SUPERCONDUCTING TRANSITION IN “BAD” METALS

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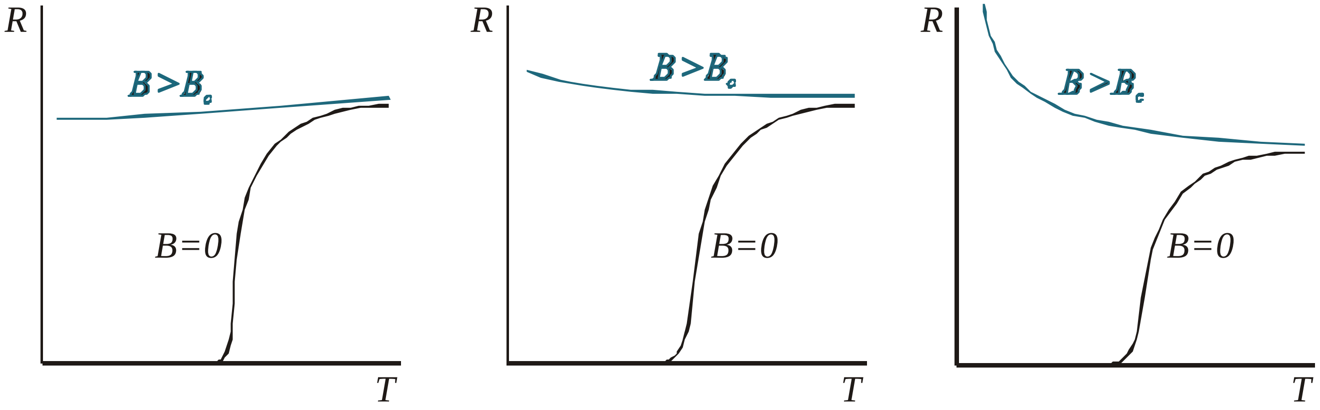
Field-induced ...

… transition superconductor -- normal-metal

?

… transition superconductor -- insulator



EXPERIMENTAL SUMMARY

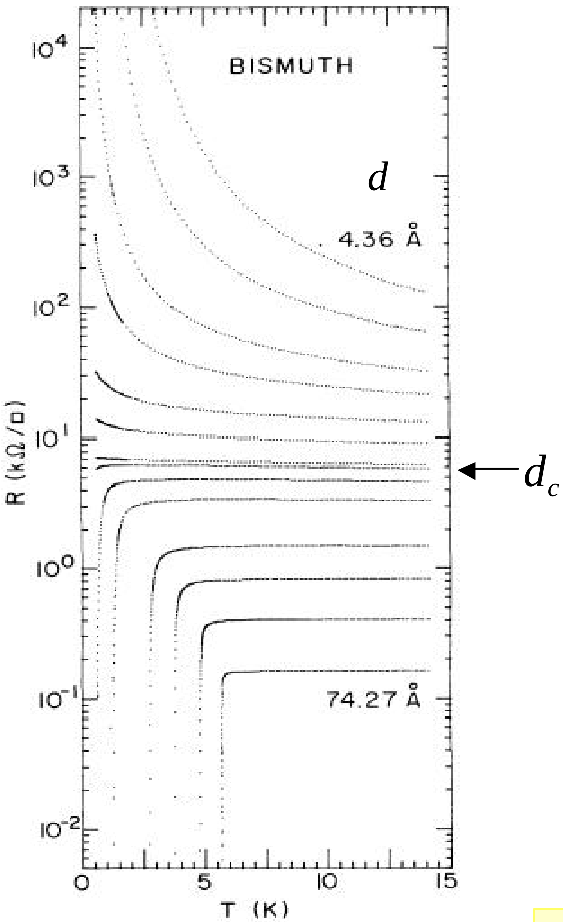
Materials

Ultrathin films (Bi, Be,...)	*A.M. Goldman et al (1989, 1993)* *E.Bielejec and W.Wu (2002)* *J. A. Chervenak and J. M. Valles, Jr (2000)*
InO_x	*A.F. Hebard and M.A. Paalanen (1990)* *V.F. Gantmakher et al. (1998, 2000)*
a-Mo_xSi_{1-x}	*S. Okuma, et al. (1998)*
a-MoGe	*A.Yazdani and A.Kapitulnik (1995)*
$Nd_{2-x}Ce_xCuO_{4+y}$	*S. Tanda et al. (1992)* *V.F. Gantmakher et al. (2003)*
TiN_x	*T.I. Baturina et al. (2002)*

Common features

1. *Fan-shaped structure of R(T) curves*
2. *Negative magnetoresistance in high fields*
3. *Scaling (??)*

Superconductor-insulator transition in ultrathin Bi films



$d < d_c$: Insulator

There are no clear data about the high-field magnetoresistance in ultrathin films

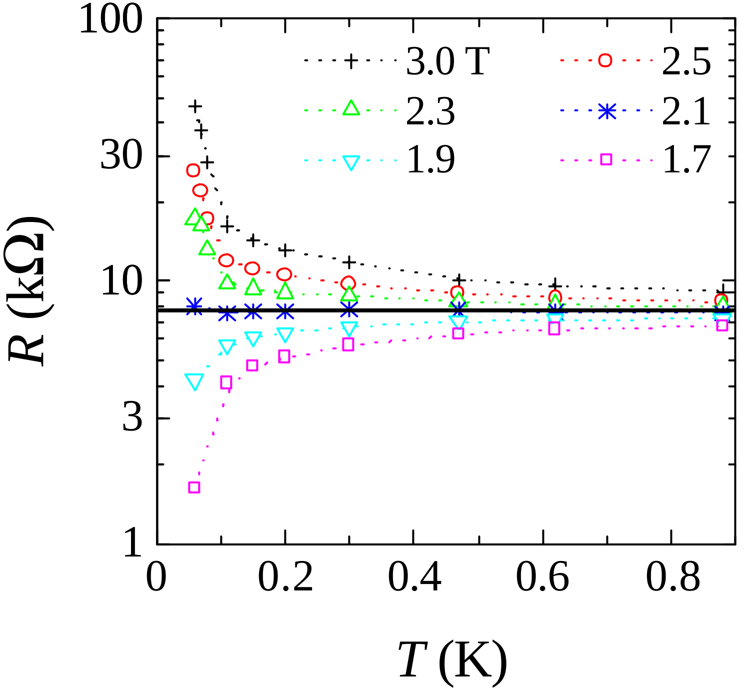
$d > d_c$: Superconductor

D.B.Haviland, Y.Liu, and A.M.Goldman (1989)

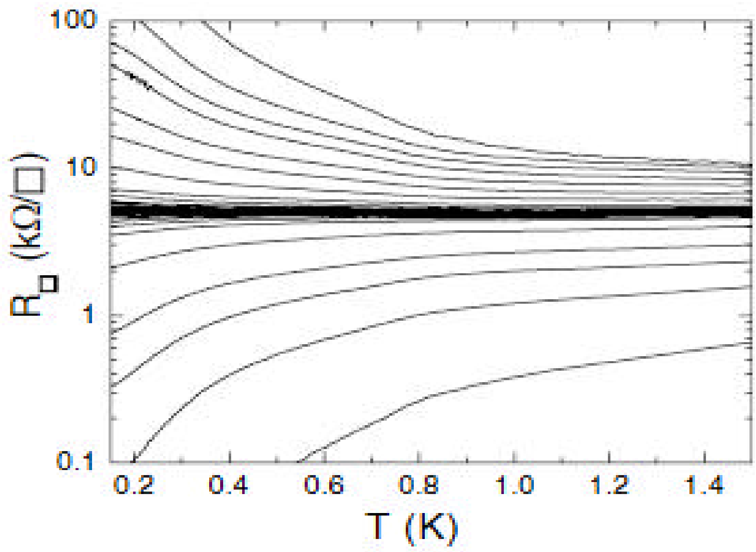
Fan-shaped curves

high resistivity

V.F. Gantmakher et al. (1998)
a-InO_x



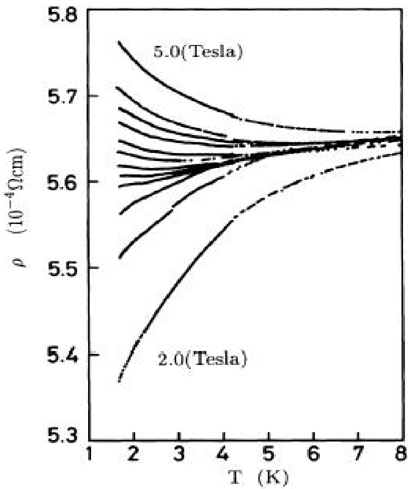
E. Bielejec and W. Wu (2002)
Be



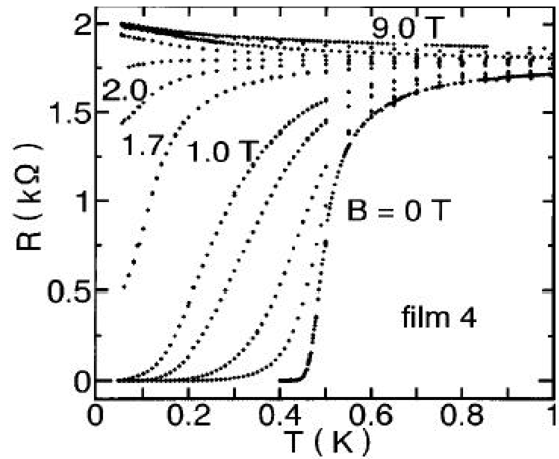
Fan-shaped curves

low resistivity

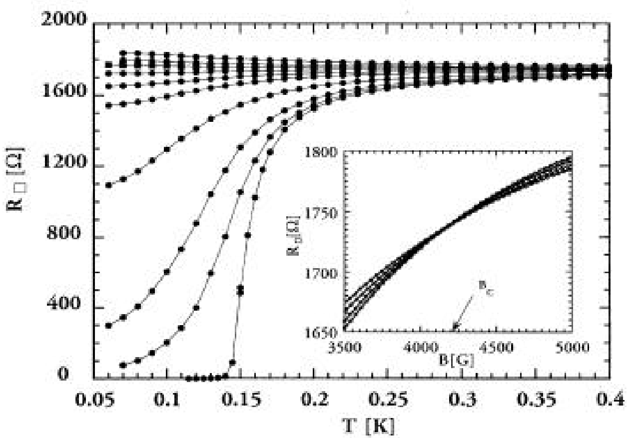
Tanda et al. (1992)
$Nd_{2-x}Ce_xCuO_4$



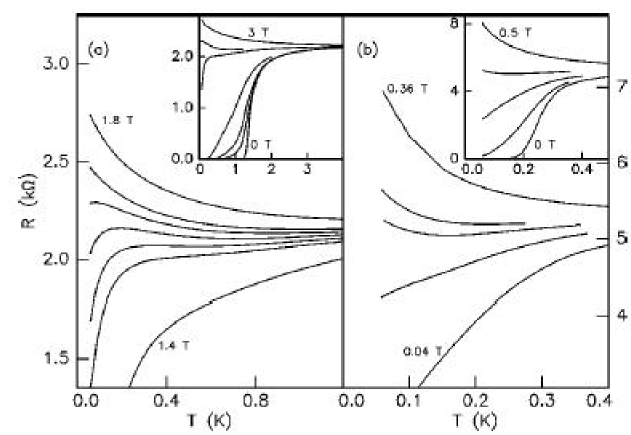
S. Okuma et al. (1998)
Mo_xSi_{1-x}



A.Yazdani and A.Kapitulnik (1995)
a-MoGe



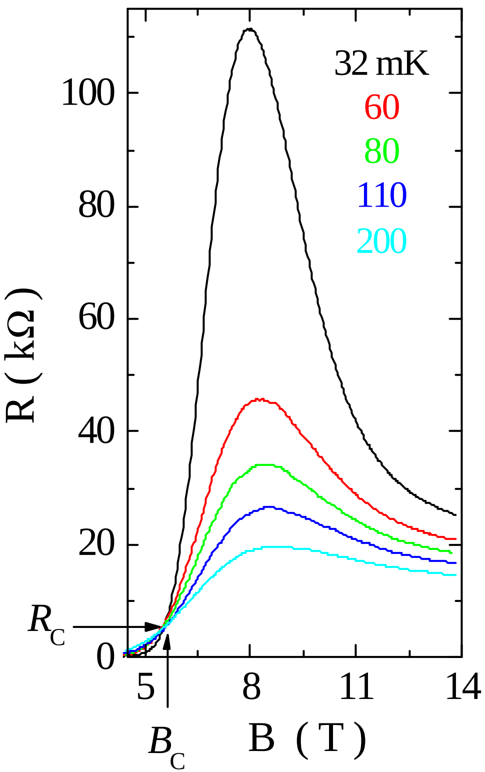
J. A. Chervenak and J. M. Valles, Jr (2000)
Bi/Sb



Negative magnetoresistance

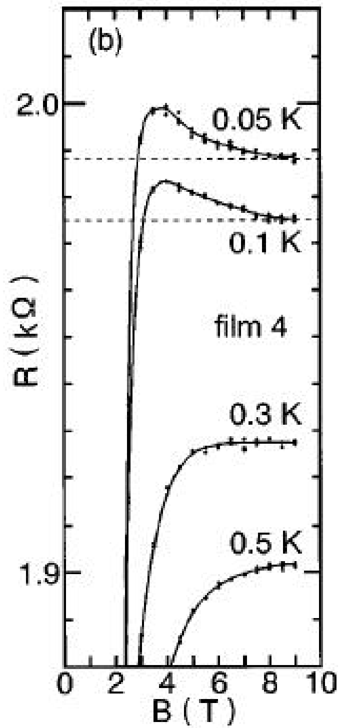
high resistivity

V.F. Gantmakher et al. (1998)
a-InO_x

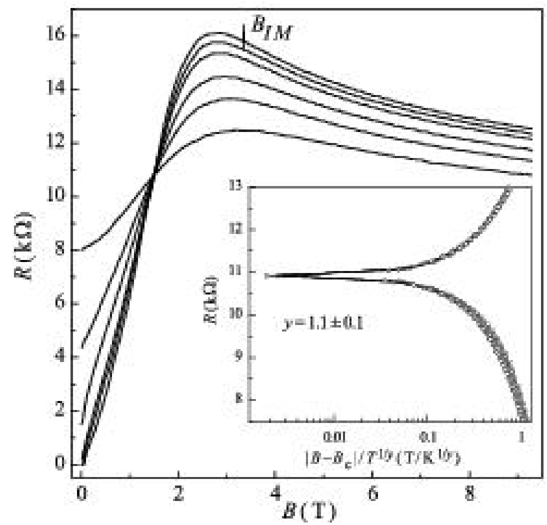


low resistivity

S. Okuma et al. (1998)
Mo_xSi_{1-x}

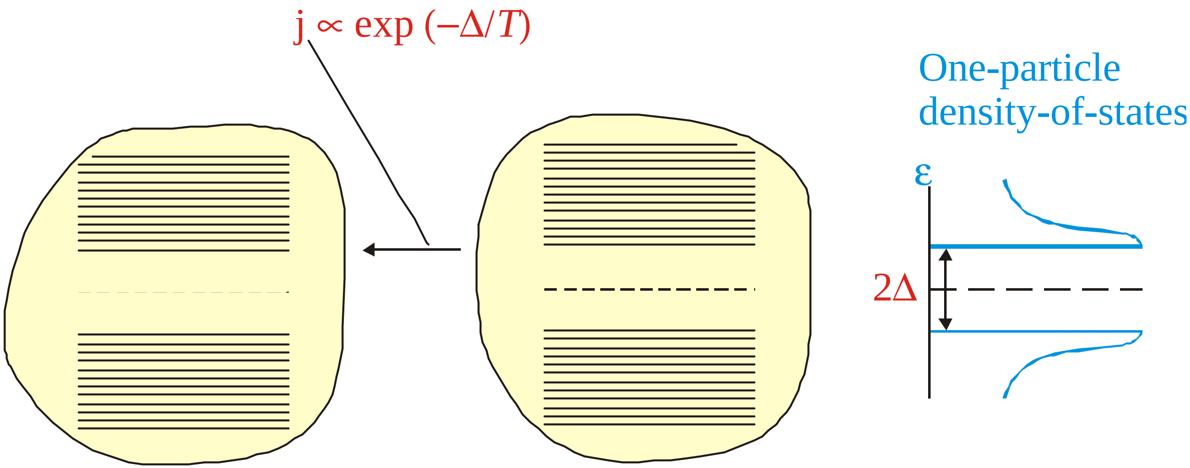


T. Baturina et al. (2002)
TiN_x

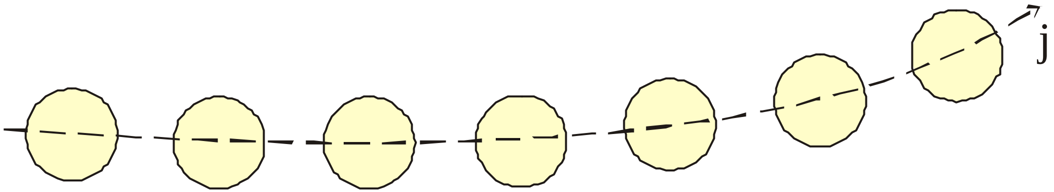


Granularity of a superconductor (2D and 3D as well)

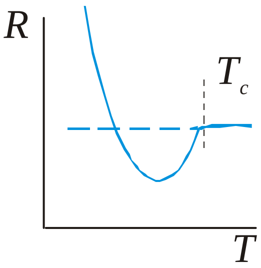
encloses a tendency to insulating behavior *(when Josephson currents are suppressed)*



and leads to negative magnetoresistance *(when magnetic field destroys the superconducting gap)*



Superconducting grains along a current line



THEORETICAL APPROACHES

M.P.A. Fisher et al. (1990) Phenomenological description of 2D transitions based on 2*e*-bosons – vortex duality

1. Predicts scaling relations with $|B - B_{c0}| / T^{1/zn}$ *as scaling variable;*

2. Assumes existence of localized electron pairs .

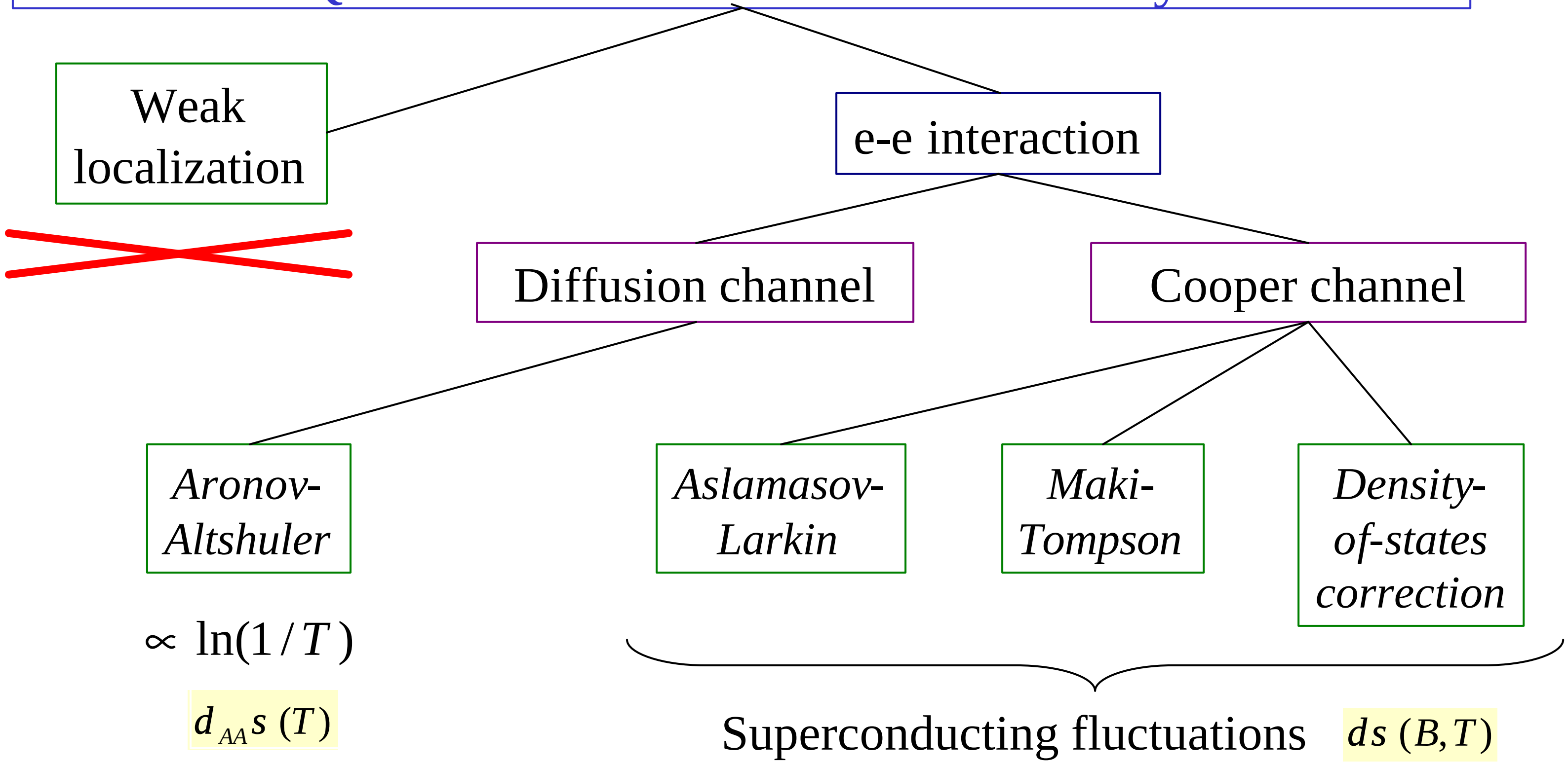
V.M. Galitski and A.I. Larkin (2001) Superconducting fluctuations **at $T \ll T_{c0}$ in magnetic field**

The main assumptions and restrictions:

1. Calculations are done in the frame of BCS theory;

2. Corrections should be smaller than the conductivity itself.

Quantum corrections to conductivity



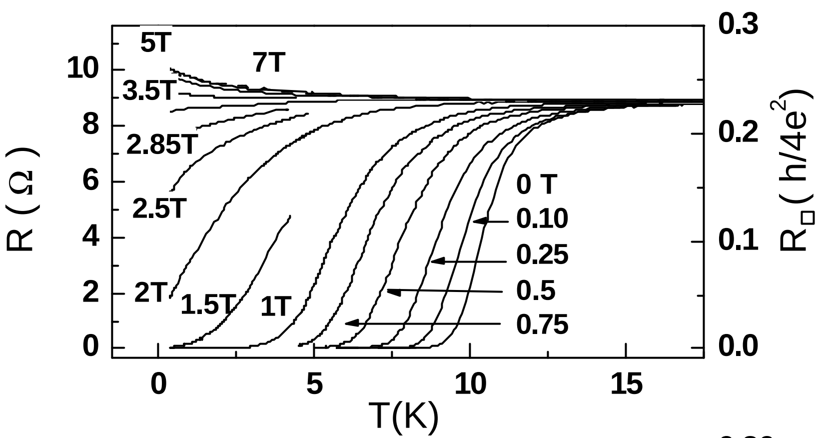
$$T_{c0}t << 1, \qquad t = T/T_{c0} << 1, \qquad b = (B - B_{c2}(T))/B_{c2}(0) << 1$$

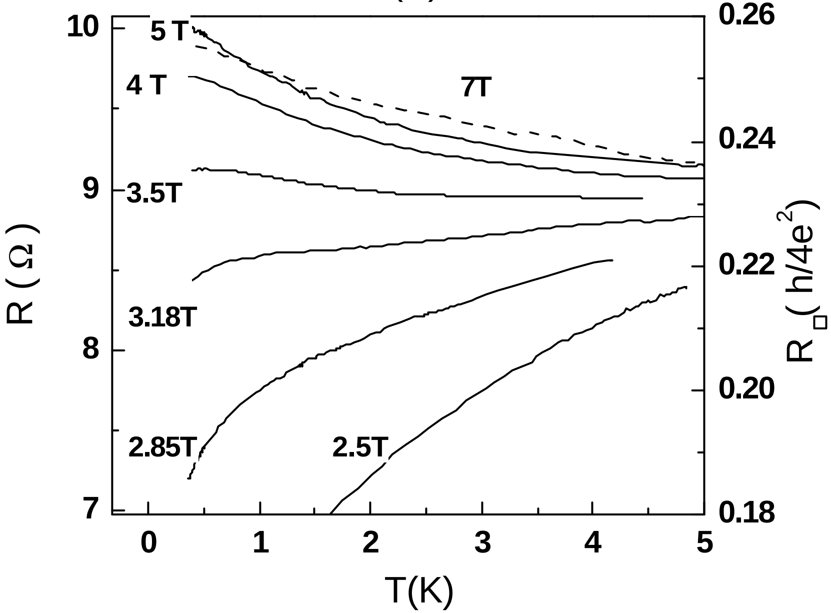
$$\delta\sigma = \frac{2e^2}{3\pi^2\hbar}\left[-\ln\frac{r}{b} - \frac{3}{2r} + \psi(r) + 4[r\psi'(r) - 1]\right]$$

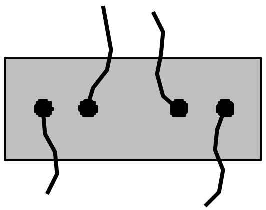
$$r = (1/2\gamma)b/t$$

$$\gamma = 1.781$$

Film $Nd_{2-x}Ce_xCuO_{4+y}$





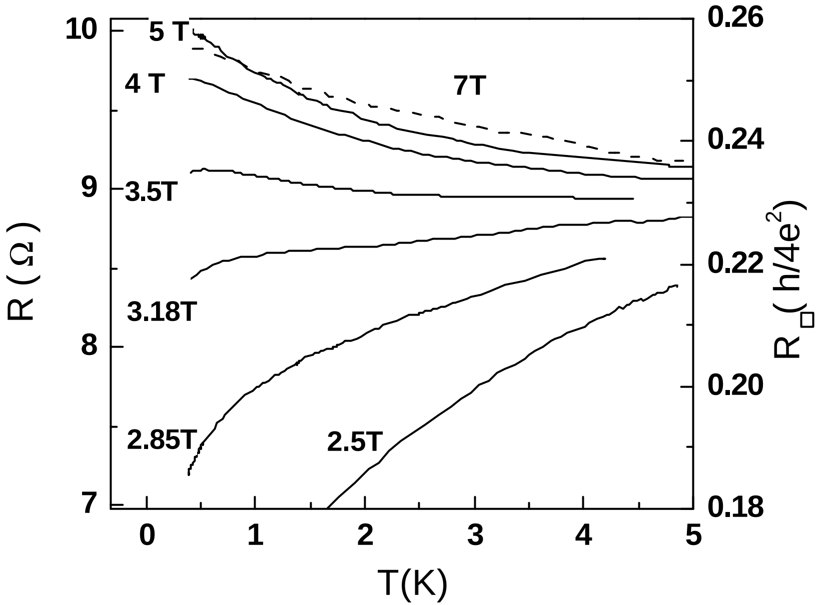


d = 1000 Å c = 12 Å

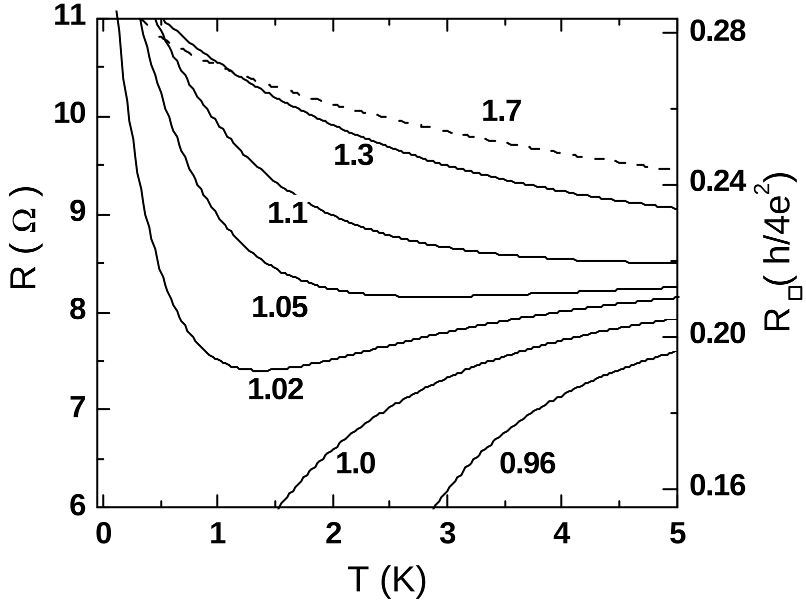
T_C = 11.5 K ΔT = 2K

$\sigma_0 = 17\ e^2/h$

Experiment



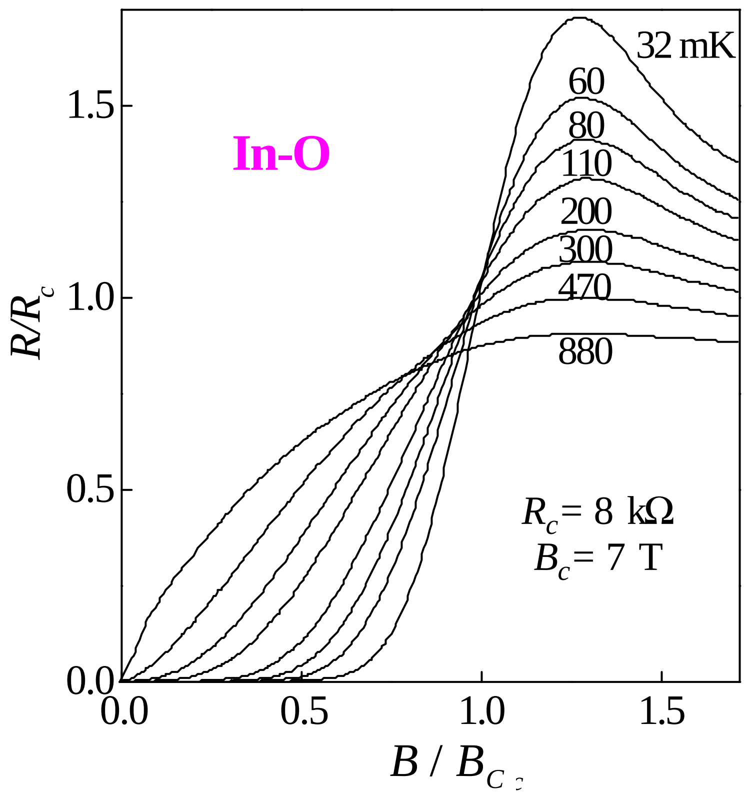
Calculations

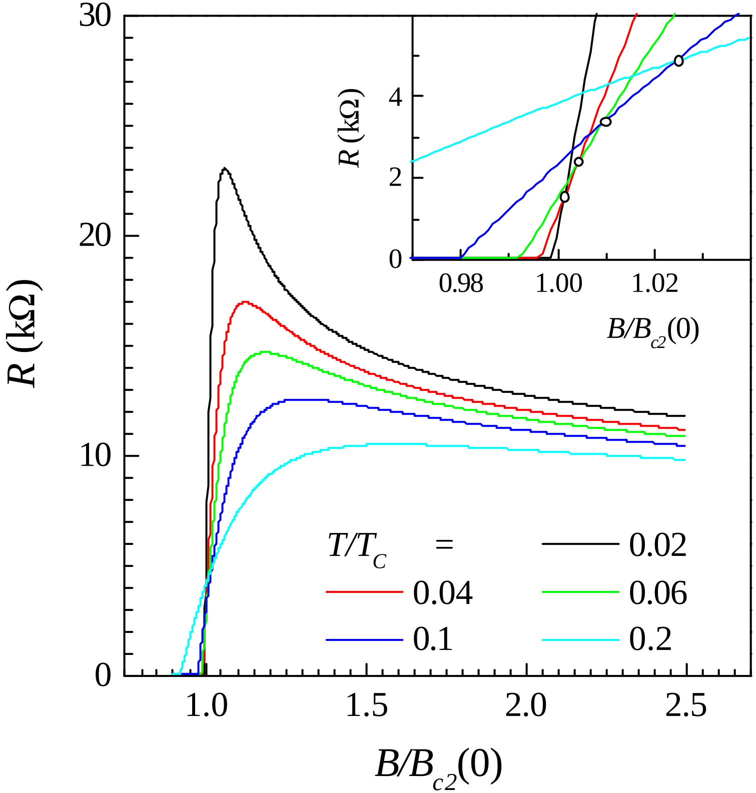


$$R(B,T) = 1/[s_0 - a\frac{e^2}{\hbar}\ln(T) + ?\, s_{fl}(B,T)]$$

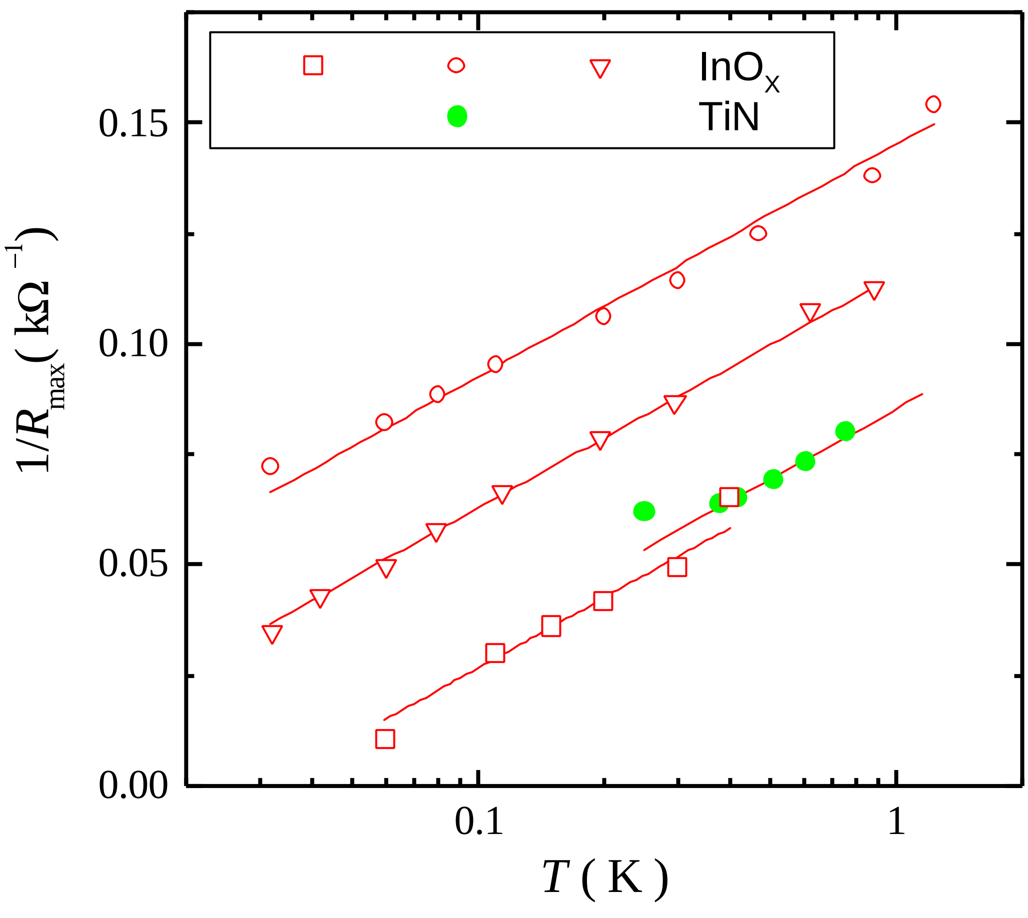
Resistance maximum

$$R(B,T) = 1/[s_0 - a\frac{e^2}{\hbar}\ln(T) + ?\,s_{\mathrm{fl}}(B,T)]$$





Height of *R(B)* vertex

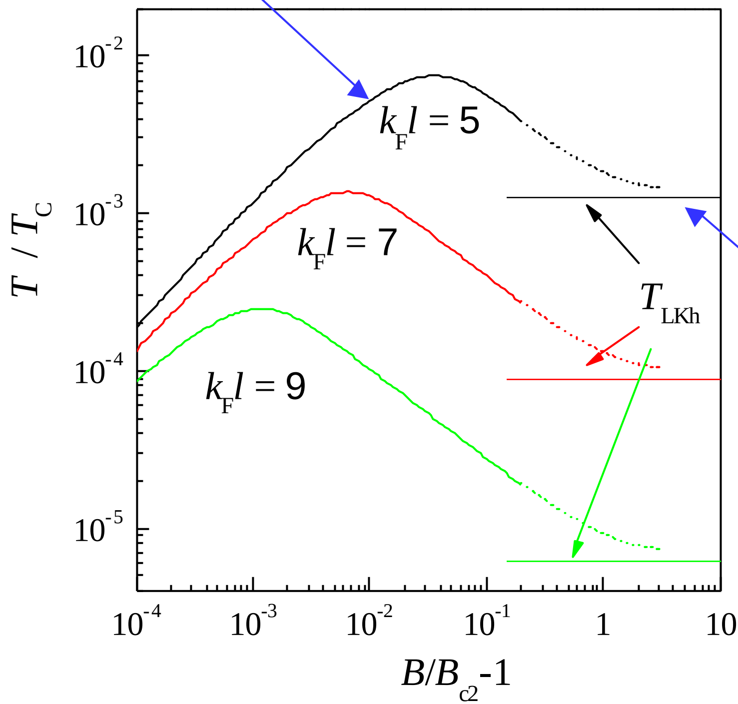


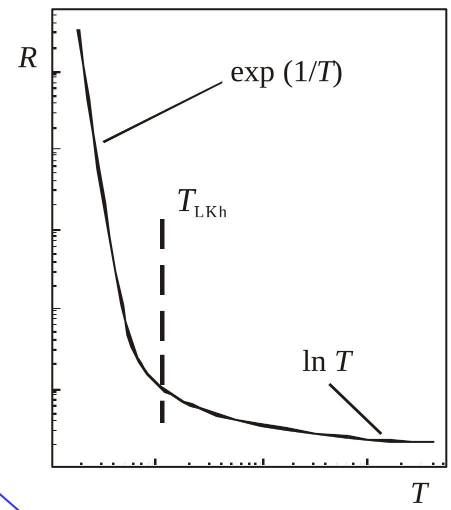
Lines $y \propto \ln x$ follow from theory by *Galitski and Larkin*

Crossover temperature

Crossover from log *to* exp *in normal metals*

$$s + d_{AA} s\,(T_0) + ds\,(B, T_0) = 0$$



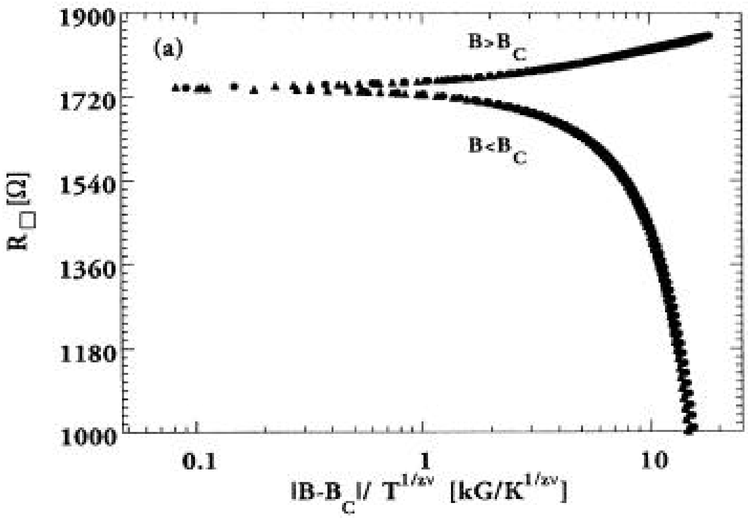


$$s + d_{AA} s\,(T_{LKh}) = 0$$

Superconducting interaction increases crossover temperature in dirty metals

Scaling

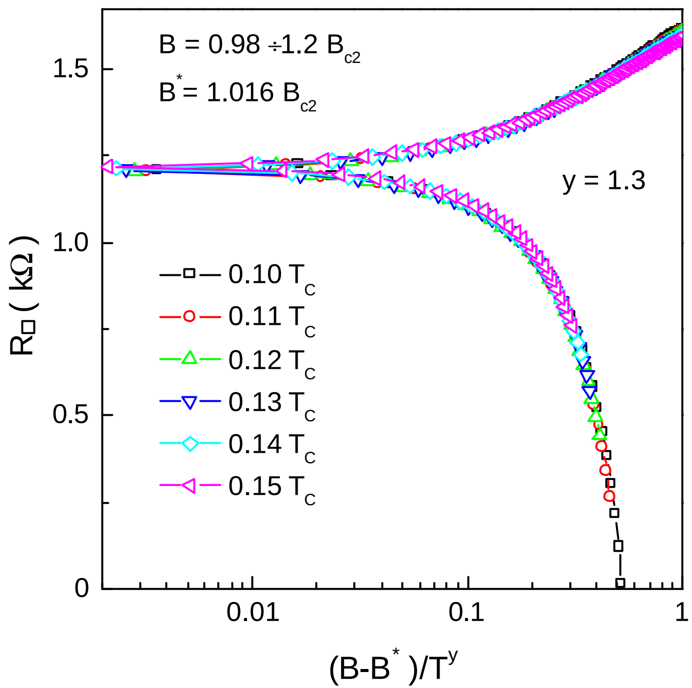
A.Yazdani and A.Kapitulnik (1995)



T_C= 0.15 K $\quad$ B_C= 4.19kG

T = 0.08 ÷0.11 K $\quad$ B-B_C < 1 kG

z ν = 1.36



Theoretical expression does not contain scaling properties, but in restricted temperature interval scaling presentation looks credible

Summary

1. *Field and temperature dependence of superconducting fluctuations describes negative magnetoresistance of materials with moderate resistivity.*

2. *This supports the idea introduced by M.P.A. Fisher et al. about pair localization in the process of superconductor-insulator transition in high-resistive materials.*

3. *Pair localization, i.e. pair correlations between the localized electrons at the Fermi level, seems to be more general phenomenon than the idea of 2e-bosons - vortex duality which gave rise to this contrivance.*

4. *Granularity of the superconductors leads to the same transport phenomena: to the superconductor-insulator transition and to the negative magnetoresistance, and hence granular and homogeneously disordered high-resistive materials are hardly distinguishable*

5. *Demonsjration of a scaling presentation cannot be decisive argument in favour of a specific model.*