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Department of
Physics & Astronomy

Avalanches, Reentrance, and Slow Relaxations in the Zeeman-limited Superconducting Phase of Disordered Al Films

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Outline:

1. Superconductivity and magnetic fields
2. The Spin-Paramagnetic transition
3. S-P phase diagram
4. Hysteresis and slow relaxations
5. Summary

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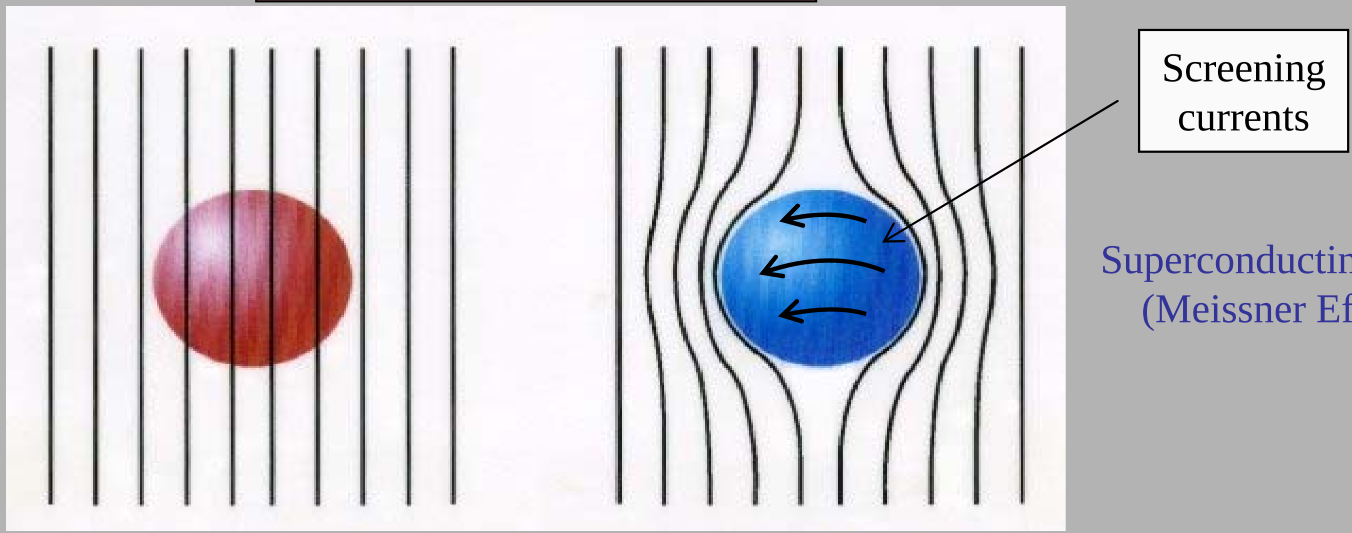
Orbital Response of a Superconductor to a Magnetic Field

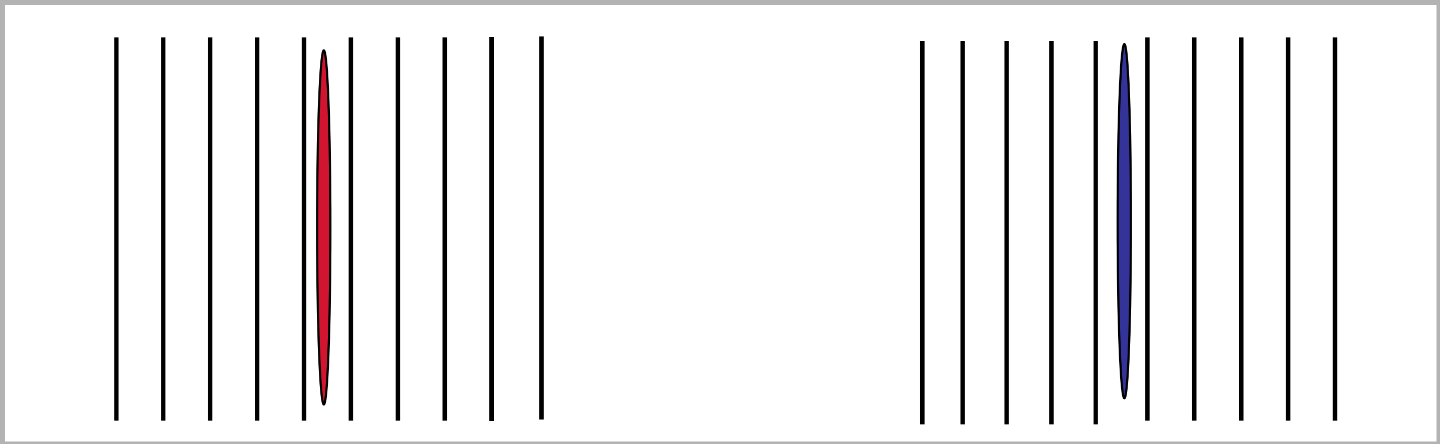
Bulk Superconducting Systems

Normal State



Superconducting State
(Meissner Effect)

Disk with width <<ξ in a parallel field

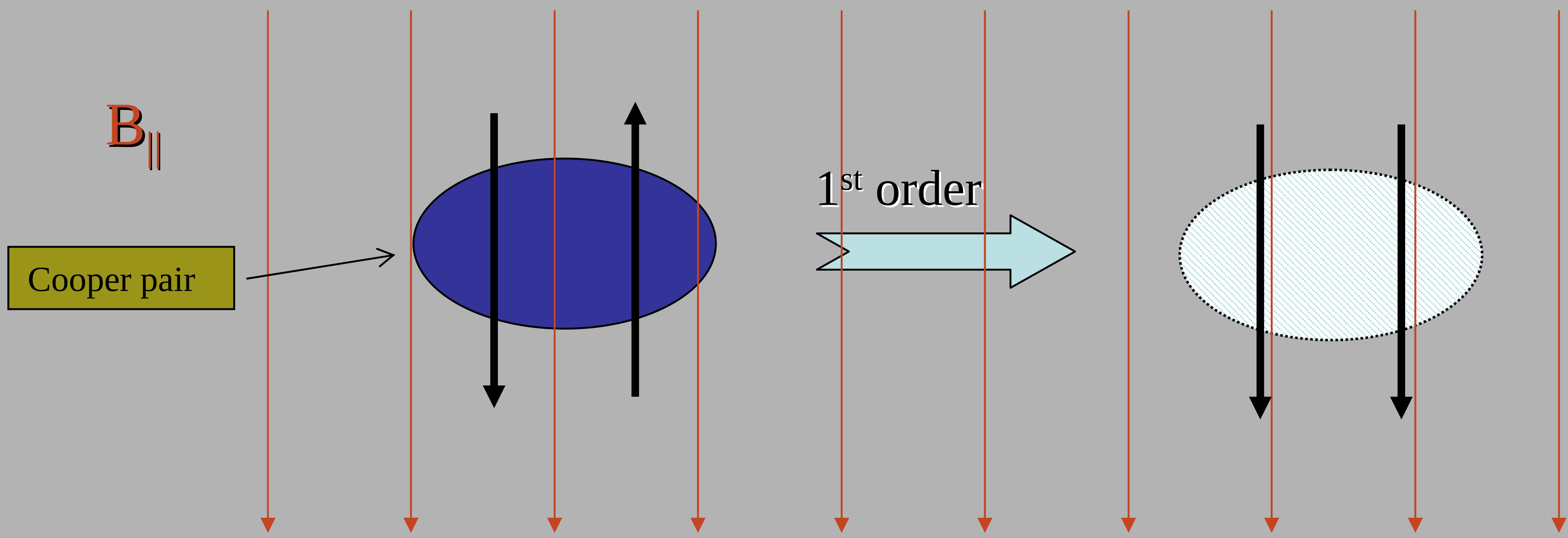


Normal State

Superconducting State
(no screening currents)

Thin Film Superconductivity in High Parallel Magnetic Fields

Assume magnetic field oriented parallel to superconducting film of thickness d $<\xi_o$ so that there can be no significant orbital response to the applied field.

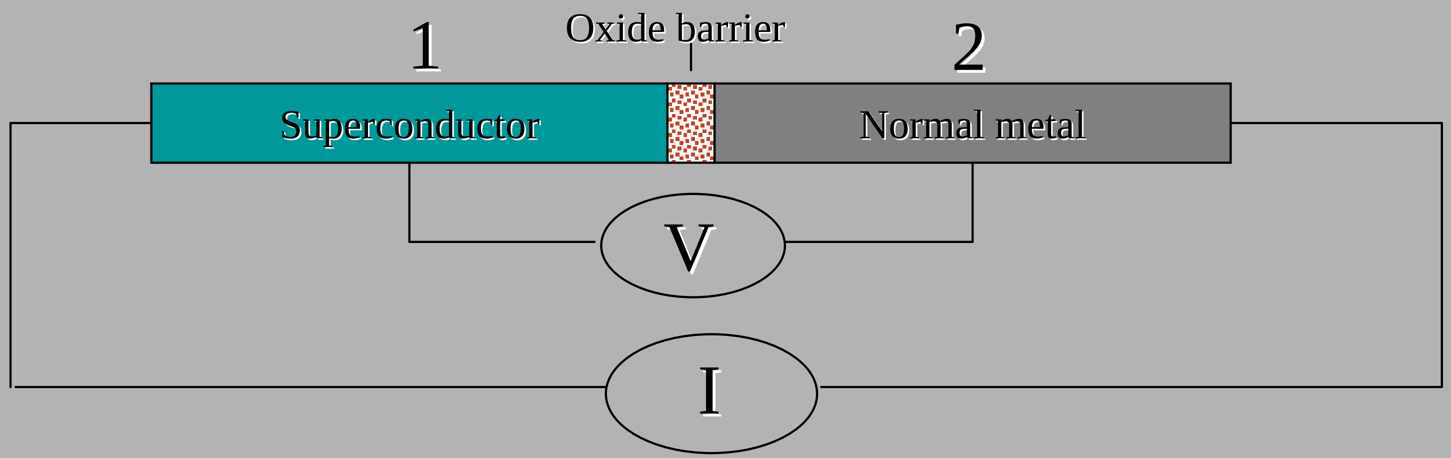


Energy: Δ $2\mu_B B_{||}$

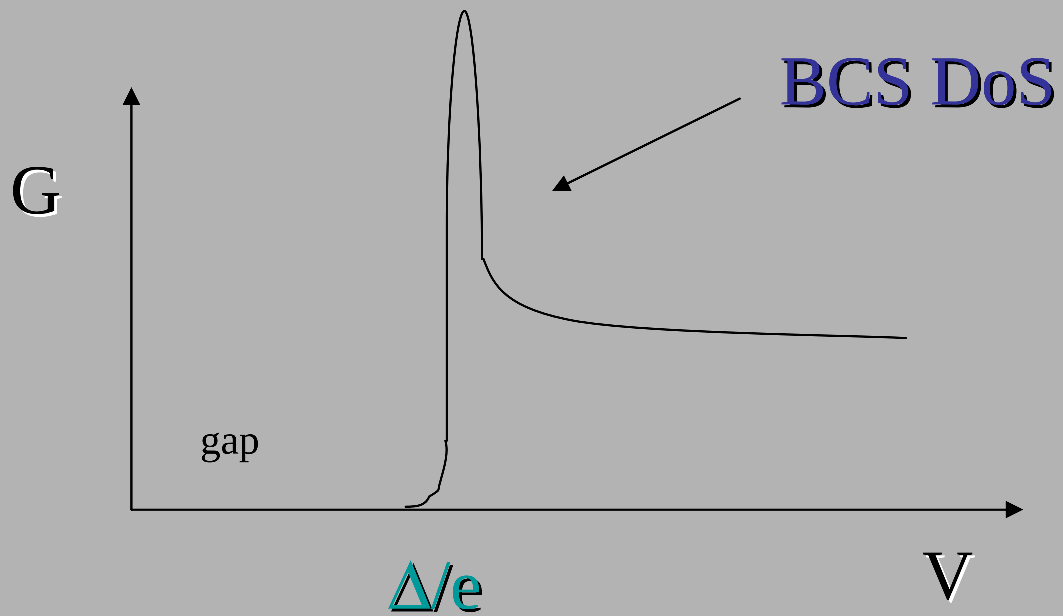
S-P Transition:

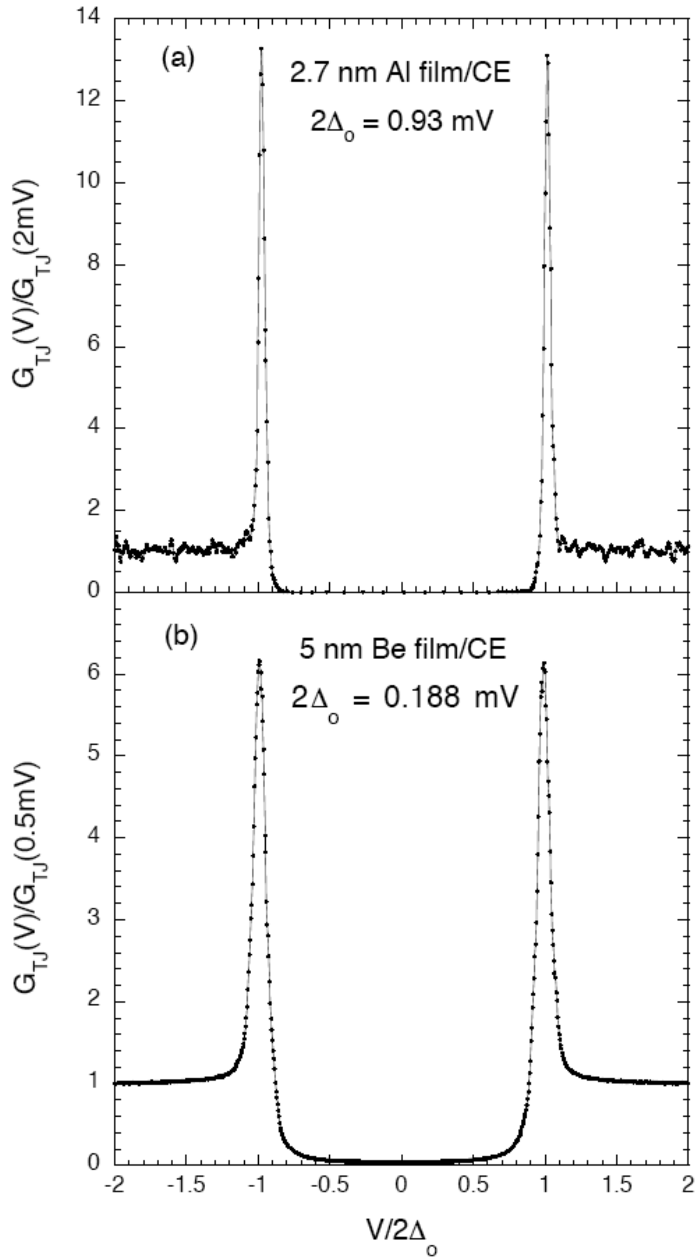
(Spin-Paramagnetic) $(g_L = 2)$

Electron Tunneling and the DOS



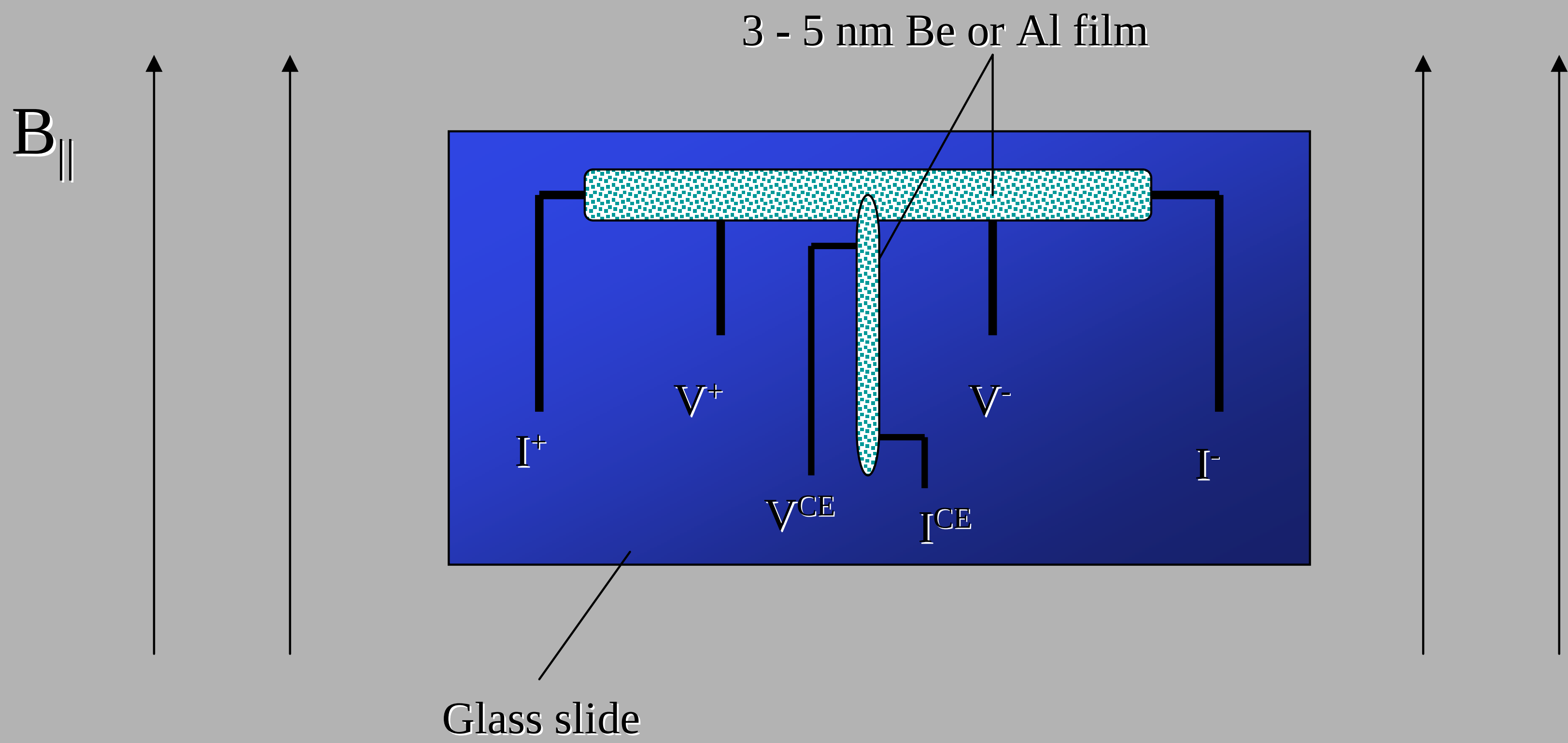
Tunneling Conductance: $G(V) \propto N_1 N_2$ $(kT \ll eV, \Delta)$





(a)
2.7 nm Al film/CE
2Δo = 0.93 mV
(b)
5 nm Be film/CE
2Δo = 0.188 mV
GTJ(V)/GTJ(2mV)
GTJ(V)/GTJ(0.5mV)
V/2Δo

Sample Geometry

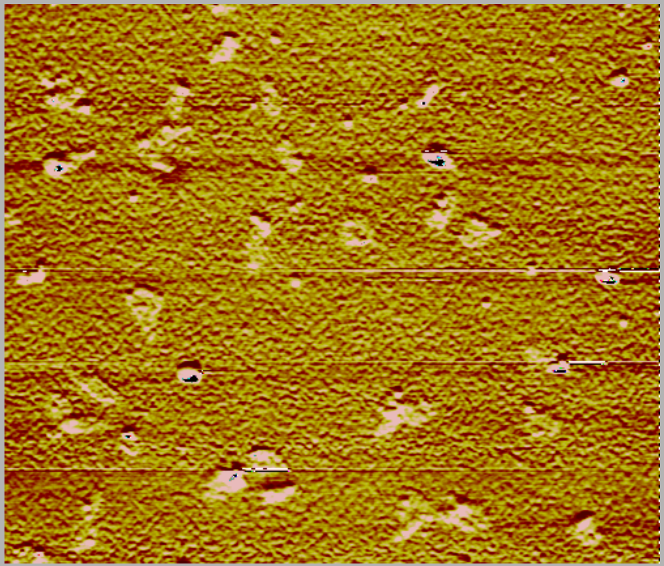


Be: T_c = 0.026 K (bulk)
T_c ~ 0.6 K (quenched film)
barrier type oxide BeO
g-factor=2; $E_z = 2\mu_B B_{\|}$

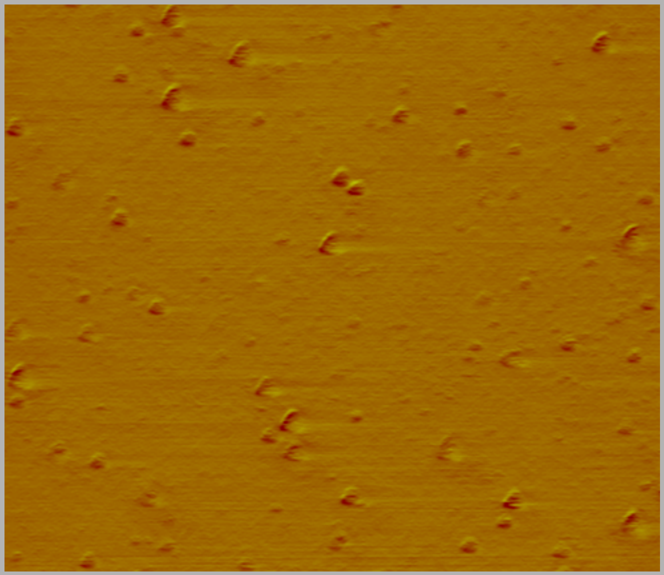
Al: T_c = 1.1 K (bulk)
T_c = 2.7 K (quenched film)
barrier type oxide Al_2O_3
g-factor ~ 1.8*; $E_z \sim 1.8\ \mu_B B_{\|}$

Film Morphology

Al



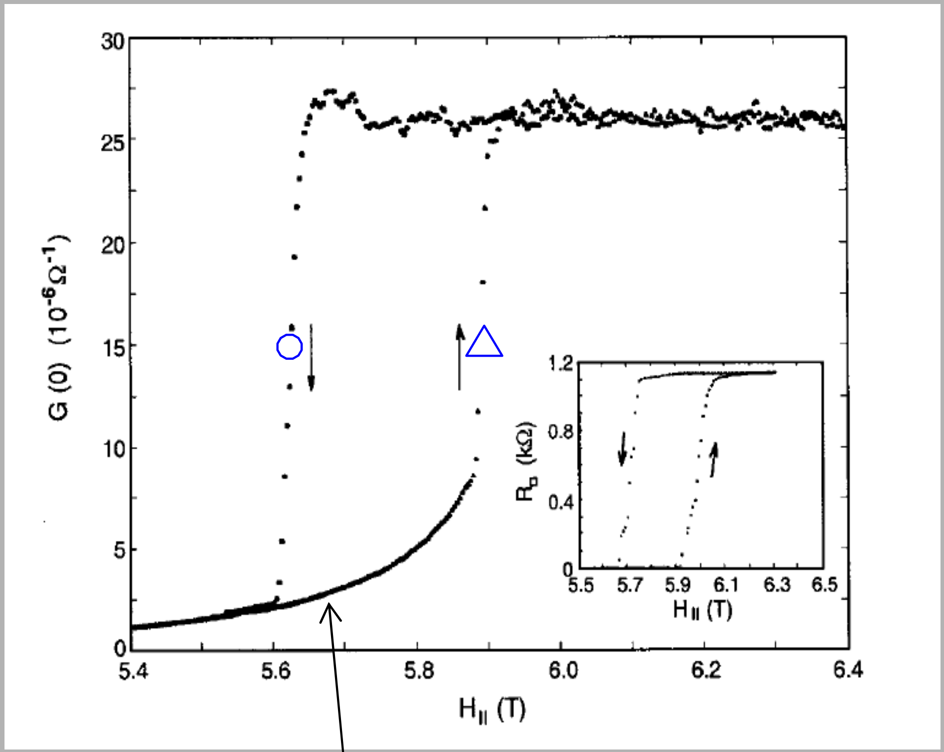
Be



- 3 nm-thick films
- Thermally evaporated @ 77K
- Fire polished glass substrate
- Films stable in air after initial oxidation

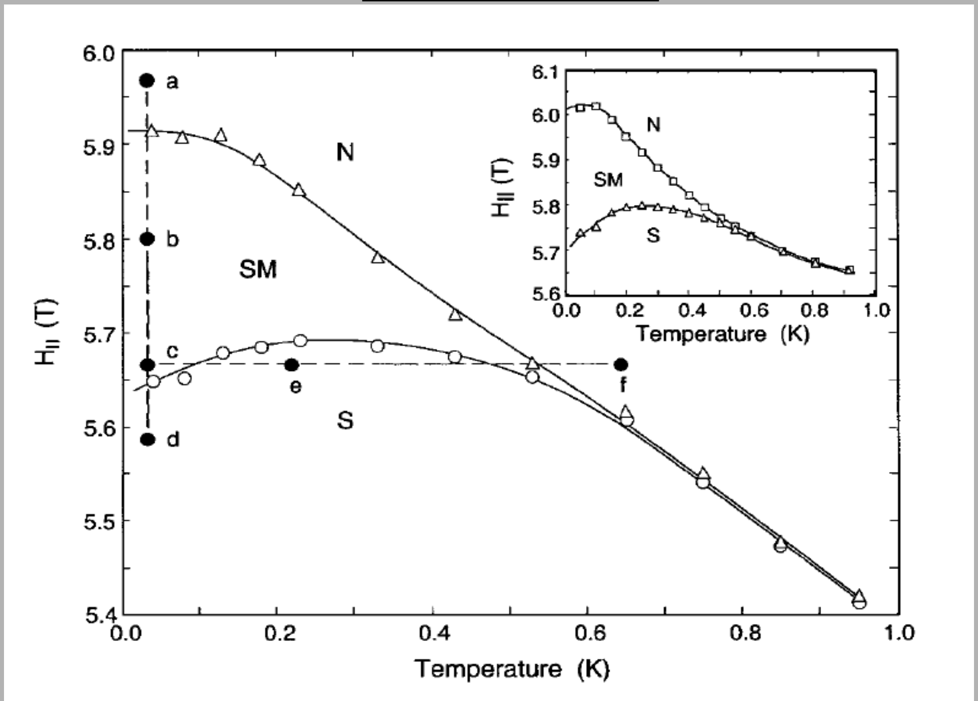
Spin Paramagnetic Phase Diagram in Al Films

DoS at Fermi Energy



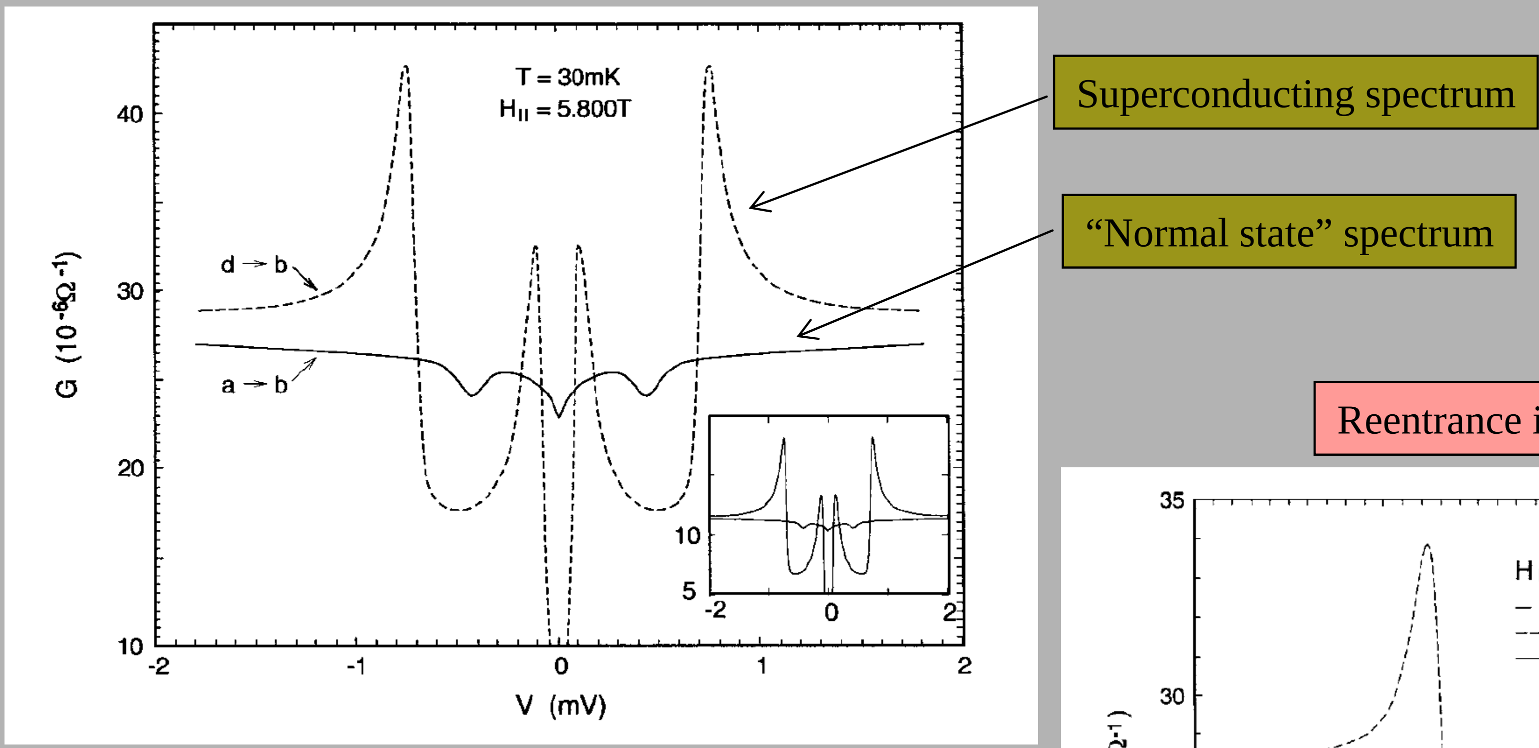
Disordered Larkin-Ovchinnikov State!

Phase Diagram

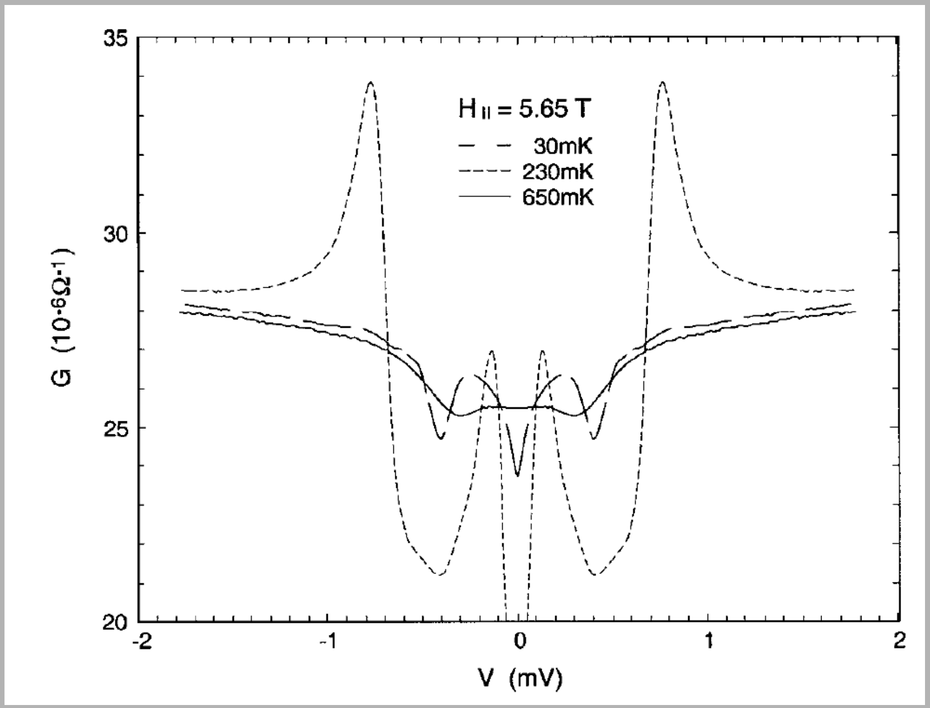


N: normal state
SM: state memory coexistance
S: superconducting phase

State Memory: two curves taken at same $H_{||}$ and T



Reentrance in Tunneling DoS

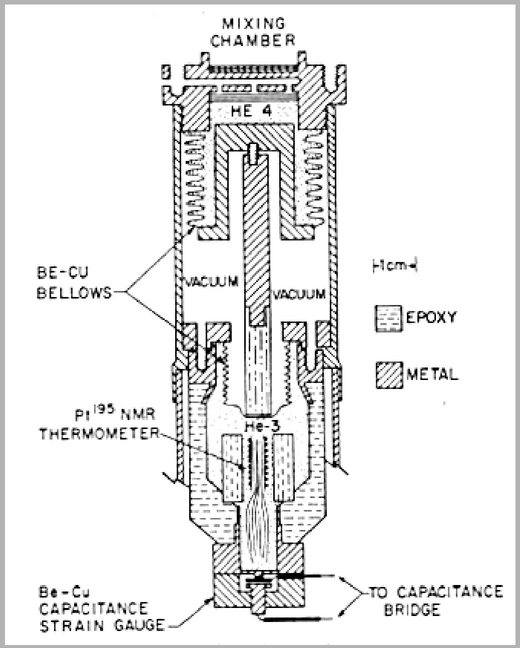


Finite Thickness S-P Transition and the Superconducting Pomeranchuk Effect

Zero thickness S-P phase diagram

Finite thickness S-P phase diagram

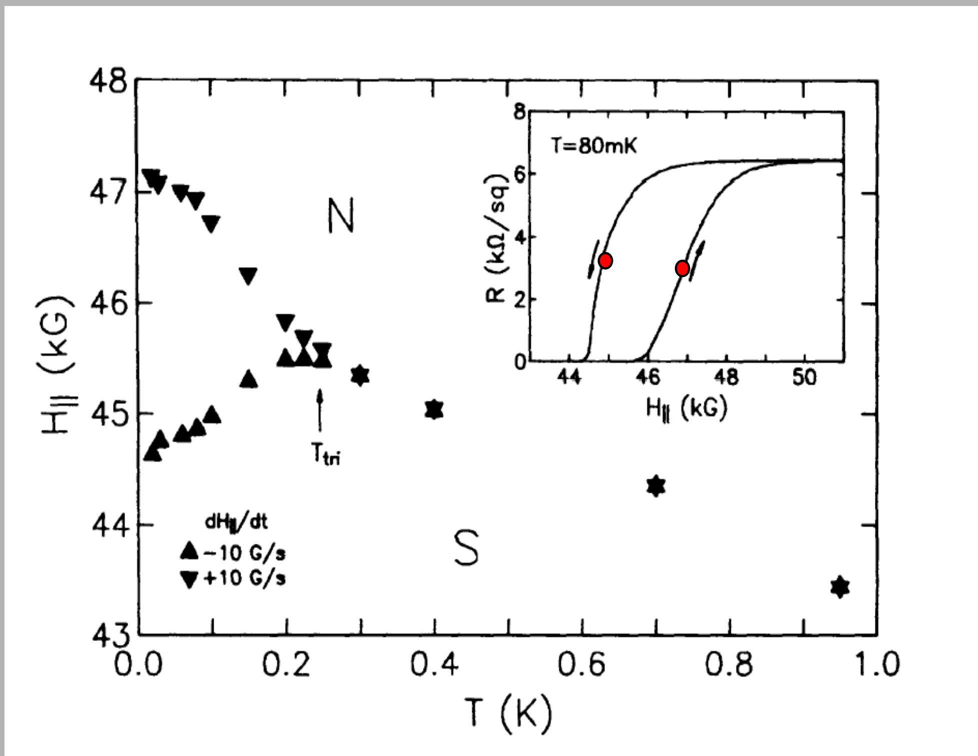
High entropy superconducting phase.



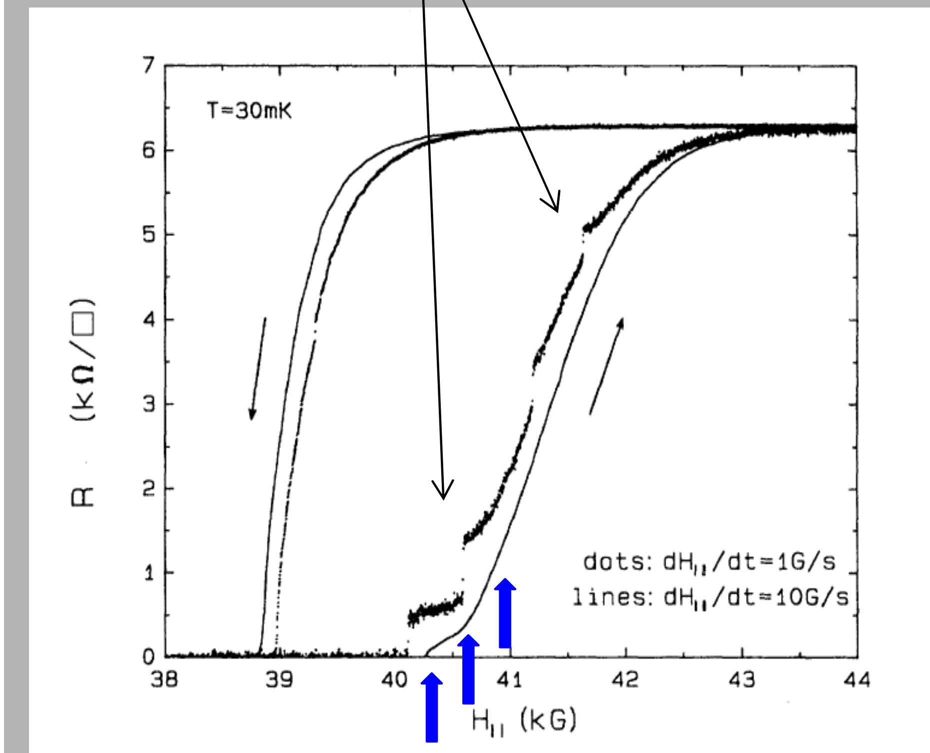
At low temperatures the entropy of liquid ^{3}He is *higher* than that of the solid. Consequently, the latent heat of fusion is of the opposite sign of that of classic liquids. Cooling can be realized by pressurizing to form solid from liquid along the melting curve. D. Osheroff used this cooling method in his discovery of superfluid ^{3}He.

Hysteresis and Avalanches in Al films

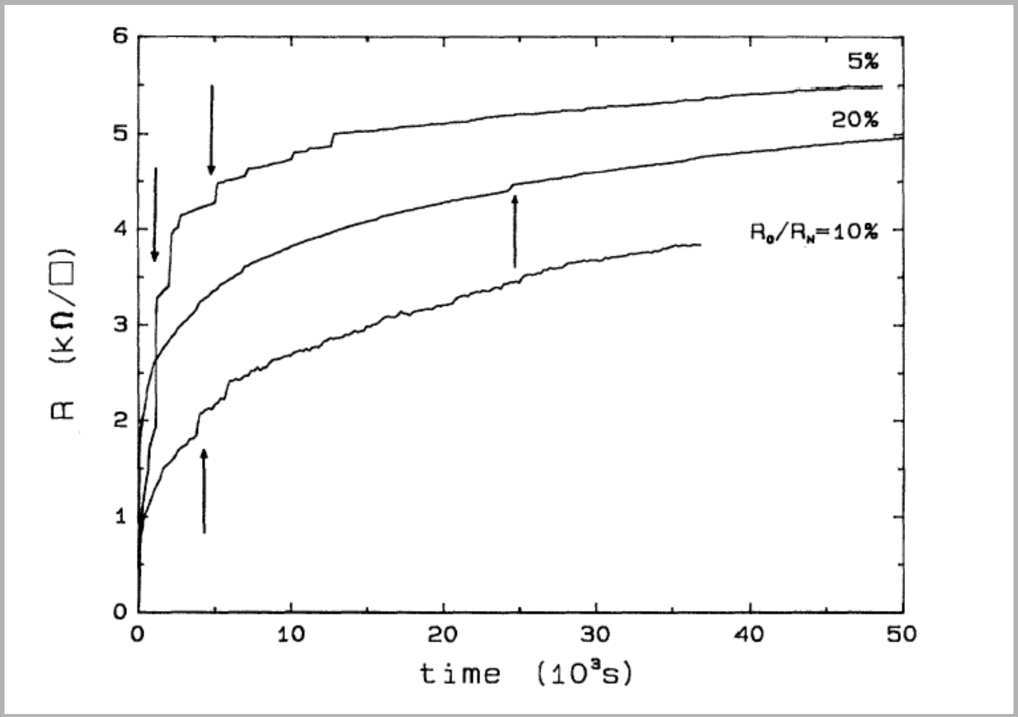
Transport



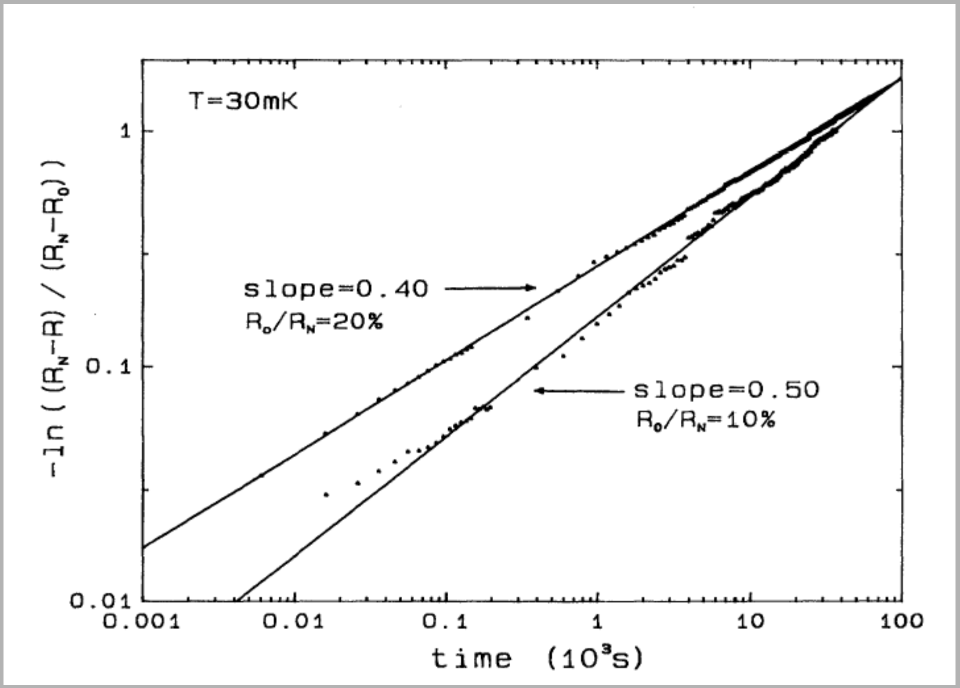
Avalanches



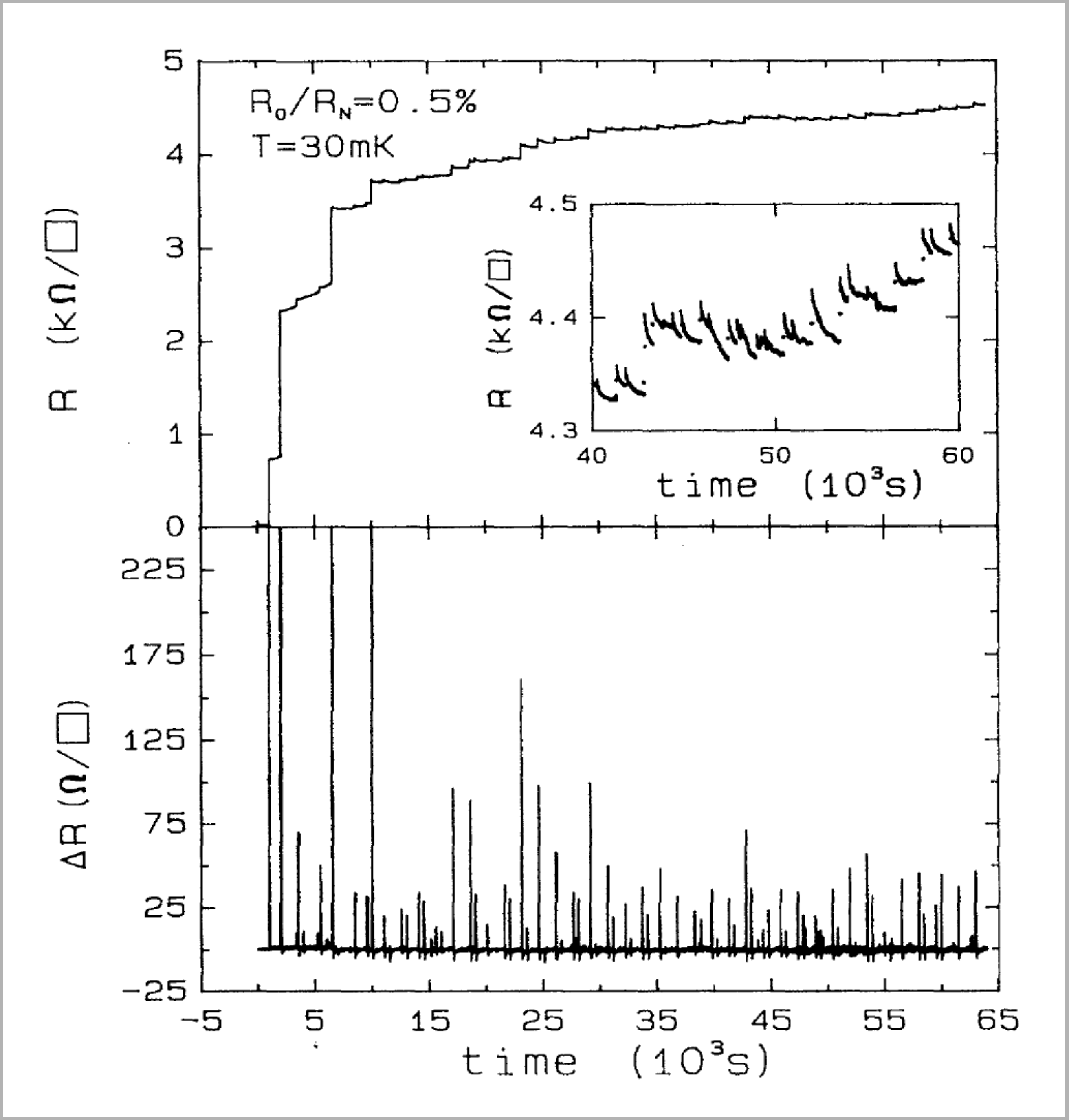
Slow Relaxation in Hysteretic Regime

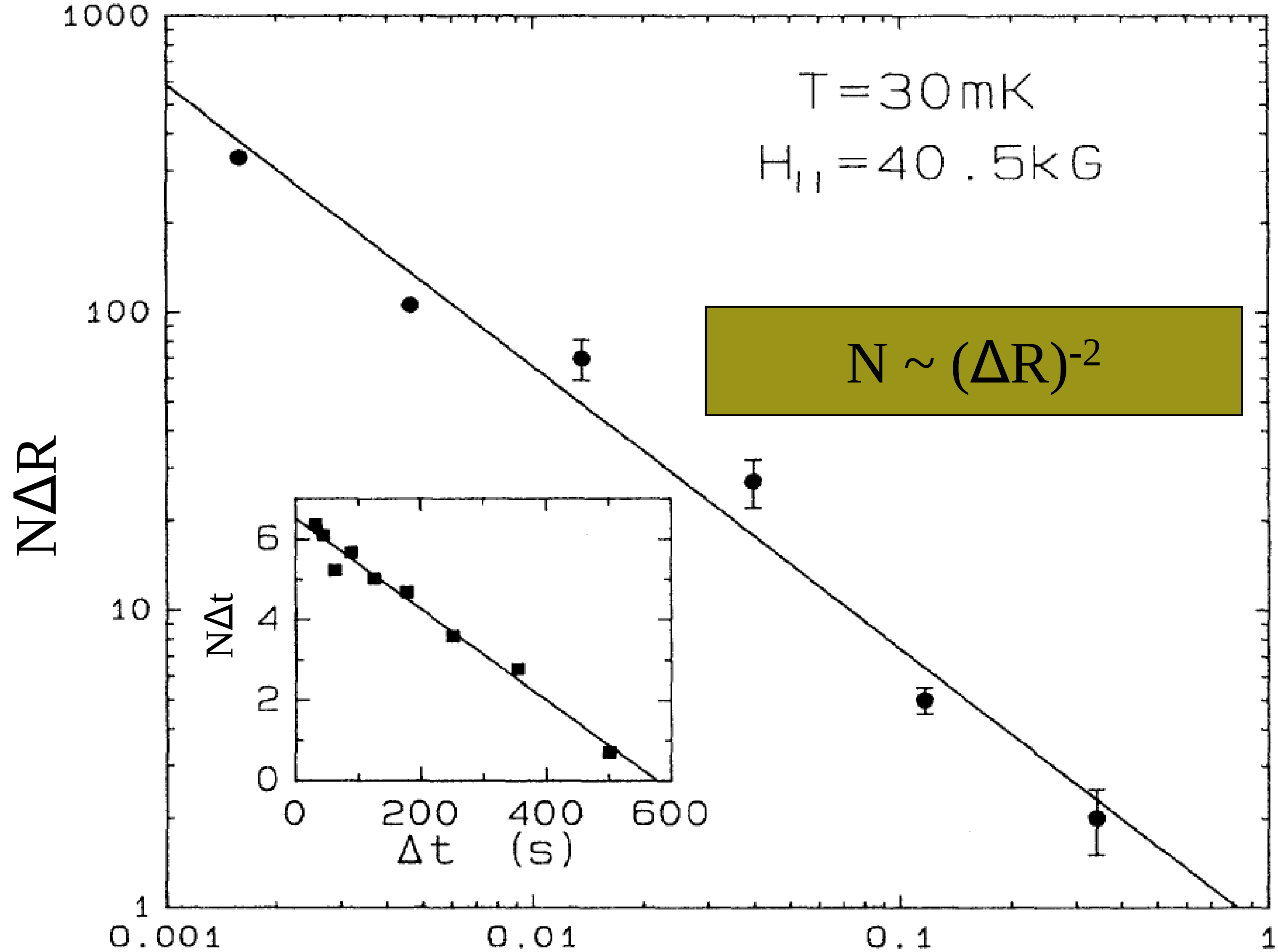


Stretched-Exponential Time Dependence

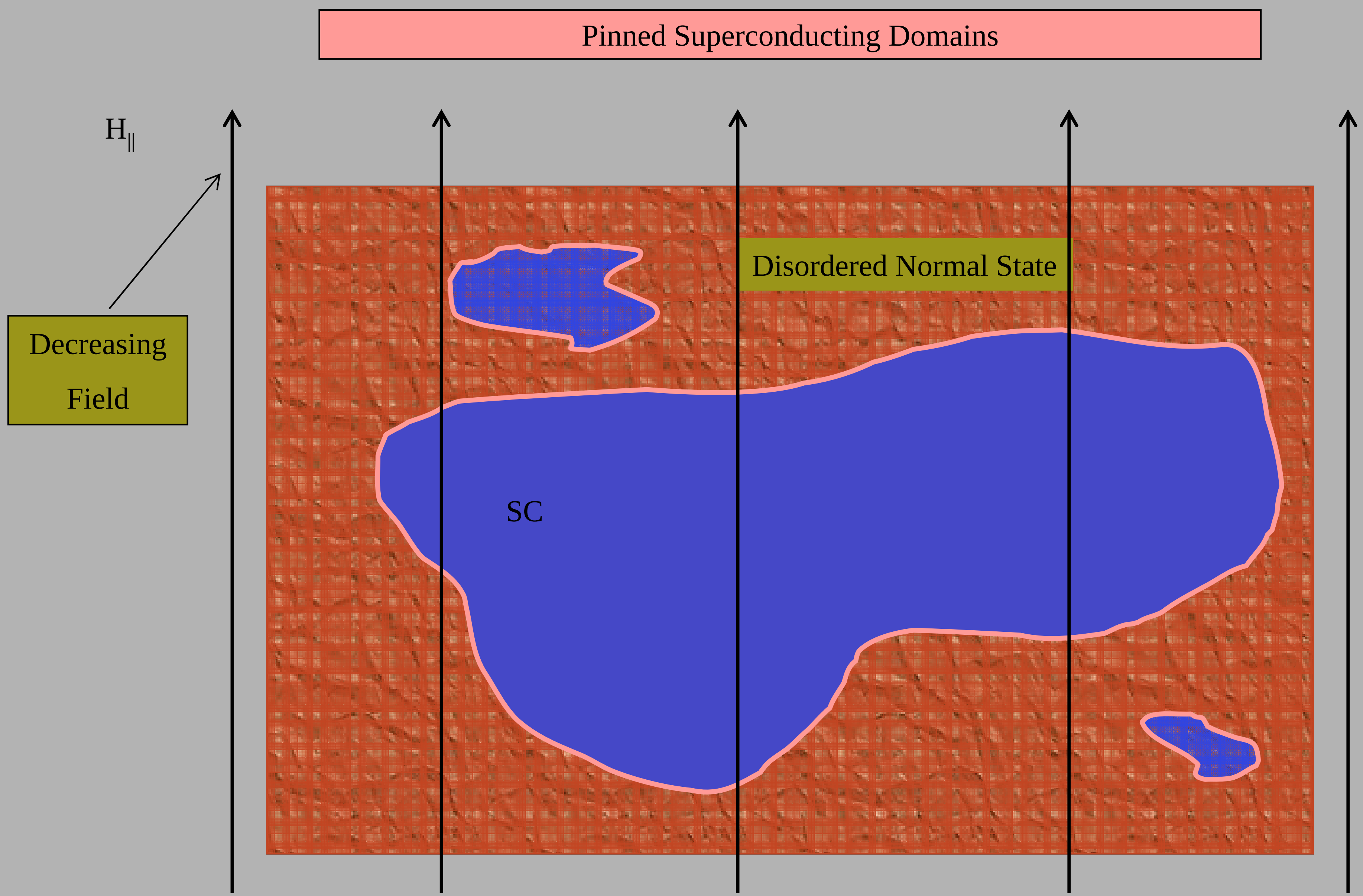


Completely Discontinuous Relaxations





T=30mK
H|| =40.5kG
N ~ (ΔR)^-2
NΔR
ΔR (kΩ/□)
NΔt
Δt (s)
1000
100
10
1
0.001
0.01
0.1
1
0
2
4
6
0
200
400
600

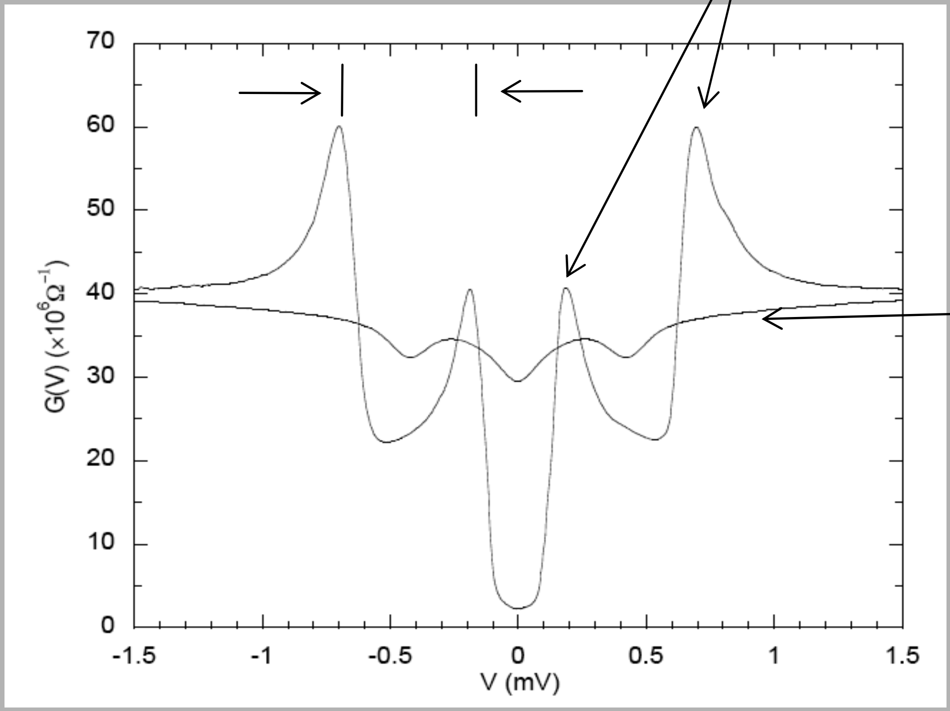


Pinned Superconducting Domains
$H_{\|}$
Decreasing Field
Disordered Normal State
SC

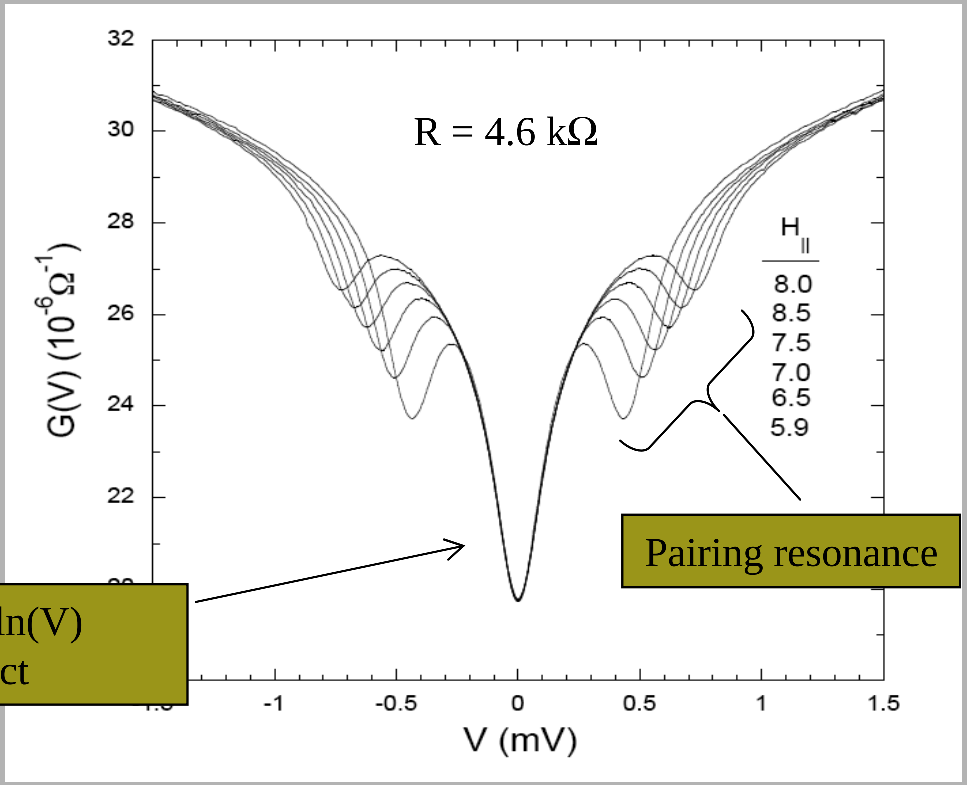
Pairing Resonance

Zeeman Splitting of BCS DoS @ $H_{\|}$ = 4.5 T

R ~ 2000 ohms



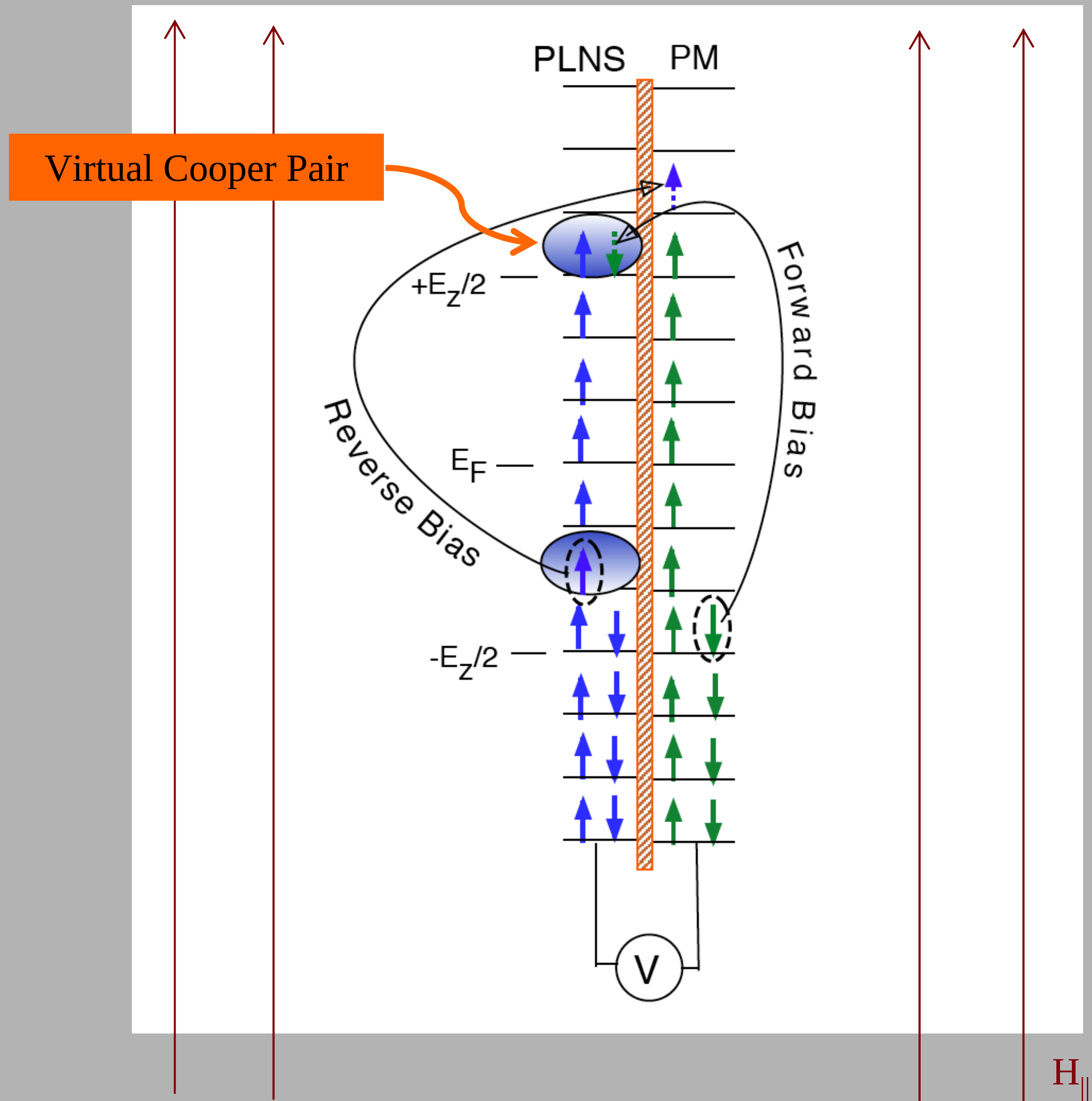
Normal State DoS @ $H_{\|}$ = 5.7 T



Pairing resonance

Coulomb Anomaly ~ ln(V)
e-e interaction effect

Origin of the Resonance

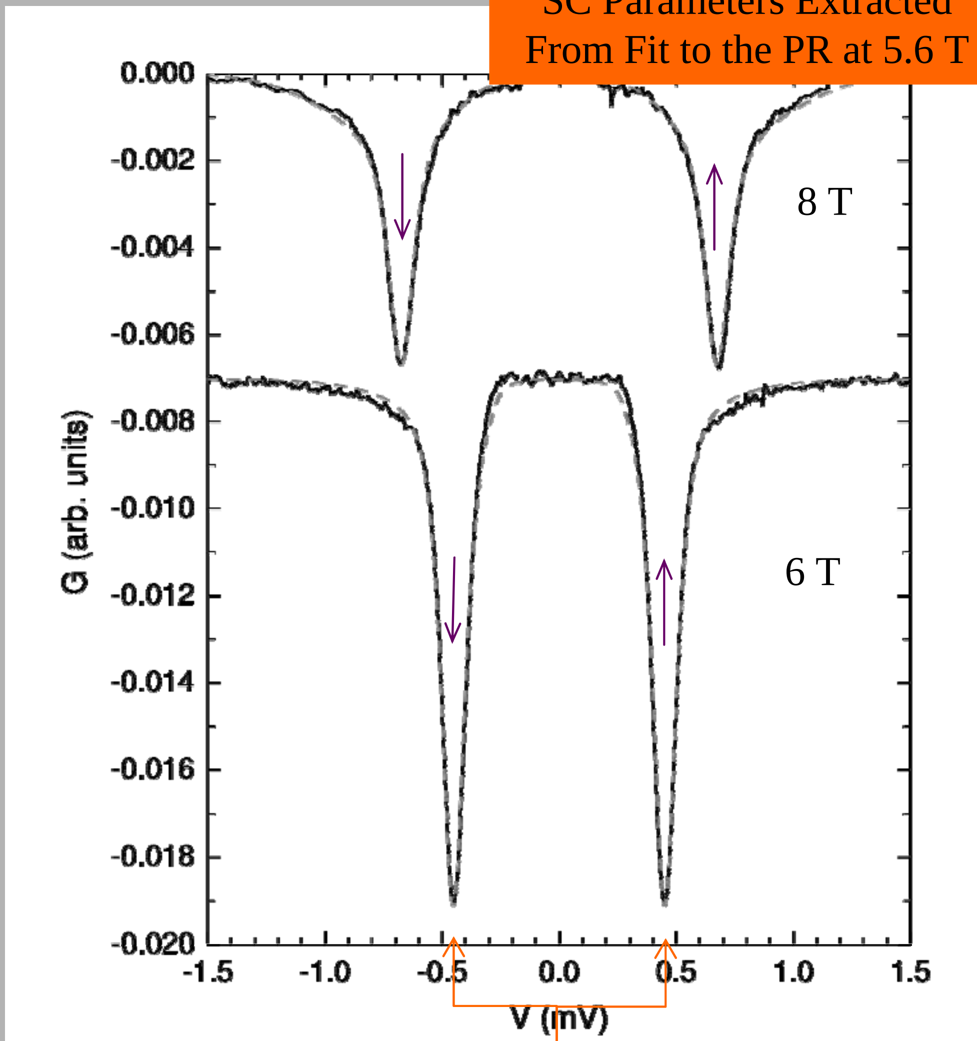


Aleiner and Altshuler, PRL 79, 4242 (1997)

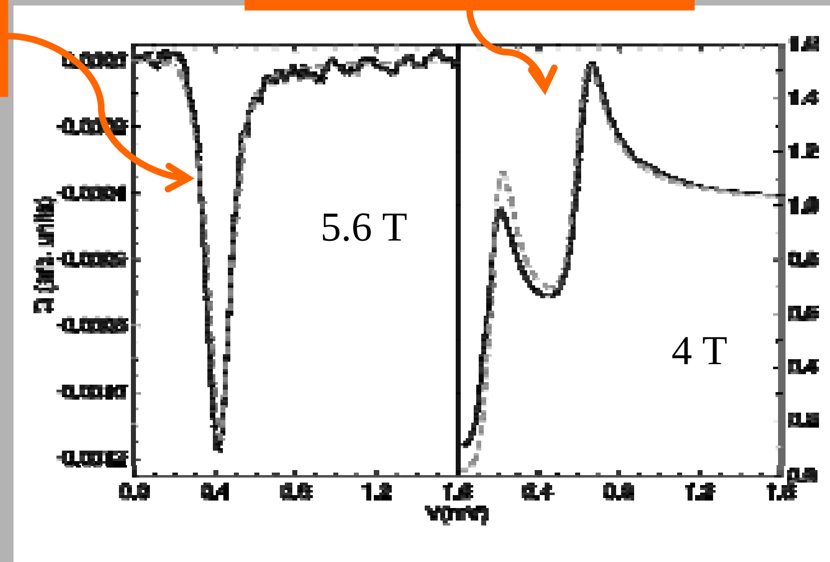
Extracting Superconducting Parameters From PR

Al-PM Tunnel Junction

SC Parameters Extracted From Fit to the PR at 5.6 T



Predicted DoS at 4 T



Catelani et al., PRB 80, 054512 (2009)

<u>Parameters Extracted From PR Fits</u>

Gap: Δ_o

SO:

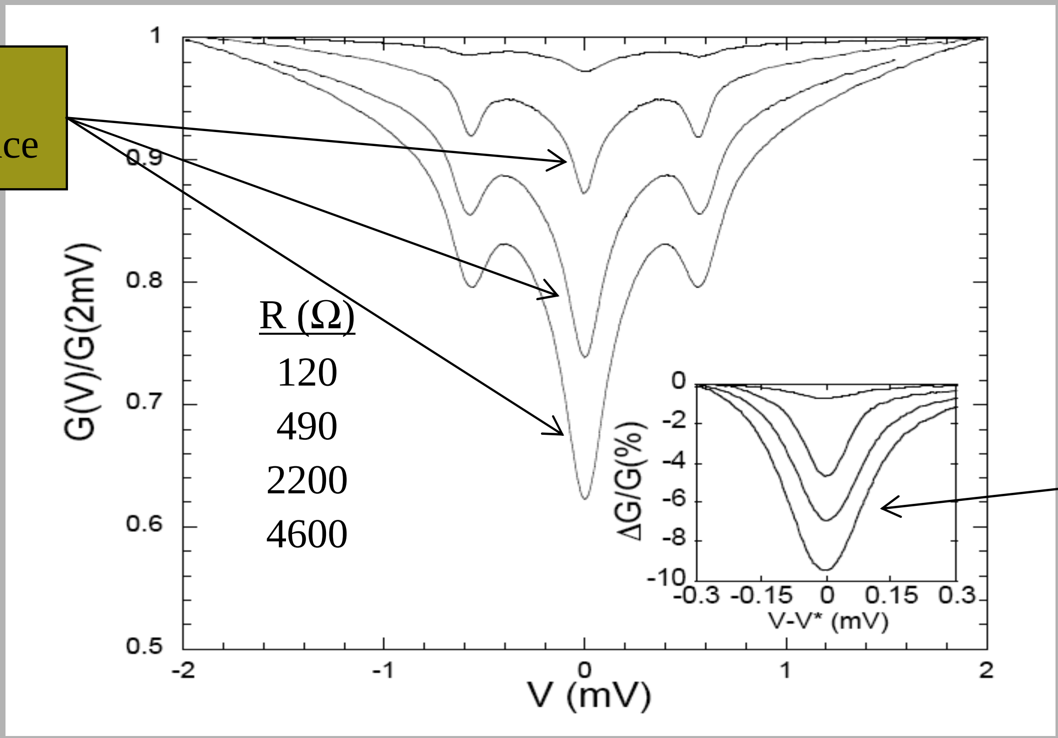
Orbital:

FL Parameter: G^0

Note:

S-I Insulator Transition from the perspective of the PR

ZBA grows rapidly
with increasing sheet resistance



The PR also deepens with increasing sheet resistance.

Can the PR survive the zero-field S-I transition, and, if so, does film morphology matter?

Summary

- Nature of the Coexistence region in the first-order spin-paramagnetic transition remains poorly understood.

- The first-order transition is intrinsically hysteretic and exhibits unusual dynamics including avalanches and slow relaxation

- We observe incoherent Cooper pairs in high-field tunneling spectroscopy.

- By fitting PR feature to theory we can determine the gap, the spin-orbit scattering rate, orbital pair breaking parameter, and the anti-symmetric FL parameter G^0.

- The PR can also be used to determine spin polarization in ferromagnetic films at fields well beyond the parallel critical field.

- Very large exchange fields can be induced and measured via the PR. Can we see an AHE in Al?