CENTRE NATIONAL
DE LA RECHERCHE
SCIENTIFIQUE

Hervé Aubin

Nernst signal generated by superconducting fluctuations
- in low-Tc disordered superconductors

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Outline

- The amorphous superconductor Nb_xSi_{1-x}
  - ❑ Cooper pairs fluctuations above T_c and/or Hc_2.
  - ❑ Quantum fluctuations in vicinity of superconductor-insulator transition

- The Nernst signal generated by Cooper pairs fluctuations in Nb_xSi_{1-x}.

- Superconducting fluctuations and Nernst signal in InO_α

- Summary

Why measuring the Nernst signal of disordered superconductors ?

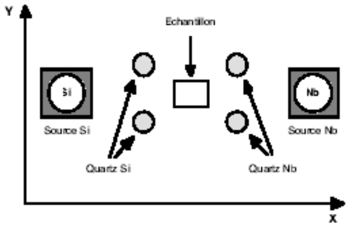
- Nernst effect is a very important probe since the discovery of a large Nernst signal in the underdoped region of the cuprates. Need to test theories of Nernst signal generated by superconducting fluctuations in systems simpler than the cuprates.

- Interesting fluctuations phenomena
  - Kosterlitz-Thouless like transitions
  - Quantum superconductor-insulator transitions
  - Bose insulators
  - Bose metals

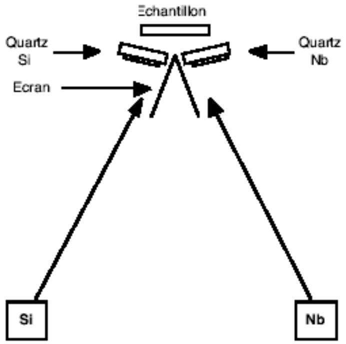
Nb_xSi_{1-x} : an homogenous amorphous superconductor

- Co-evaporation of Nb and Si

→ Nb_xSi_{1-x}

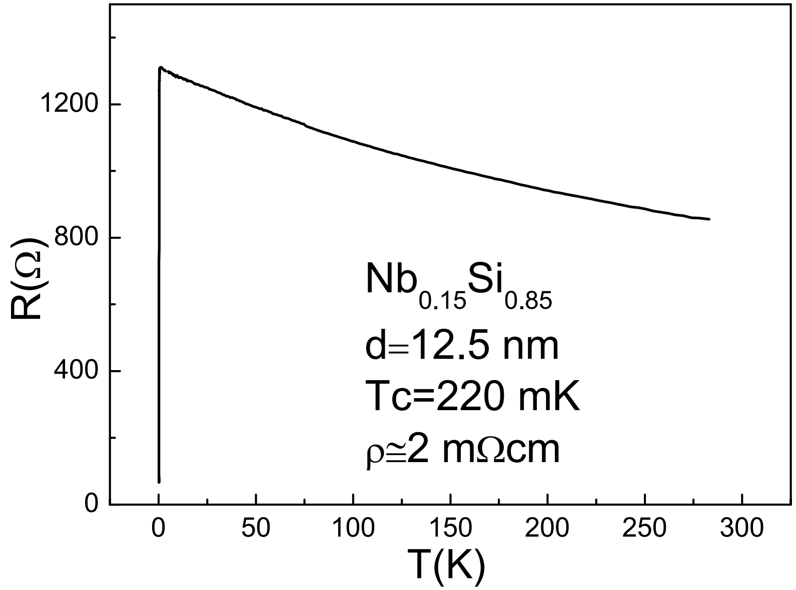


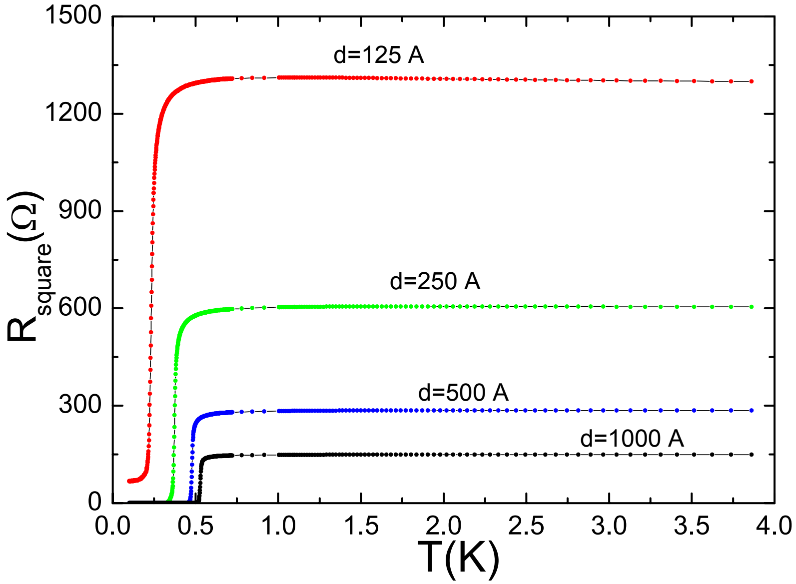
Vue de dessus



Vue en coupe verticale

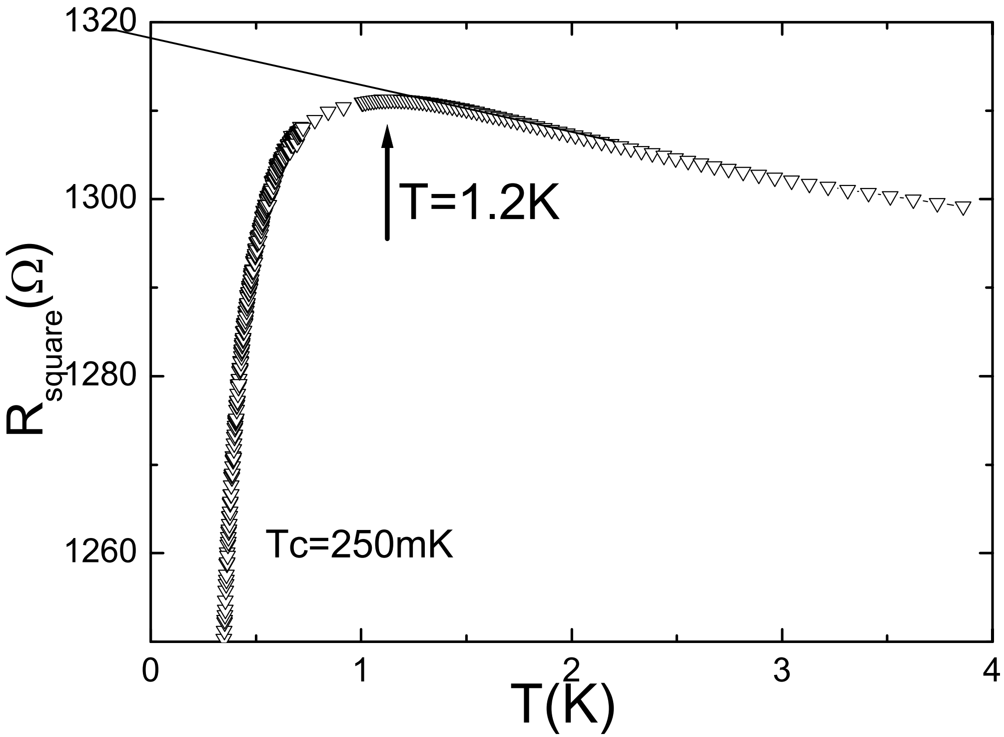
L. Dumoulin's group





A. M. Finkel'stein, JETP Lett. **45**, 46 (1987)

- Above Tc, Cooper pairs fluctuations (amplitude and phase fluctuations), →Paraconductivity



Nernst effect can detect Cooper pairs fluctuations up to 30 * Tc.

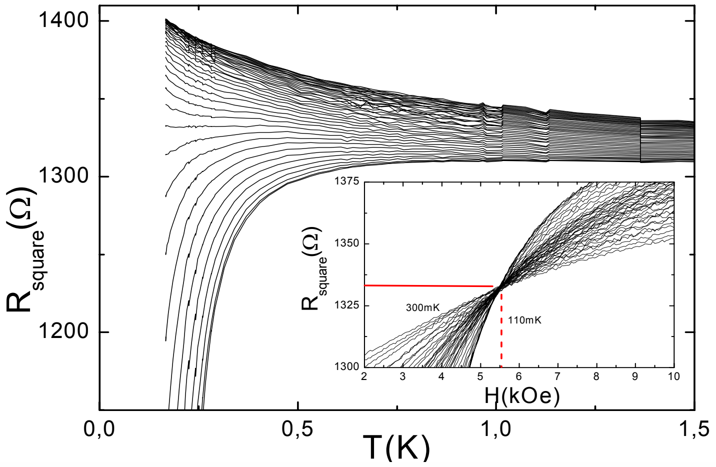
Theory : Fluctuations described in Gaussian approximation

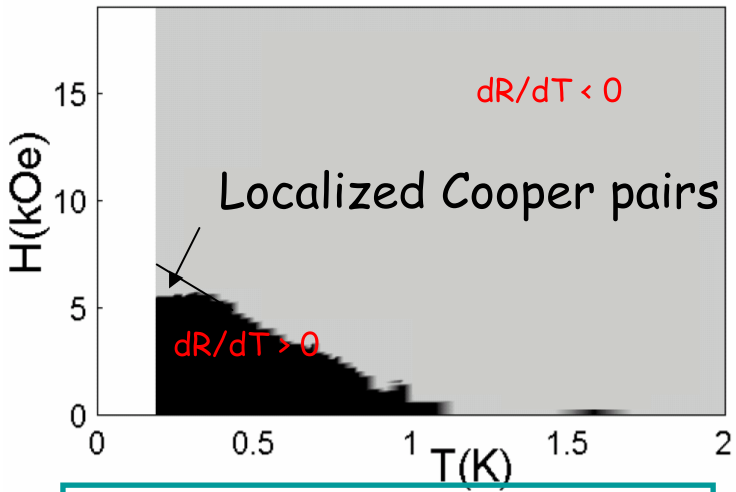
-Aslamazov – Larkin; Physics Letters, 26 A, 238 (1968)

-Maki-Thomson

-Density of States

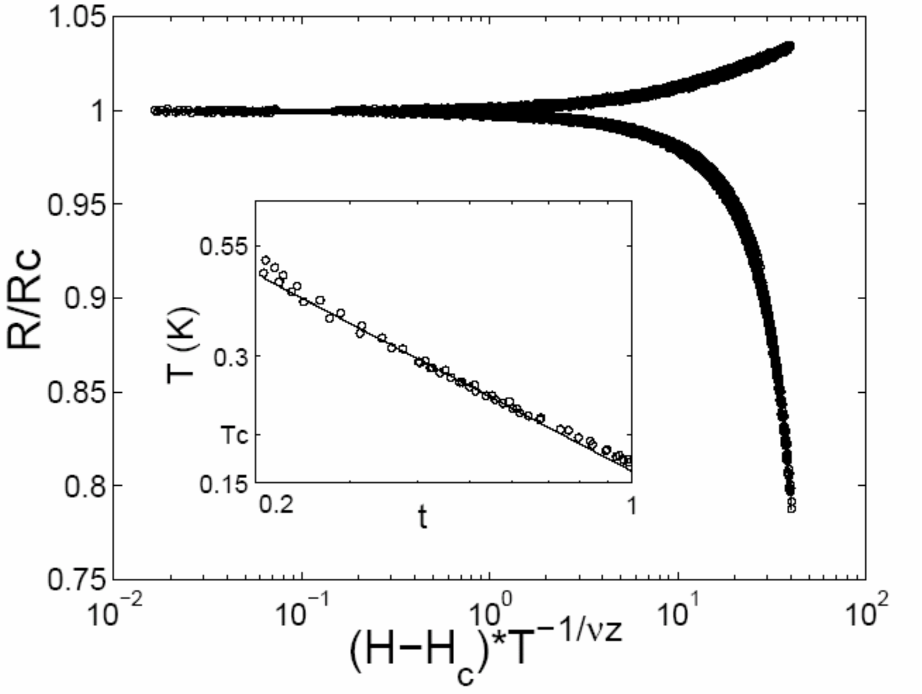
Magnetic field induced Quantum Superconductor-Insulator transition (Field perpendicular to sample plane)





Rc~1330Ω et Hc~5.5kOe

Finite Size Scaling → Quantum Fluctuations



νz~0.7

(H. Aubin et al. PRB 73, 094521 (2006))

Thermoelectric coefficients

$$S = \frac{-E_x}{\nabla_x T}$$

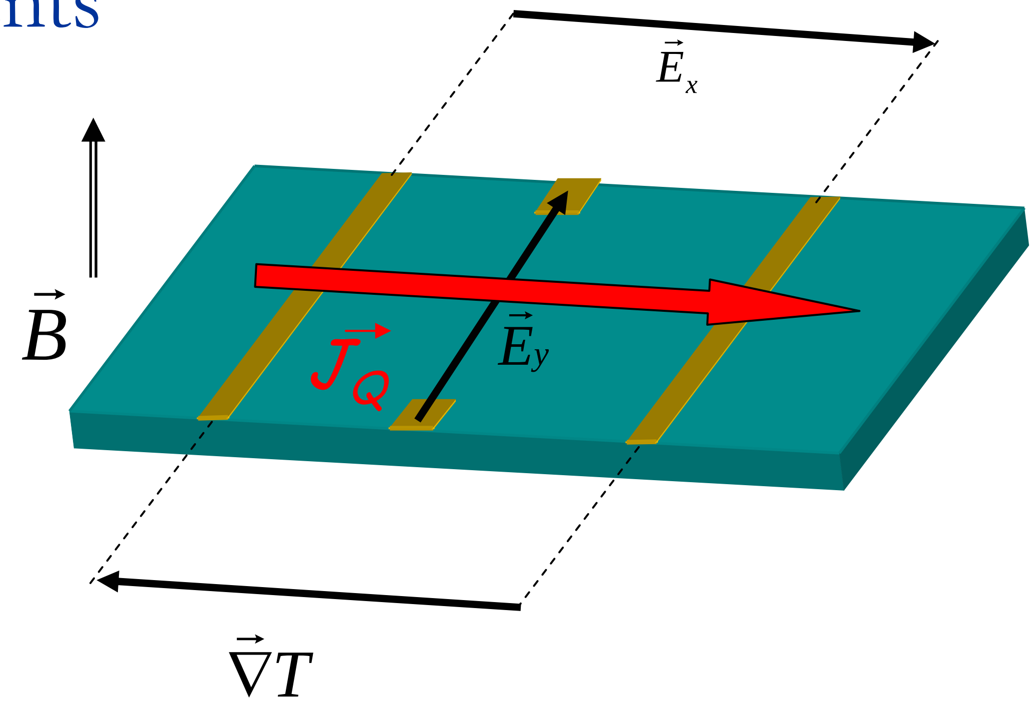
Seebeck effect

$$N = \frac{-E_y}{\nabla_x T}$$

Nernst signal

$$\nu = \frac{-E_y}{B_z \nabla_x T}$$

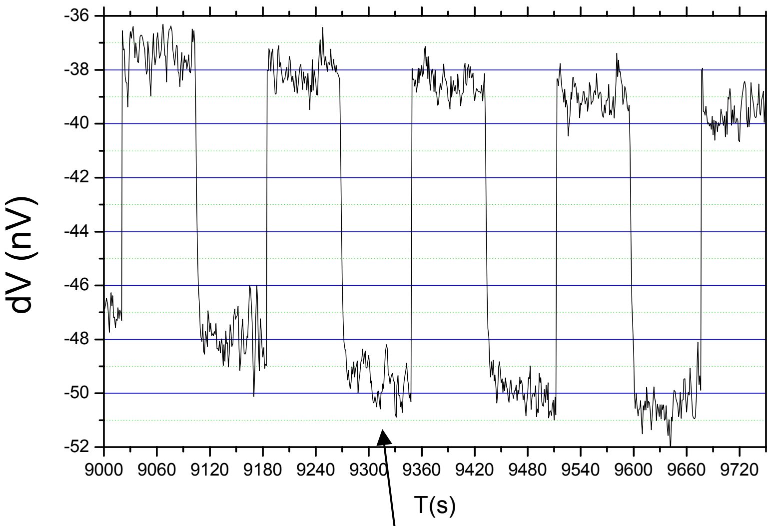
Nernst coefficient



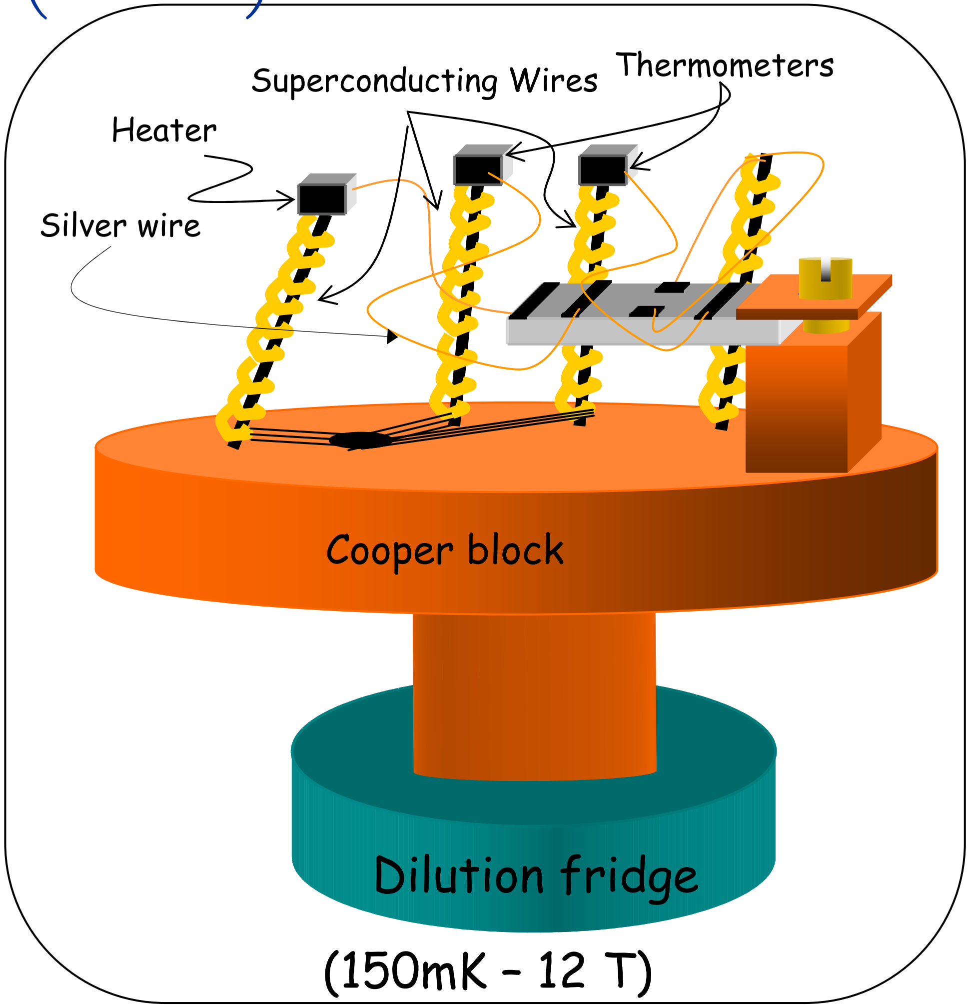
$$\begin{pmatrix} \vec{J}_e \\ \vec{J}_Q \end{pmatrix} = \begin{pmatrix} \sigma & \alpha \\ \alpha T & \kappa \end{pmatrix} (-\vec{\nabla} T)$$

$$\upsilon = \frac{1}{B} \frac{\alpha_{xy}\sigma_{xx} - \alpha_{xx}\sigma_{xy}}{\sigma_{xx}^2 + \sigma_{xy}^2} \approx \frac{1}{B} \frac{\alpha_{xy}}{\sigma_{xx}}$$

Experimental setup – K. Behnia
1 heater -2 thermometers (RuO2)



Sensitivity 1nV
DC-BW 1Hz



Nernst signal generated by moving vortices

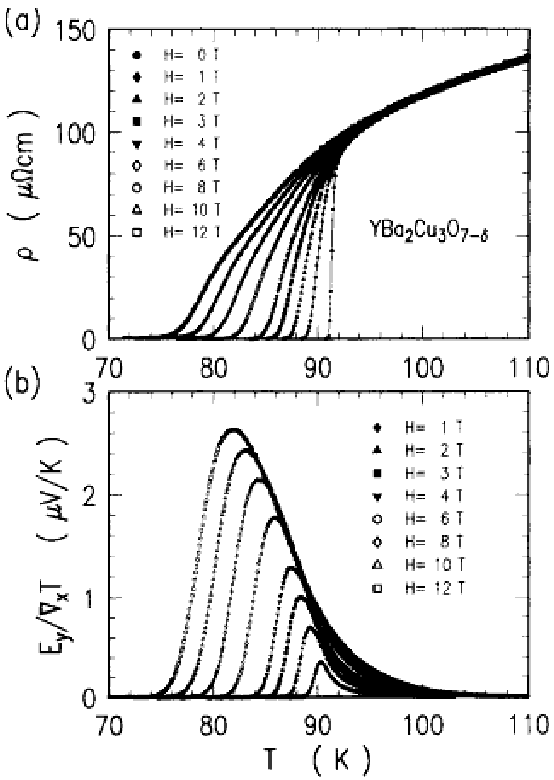
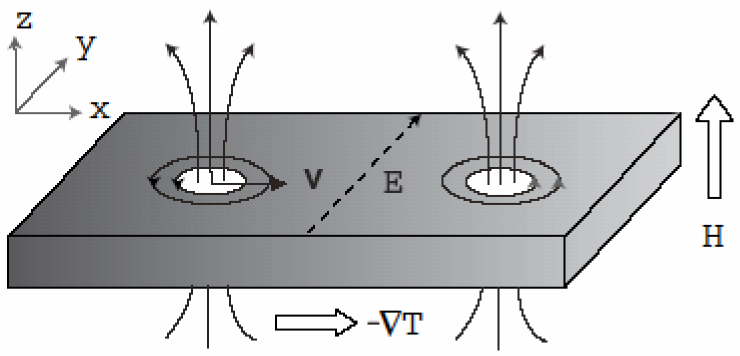


FIG. 3. Resistivity ρ (a) and normalized Nernst electric field $E_y/\nabla_x T$ (b) versus temperature for an epitaxial, c-axis-oriented $YBa_2Cu_3O_{7-\delta}$ film at different magnetic fields applied parallel to the c axis of the film.

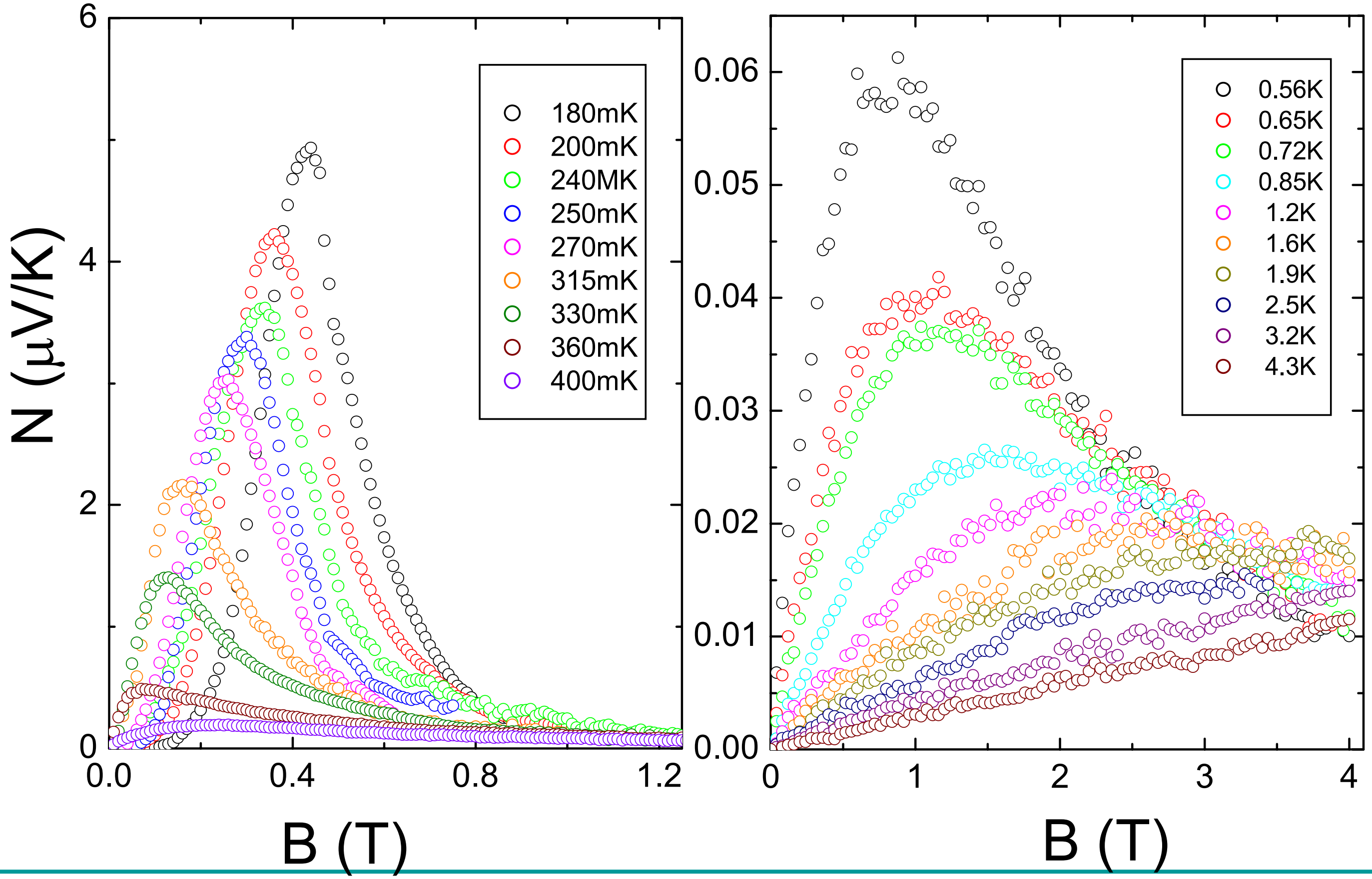


$$F=-S_\phi \nabla T$$

Vortices displaced by heat flow induces a transverse electrical field – the Nernst signal

Ri. H.-C et al
Phys. Rev. B 50, 3312–3329 (1994)

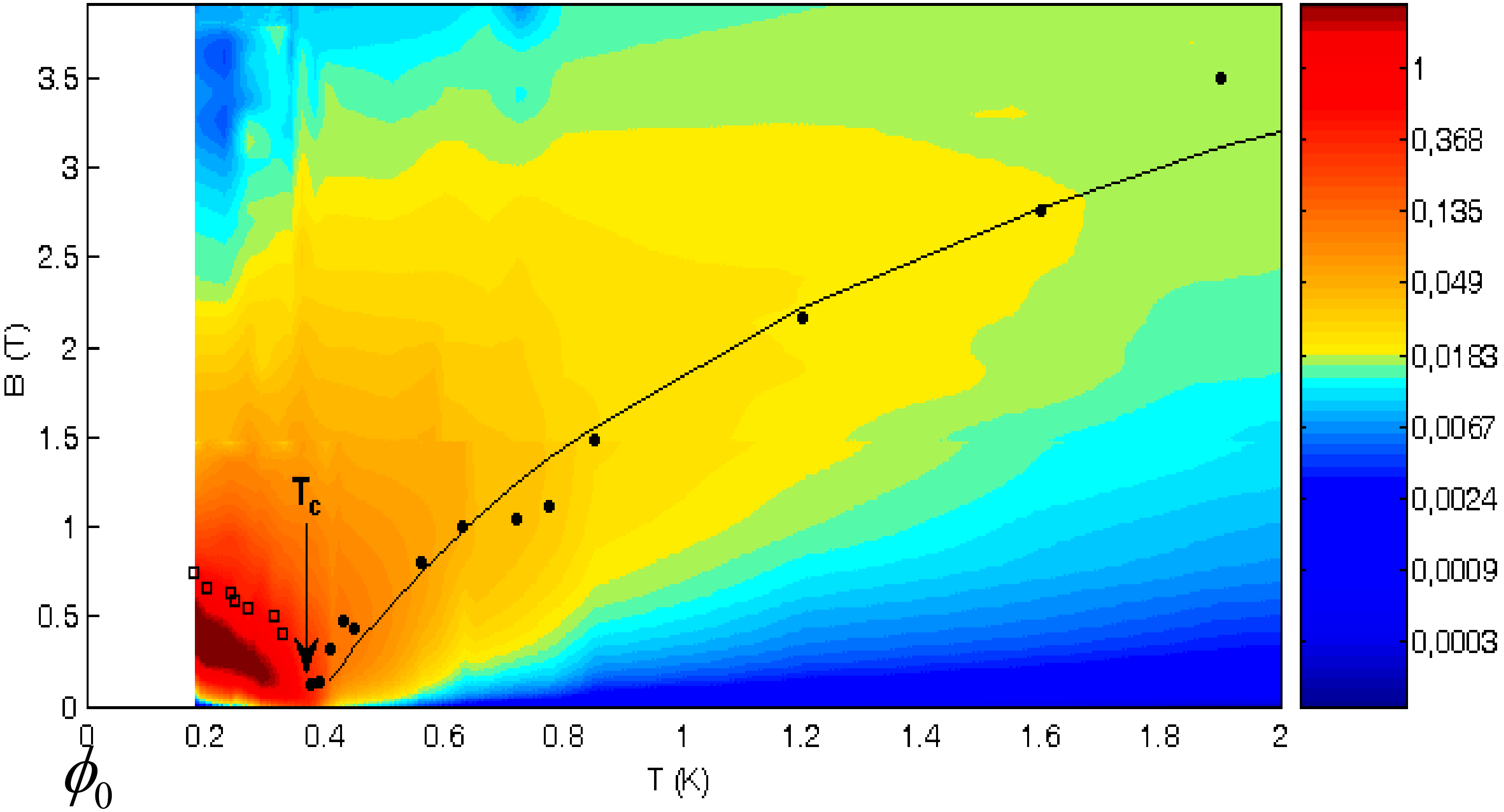
Nernst signal as function of magnetic field
$Nb_{0.15}Si_{0.85}$, T_C =380mK



Below T_c

Above T_c

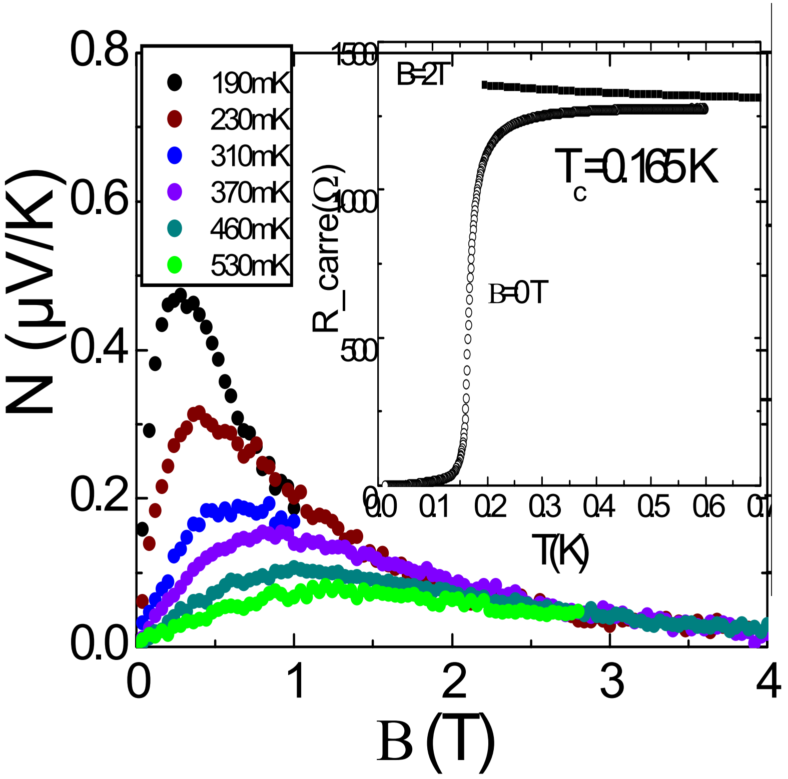
Two characteristic fields that evolve symmetrically with respect to critical temperature

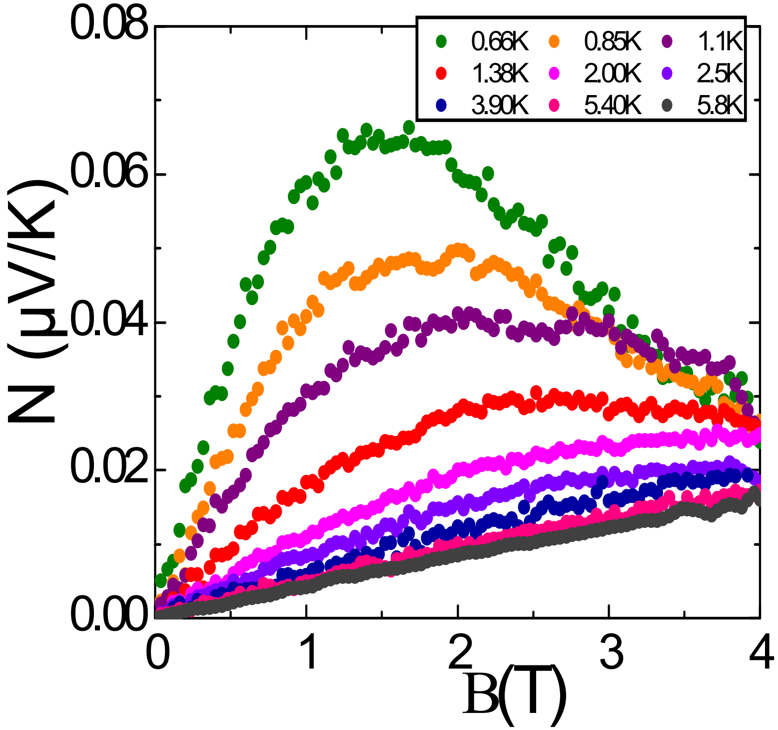


$$H^* = \frac{\phi_0}{2\pi\xi_d^{\ 2}}$$

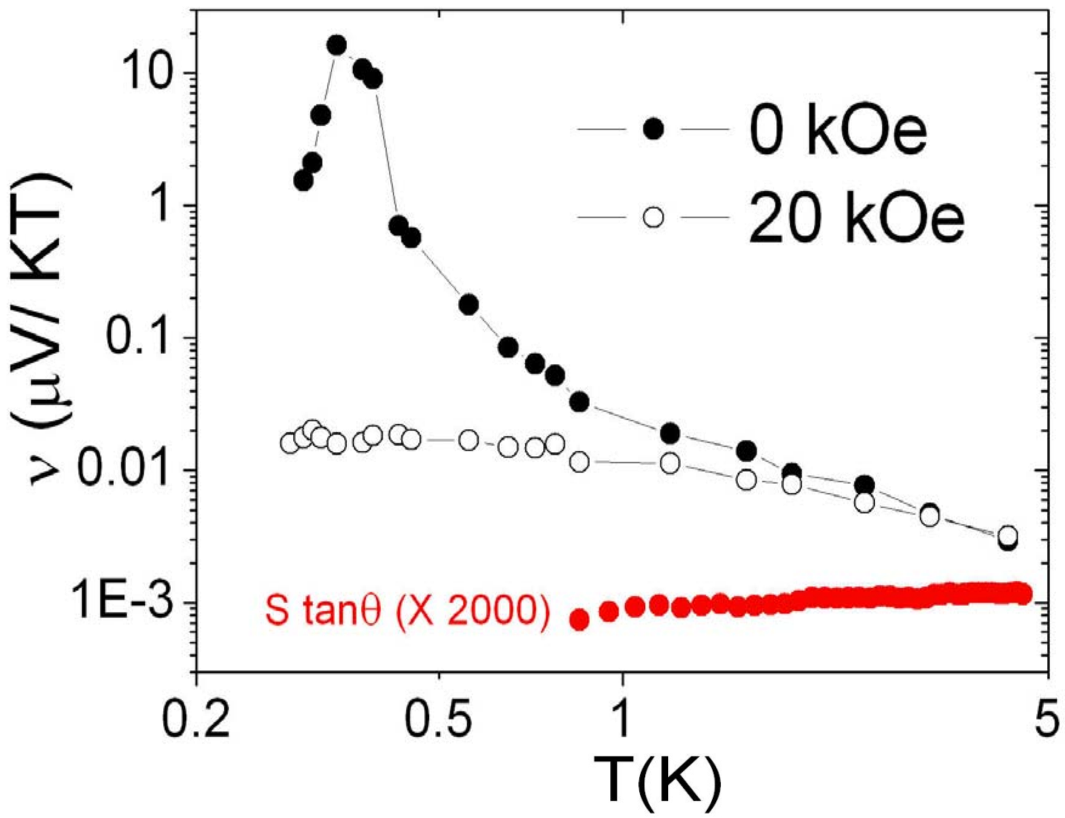
Below Tc, gives the critical field.
Above Tc, gives the ghost critical field

Nernst signal above Tc (d=12.5 nm ,Tc=165mK)





Normal state Nernst signal is very weak



ν_n <~ $S \tan\Theta$,
Θ Hall angle

The relevant length scales :

Cooper pairs : correlation length

Normal electrons : elastic mean free path

What generates the Nernst signal above Tc ?

- The temperature dependence of maximum in the Nernst signal is controlled by the superconducting correlation length

- We checked that the normal electrons do not have any contributions

- There is no reason to believe that exist, above Tc, a regime controlled by phase fluctuations only.

→Coopers pairs fluctuations, described by theories in the Gaussian approximation, should explain the data.

Theory : Nernst signal generated by fluctuations of the superconducting order parameter in Gaussian approximation.

(I. Ussishkin, S. Sondhi, D. Huse Phys. Rev. Lett. 89, 287001 (2002))

- At 2D
- At low magnetic field
- Close to Tc

$$\boxed{\nu_{USH} = R_{square}\left(\frac{\mathrm{k_B e^2}}{6\pi\hbar^2}\right).\xi_{\mathrm{d}}^{2}}$$

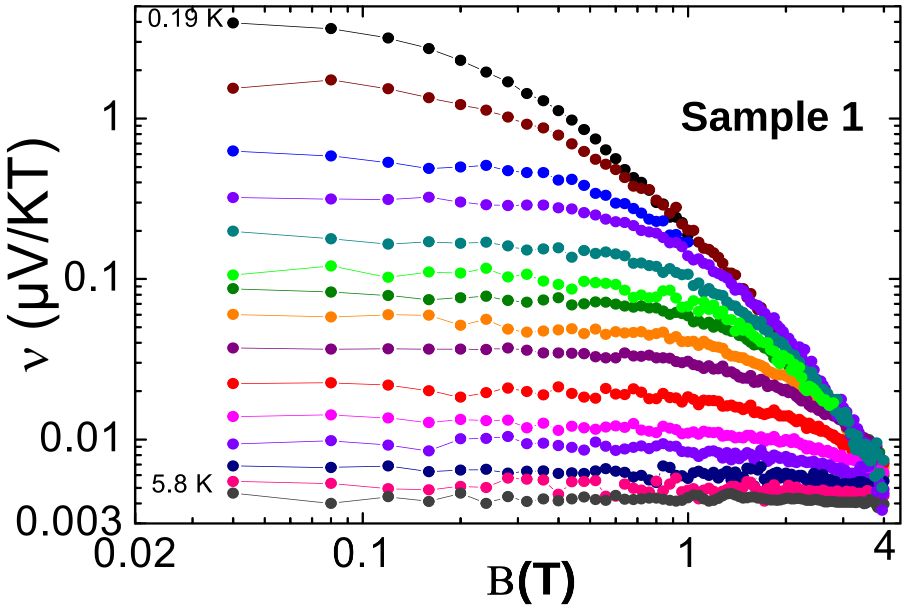
BCS correlation length : $$\xi_d = \frac{1}{\sqrt{\varepsilon}}0.36\sqrt{\frac{3}{2}\frac{\hbar v_F \ell}{k_B T_c}}$$ and $$v_F \ell = \left(\frac{\pi k_B}{e}\right)^2 \frac{\sigma}{\gamma_e}$$

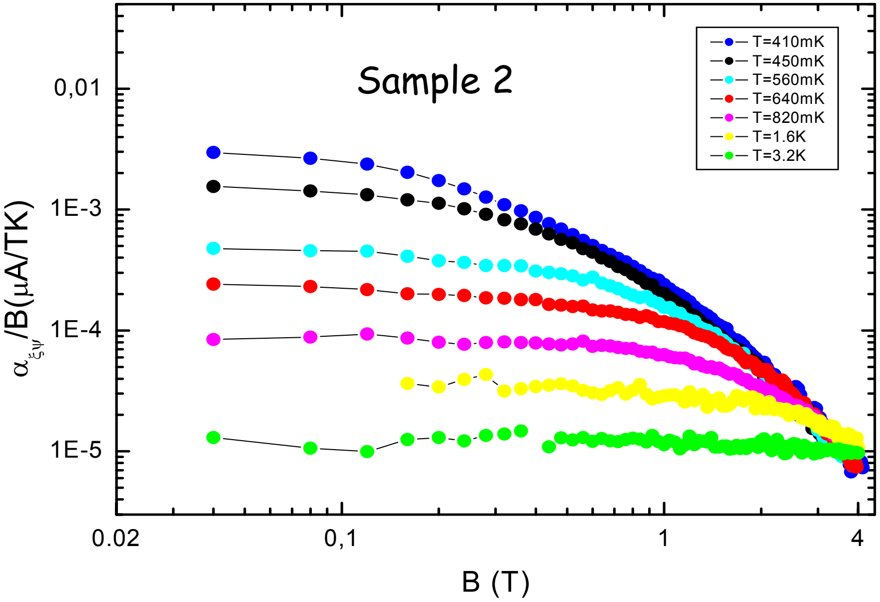
Reduced temperature : $$\varepsilon = \ln\left(\frac{T}{T_c}\right)$$

Nernst coefficient (Tc =165mK)

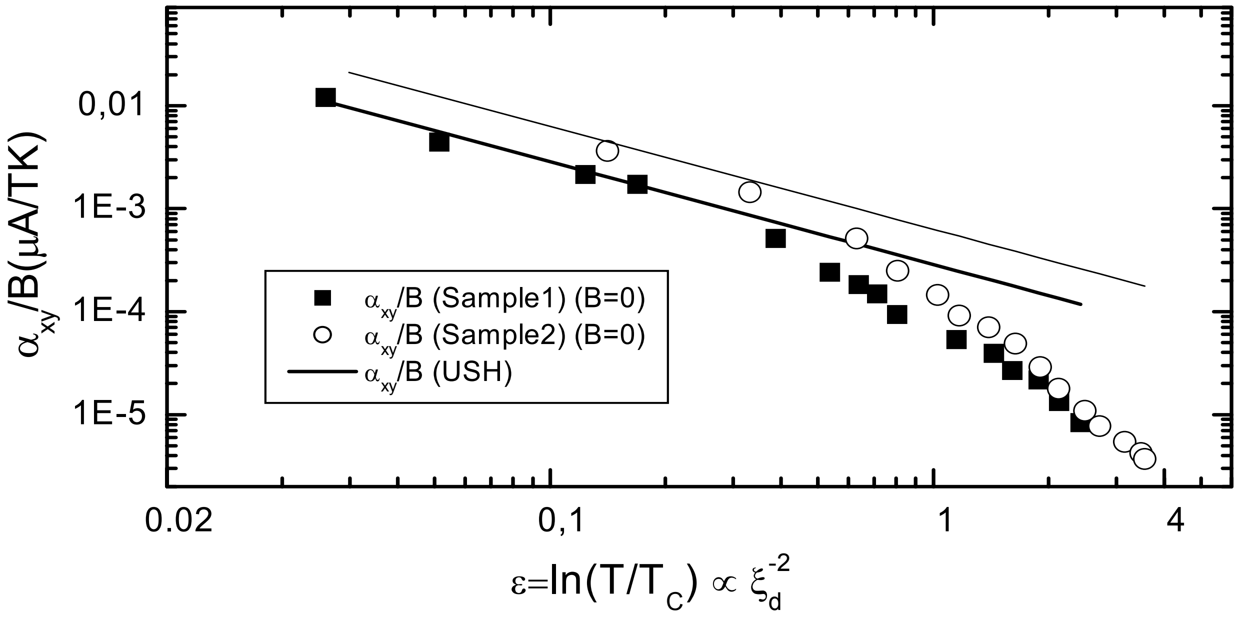
Sample 1
T_c=165 mK

Sample 2
T_c=380 mK

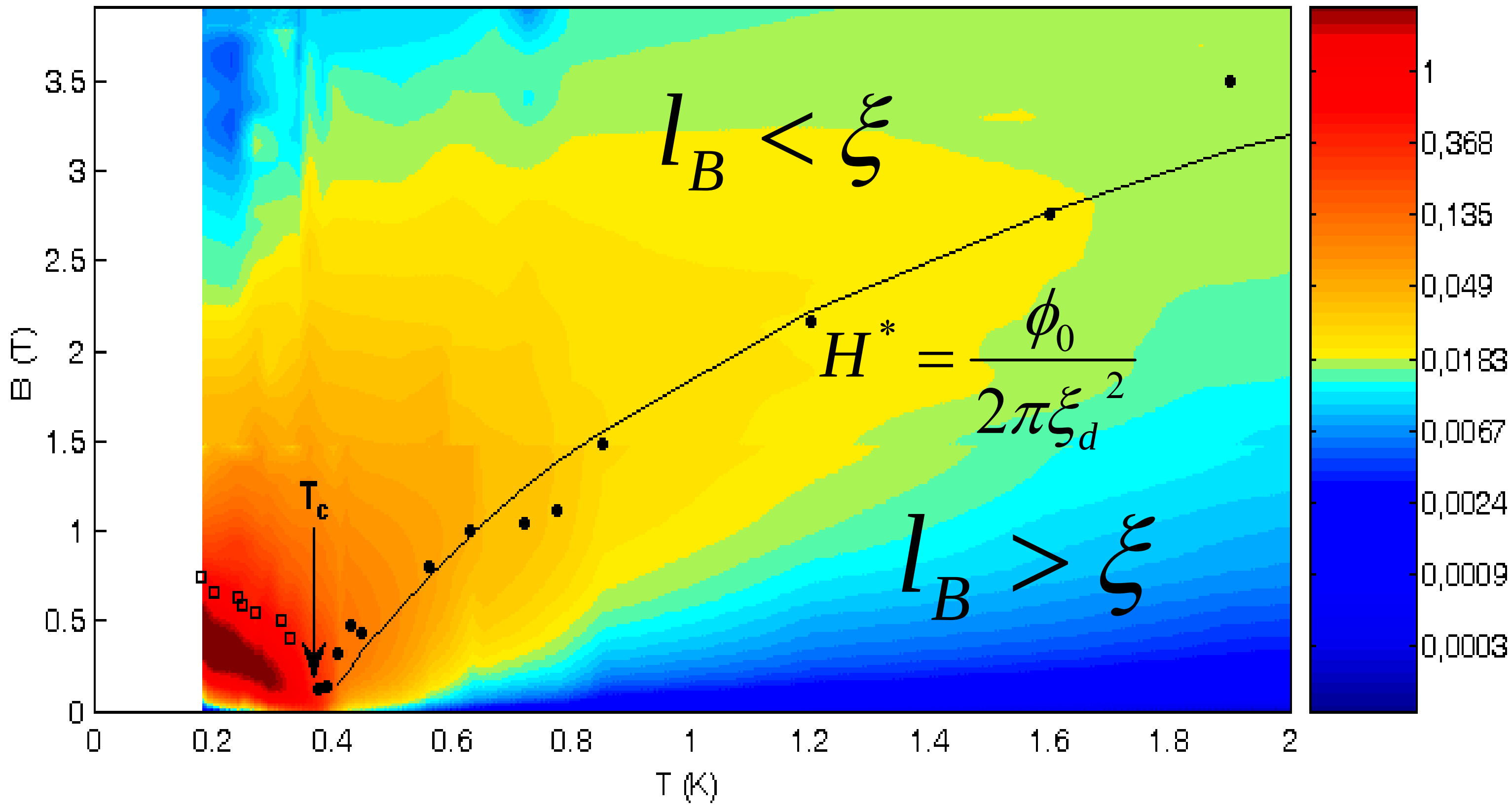




The amplitude of signal is consistent with theory , close to Tc (B->0), with no adjustable parameters.



A. Pourret et al. Nature Physics 2, 683 (2006)



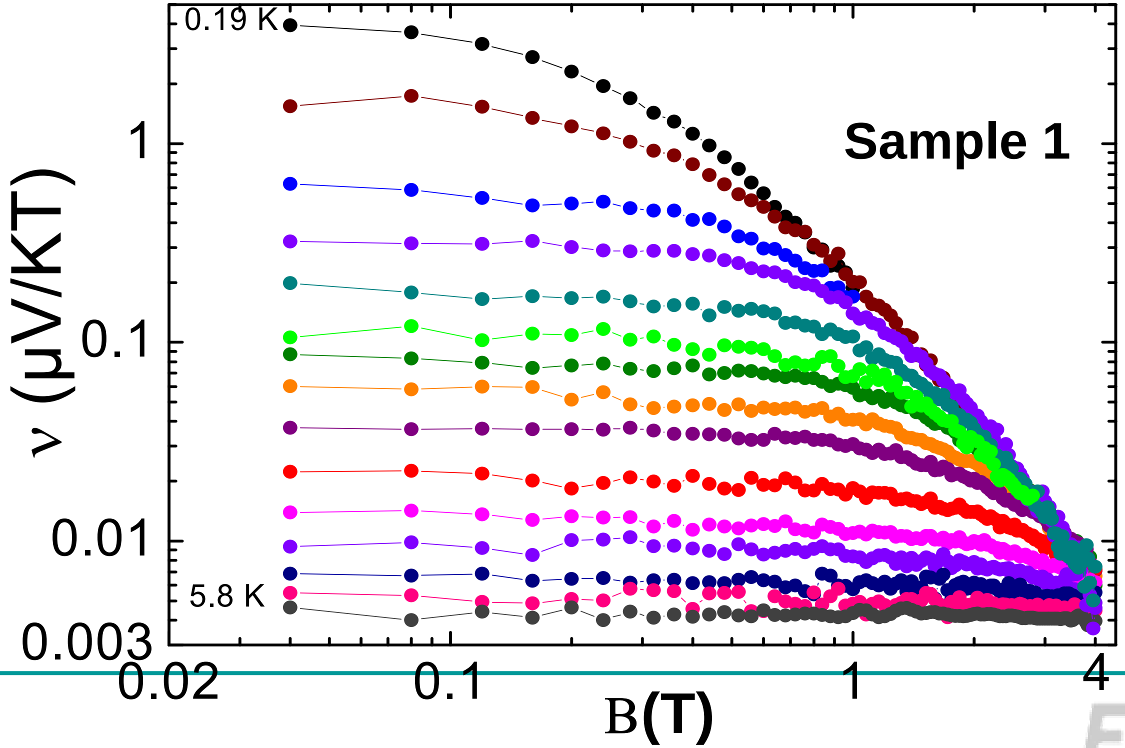
Magnetic length : $l_B = \sqrt{\frac{\phi_0}{2\pi B}}$

The size of superconducting fluctuations is determined by the shortest of the two lengths :

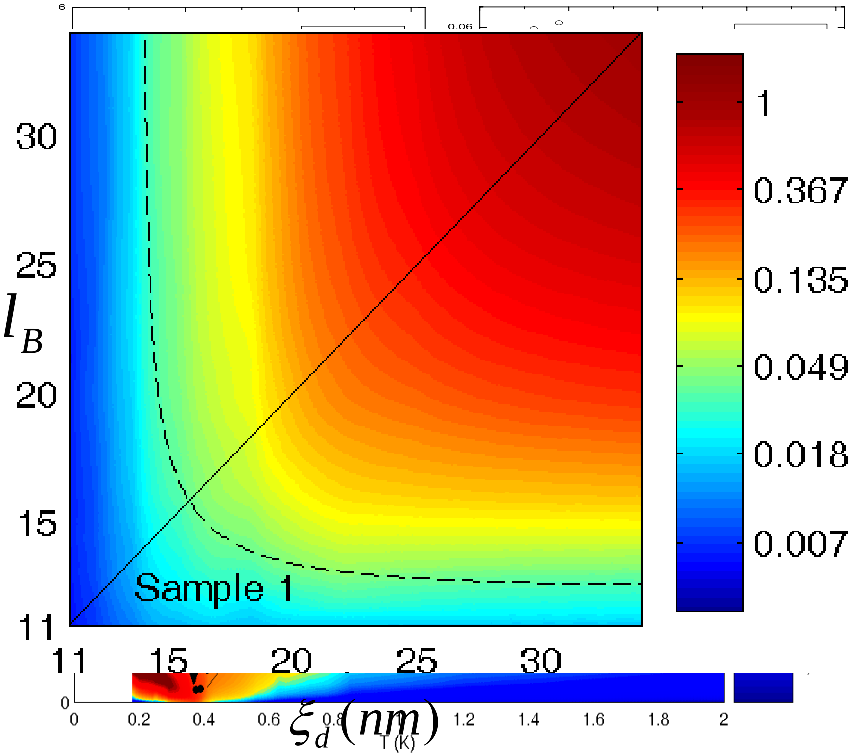
- the correlation length ξ (at zero field)

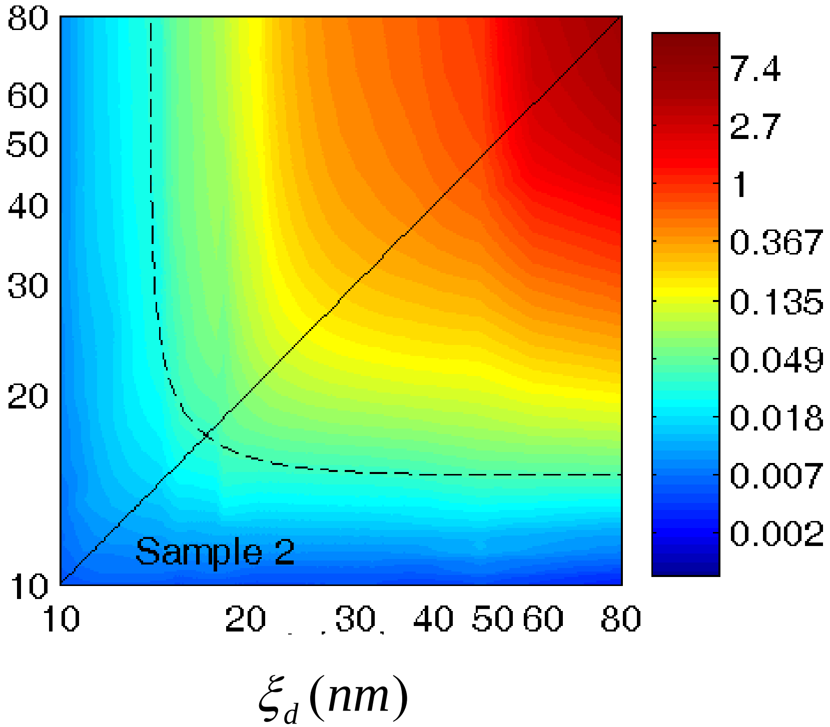
- the magnetic length $l_B = \sqrt{\dfrac{\phi_0}{2\pi B}}$

- Skocpol and Tinkham, Rep. Prog. Phys. (1975)



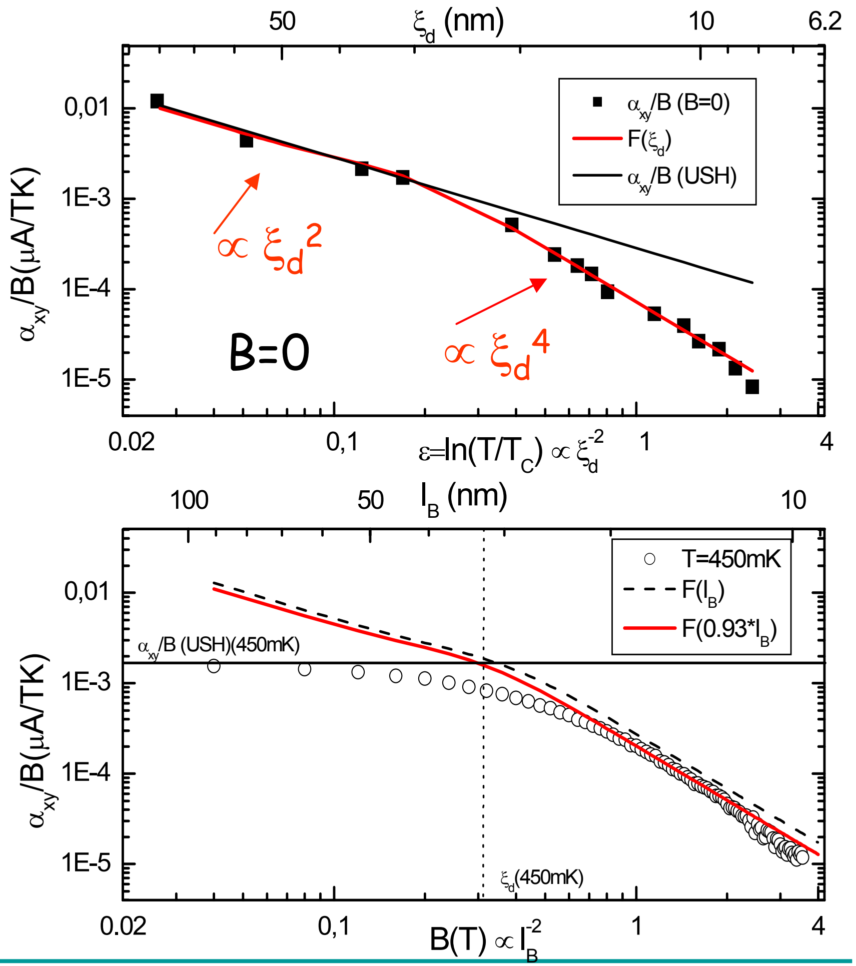
The Nernst signal is determined only by the size of superconducting fluctuations



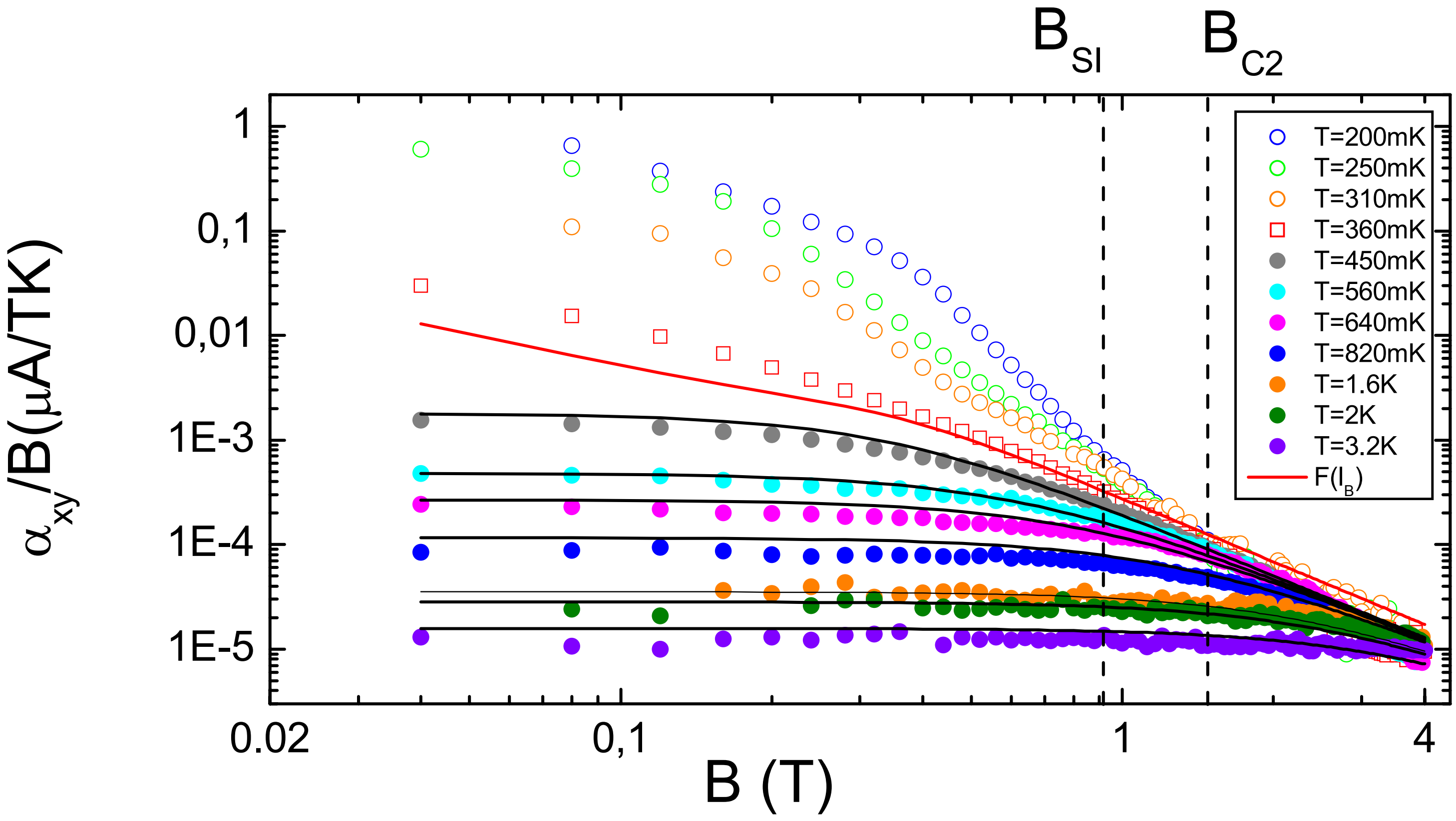


The magnitude of the Nersnt coefficient at high magnetic field can be predicted from the temperature dependence of the Nernst coefficient in the low-field limit.

The same function F(ξ) determine α_{xy}/B:
with $\xi = \xi_d$ when H < H*
and $\xi = l_B$ when H > H*

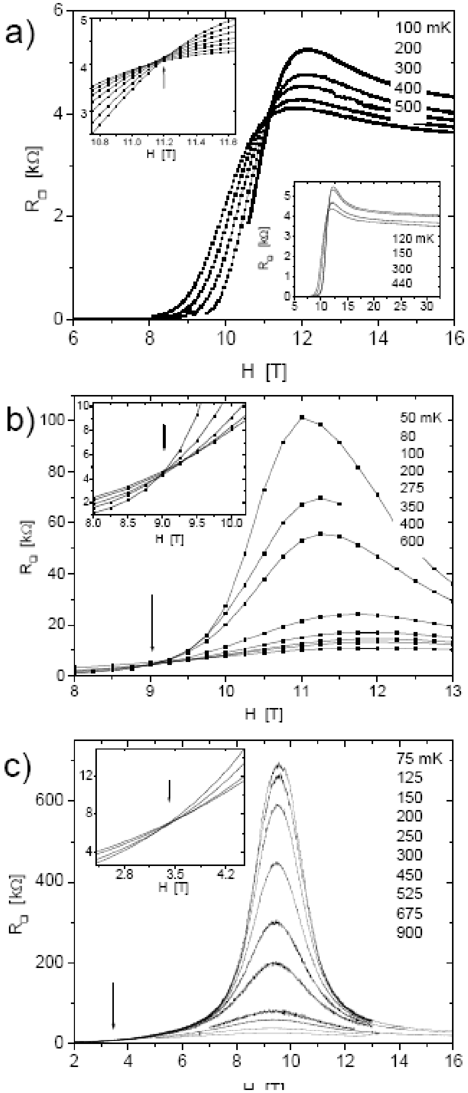


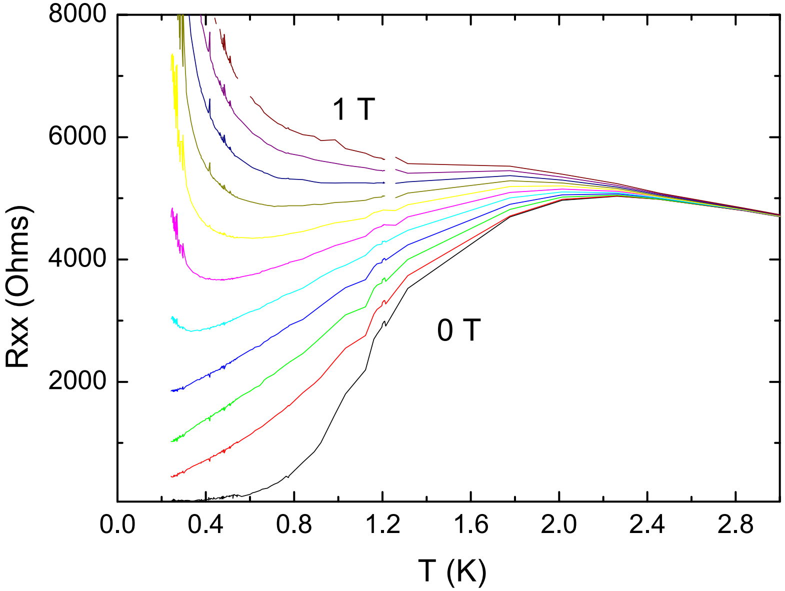
- At Tc, Nernst coefficient is determined by l_B on the whole magnetic field range, because $\xi \rightarrow \infty$

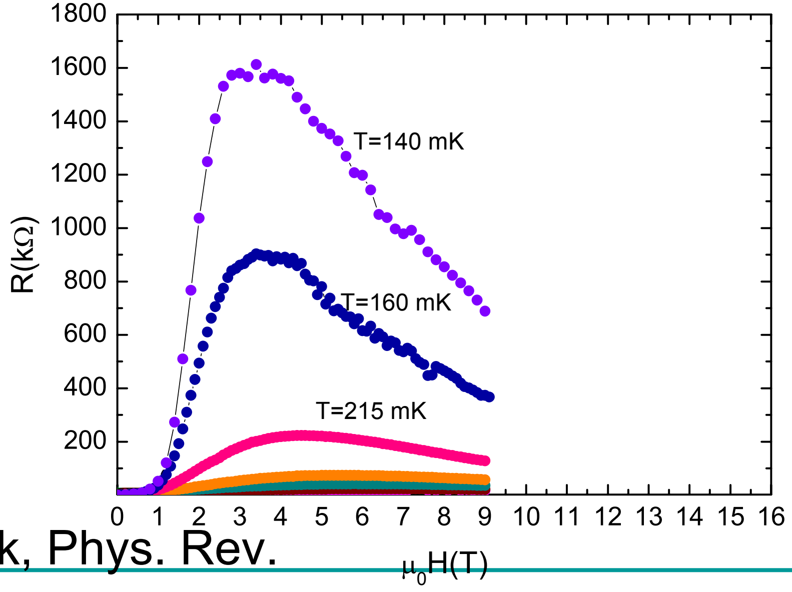


A. Pourret et al./Cond.mat0701376

InO$_\alpha$

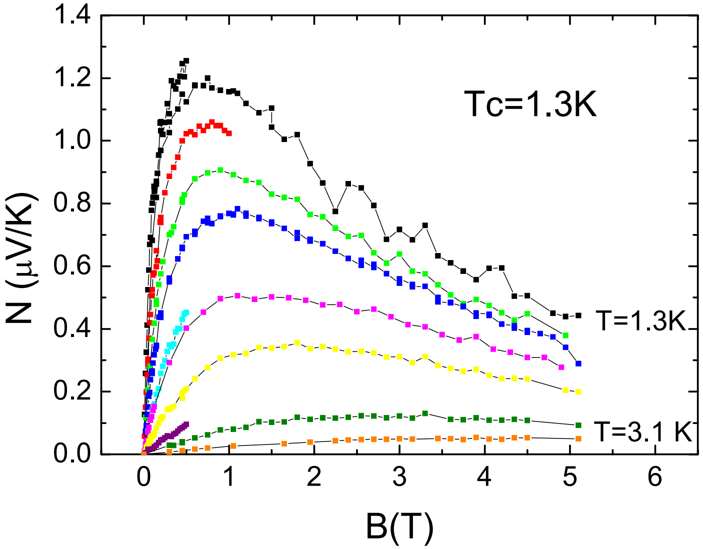




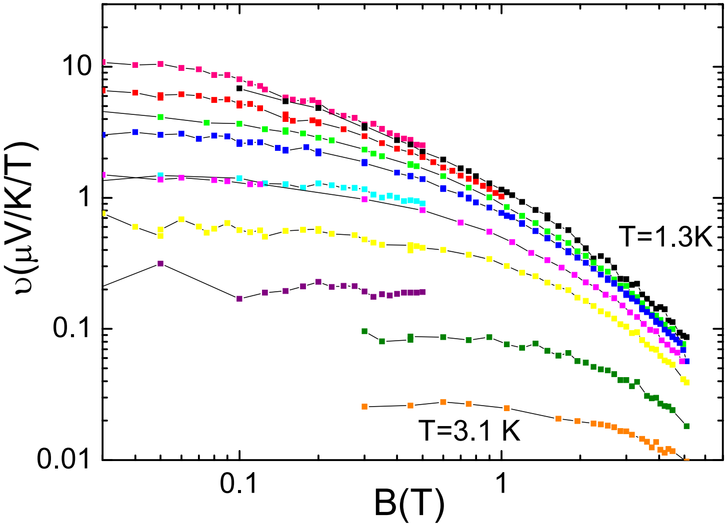


M. A. Steiner, G. Boebinger, and A. Kapitulnik, Phys. Rev. Lett. **94**, 107008 (2005).

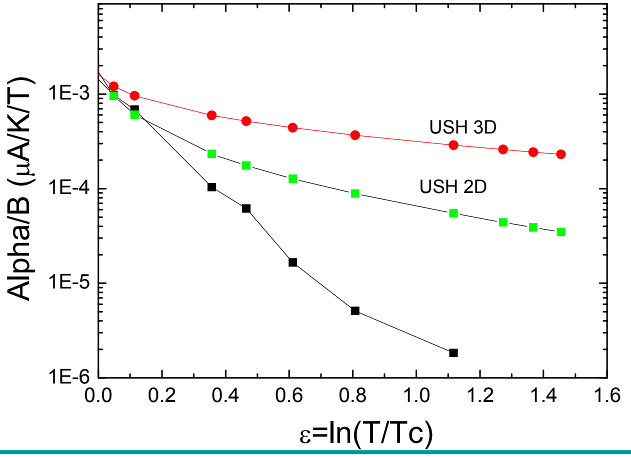
InO$_{\alpha}$



1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
N (μV/K)
0
1
2
3
4
5
6
B(T)
Tc=1.3K
T=1.3K
T=3.1 K



10
1
0.1
0.01
υ(μV/K/T)
0.1
1
B(T)
T=1.3K
T=3.1 K



1E-3
1E-4
1E-5
1E-6
Alpha/B (μA/K/T)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
ε=ln(T/Tc)
USH 3D
USH 2D

Summary

- We checked that, close to Tc, and in the low field limit, USH theory gives the correct magnitude for the Nernst effect due to Gaussian fluctuations of the superconducting order parameter.

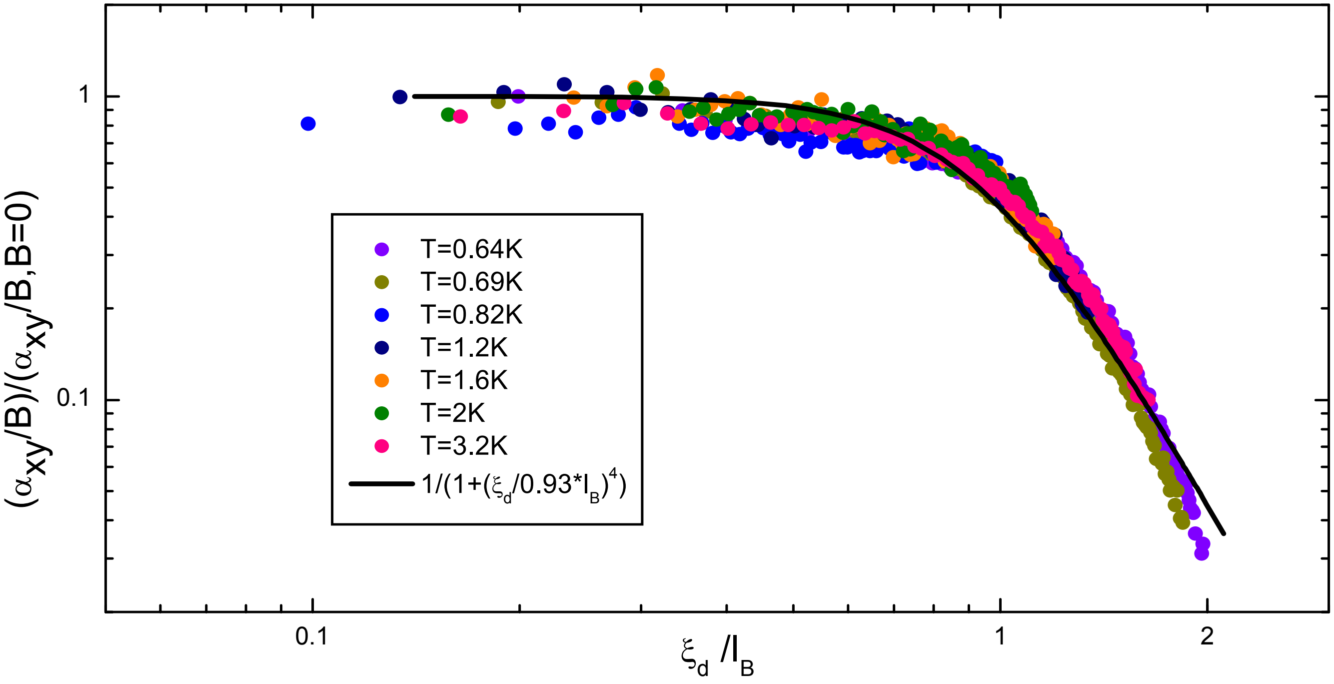
- We have shown that, at very high temperature and magnetic field, beyond the regime of validity of the theory, the Nernst coefficient is controlled only by the size of superconducting fluctuations.

- In thin disordered superconductors, short-lived Cooper pairs generate a Nernst signal that can be measured up to very high temperature (at least 30*Tc), and very high magnetic field (at least 4*Hc2).

Cross-over between the high-field and low-field regime

In the region $\alpha/B \propto \xi^4$, $F(\xi)/ F(\xi_d)= 1/(1+(\xi_d/l_B)^4)$

C=0.93 for sample 1
C=1.12 for sample 2

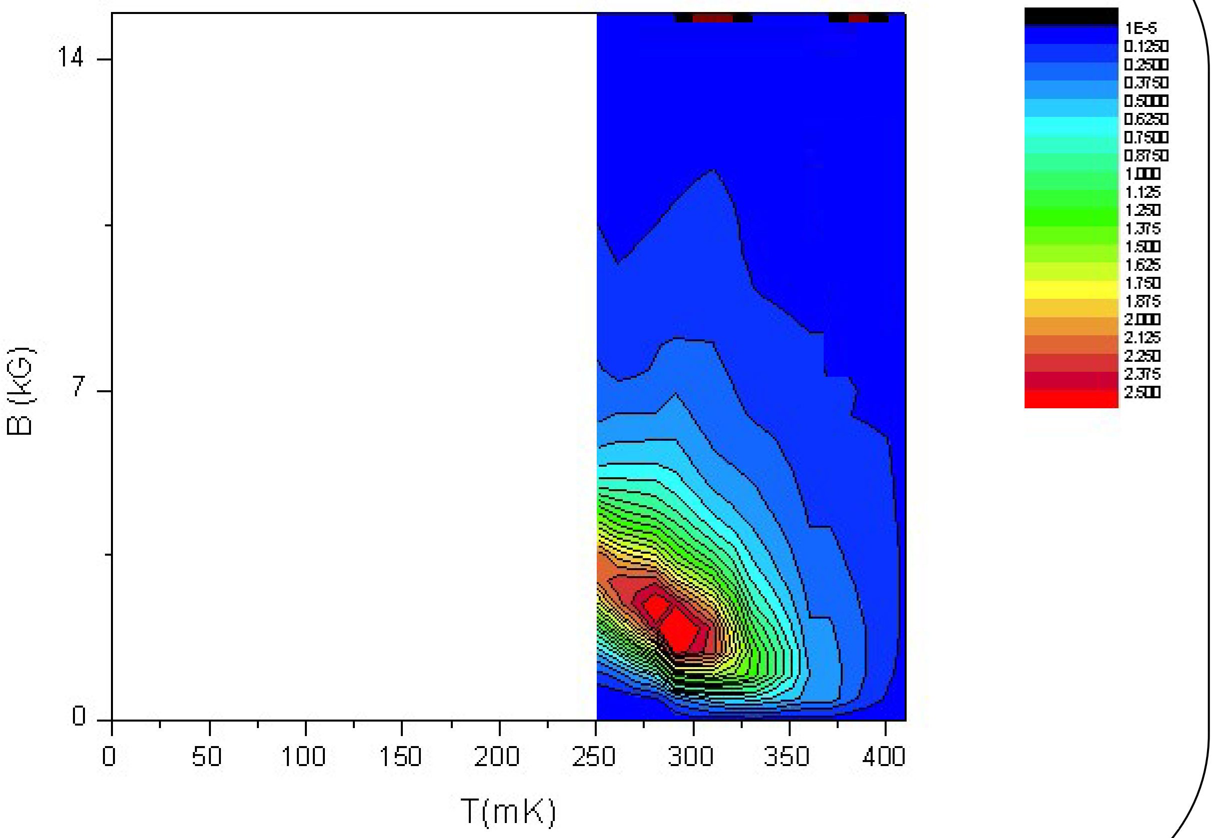


Cross-over is given by:

$$\frac{1}{\xi} = \left(\frac{1}{\xi^4} + \frac{1}{(c*l_B)^4}\right)^{\frac{1}{4}}$$

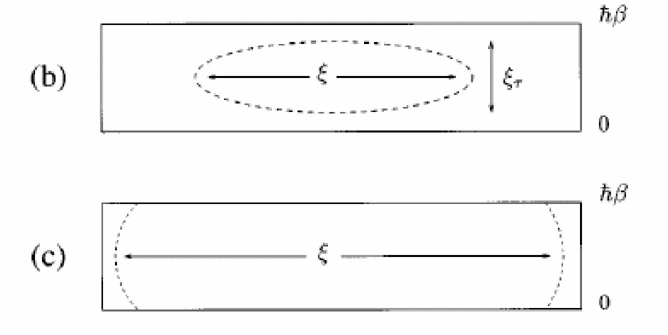
A. Pourret et al./Cond.mat0701376

Effet Nernst du aux vortex



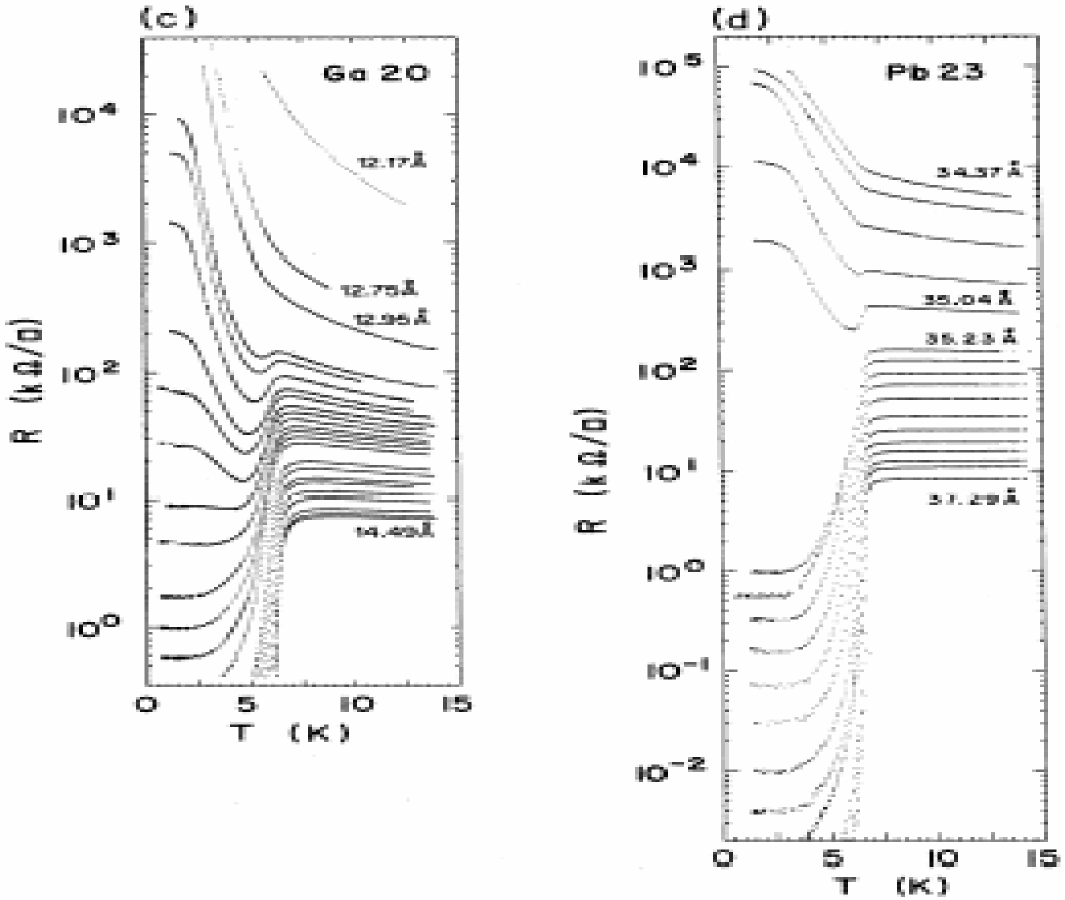
Récapitulatif

Echantillon	D(nm)	T_c(K)	H^{IS} (T)	H^{P} (T)	H^{ORB} (T)	ξ_d (T=0)(nm)
1	12.5	0.165	0.36	0.3	0.85	19.7
2	35	0.38	0.91	0.7	1.95	13



$$L_\tau / \xi_\tau = \delta / T^{1/\nu z}$$

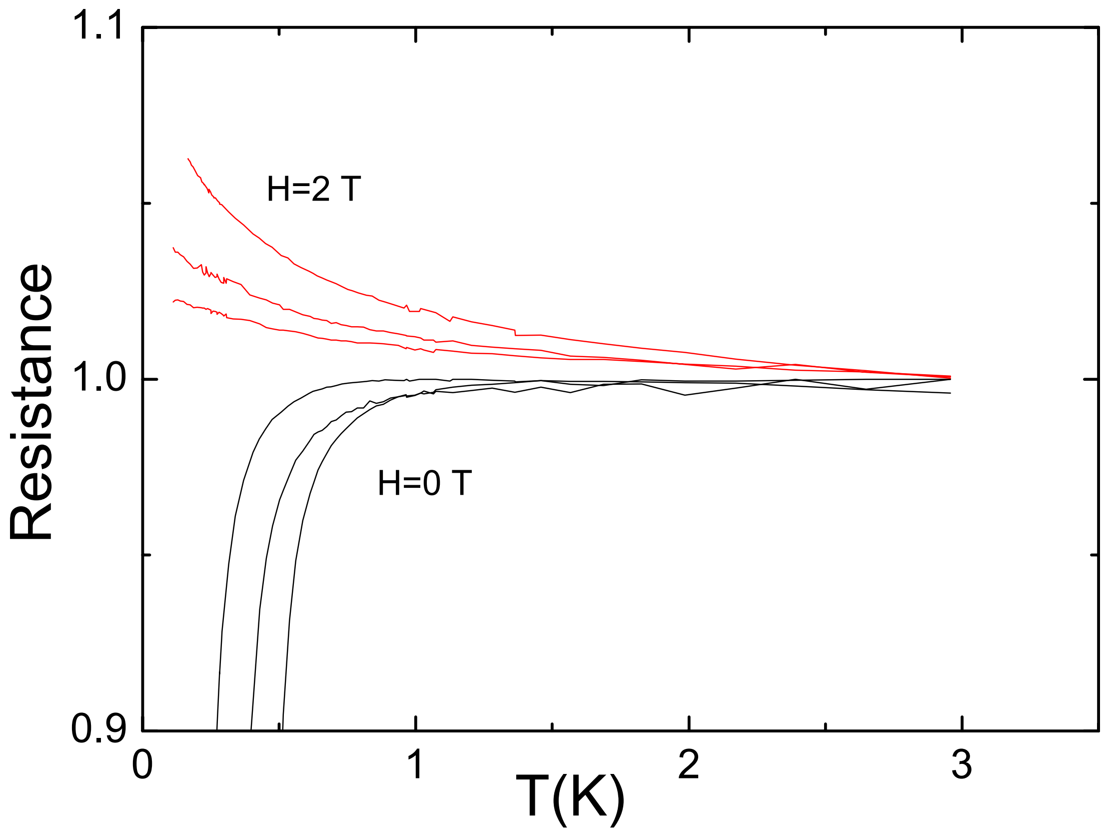
Granular superconductors



Jaeger H.M. et al.
Phys. Rev. B 40,182-196
(1989)

FIG. 2. The evolution of $R(T)$ curves for (a) Al, (b) In, (c) Ga, and (d) Pb, obtained *in situ* after successive increments of film thickness. Note that in all cases the entire evolution from insulating to globally superconducting spans an interval of nominal thickness of less than one monolayer.

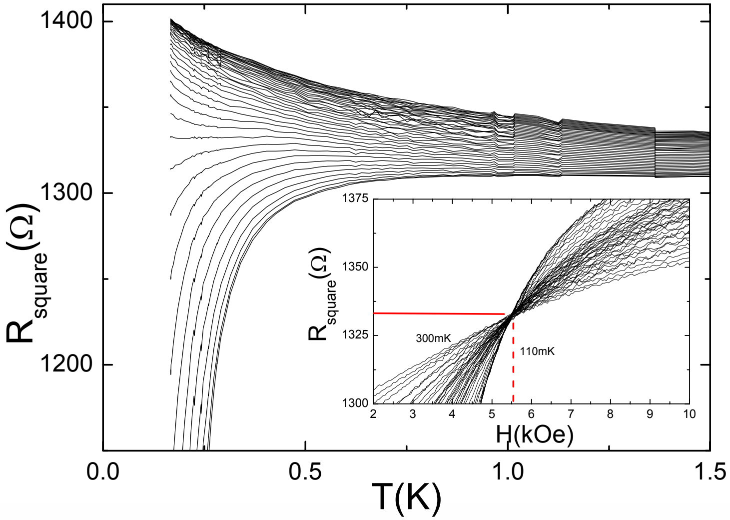
At low temperature, and high magnetic field, the resistivity depends on the thickness of the films.

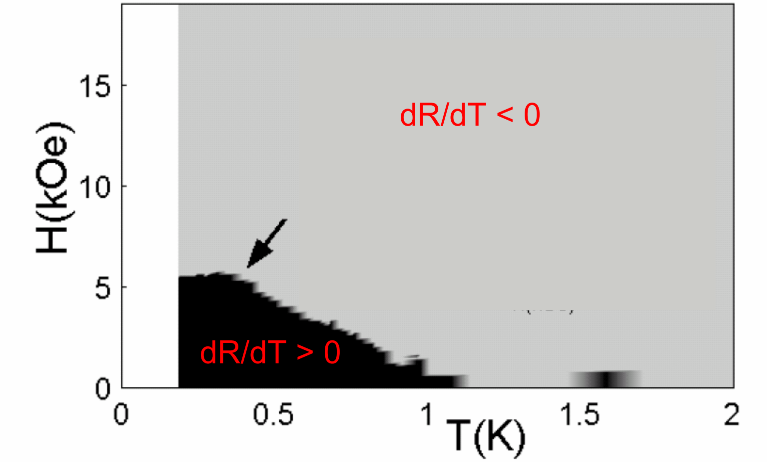


perpendicular field →Bose condensation of vortex glass

Quantum transition

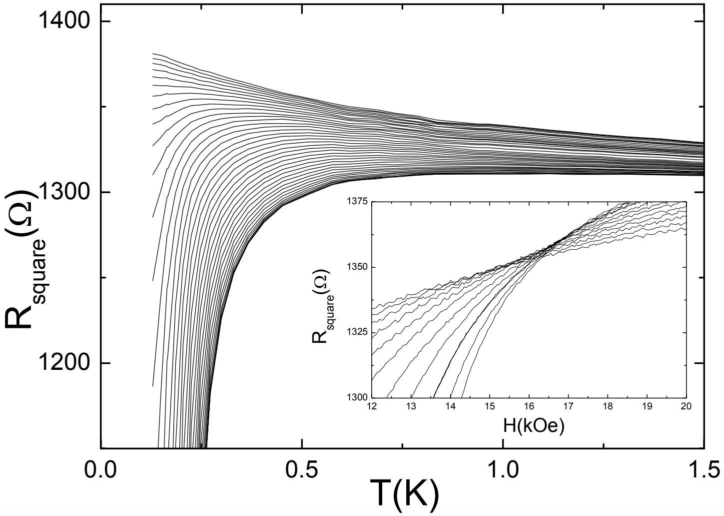
(M. P. A. Fisher, Phys. Rev. Lett. 65, 923 (1990))

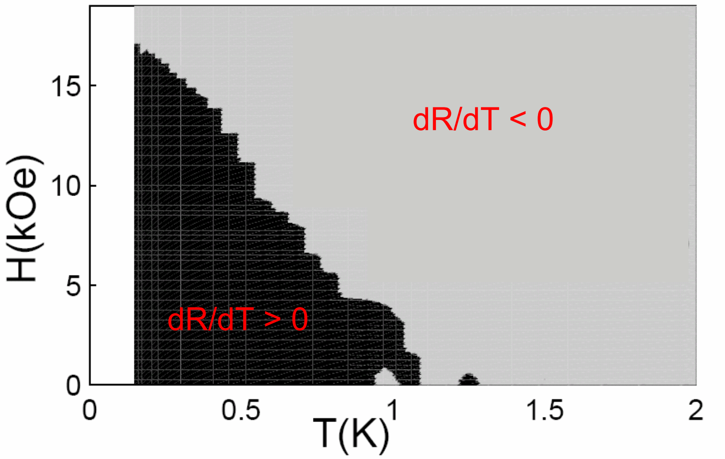




parallel field → no vortices

Classical transition





H. Aubin et al. cond-mat/0601024
(to be published PRB)

Les conséquences du désordre sur : l’amplitude du paramètre d’ordre supraconducteur

- Théorème d’Anderson → Les paires de Cooper sont « robustes » vis-à-vis de la diffusion sur les impuretés

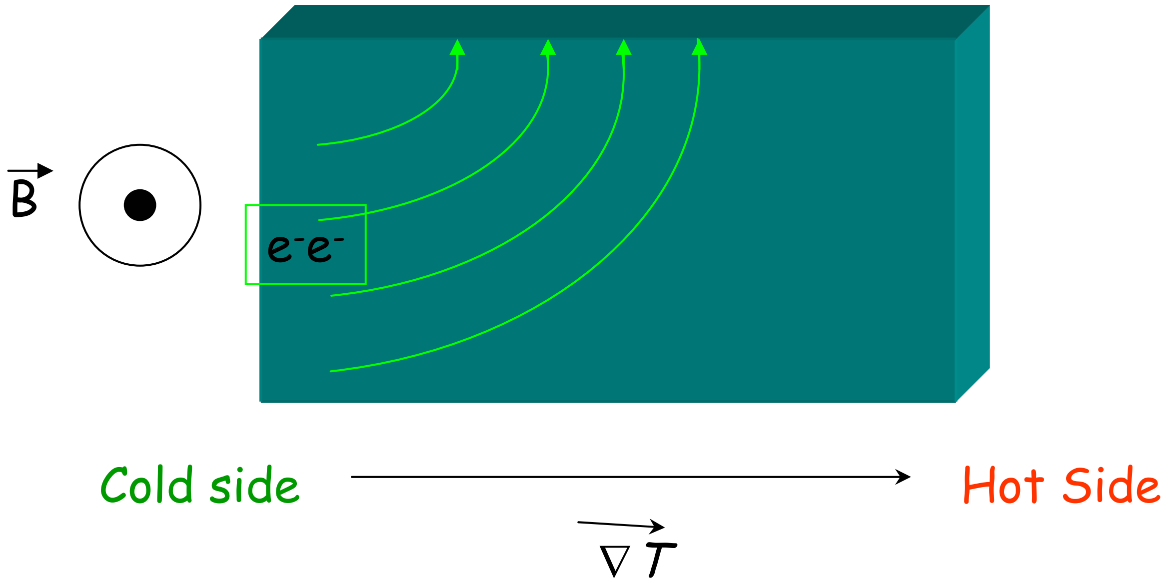
- Localisation → Augmentation des interactions de Coulomb due à la réduction de l’écrantage

$$Tc_{BCS} \propto e^{-1/N(\varepsilon)Ve-e}$$

  - Diminution de l’attraction effective V e-e
    → Tc_{BCS} diminue
  - Réduction de la densité d’états (gap de Coulomb)
    → Tc_{BCS} diminue

Fukuyama, Maekawa (~1980-1985)

How short-lived Cooper pairs, alone, can generate a Nernst signal ?



-Cooper pairs on cold side live longer than those on hot side
-This produces a net current of Cooper pairs
-This current, deflected by the magnetic field, gives the Nernst signal