, in a superconducting disk of radius a and a perpendicular sinusoidal magnetic field, as a function of t/P for two different frequencies, $1\tilde{\omega}$, solid line and $100\tilde{\omega}$, dashed line, $\tilde{\omega} = \frac{2\pi E_c}{\mu_0 a J_c}$. Throughout most of the sample, the current can be described by a square waveform. (b) Calculated vortex mean velocity v, obtained from molecular dynamic simulations, as a function of t/P.

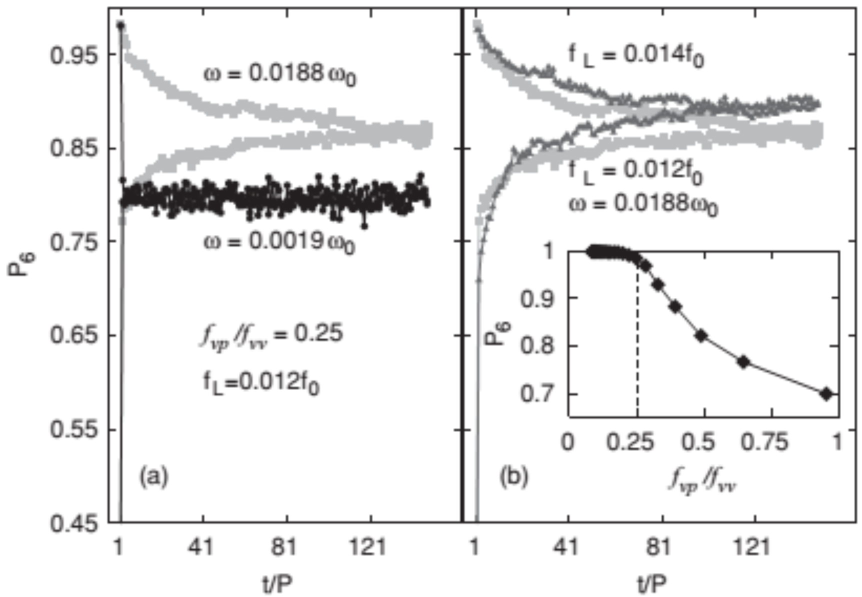


FIG. 4. P_6 versus t/P starting from an ordered and a disordered configuration. (a) For two different ω and fixed f_L. (b) For two different f_L and fixed ω. (Inset) P_6 versus f_{vp}/f_{vv}, showing a spontaneous creation of disclinations, and a decrease in P_6 at around $f_{vp}/f_{vv} = 0.25$.

- *D. Pérez Daroca et al., PRB **84**, 012508 (2011).*

SANS data analysis

Resolution model

$$S(q_L) \propto \frac{1}{1+(\zeta_L q_L)^2},$$

$$I(\theta) = \int_{-\infty}^{\infty} \frac{I_0}{\pi} \frac{\gamma}{\gamma^2 + (\theta' - \theta_0)^2} \frac{2}{\sqrt{2\pi} w_{res}} \exp\left[2\left(\frac{\theta' - \theta}{w_{res}}\right)^2\right] d\theta'. \qquad \gamma = \frac{1}{Q_0 \zeta_L}$$

Estimating ω_{res} and L_{res}

From the experimental setup: (0.104 ± 0.003) deg.

By minimizing

$$-2\log \tilde{\mathscr{L}}(I_0, \theta_0, \gamma, w_{res}) = \left(\frac{w_{res} - \tilde{w}_{res}}{\Delta \tilde{w}_{res}}\right)^2 + \sum_{j=1}^{N} \left(\frac{I_j - I(\theta_j)}{\Delta I_j}\right)^2.$$

$$\hat{w}_{res} = (0.107 \pm 0.004)\ \mathrm{deg}$$

$$\gamma \gtrsim 0.014\,\mathrm{deg},\ \mathrm{or}\ \zeta_L \lesssim 40\,\mu\mathrm{m} \sim L_{res}$$

Vortex displacements

During the shaking procedure:

$$\Delta a_0 \sim (a_0/2)(h_{sh}/B) \sim (a_0/2)(h_{sh}/H).$$

(Full penetration)

$$u(r) \sim r\ (\Delta a_0/a_0)$$

$$h_{sh} \sim 7 \text{ Oe and } H = 5 \text{ kOe, so } \Delta a_0 \sim 0.05 \text{ nm.}$$

$$u(r) > a_0 \text{ for } r > 100\ \mu\text{m},$$

u >> a_0 in the most of the sample (R~2.5 mm)

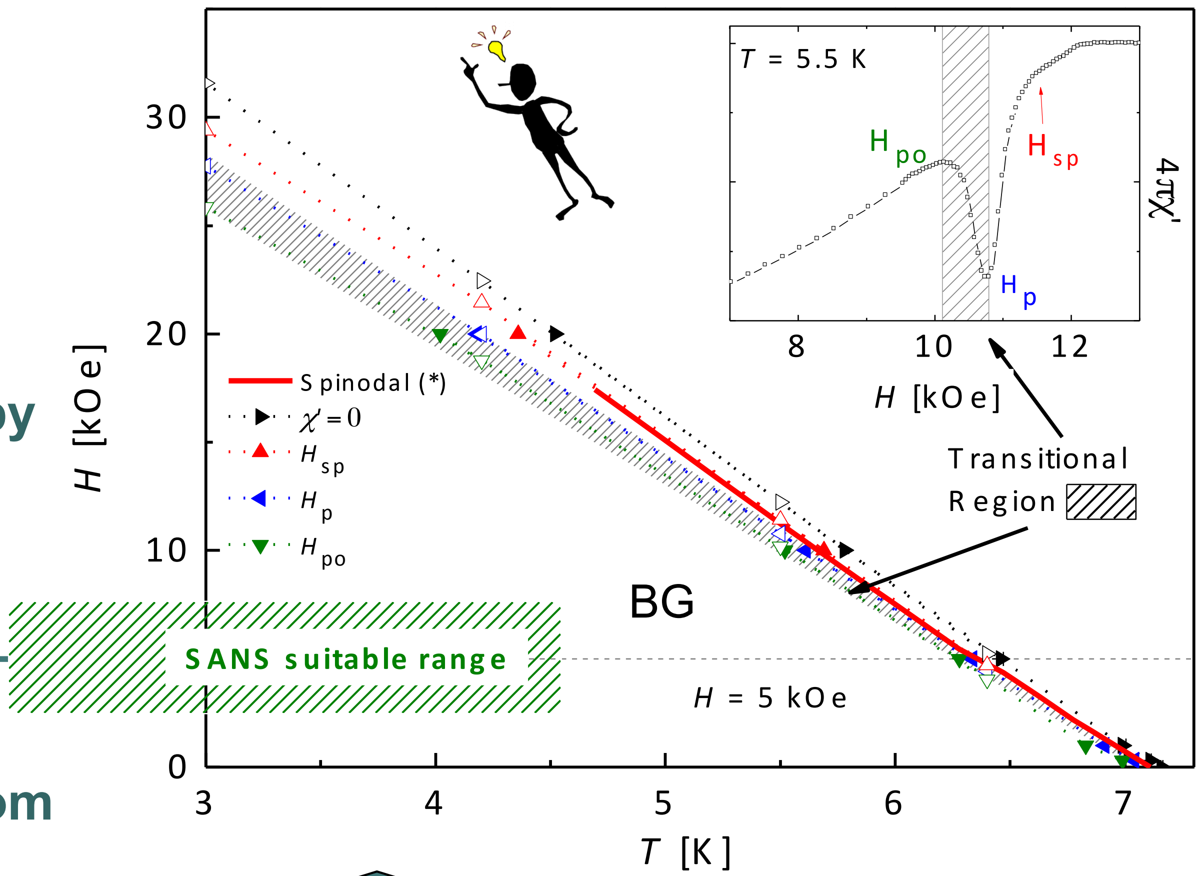
During the measurement:

$$h_{ac} = 2.5 \text{ mOe,}$$

$$u(r) < 3 \text{ nm} < \xi_0 < a_0,$$

Sample characteristics and phase diagram

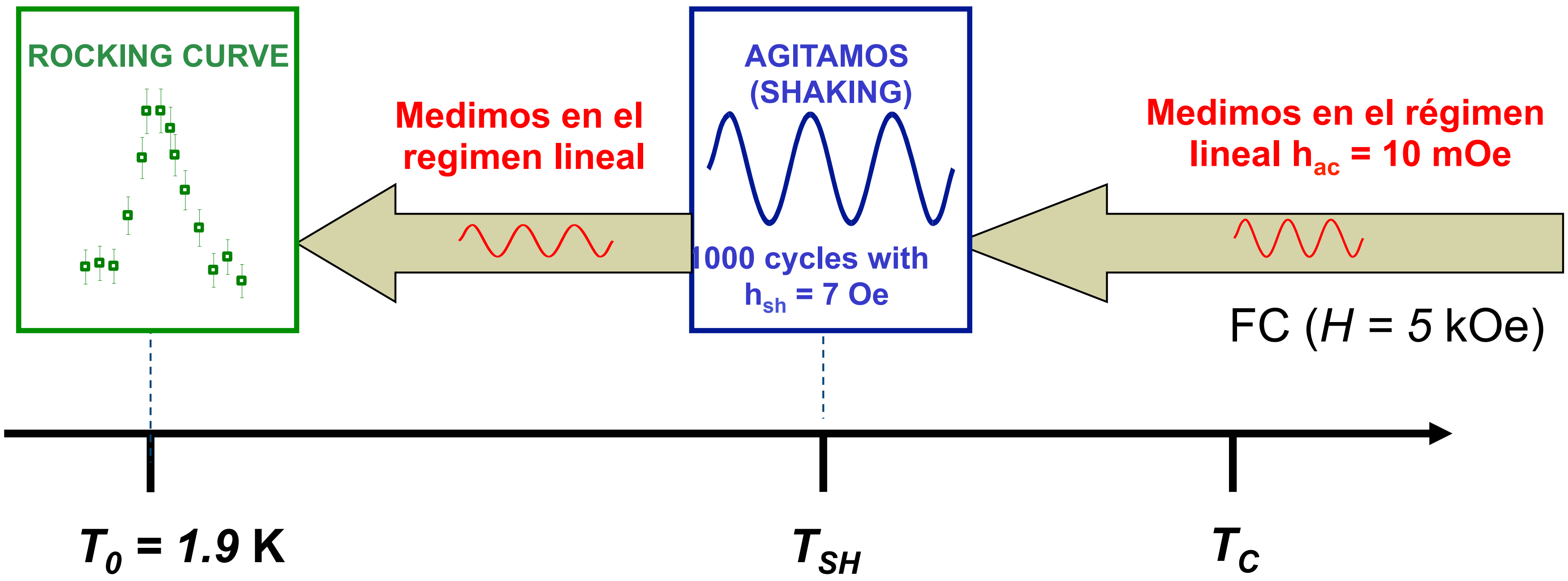
- $2H\text{-}NbSe_2$ single crystal
- Clean
- Large $(5.6 \times 4.7 \times 0.2) mm^3$
- From Bell Labs, provided by G. Nieva (CAB, Argentina)



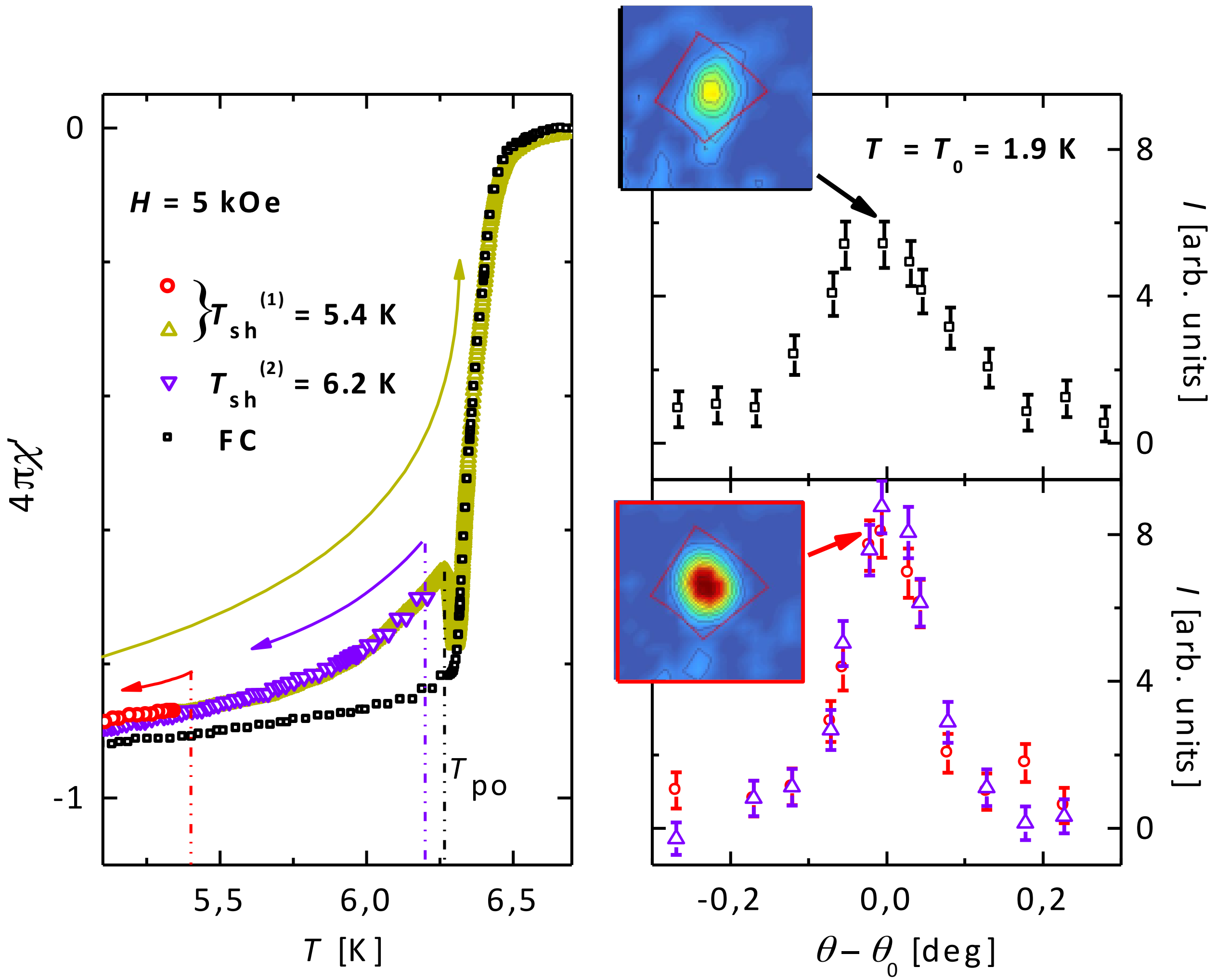
Phase Diagram of a crystal from the same batch Non-linear AC susceptibility in MPMS

Procedimiento experimental

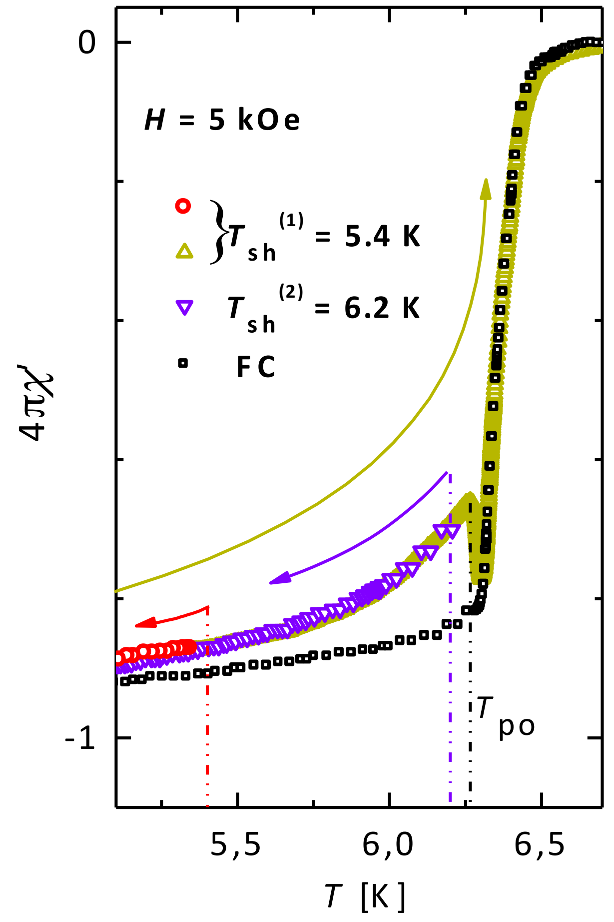
Moldeamos el sistema en T_{sh}; Medimos neutrones en T_0

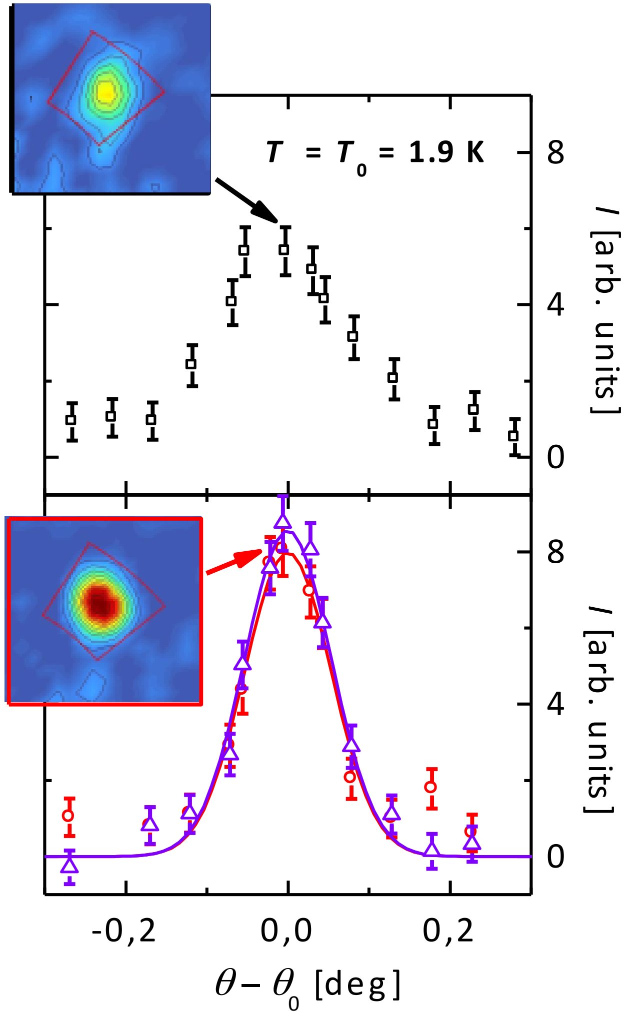


Shaking the VL in the BG



Shaking the VL in the BG





$$I(\theta) \approx \frac{2I_0}{\sqrt{2\pi}w_{res}} \exp\left[2\left(\frac{\theta-\theta_0}{w_{res}}\right)^2\right]$$

$\zeta_L >> 1/\omega_{res}$