Quantum Little-Parks effect

מכון ויצמן למדע
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INTRODUCTION

- Mesoscopic superconducting devices often have non-zero resistance due to strong fluctuations of the superconducting order parameter
- The design of mesoscopic superconducting devices demands a firm understanding of what affects the electrical conductivity of mesoscopic superconductors
- Here we develop a new and exact tool to study the conductance of superconductors, and draw maps of the microscopic current flow to expose the microscopic mechanisms
- We study of the Little-Parks effect in small diameter cylinders, finding a new mechanism for their breakdown that reproduces characteristics steps seen in their resistance

FORMALISM

- To study the conductivity of mesoscopic superconductors we use the Meir-Wingreen formula for the current

$$J = \frac{\mathrm{i}e}{2h}\int \mathrm{d}\epsilon \Big[\mathrm{Tr}\left\{\left(f_{\mathrm{L}}(\epsilon)\Gamma^{\mathrm{L}} - f_{\mathrm{R}}(\epsilon)\Gamma^{\mathrm{R}}\right)\times\left(G^{\mathrm{r}}_{\mathrm{e}\sigma} - G^{\mathrm{a}\sigma}_{\mathrm{e}}\right)\right\} + \mathrm{Tr}\left\{\left(\Gamma^{\mathrm{L}} - \Gamma^{\mathrm{R}}\right)G^{<}_{\mathrm{e}\sigma}\right\}\Big]$$

- Describe the superconductor with the disordered negative-*U* Hubbard model
- To take full account of phase and amplitude fluctuations that drive the system resistive we use a Monte Carlo summation to calculate the thermal average

VERIFICATION

To verify that the phase and amplitude fluctuations can fully capture known properties of superconducting system we verified it against a series of well-established results:

1) Kosterlitz-Thouless transition
2) Nonlinear *IV* characteristic
3) Length dependence of conductivity
4) BTK transmission coefficient
5) Three-body interactions
6) Josephson tunneling
7) Little-Parks effect

[GJ Conduit & Y Meir, Phys. Rev B. (2011)]

LITTLE-PARKS

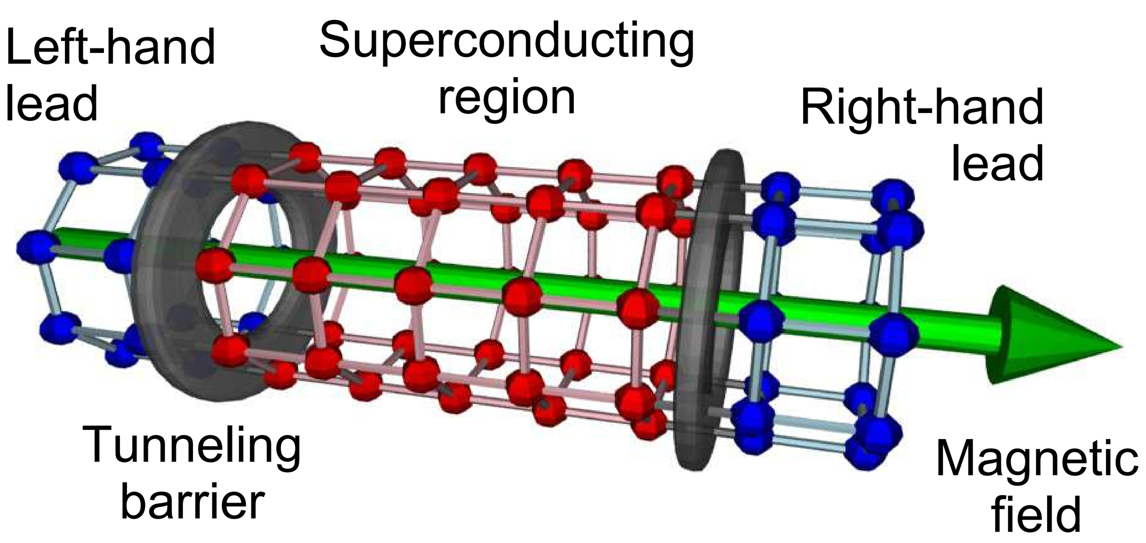


Fig. 1. Experimental setup: Within the Hubbard model the central superconducting region (red) sites are connected between the leads (blue). Magnetic flux threads through the cylinder.

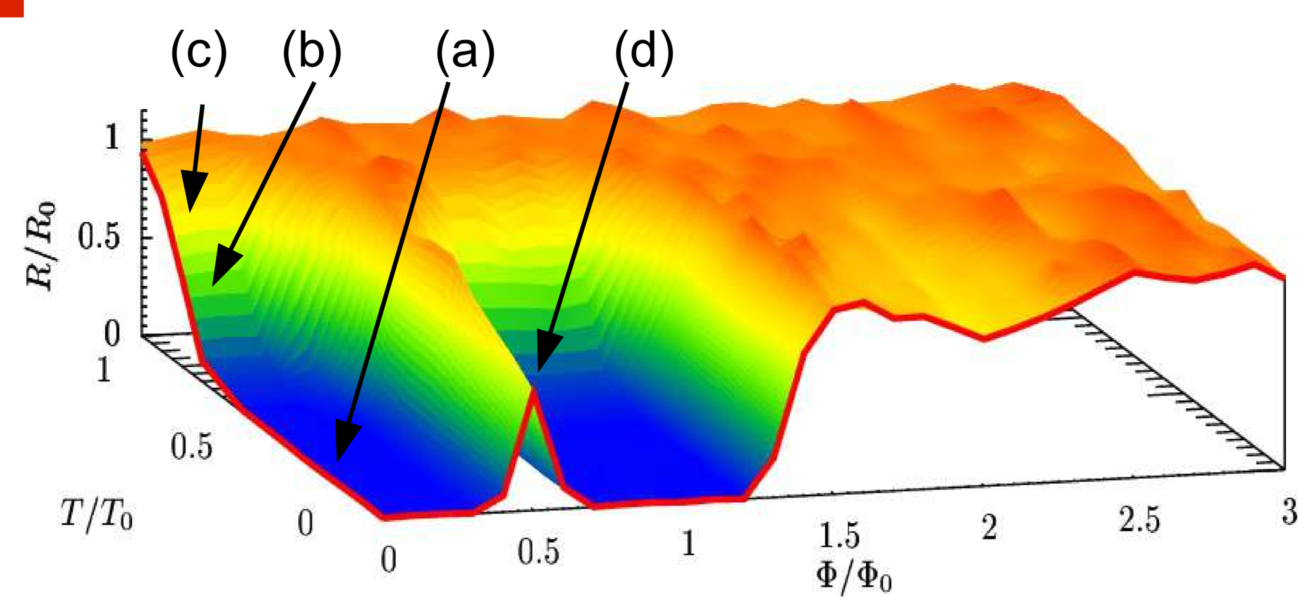


Fig. 2. Variation of resistance with magnetic field and temperature. The points (a-d) label the current maps shown below

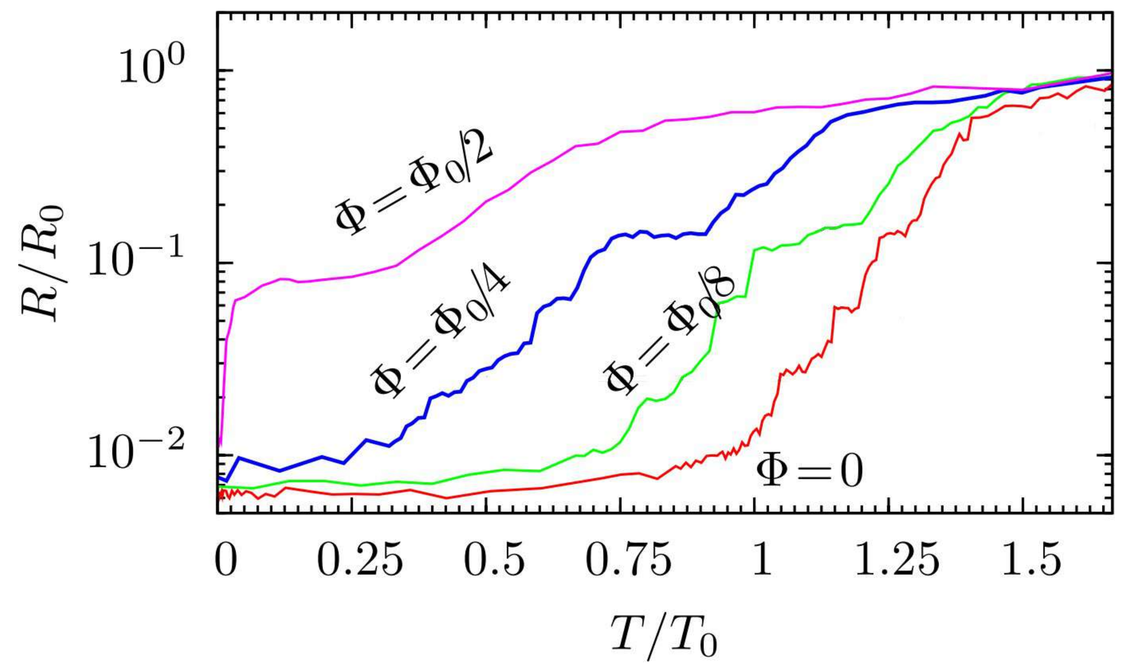


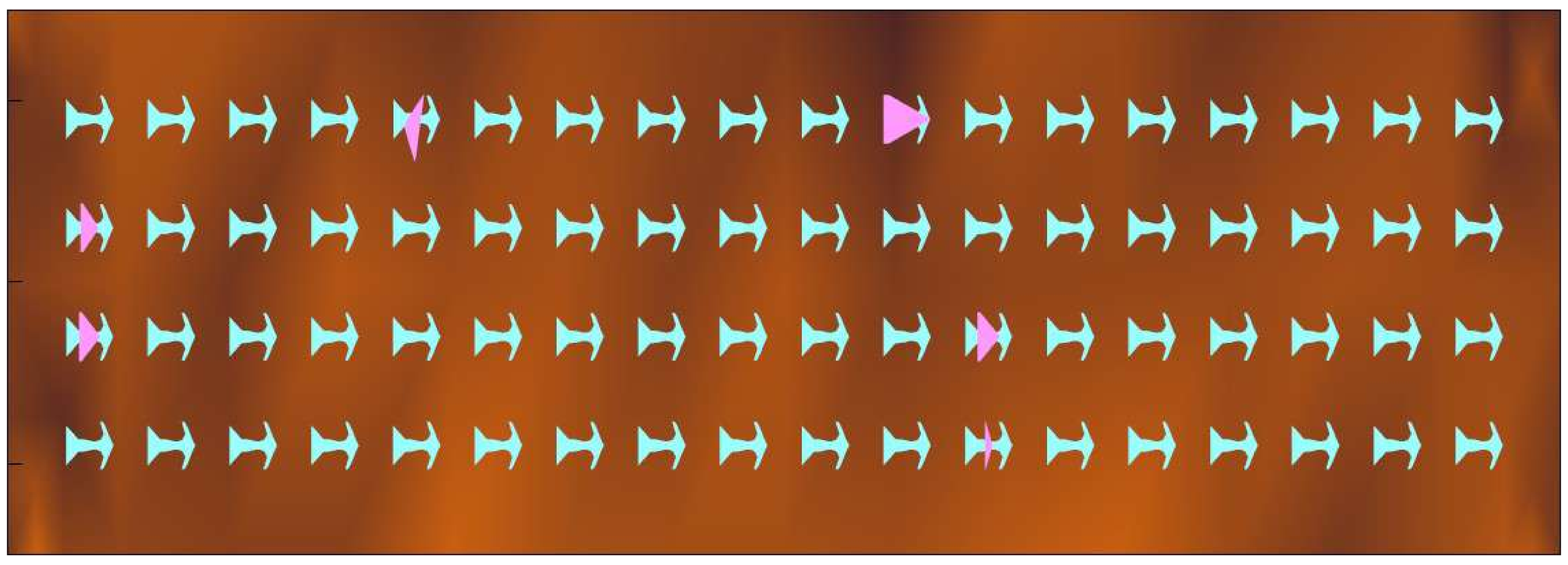
Fig. 3. Examining cuts at constant flux. At Φ=0 see the emergence of three steps in the resistance, which are further explored with the current maps below.

The Little-Parks effect is seen in a superconducting cylinder threaded with magnetic flux. When half-integer flux is threaded the anti-periodic boundary conditions disrupts the superconducting state. In small cylinders with a diameter comparable to the superconducting coherence length this leads to the total destruction of the superconducting state, and moreover with increasing temperature the resistance rises in a series of steps.

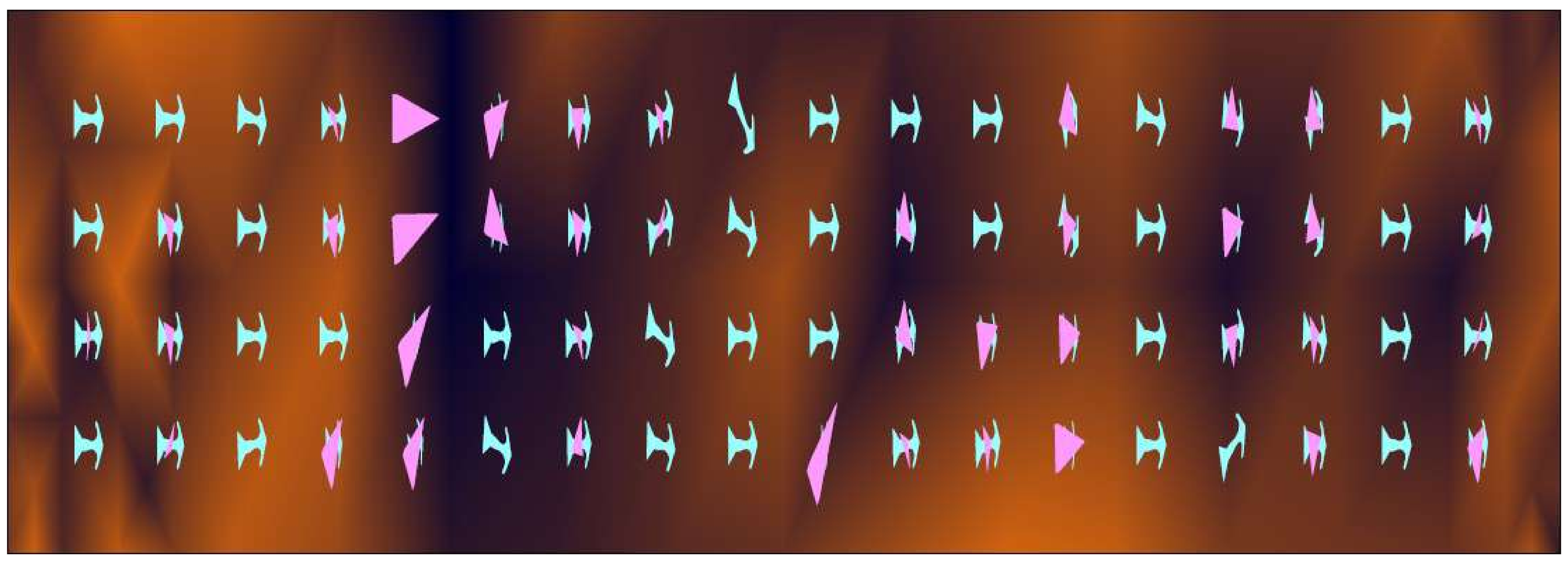
CURRENT MAPS

We construct maps of the current flow to diagnose the microscopic mechanism behind the superconductor-insulator transition and the emergence of the resistance steps

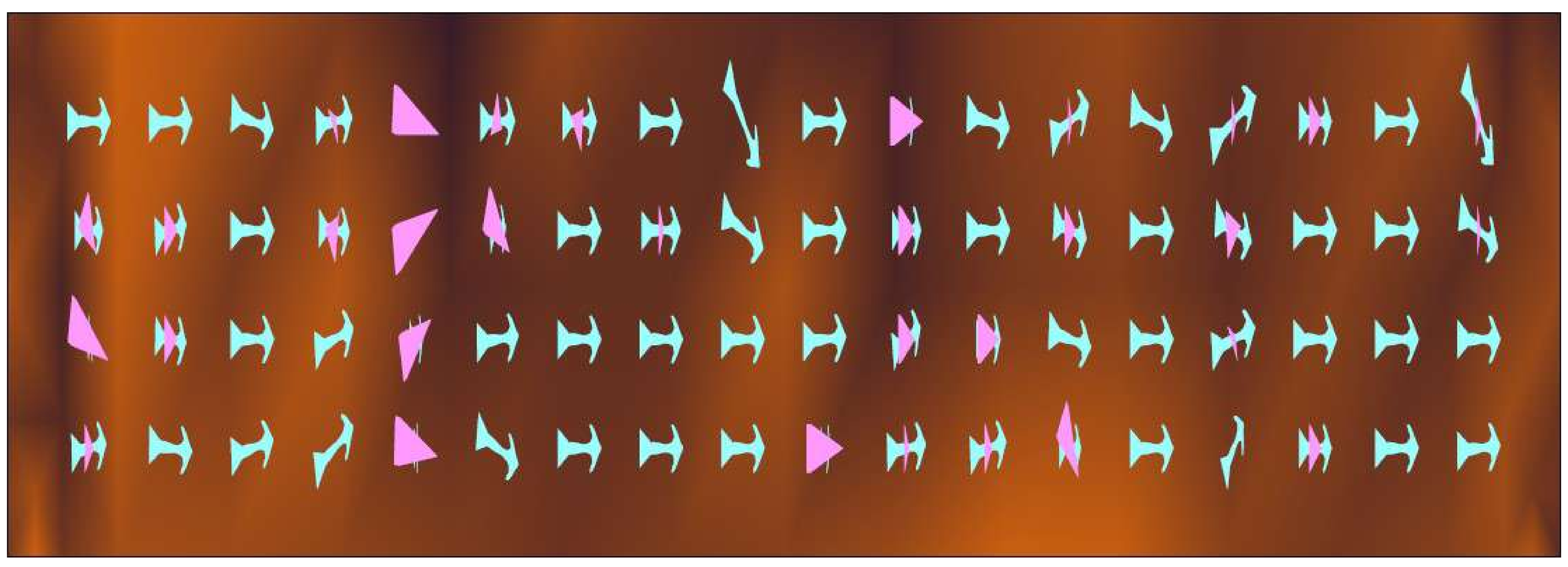
(a) Wire entirely superconducting with zero resistance, all the current is supercurrent (cyan arrow)



(c) At higher temperature still a second normal region emerges, forming the second resistance step



(b) With increasing temperature a normal state bisects the wire and normal current flows (magenta pointer), giving the first resistance step



(d) When a half-flux quantum is threaded the wire is partially normal, but a normal region at the same place as in (b) splits the superconductor