Dimensional crossover in the superconductor/insulator transition of $La_{2-x}Sr_xCuO_4$

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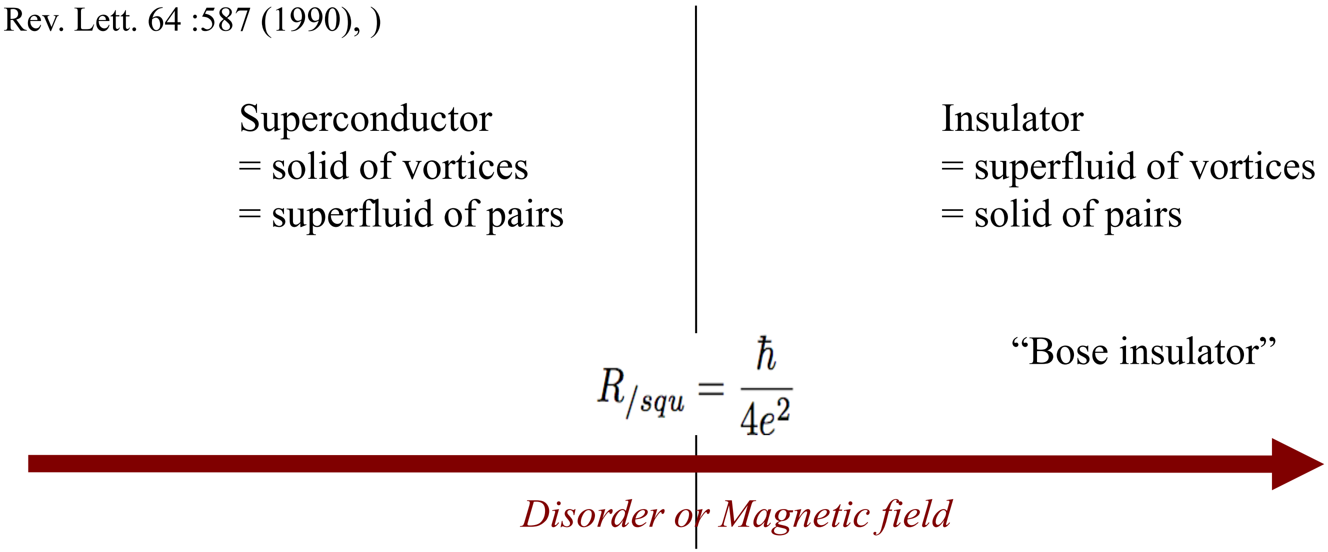
Electronic fundamental state in 2D ?

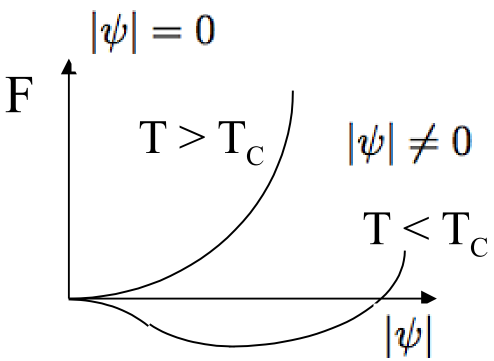
- R= 0 or infinity at T=0 (Lee & Ramakrishnan Rev. Mod. Phys., 57, 287. (1985))
- May superconductivity survive localization ? (Ma & Lee. Phys. Rev. B., 32 :5658 (1985))
- Bose insulator model (Fisher, Phys. Rev. Lett. 65 :923 (1990) ; Fisher, Grinstein & Girvin. Phys. Rev. Lett. 64 :587 (1990),)



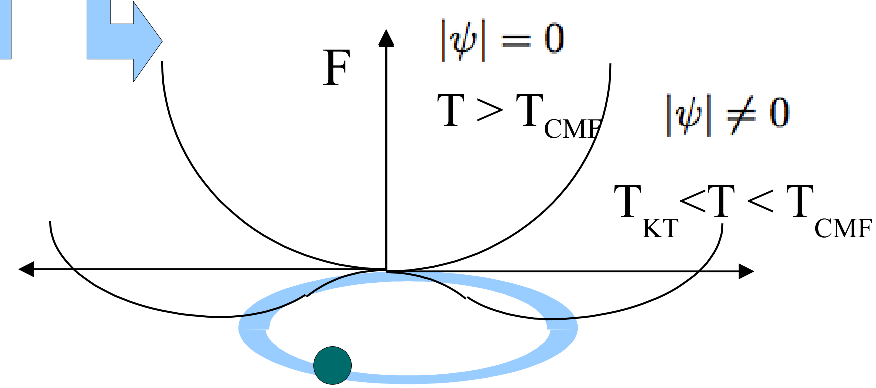
Phase fluctuations in a « classical » transition

What governs the superconductor/insulator transition ?

$$\psi = |\psi| \, e^{i\phi}$$



Conventional phase transition



Berezinskii-Kosterlitz-Thouless transition

Observations of QSIT

Hebard, PRL 65, 927 (1990)

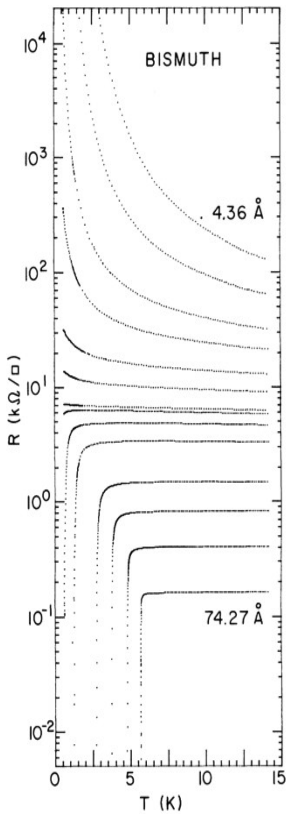


FIG. 1. Evolution of the temperature dependence of the sheet resistance $R(T)$ with thickness for a Bi film deposited onto Ge. Fewer than half of the traces actually acquired are shown. Film thicknesses shown range from 4.36 to 74.27 Å.

$$R_{sq} = \frac{\hbar}{4e^2}$$

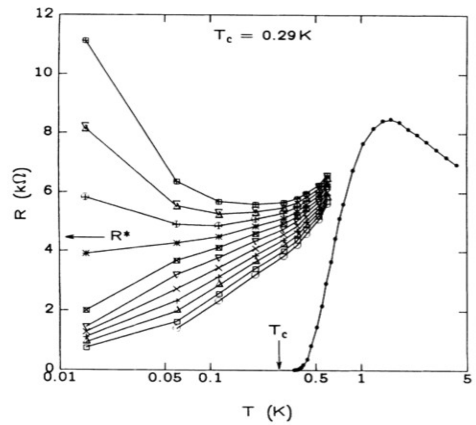
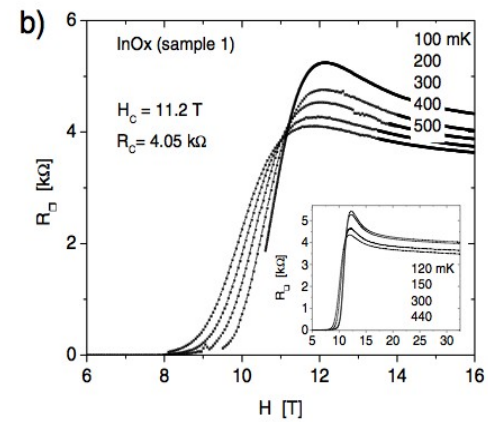


FIG. 1. Logarithmic plots of the resistance transitions in zero field (●) and nonzero field (open symbols) for a film with T_c =0.29 K. The isomagnetic lines range from B =4 kG (○) to B =6 kG (□) in 0.2-kG steps. The horizontal and vertical arrows identify R^* and T_c, respectively.

InOx (granular)



Haviland, PRL 62, 2180 (1989)

But also :

Homogeneous ultrathin Bi and Pb

MoGe J. Graybeal (1984), A. Yazdani (1995), steiner (2005)...

NbSi Aubin (2006)

….

Footprints of a QSIT

- Plateau in the R(T) curve for one value of H or δ
- Critical exponents

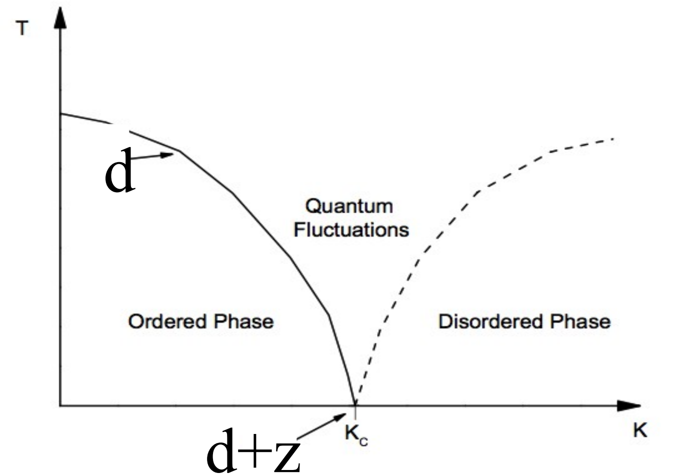
$$\xi \propto |K - K_C|^{-\nu} \qquad \tau \propto \xi^z$$

- Scaling $$\frac{R_{sq}}{R_C} = |H - H_c| T^{-1/\nu z}$$

→ universality class of the transition

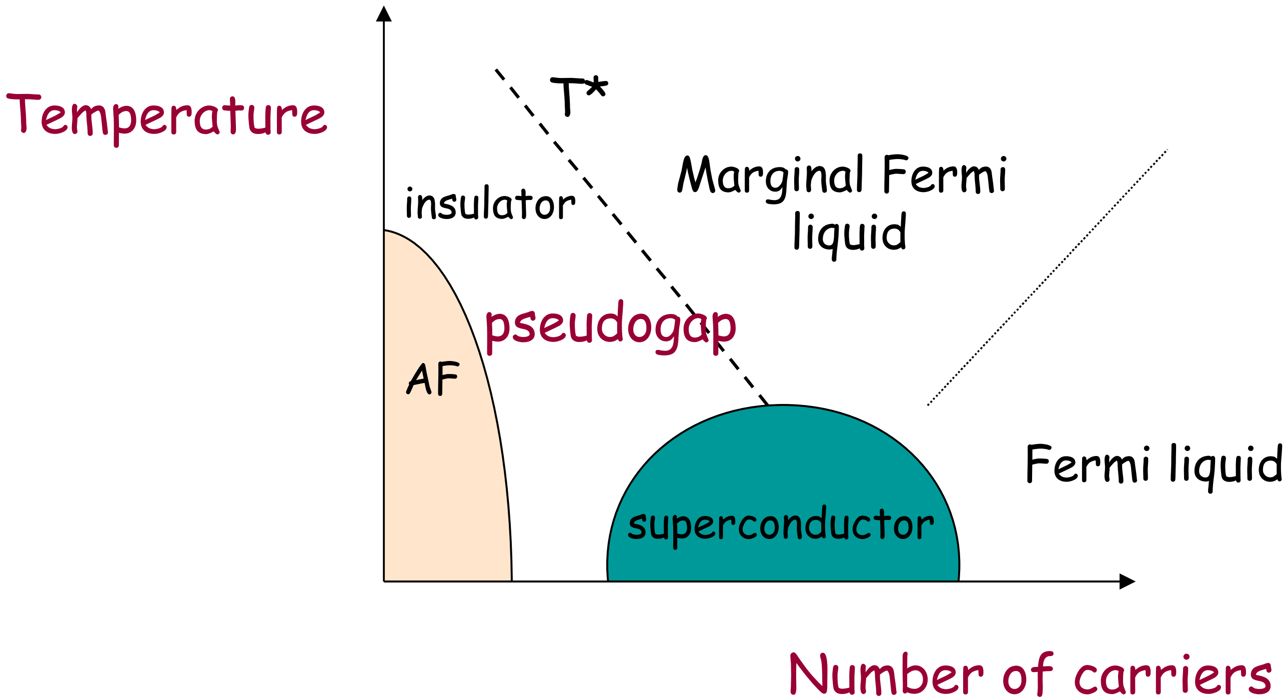
Bose insulator $\nu > 1$

2d+1 xy model νz=2/3 with z=1

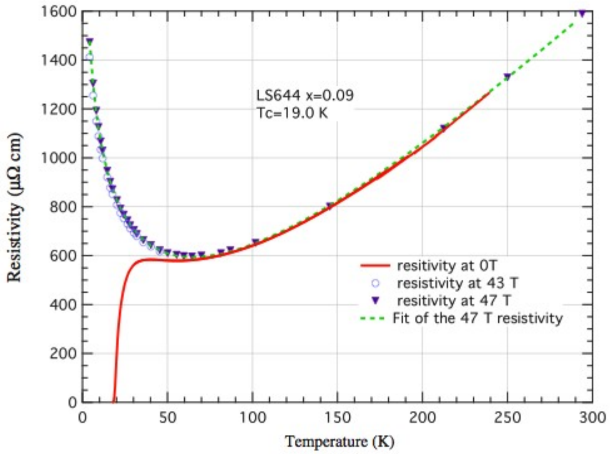


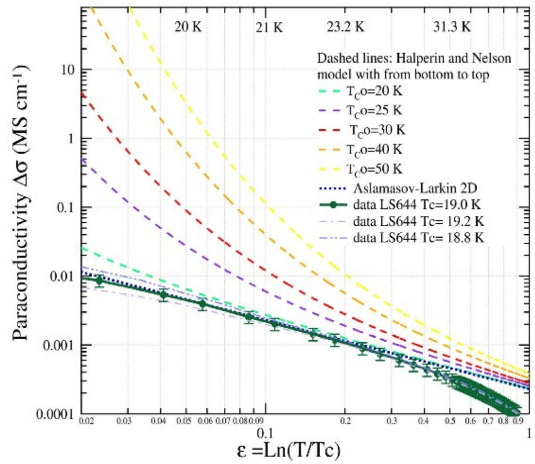
- Perpendicular versus parallel field (mechanism?)

Cuprates phase diagram



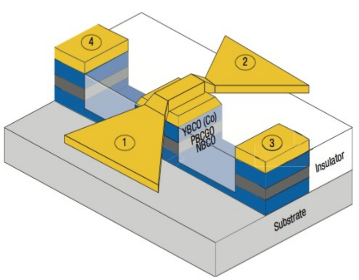
What about cuprates ?
1- the superconducting transition in T

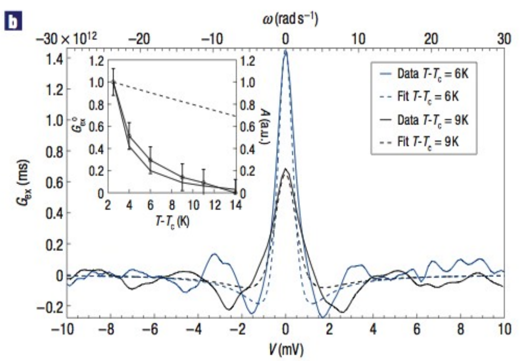




Leridon PRB 2007

Bergeal Nature Physics 2008

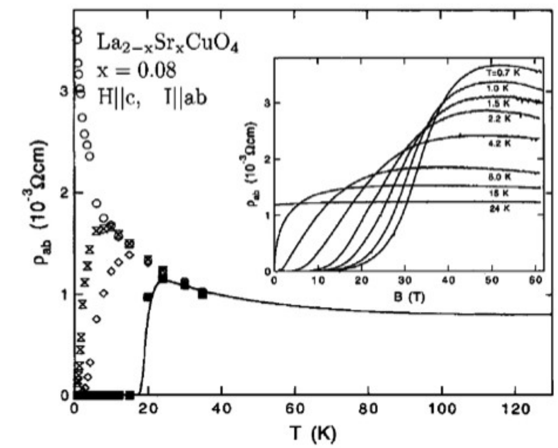




No space for phase fluctuations !

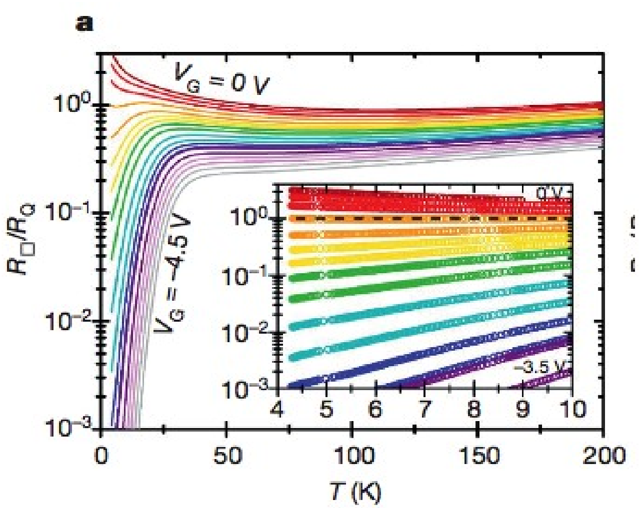
What about cuprates ?
2- The transition at T=0

- Steiner (2005)

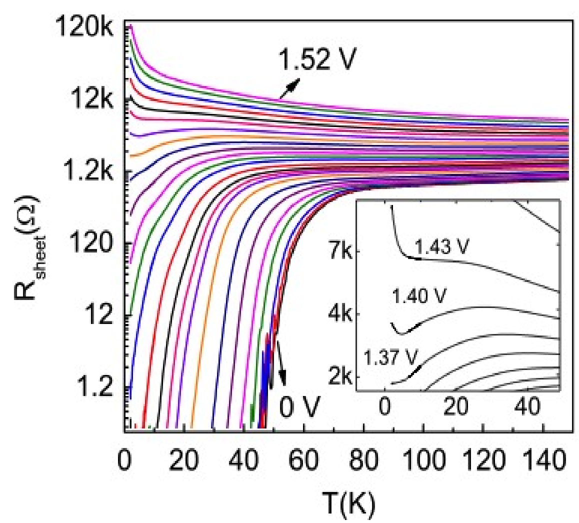


- Wang (1991), Seidler (1992)
- Monolayers

(as a function of electric field)

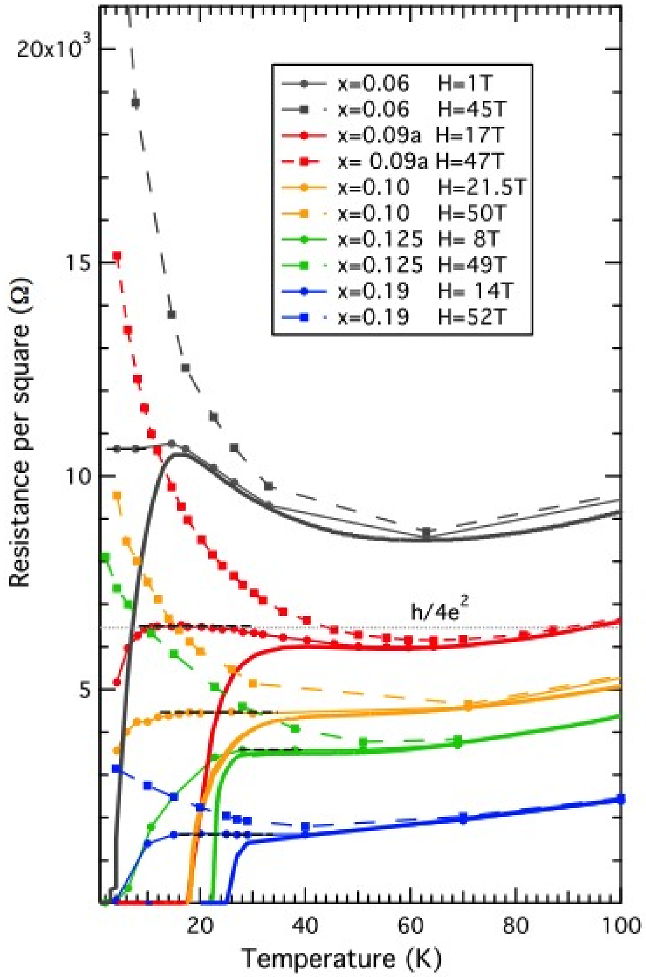


LSCO, Bolllinger Nature 2011



YBCO, Leng PRL(2011)

Systematic study under high pulsed magnetic field



Nine LSCO thin films :

dc magnetron sputtering
on SrTiO3(Leuven)
PLD on LaSrAlO4
d=100 nm
XRD

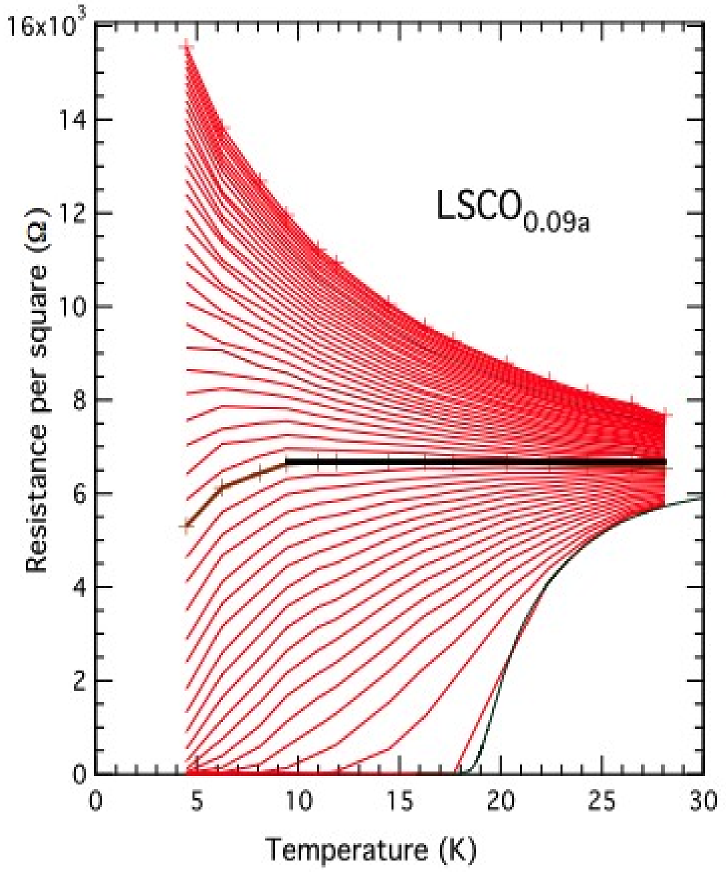
Measurements KU Leuven
or Toulouse LNCMI

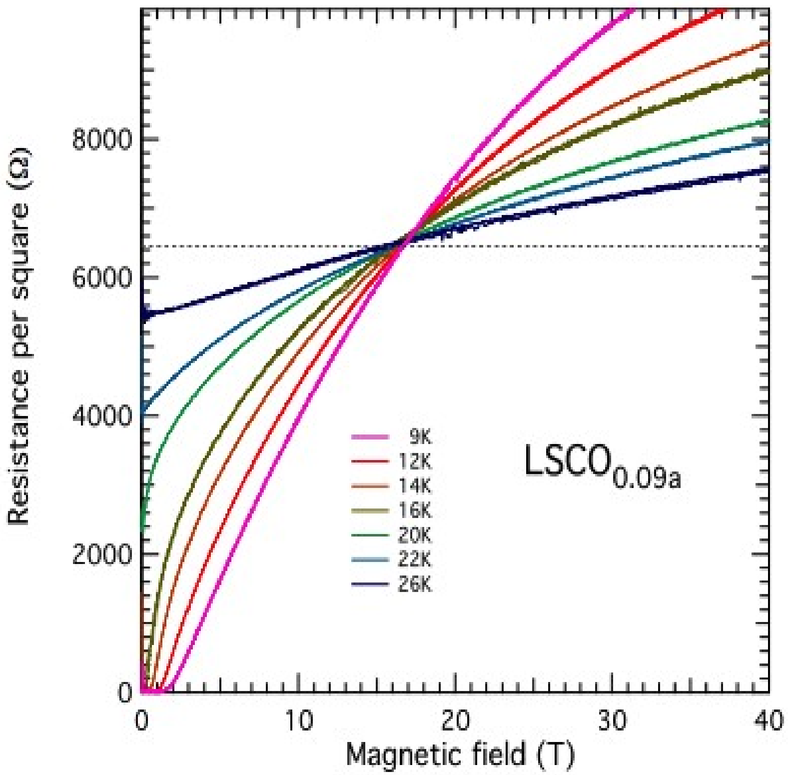
State under high field

$$\rho = \rho_1 \log\left(\frac{T_0}{T}\right) - aT$$

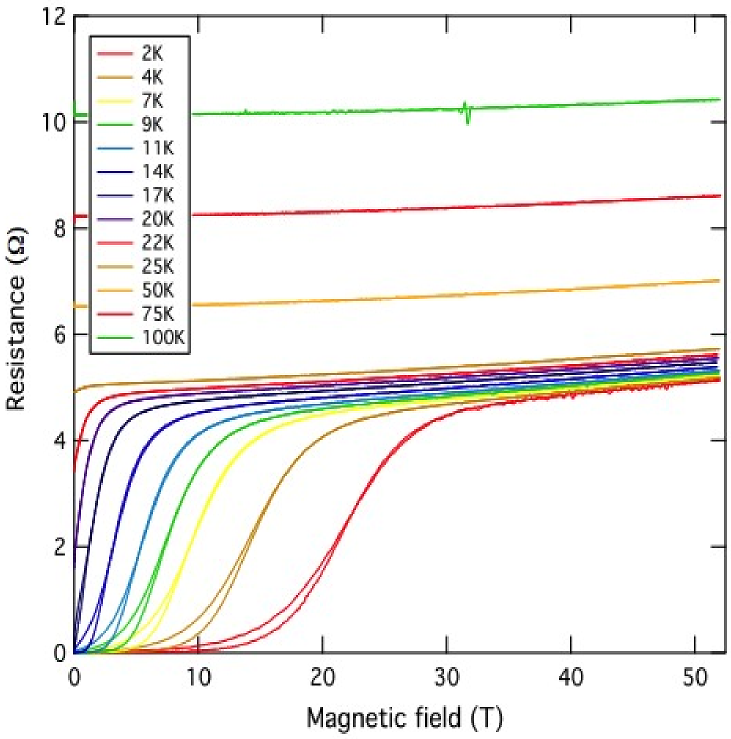
Bose metal ? Das and Doniach (1999)

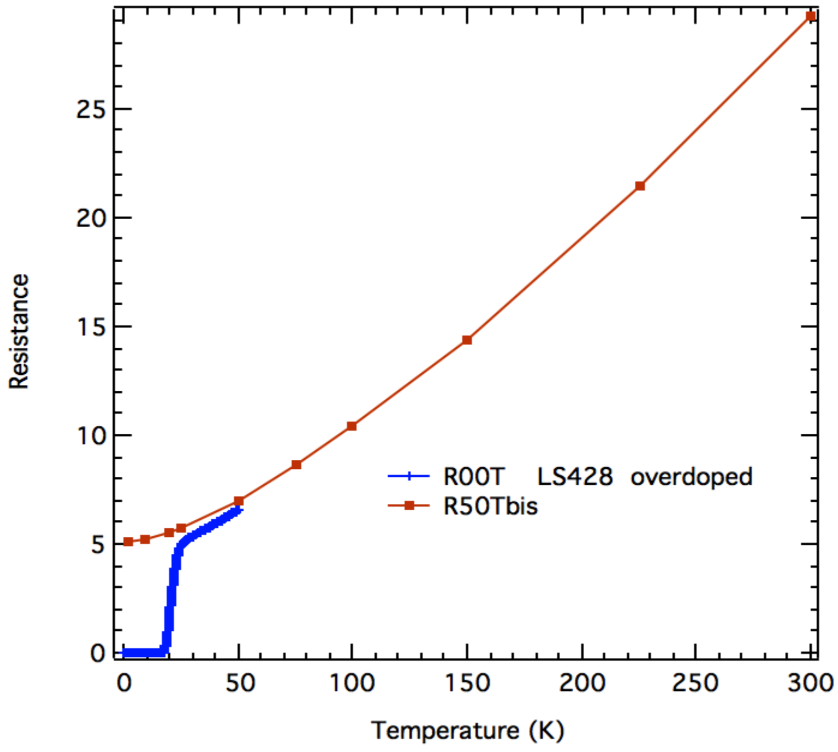
Plateau and crossing points





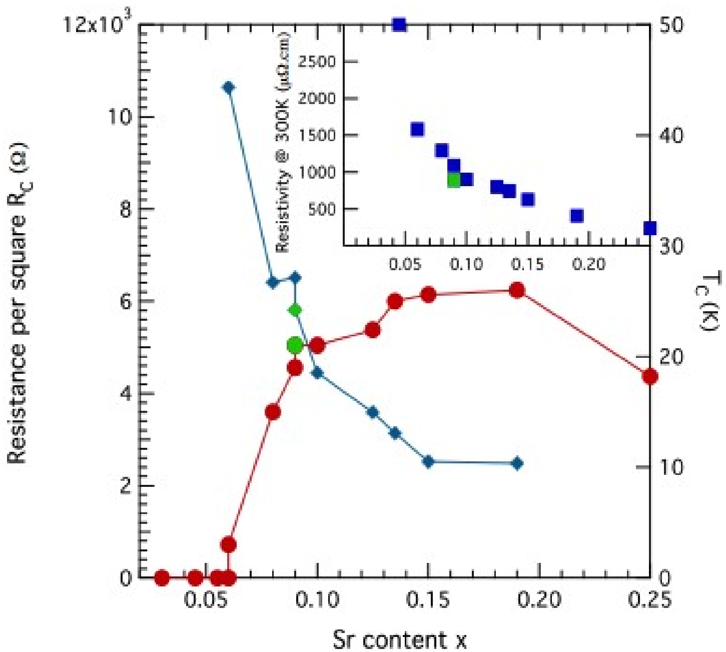
Overdoped samples

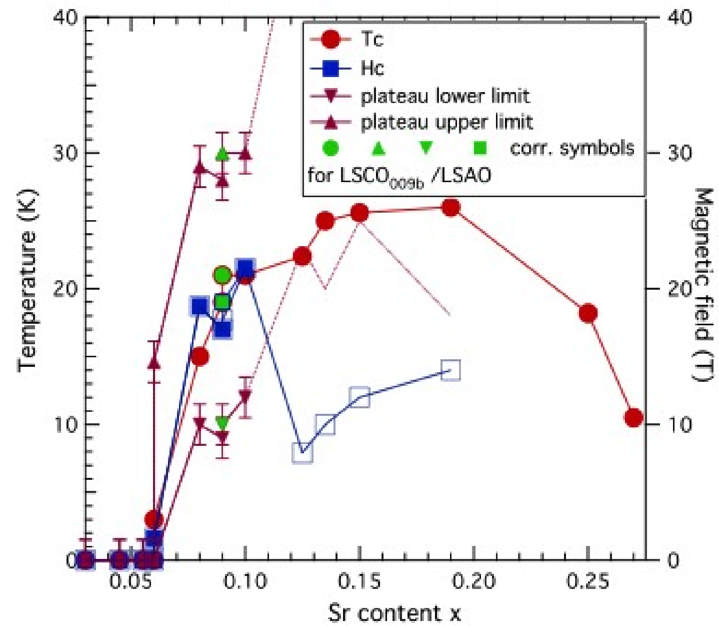




x=0.25

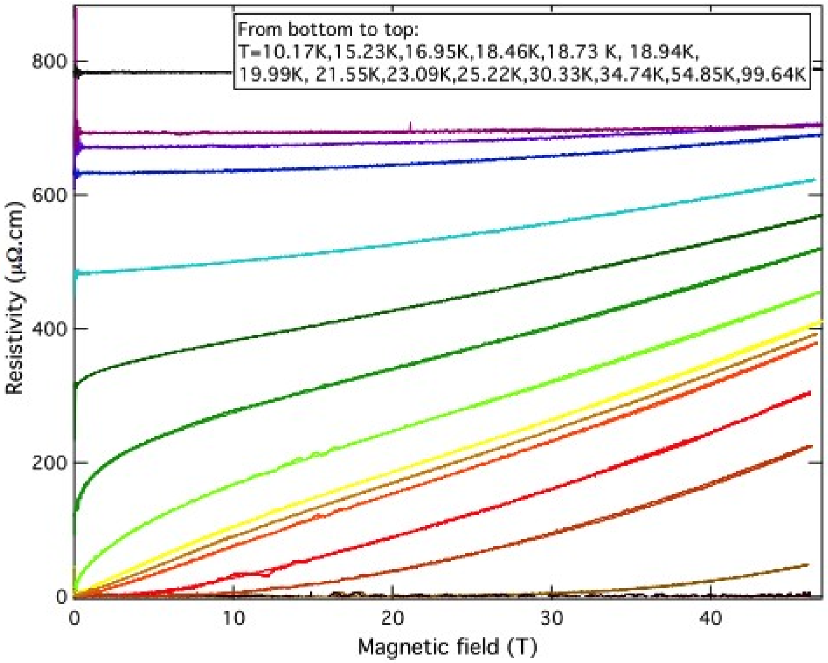
Measurements

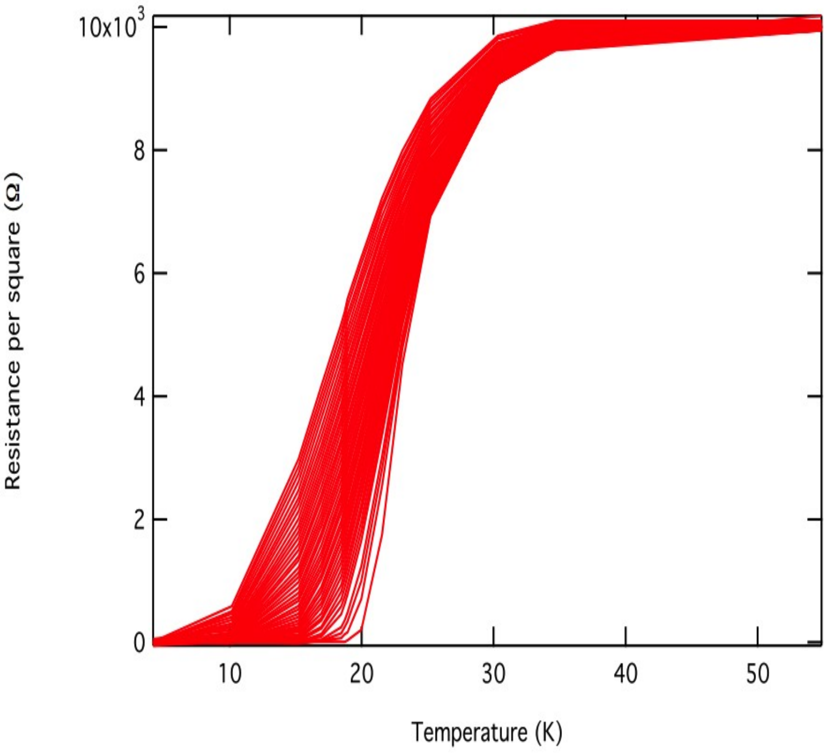




- No-crossing point for the overdoped films
- Crossing-point for $0.06 \leq x \leq 0.1$
- $H_C \propto T_C$ with 1K=1T

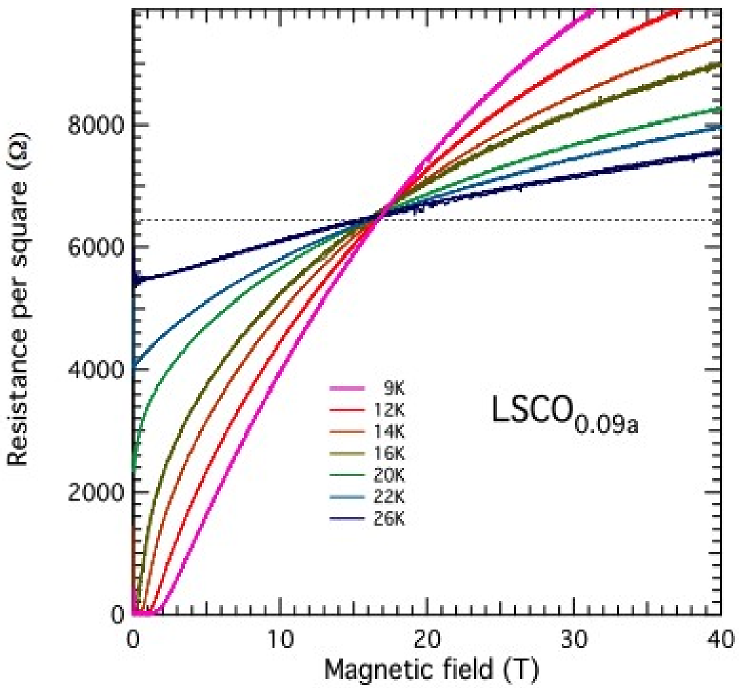
Parallel magnetic field data

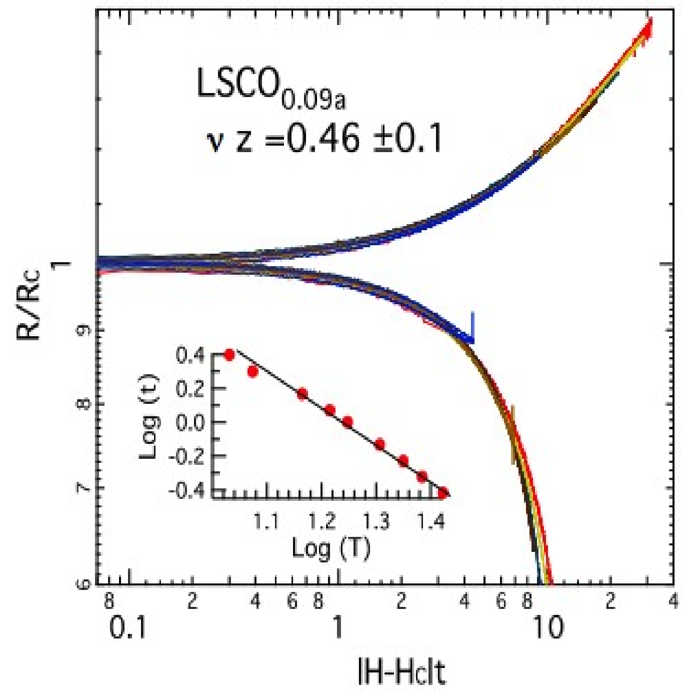




No crossing point : Different mechanism

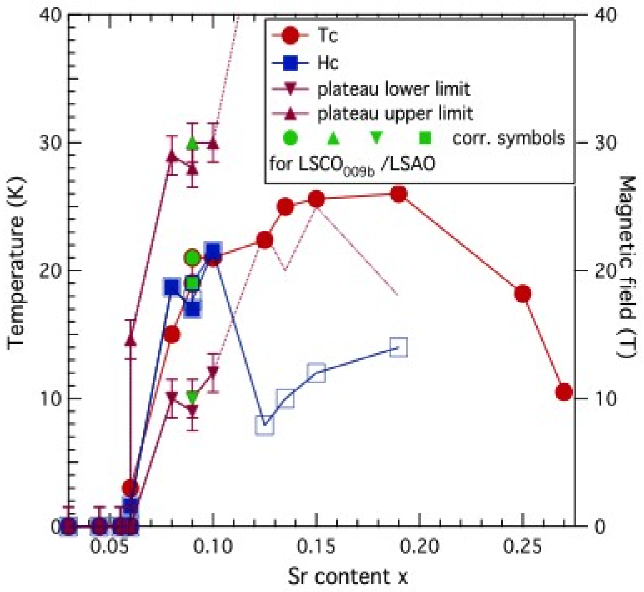
Scaling analysis





Scaling analysis

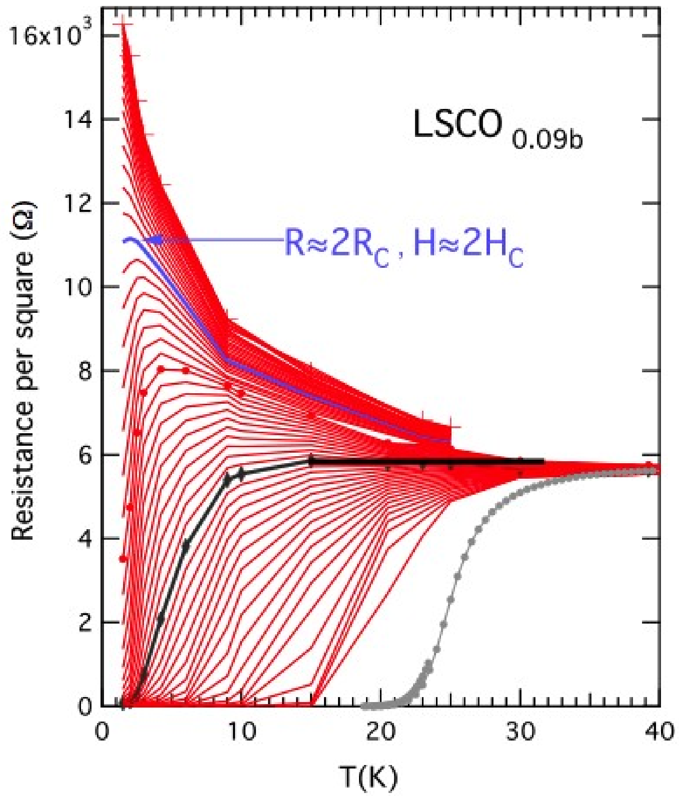
Sample name	Sr content	T_C K	H_C T	R_C Ohms	νz
LSCO0.06	0.06	3	1.6	10638	-
LSCO0.08	0.08	15	18.7	6408	0.54 ± 0.1
LSCO0.09a	0.09	19	16.8	6509	0.46 ± 0.1
LSCO0.09b	0.09	21	19	5811	0.43 ± 0.1
LSCO0.10	0.10	21	21.5	4445	0.63 ± 0.1



- 2d+1 xy model (with z=1) $\nu z = 0.66$
- Boson insulator : $\nu > 1$
- $H_C \propto T_C^{2/z}$ (Hebard & Paalanen, Phys. Rev. Letters, 65 :927 (1990))

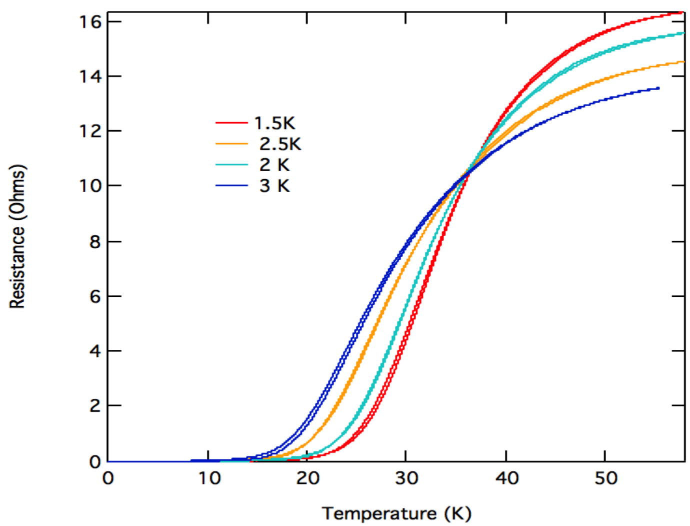
which would give z=2 ?

Additional measurements

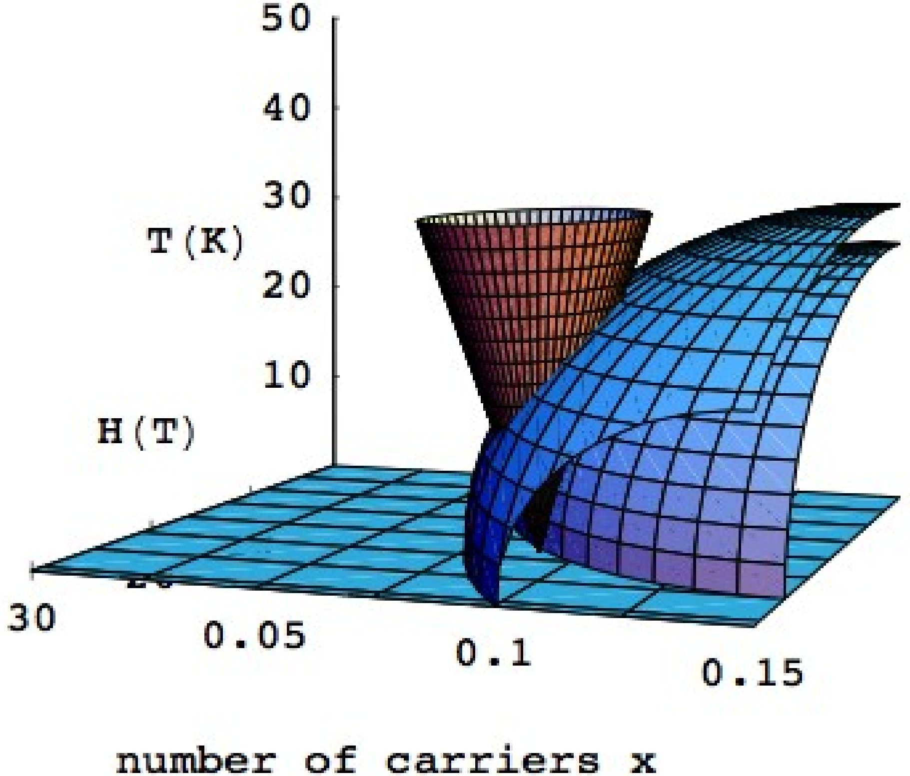


Second QCP ?

$\nu z \gtrsim 1$



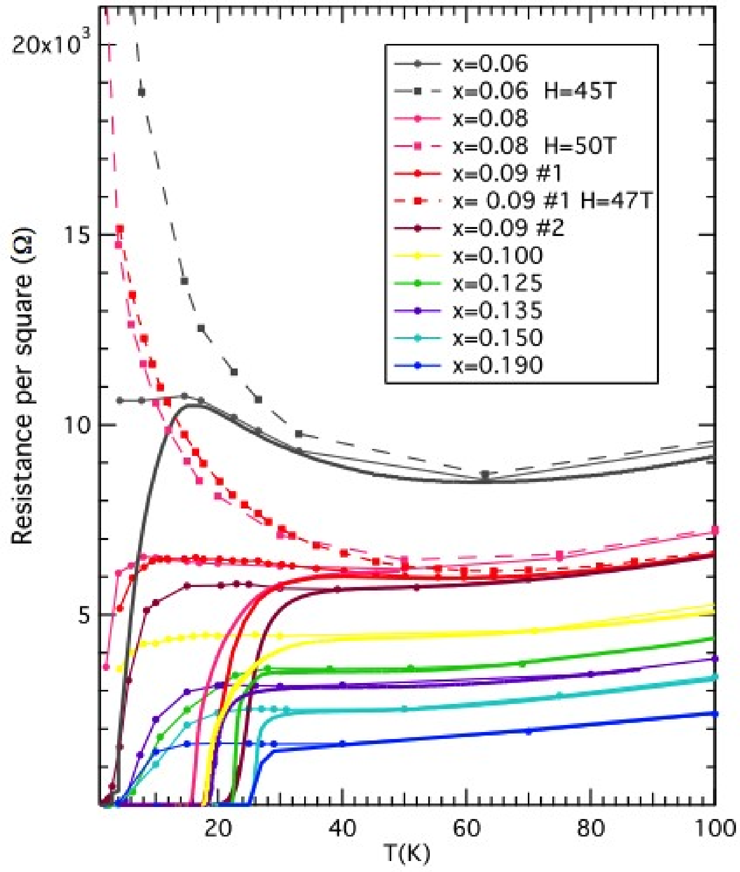
2D-3D Crossover ?



summary

- No-crossing point for the overdoped films
- Crossing-point for all superconducting films with $0.06 \leq x \leq 0.1$
- $H_C \propto T_C$ with 1K=1T
- Critical exponents close to 2d+1 xy model (but lower)
- Existence of a second QCP (to better explore)
- Observations not in favor of Bose Insulator
- Probable dimensional crossover from 2D to 3D

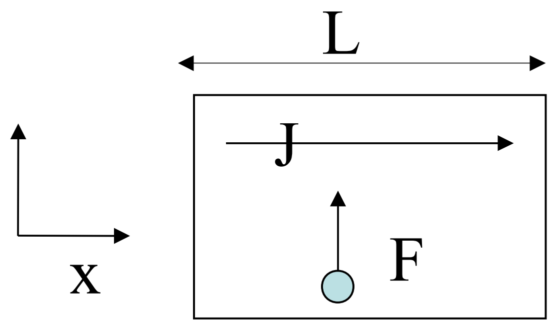
All samples



20x10^3
15
10
5
20
40
60
80
100
T(K)
Resistance per square (Ω)
x=0.06
x=0.06 H=45T
x=0.08
x=0.08 H=50T
x=0.09 #1
x= 0.09 #1 H=47T
x=0.09 #2
x=0.100
x=0.125
x=0.135
x=0.150
x=0.190

Boson localization approach (MPA Fisher)

Dual picture: a charged particle moving around a flux line OR a flux line circling a charge



$$J = \sigma E_x = \sigma V/L$$

$$J_v = \sigma_v \frac{h}{e} E_y$$

$$J_v = n v_D = n \mu F_M$$

$$\sigma \sigma_v = \frac{4e^2}{h}$$

$$V = \frac{\hbar}{2e} \frac{d}{dt} \Delta\theta$$

$$\frac{d}{dt} \Delta\theta = 2\pi L J_v$$