Superconductor-insulator transition (SIT) in thin films driven by an orbital parallel magnetic field effect

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Yuval Oreg

Special thanks to Gil Refael

Phys. Rev. B **79**, 214515 (2009)

Experimental results-perp field

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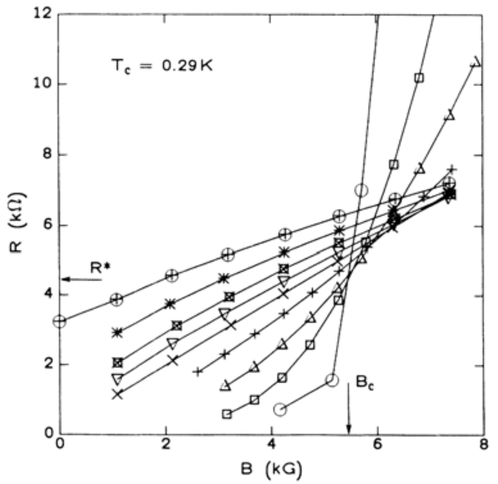

A. F. Hebard and M. A. Paalanen,
Phys. Rev. Lett. 65, 927 - 930 (1990)

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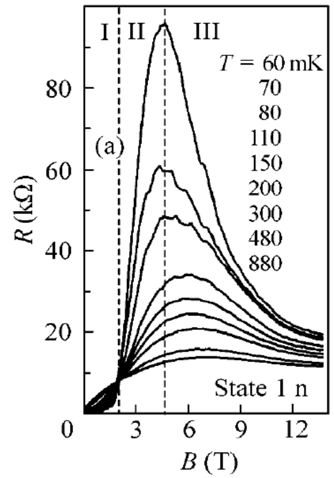

V. F. Gantmakher *et al.*,
Sov. JETP Lett. 71,(11) 473.

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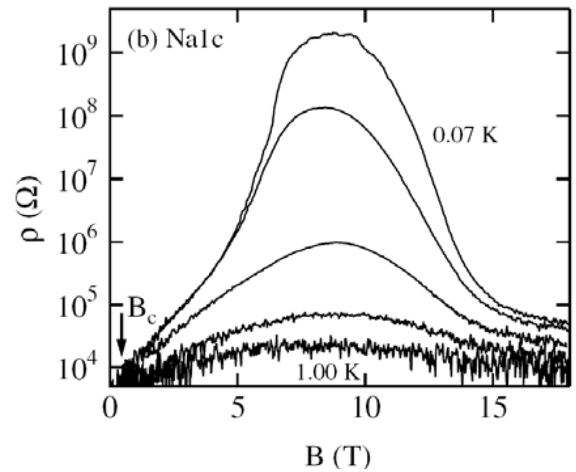
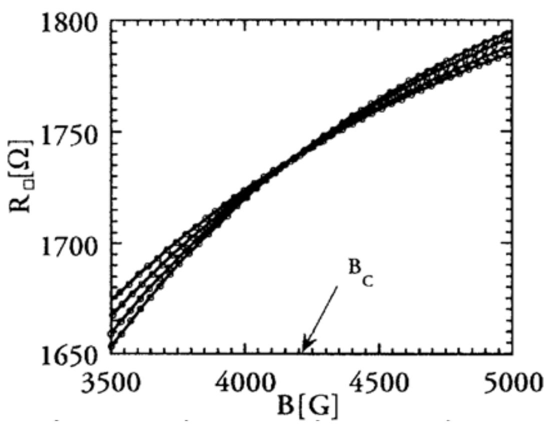


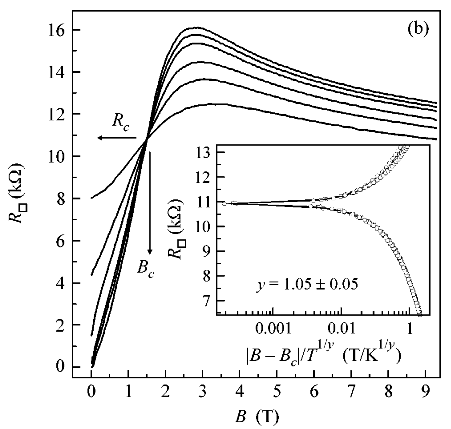
G. Sambandamurthy et al.,
Phys. Rev. Lett. 92, 107005 (2004).

MoGe



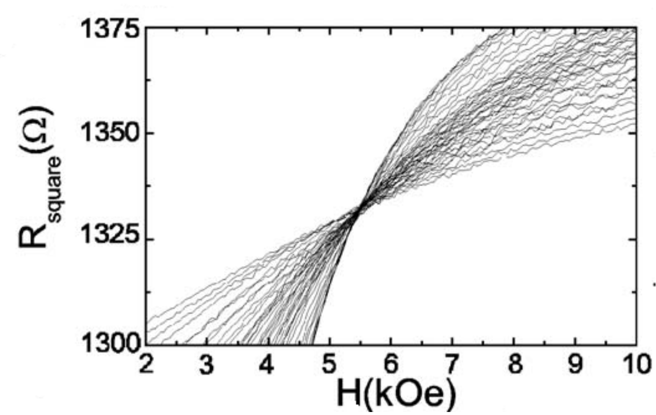
A. Yazdani and A. Kapitulnik,
Phys. Rev. Lett. 74, 3037 (1995)

TiN



T. I. Baturina et al.,
Sov. JETP Lett. 79, (7) 337.

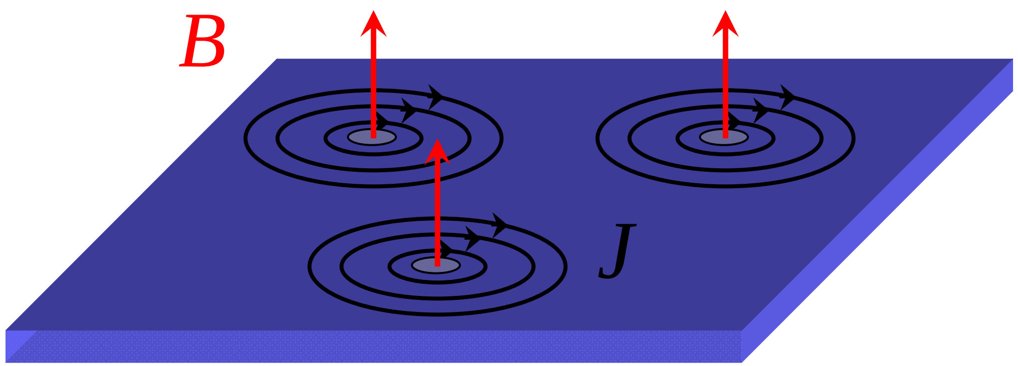
NbSi



H. Aubin et al.,
Phys. Rev. B 73, 094521 (2006)

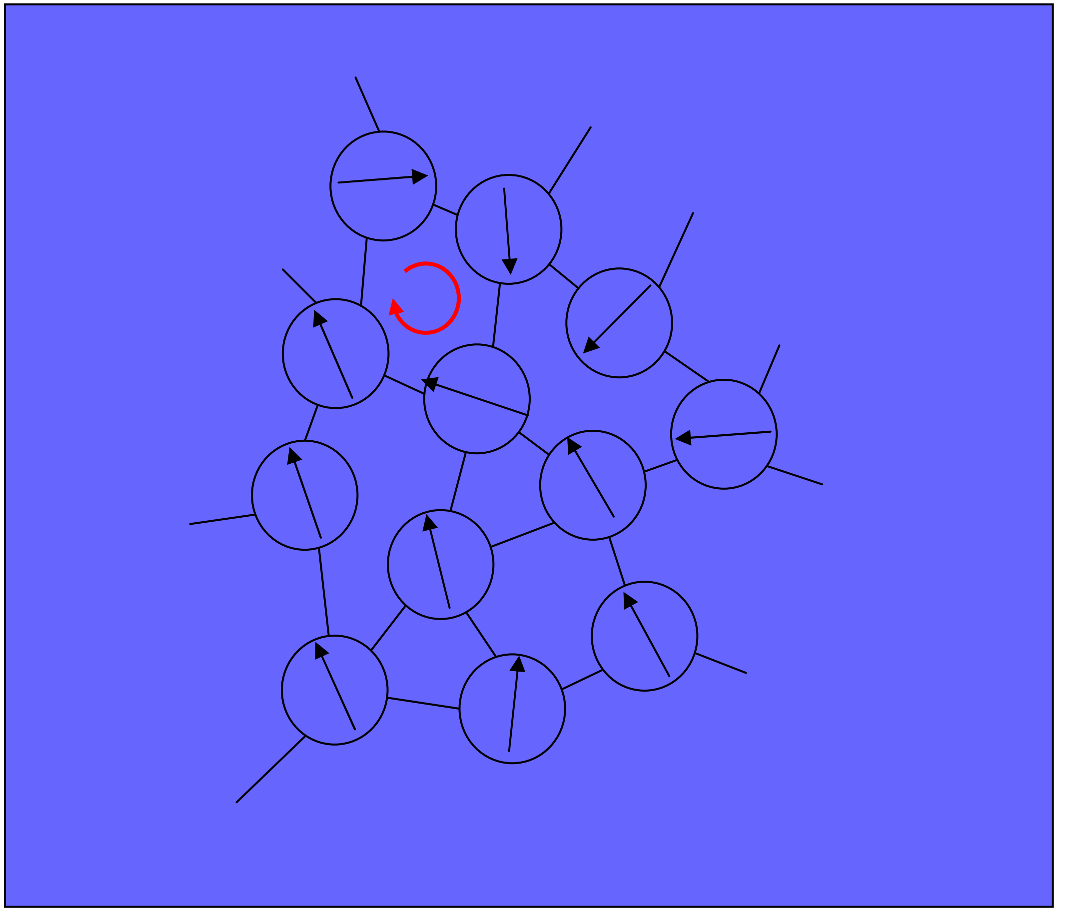
Theoretical interpretation
perpendicular field

1. Perpendicular magnetic field penetrates the film in the form of vortices:



As the field increases vortices delocalize and Bose-condense leading to an insulating behavior.

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

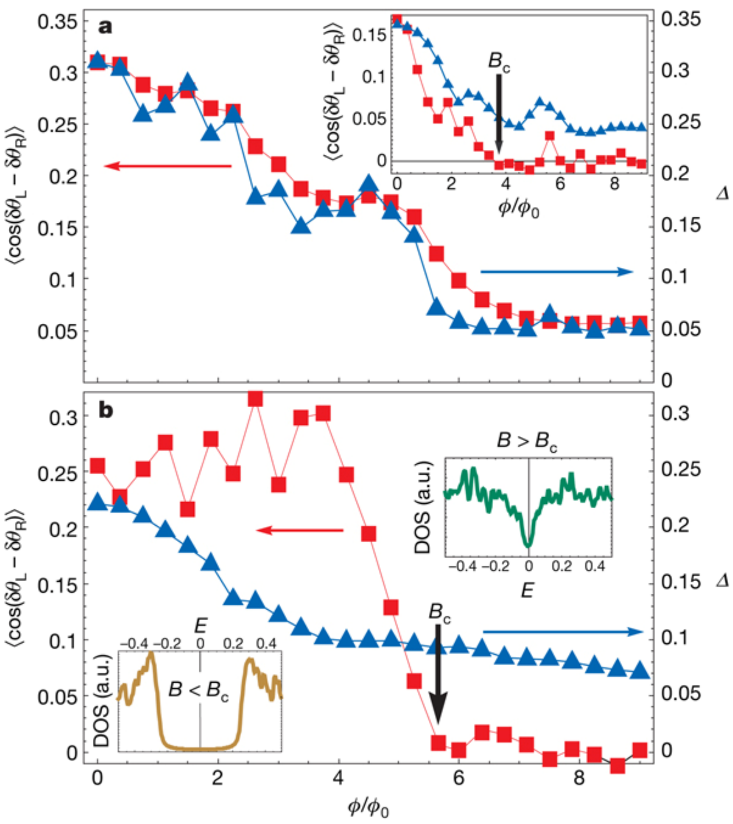


Theoretical interpretation perpendicular field

2. Perpendicular magnetic field enhances thermal phase fluctuations that destroy phase correlations between SC islands.

▲ amplitude

■ phase



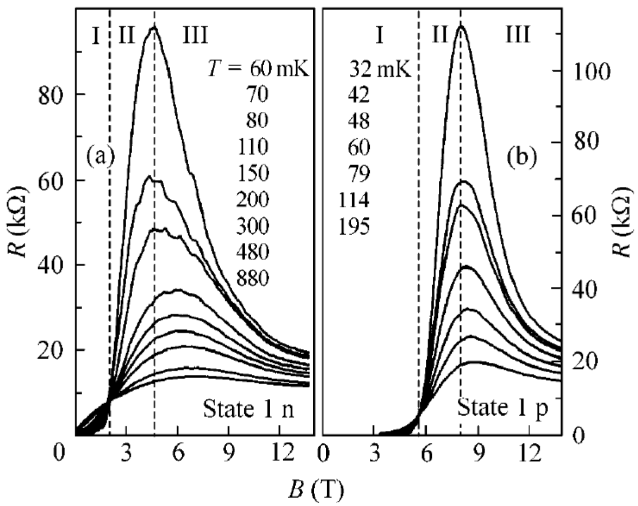
Low disorder

Strong disorder

A. Ghosal, *et al.*
Phys. Rev. Lett. **81**, 3940 (1998)
Phys. Rev. B **65**, 014501 (2001)

Y. Dubi, Y. Meir, and Y. Avishai, Nature 449, 876 (2007).

Experimental results – parallel field



V. F. Gantmakher *et al.*,
Sov. JETP Lett. 71,(11) 473.

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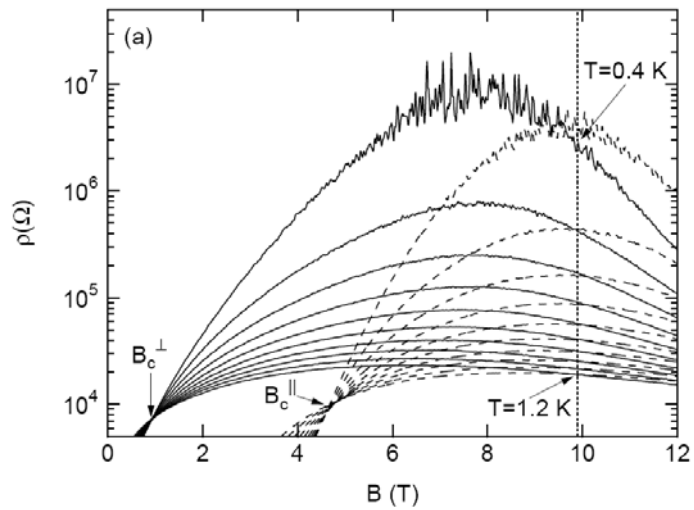
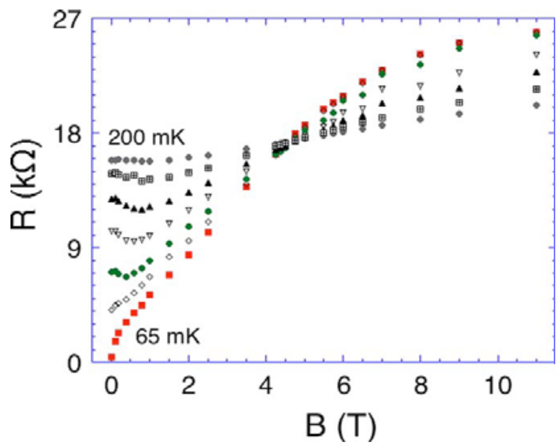


A. Johansson, *et al.,*
condmat , 0602160 (2006).

Bi

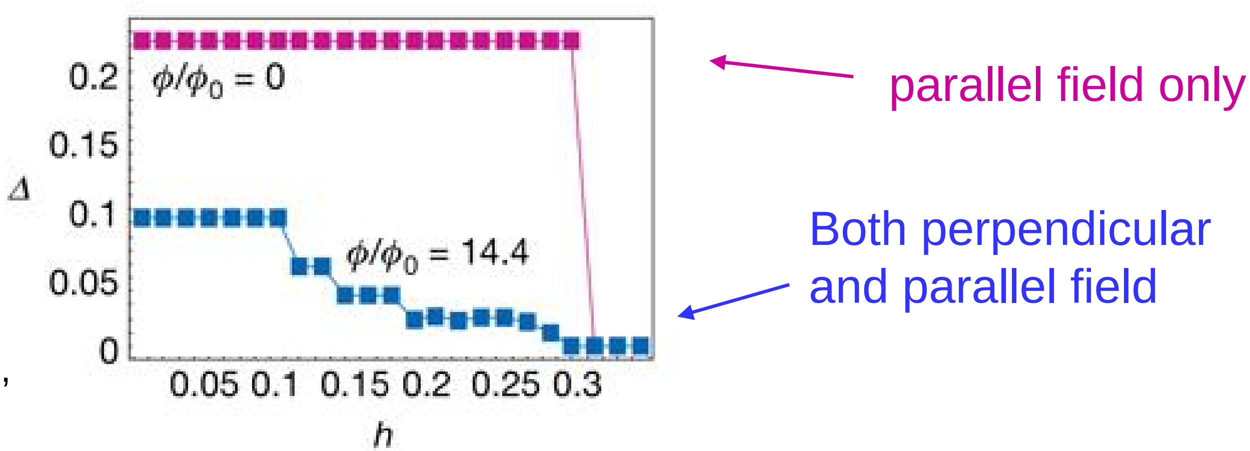


K. A. Parendo, et al.,
Phys. Rev. B 73, 174527 (2006)

Existing models - not applicable to parallel field

1. No vortex penetration in parallel field.

2. Parallel spin-exchange field causes the order parameter phase and amplitude to vanish abruptly



Y. Dubi, Y. Meir, and Y. Avishai, Nature 449, 876 (2007).

Motivation

Phase fluctuations enhanced by orbital effects of the perpendicular field can explain the qualitative behavior seen in experiments.

Can the transition in the parallel field be a result of a similar mechanism?

Main result

Parallel field decreases the SC order parameter and reduces its phase stiffness.

Quantum fluctuations of the phase are enhanced and can lead to an INS behavior.

Phase stiffness with parallel field

The phase action:

$$S[\phi] = \frac{K_0}{2}\int d^2 r dz \left\{ (\nabla\phi)^2 + \frac{(\partial_z \phi)^2}{N_\perp^2} \right\}$$

$$N_\perp = p_F d$$

$$K_0 = \frac{\pi \nu_0 d D}{2} e^{-2\frac{B^2}{\tilde{H}^2}} \equiv \frac{1}{2}\frac{R_Q}{R} e^{-2\frac{B^2}{\tilde{H}^2}}$$

For $K_0 >> 1$ the SC phase is rigid.

For $K_0 << 1$ the phase is strongly fluctuating

A critical value K_0^C marks the onset of strong phase fluctuations.

Prediction: critical parallel field

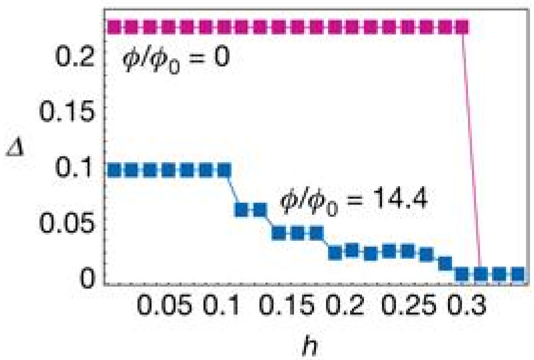
The critical parallel magnetic:

$$B_C^2 = \frac{1}{2}\tilde{H}^2\left\{\ln\left(\frac{R_Q}{R}\right) - \ln 2K_0^C\right\}$$

$$\tilde{H}^2 = \frac{12\ T_C\ \Phi_0^2\ \nu_0}{\pi\ \gamma\ d}\frac{\Delta_0(B_C)}{\Delta_0}\frac{R}{R_Q} \approx H_{C\|}^2$$

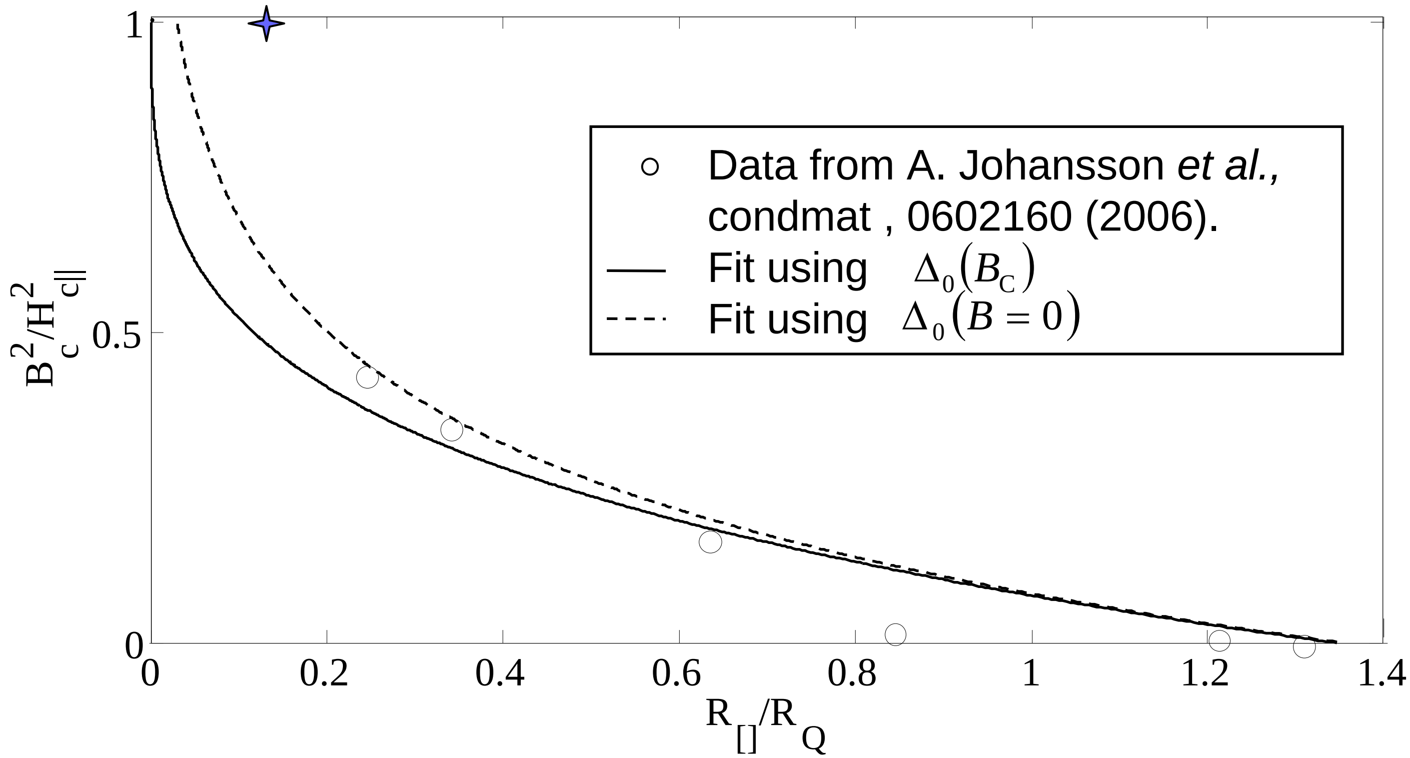
Critical field – main points

- All details are in K_0^C .
- Spin exchange not considered.
  - – Strong spin-orbit scattering in MoGe, NbSe and Bi.
  - – Numerically – spin exchange gives a SC-metal transition.



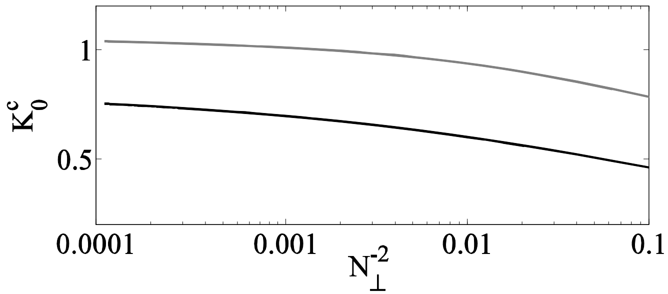
The dependence of B_C on R , d and T_C, can determine which mechanism dominates the transition.

Relation to experiments



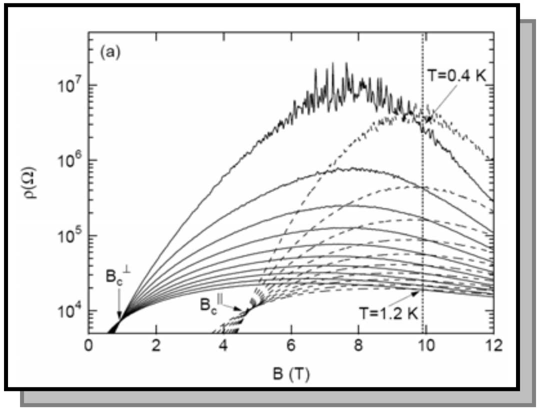
Fitted using $\nu_0 = 4.8\times10^{33}\text{erg}^{-1}\text{cm}^{-3}$ and $K_0^C = 0.37$.

Three times larger than expected from carrier densities.



Summary

- Orbital effects of a parallel field can drive a SIT in disordered films.



- The field reduces the phase stiffness leading to strong quantum phase fluctuations and ultimately to an insulating behavior.

- The model allows to discriminate spin and orbital effects.