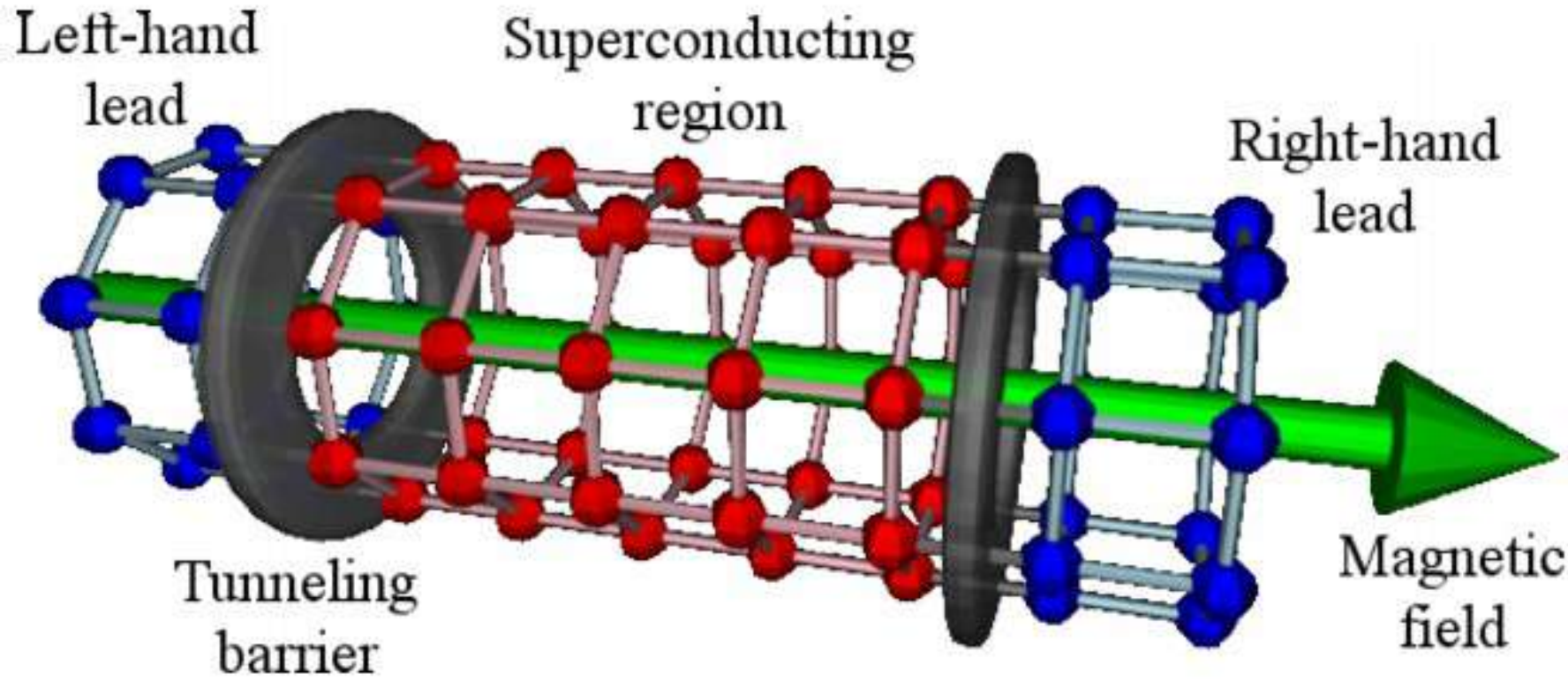
An *ab initio* study of the Little-Parks effect

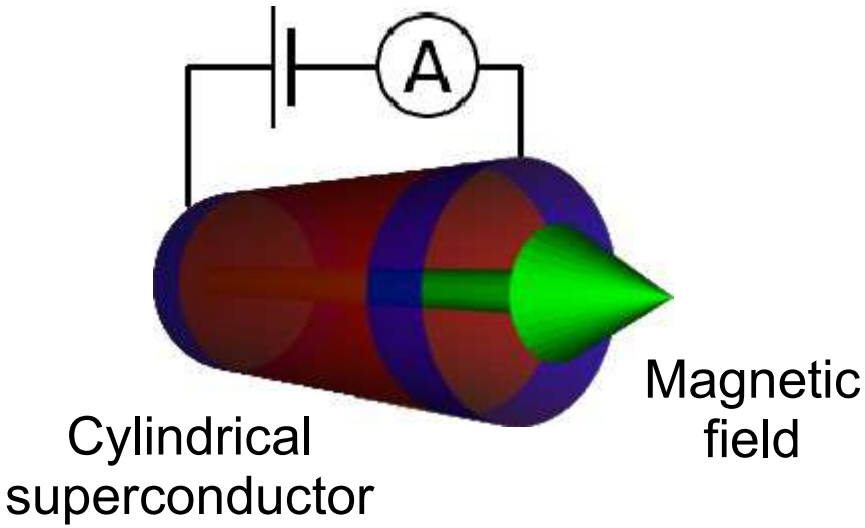


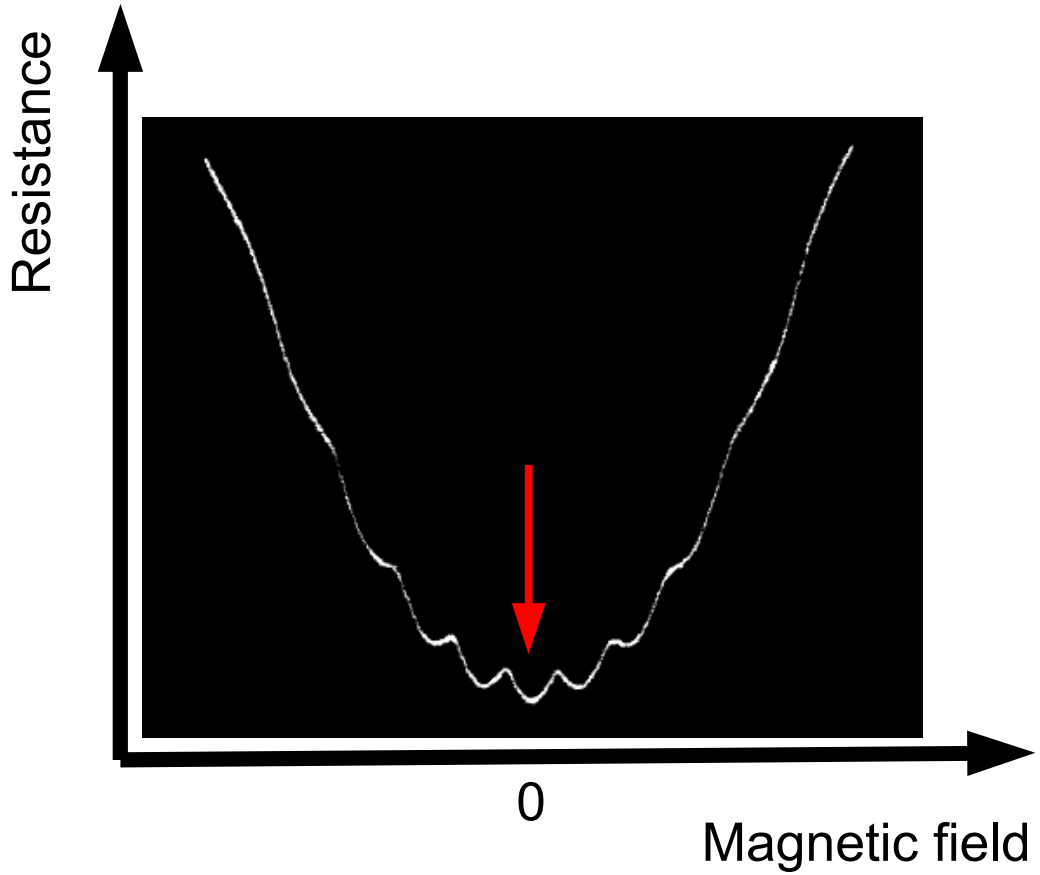
Gareth Conduit, Yigal Meir

Ben Gurion University

Little-Parks in a large diameter cylinder

- Cylindrical superconductor held at transition temperature and threading flux is increased





Little & Parks, PRL 1962

Little-Parks in a large diameter cylinder

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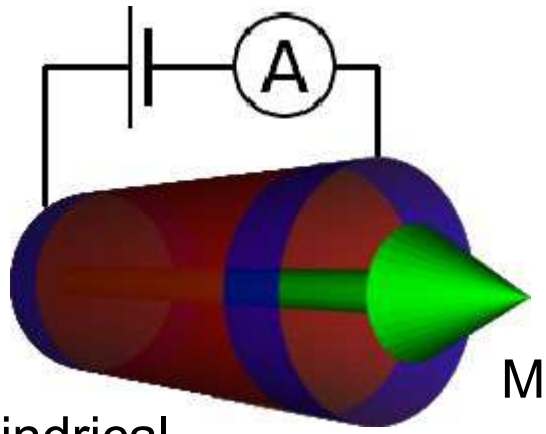
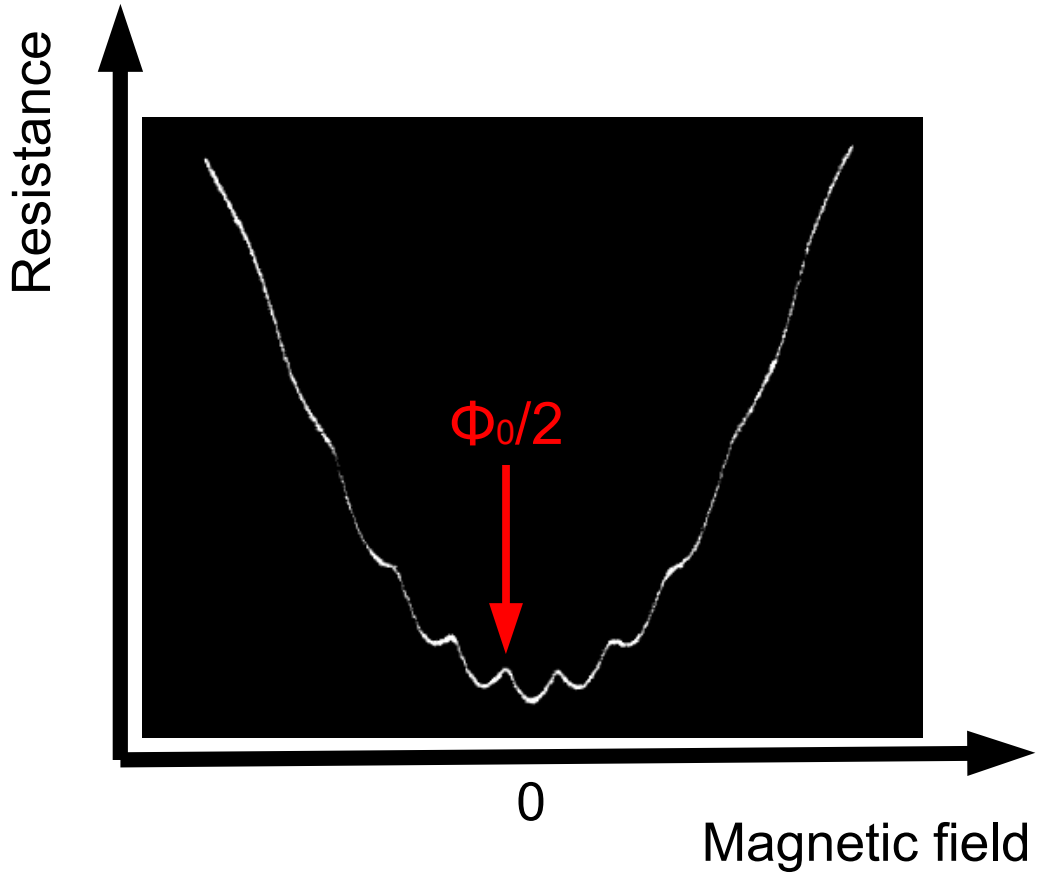


Cylindrical superconductor

Magnetic field



Little & Parks, PRL 1962

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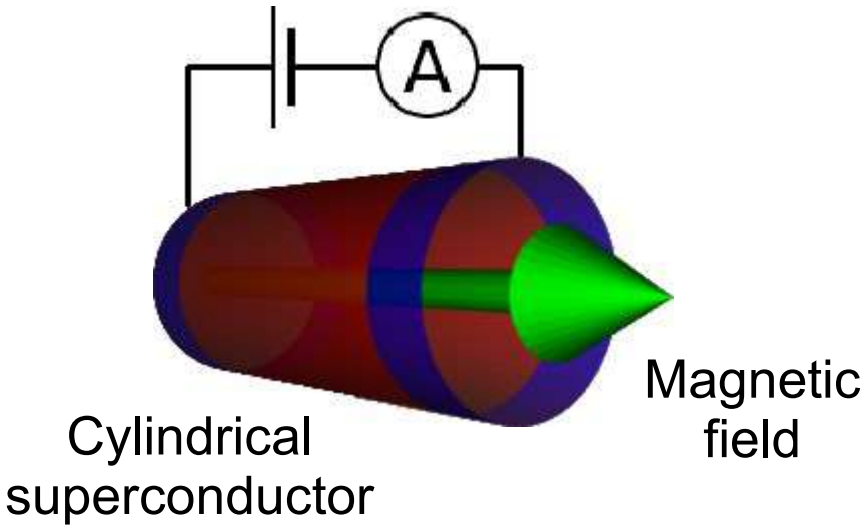
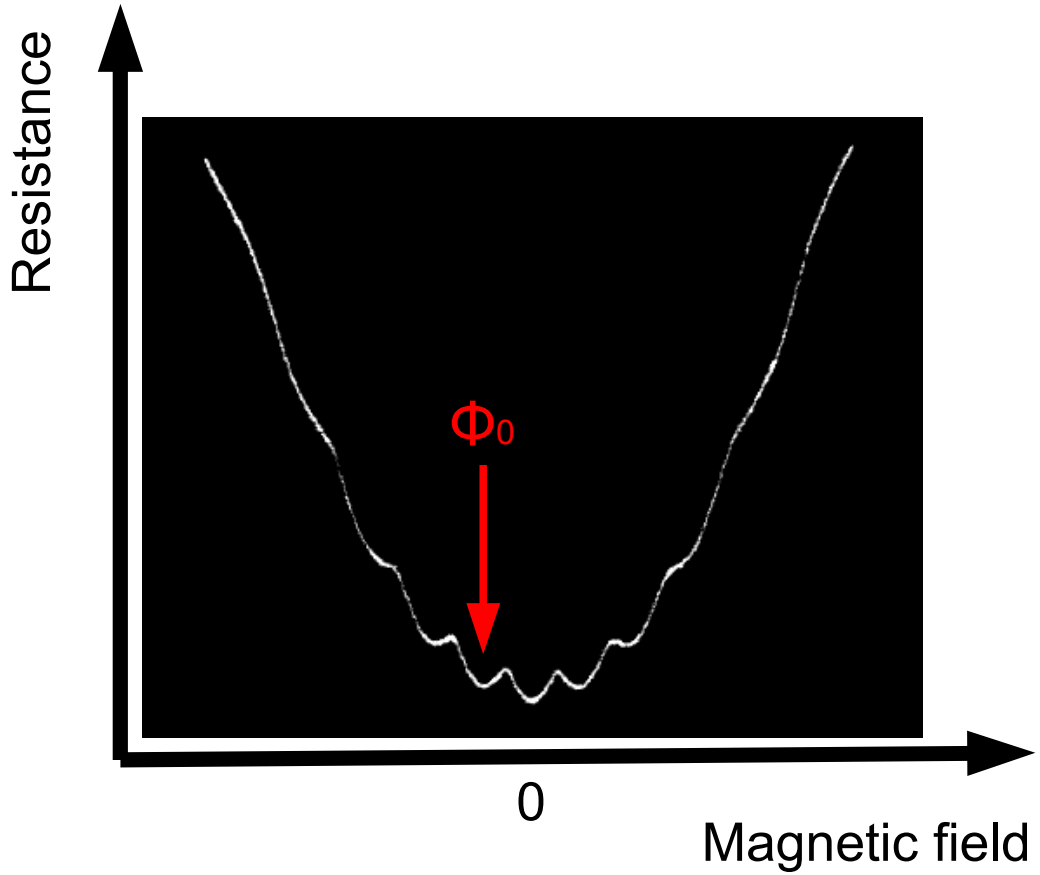
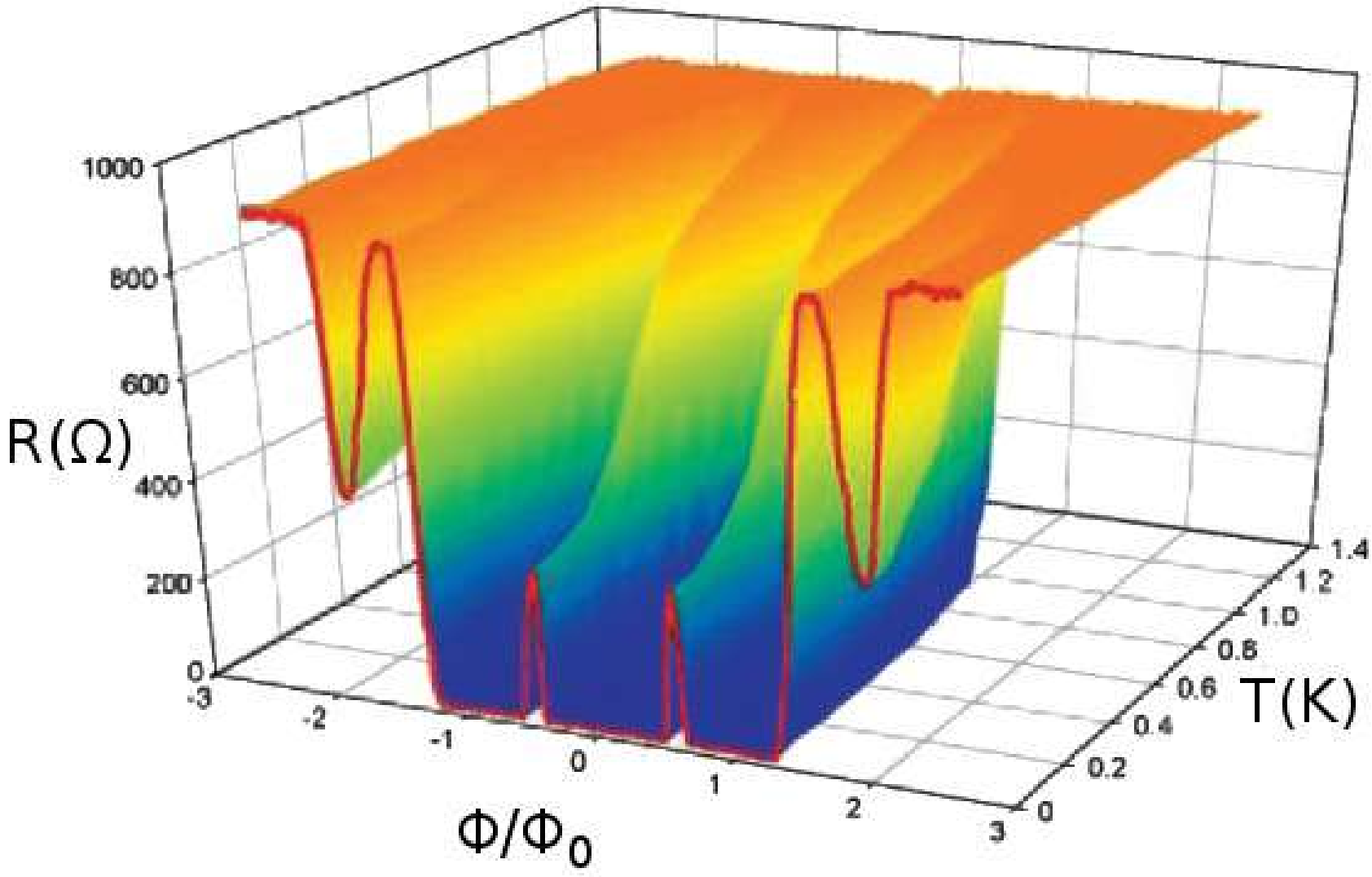




Little & Parks, PRL 1962

Little-Parks in a small diameter cylinder

- Reduce cylinder diameter to superconducting correlation length [Liu *et al*., Science 2001; Wang *et al*., PRL 2005]

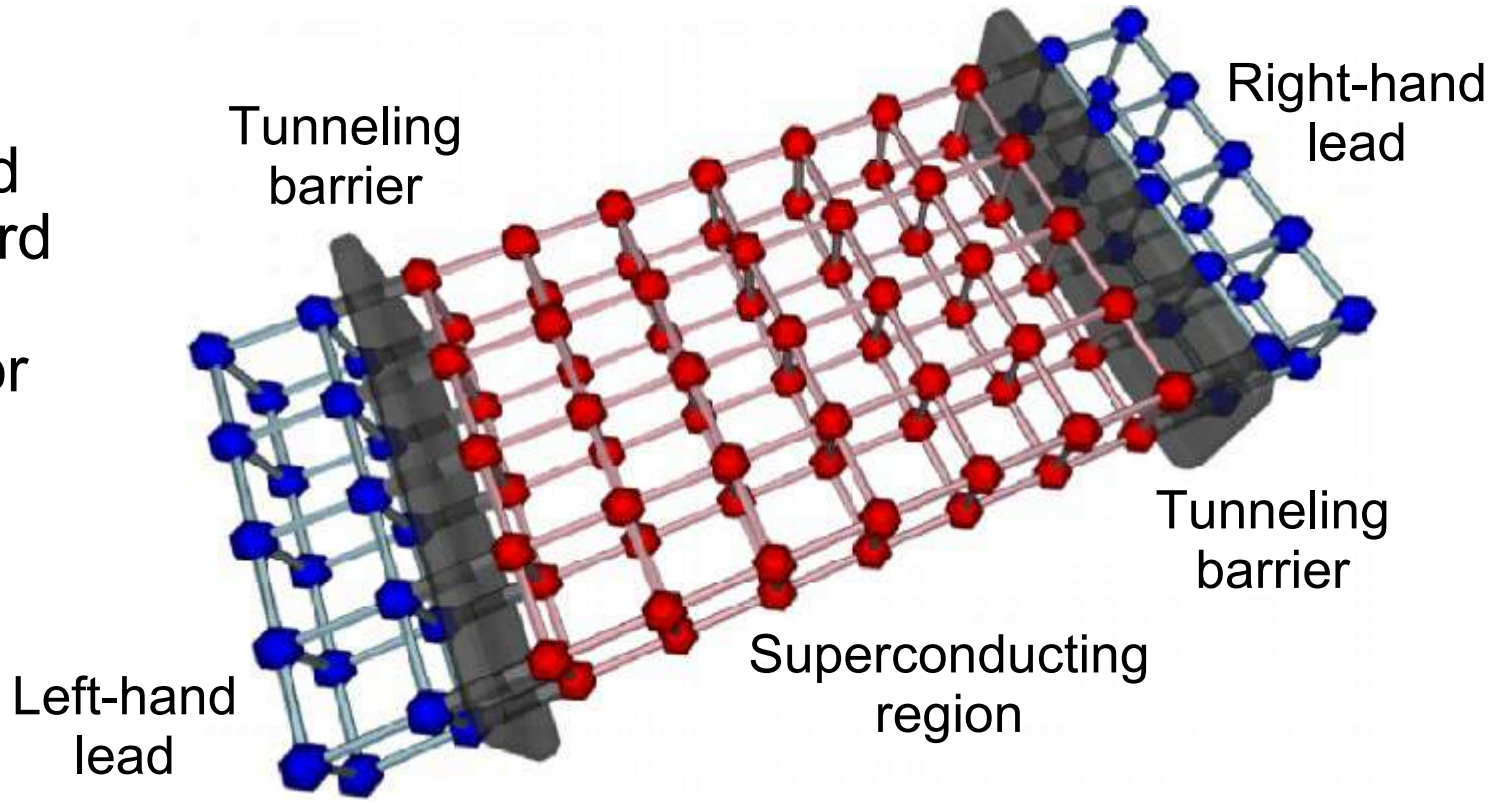


How to calculate the current

- General expression for the current [Meir & Wingreen, PRL 1992]

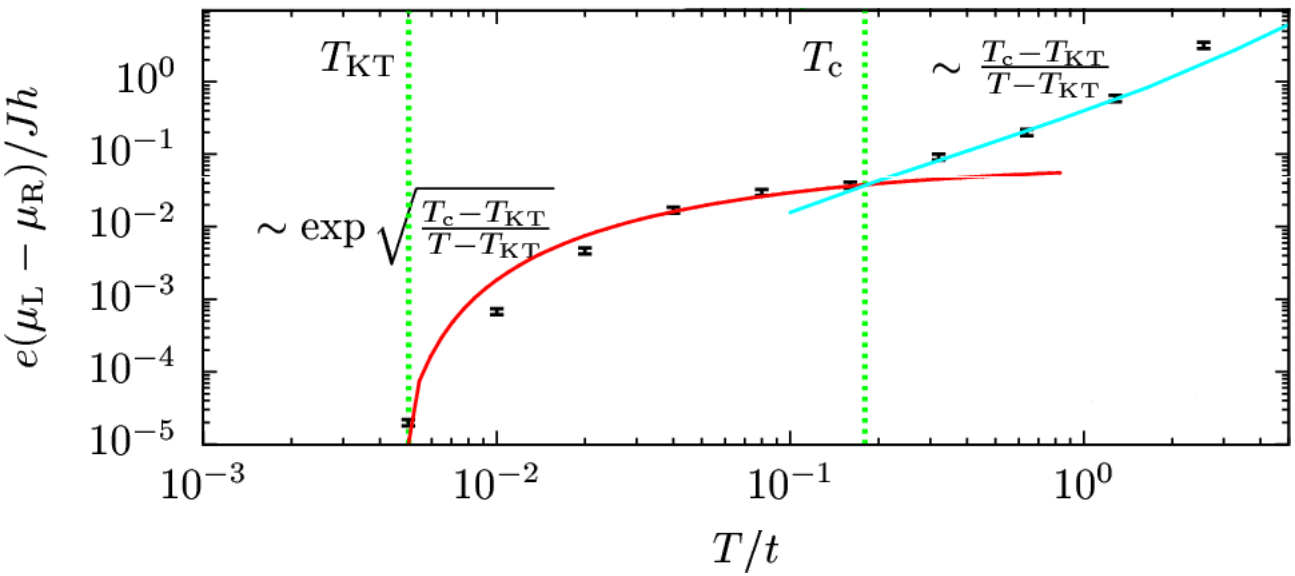
$$J = \frac{ie}{2h} \int d\epsilon \Big[\mathrm{Tr}\left\{ \left(f_{\mathrm{L}}(\epsilon)\Gamma^{\mathrm{L}} - f_{\mathrm{R}}(\epsilon)\Gamma^{\mathrm{R}} \right) \left(G^{\mathrm{r}}_{\mathrm{e}\sigma} - G^{\mathrm{a}\sigma}_{\mathrm{e}} \right) \right\} + \mathrm{Tr}\left\{ (\Gamma^{\mathrm{L}} - \Gamma^{\mathrm{R}})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

- Use the disordered negative-*U* Hubbard model to describe the superconductor
- Calculate the thermal average with Monte Carlo method



Verification

- **Resistivity at the Kosterlitz-Thouless transition**
- Nonlinear *IV* characteristics
- Length dependence of conductivity
- BTK transmission coefficient
- Three-body interactions
- Josephson junction
- Little-Parks effect in large diameter cylinder



Halperin & Nelson, J. Low Temp. Phys 1979

Ambegaokar *et al*., PRB 1980

Verification

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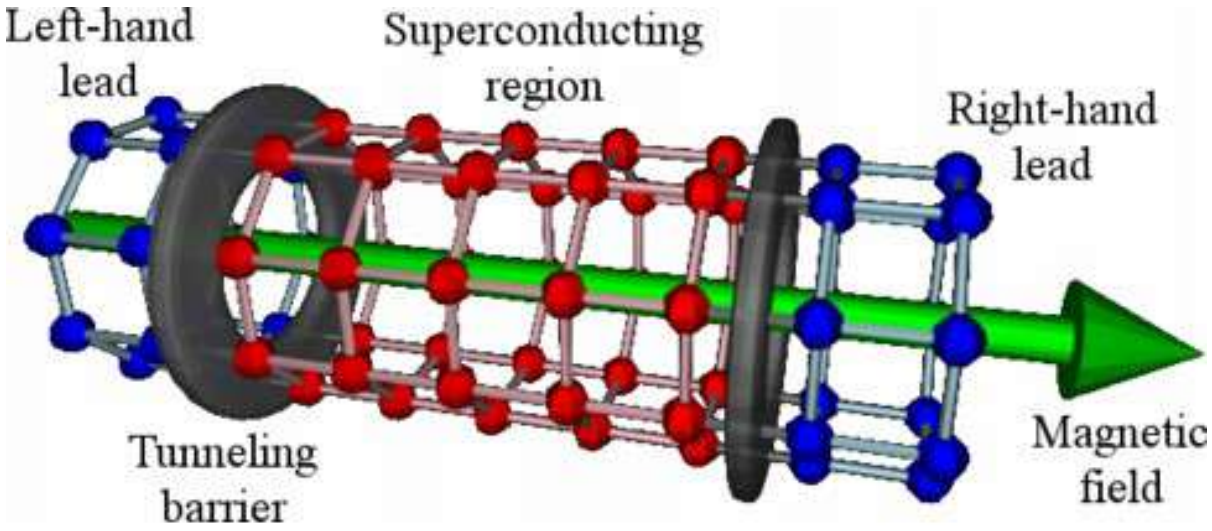
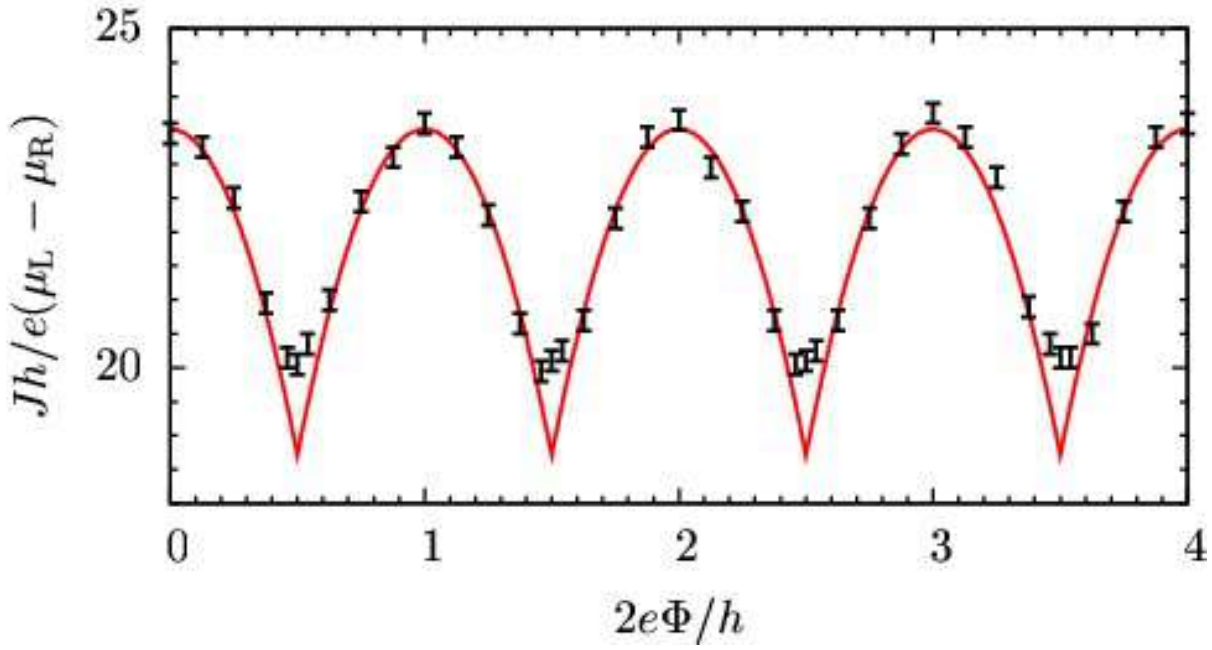
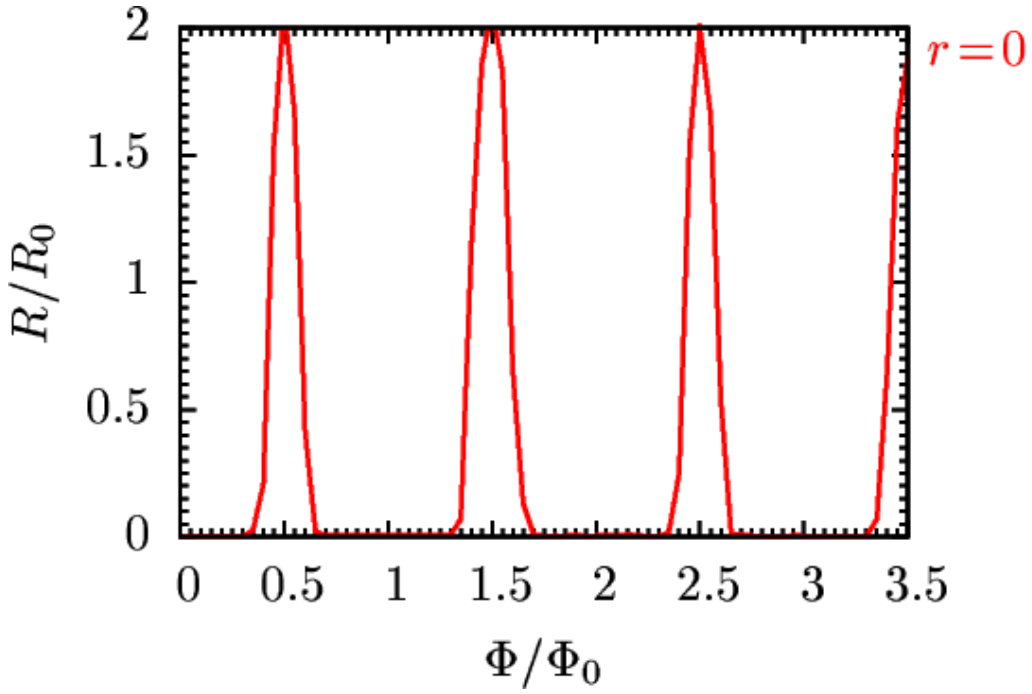
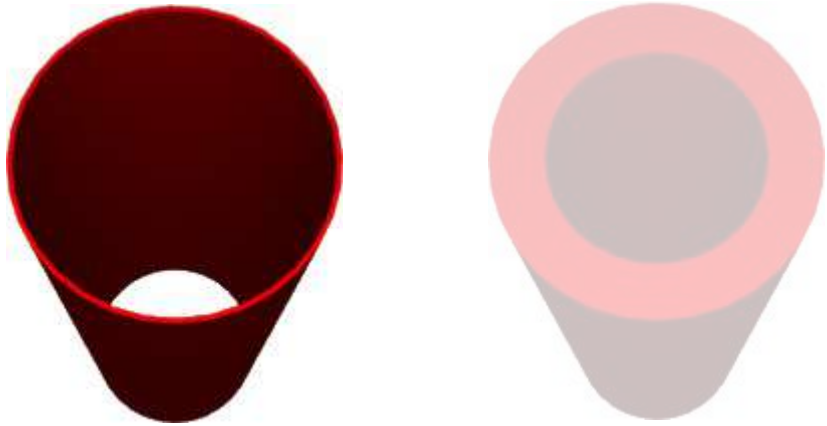




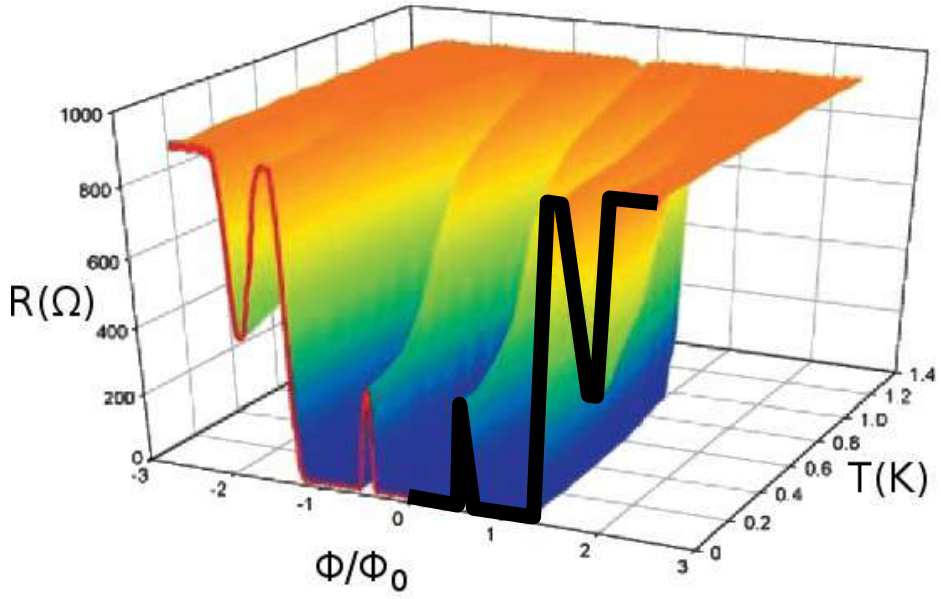
Little-Parks in a small diameter cylinder

Theory:



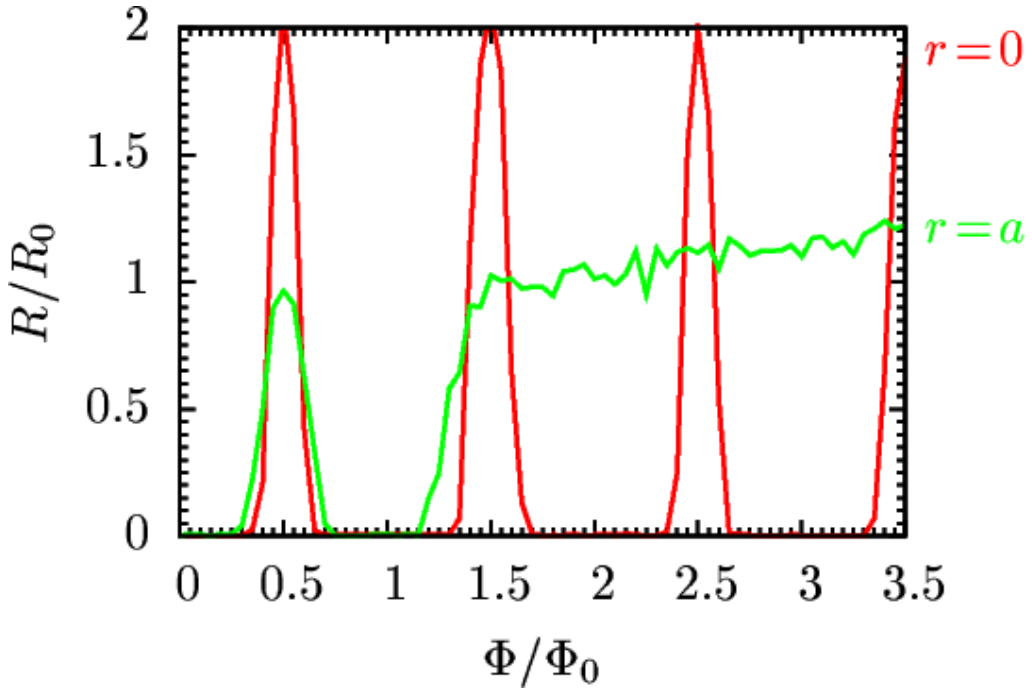


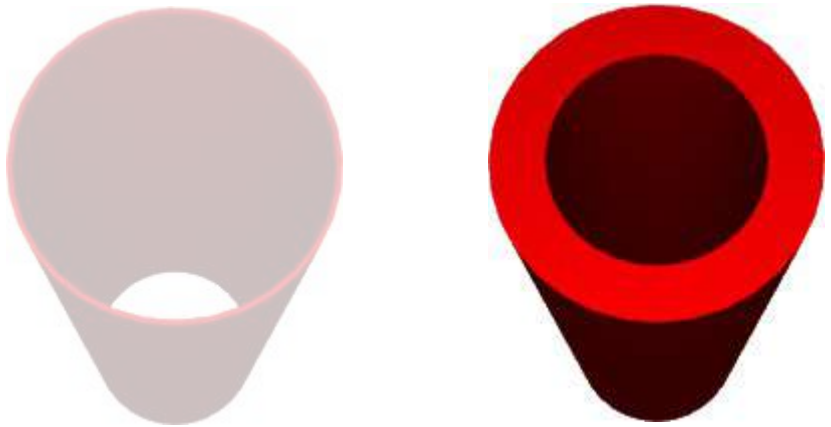
Experiment:



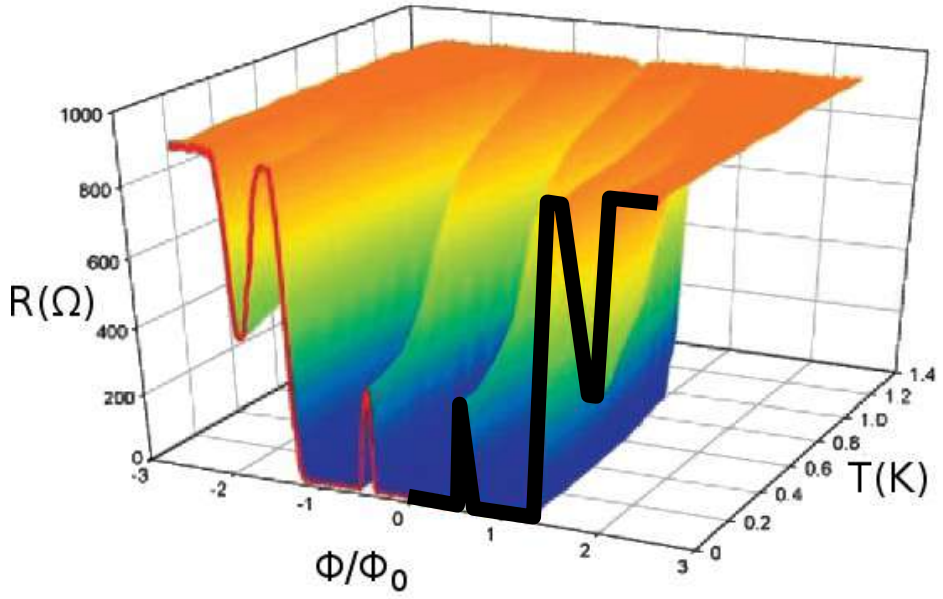
Little-Parks in a small diameter cylinder

Theory:



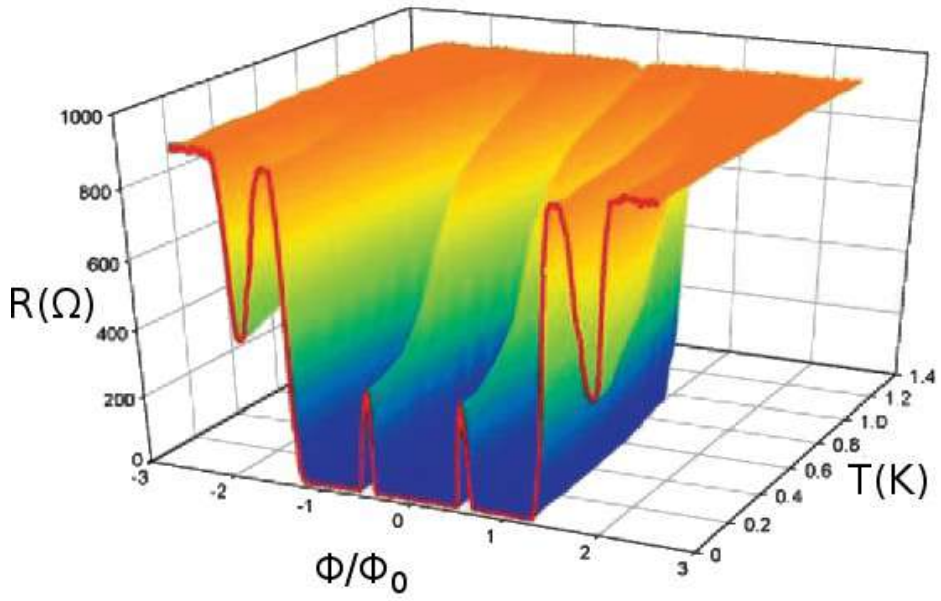


Experiment:

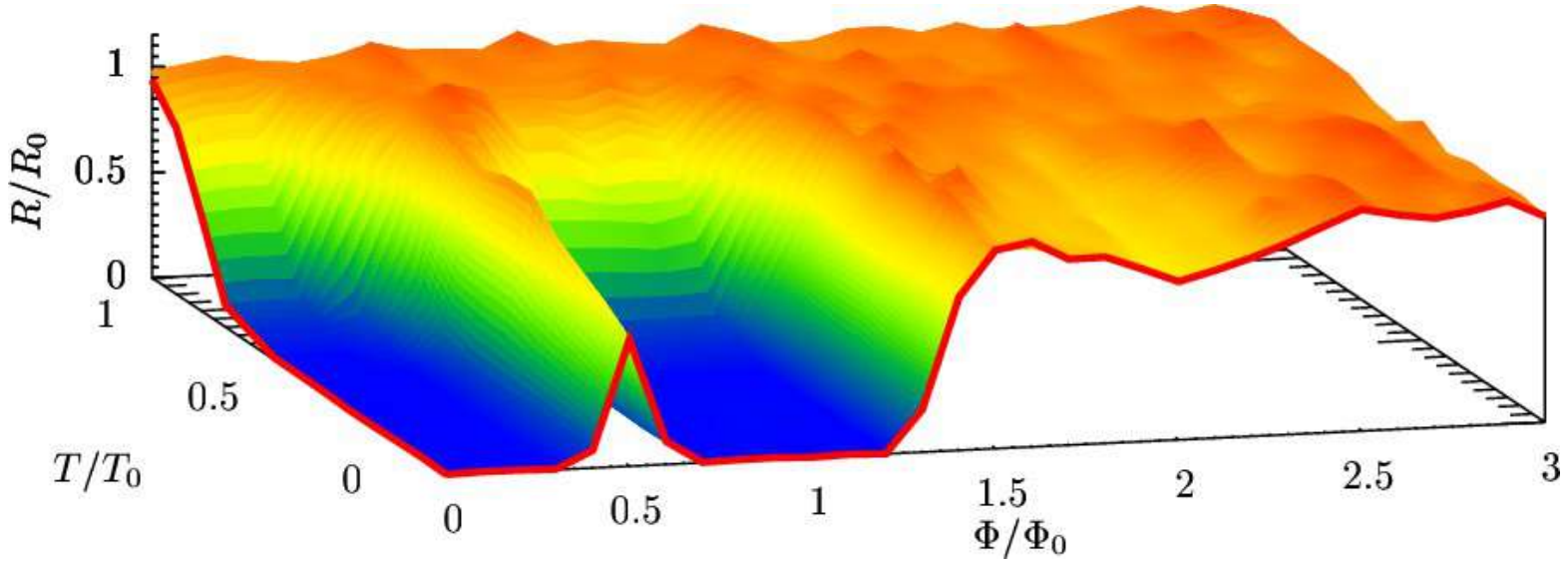


Little-Parks in a small diameter cylinder

Experiment:



Theory:



Little-Parks in a small diameter cylinder

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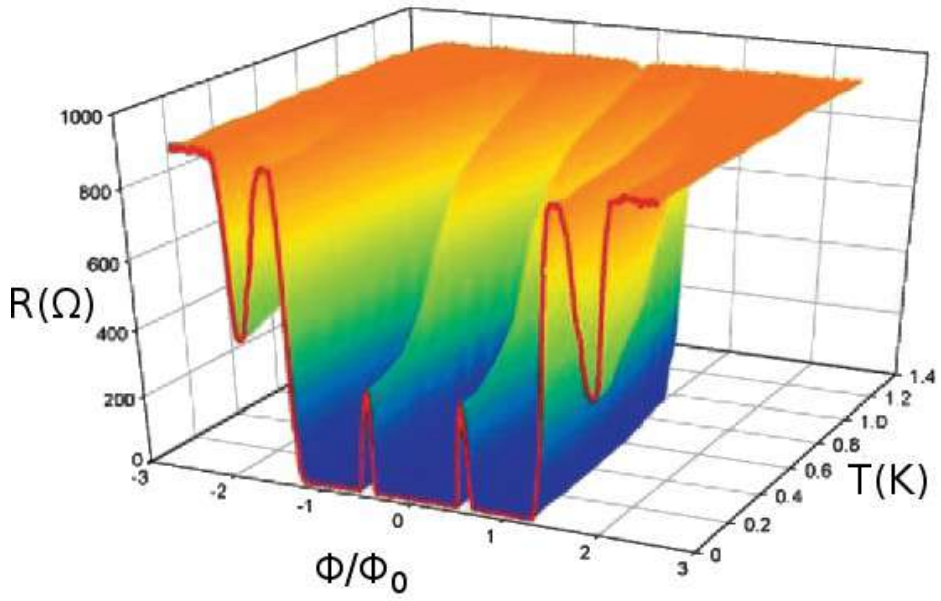
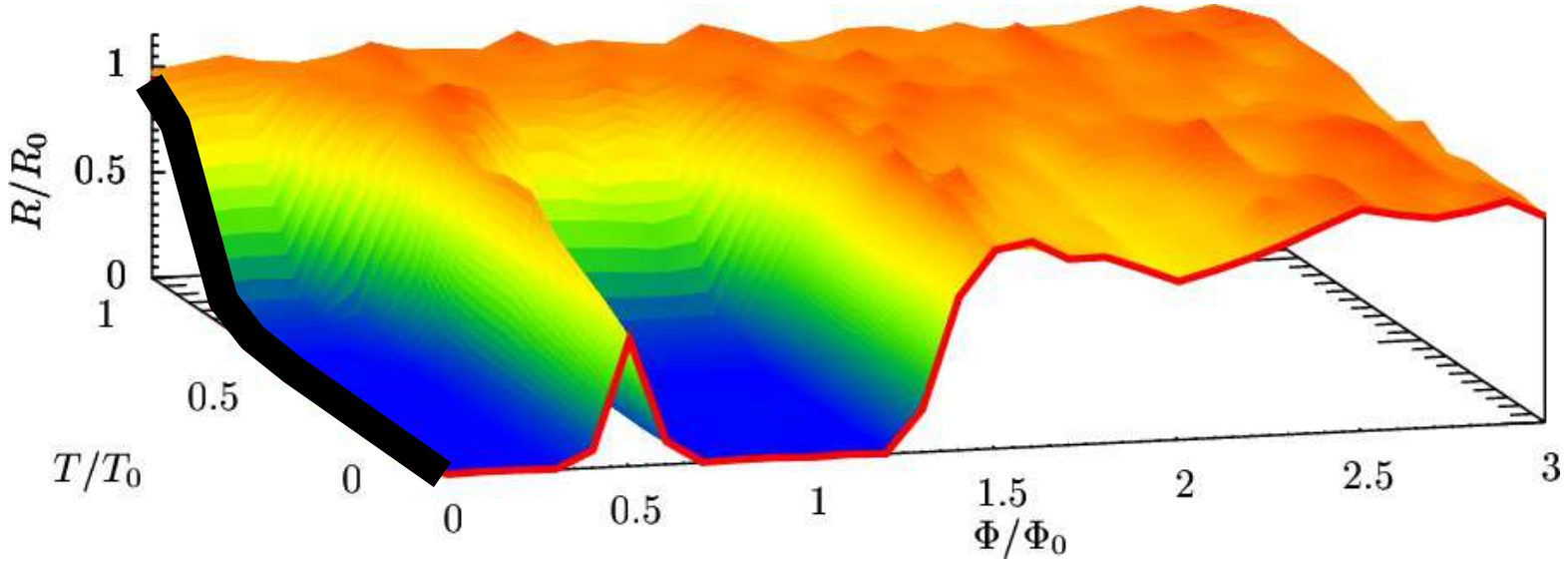
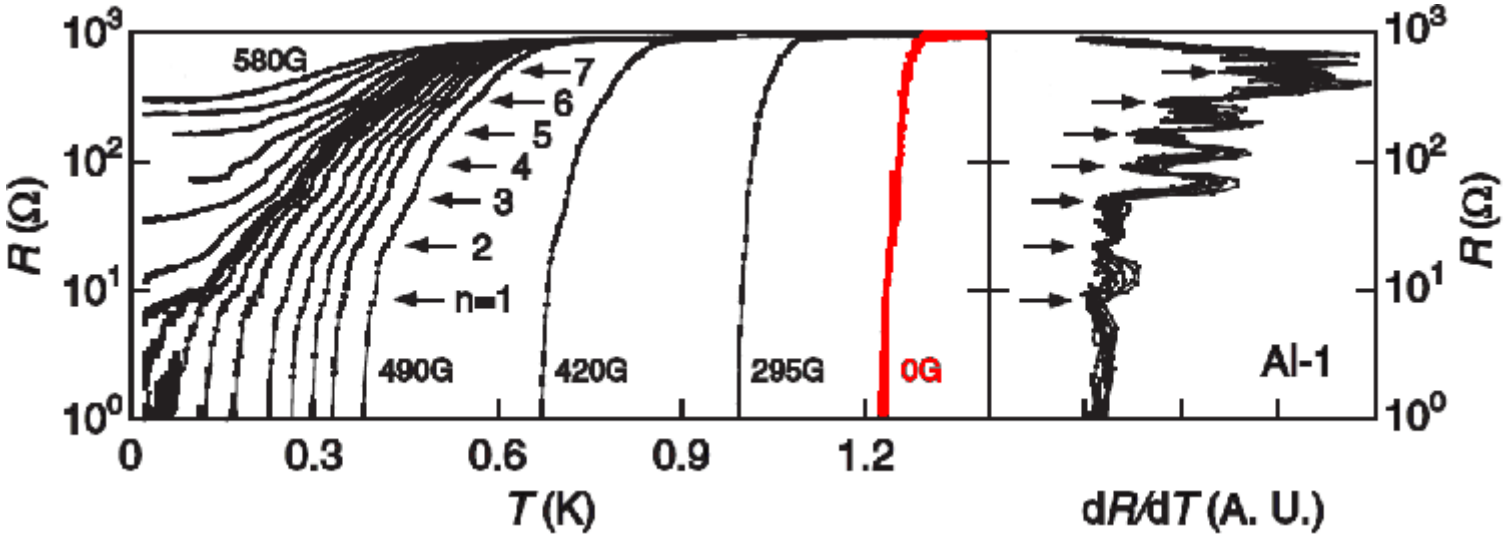


Theory:

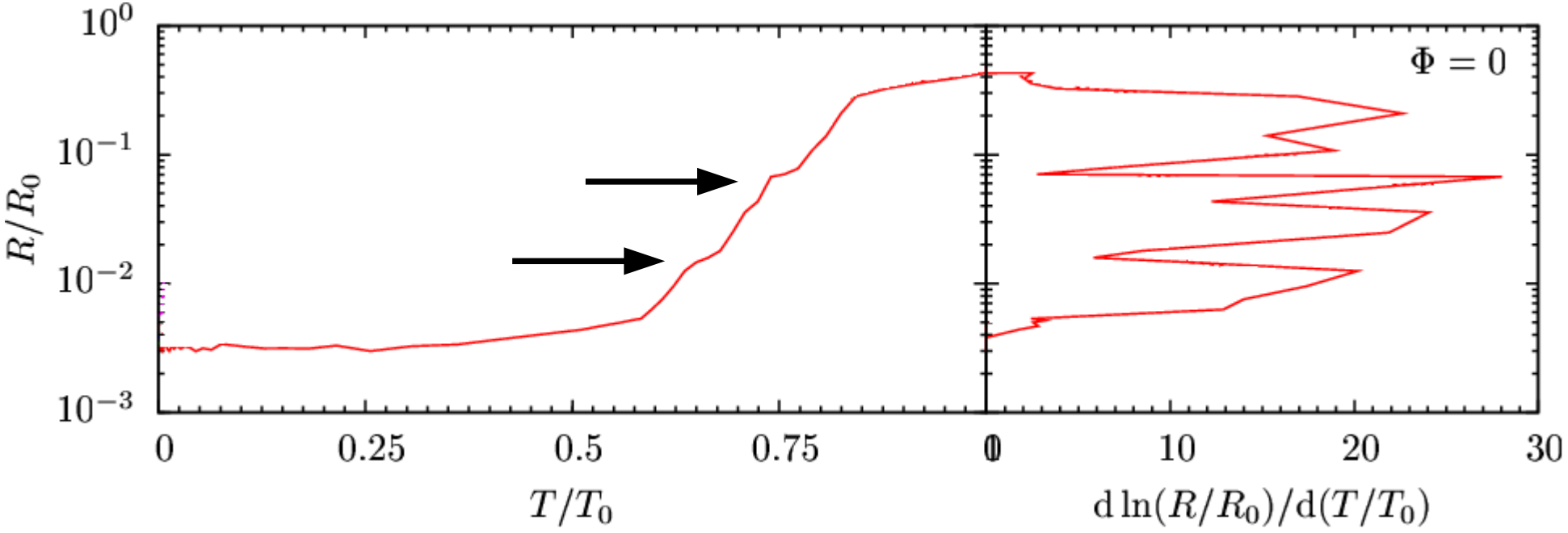


Evidence of phase reconstruction

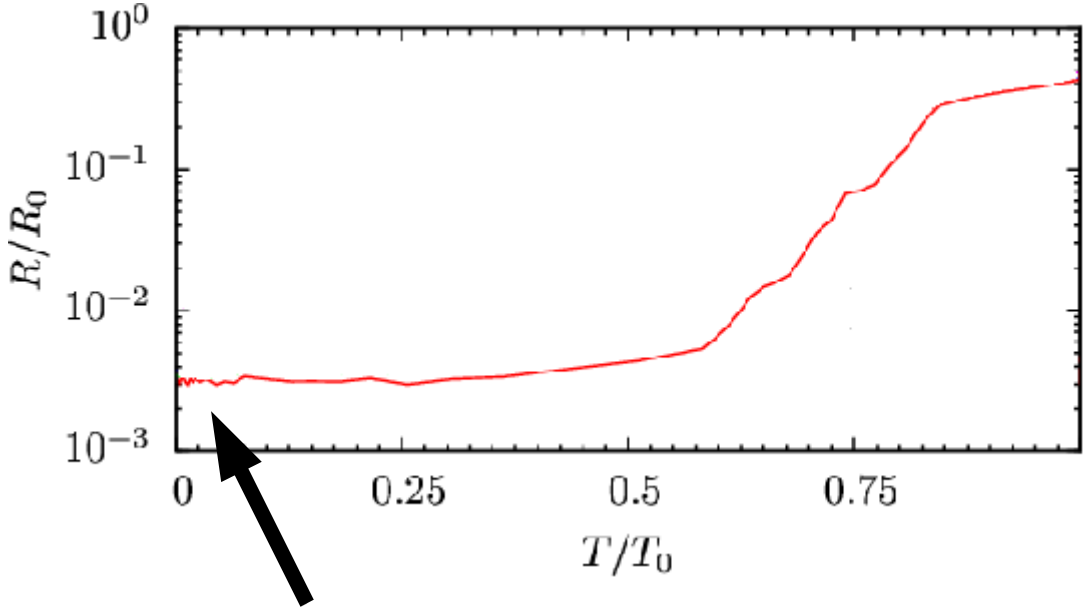
- Experiment:



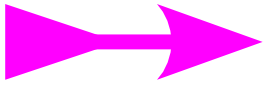
- Theory:



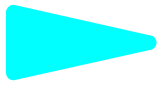
Completely superconducting



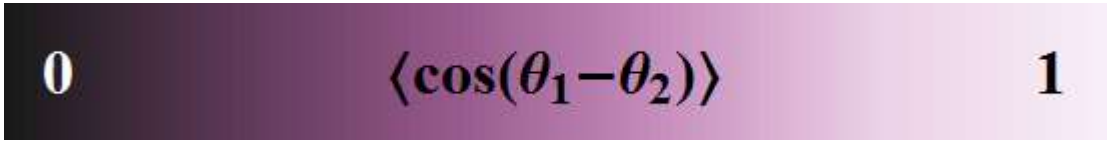
$$\frac{V-\mu_R}{\mu_L-\mu_R}$$

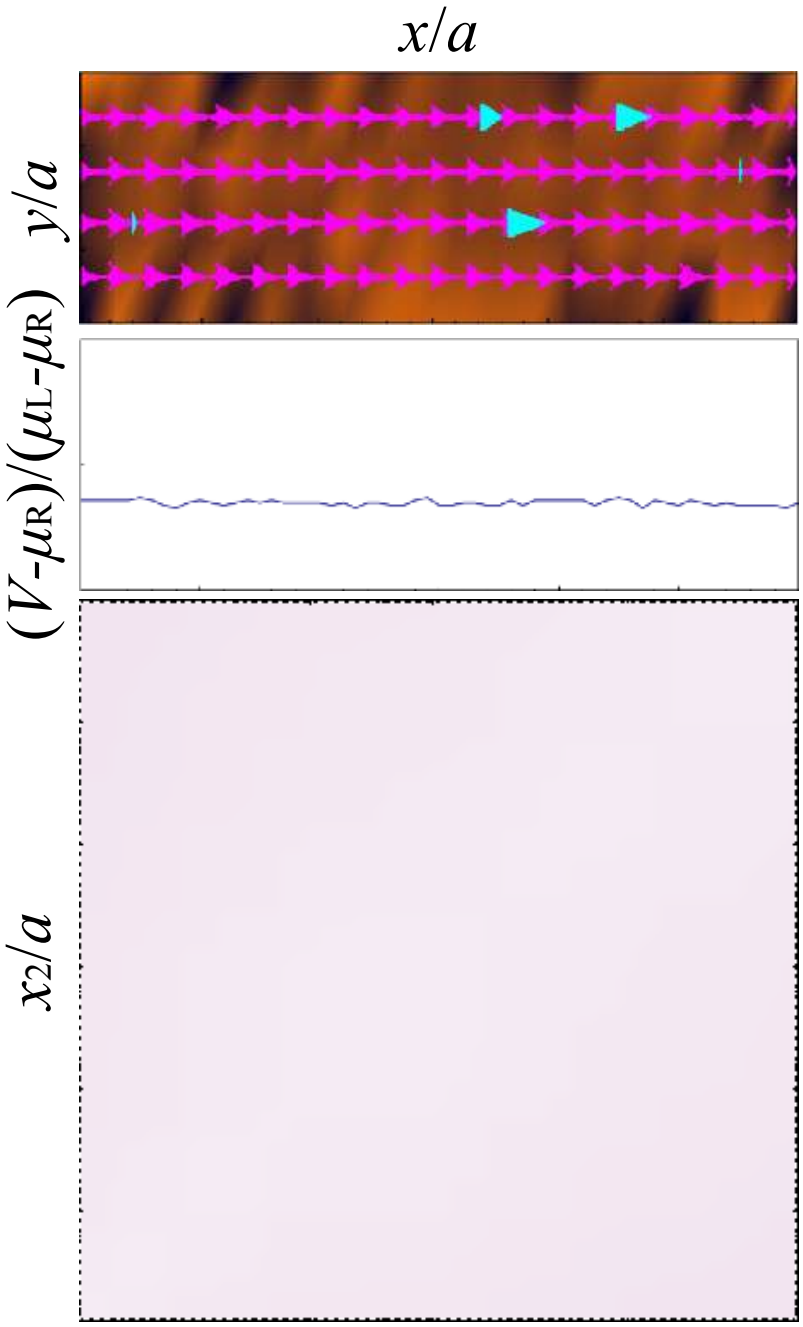


Superconducting current

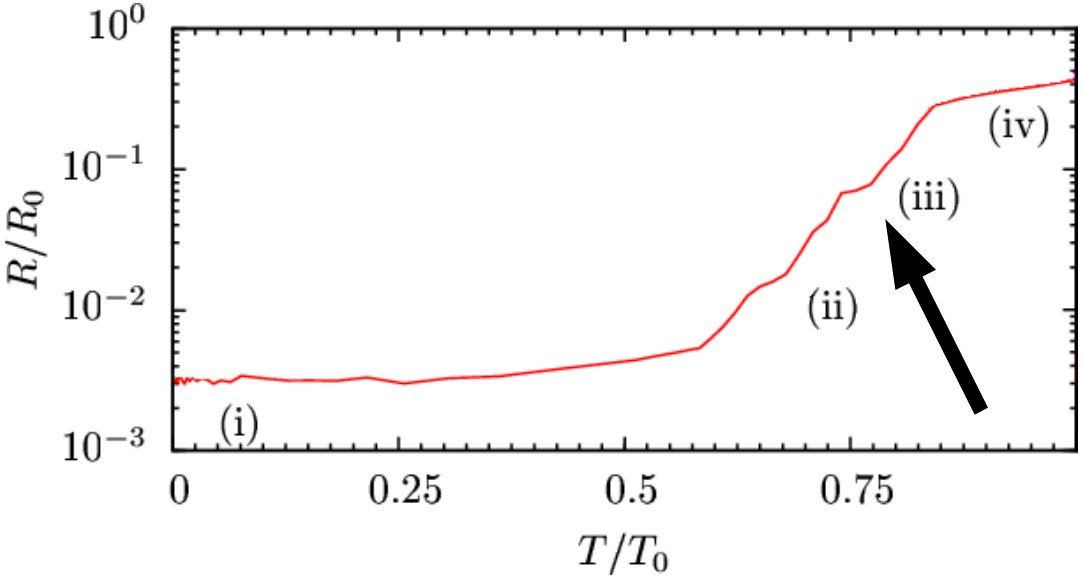


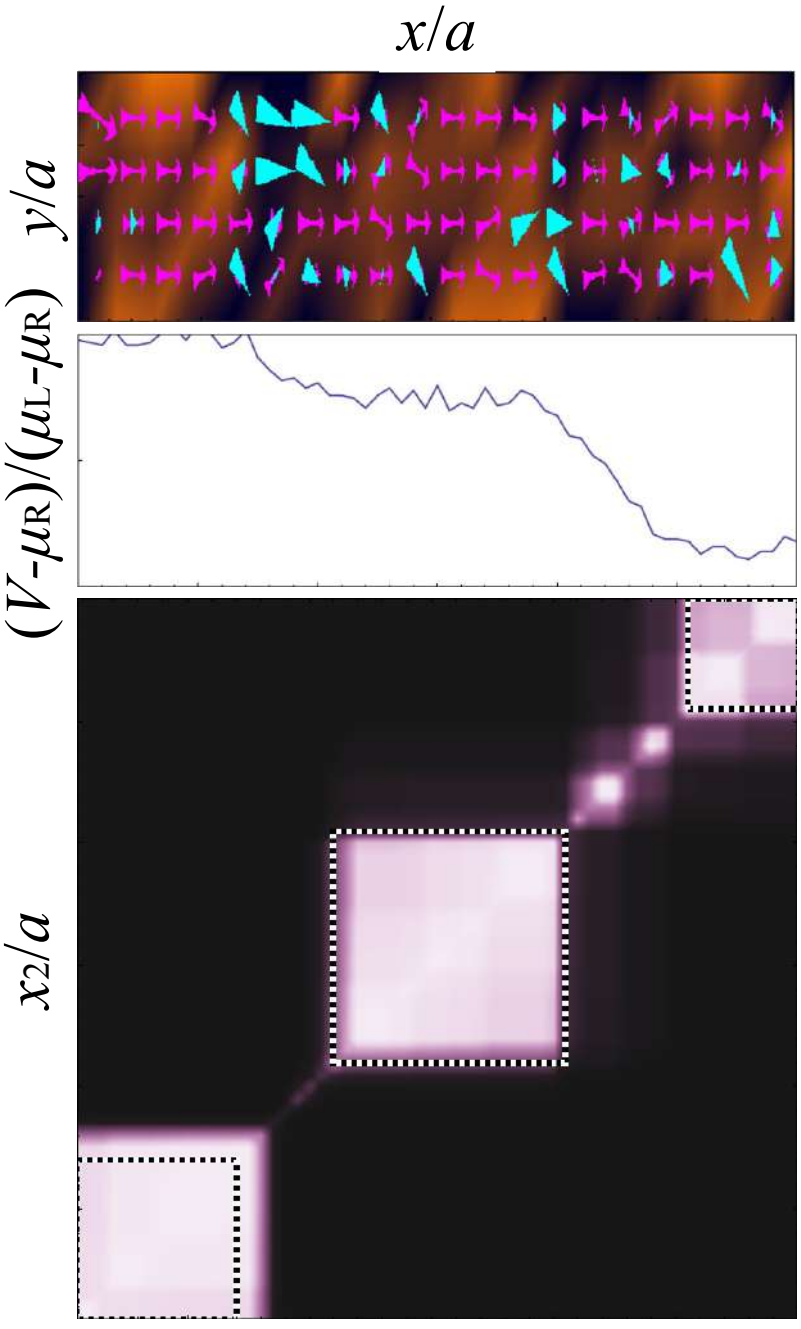
Normal current





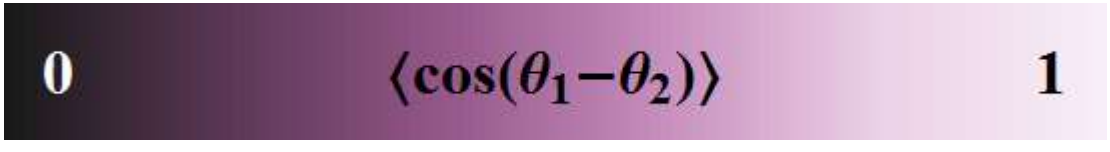
Three superconducting regions



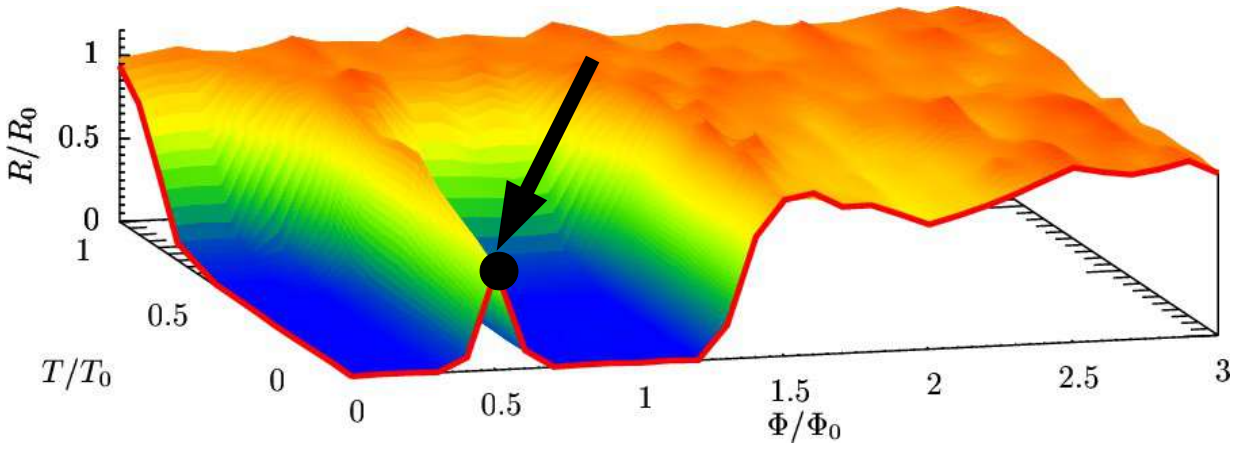


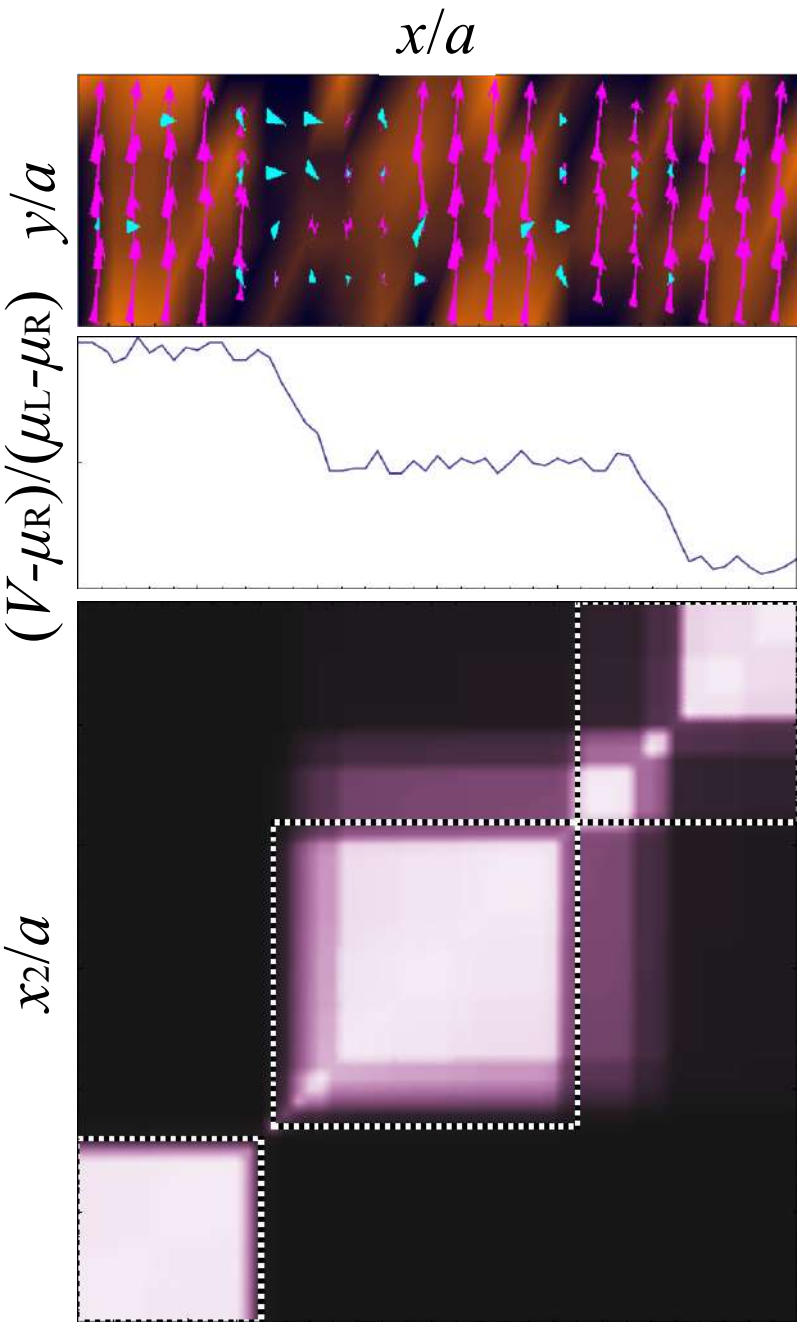
Superconducting current

Normal current



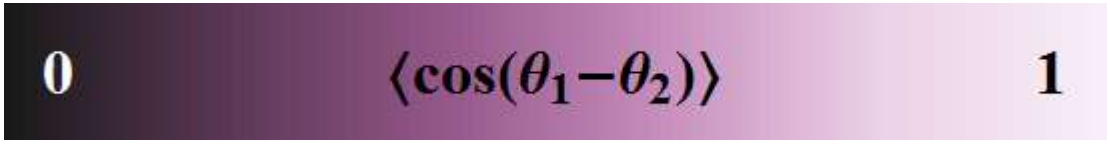
Half flux quantum normal state





Superconducting current

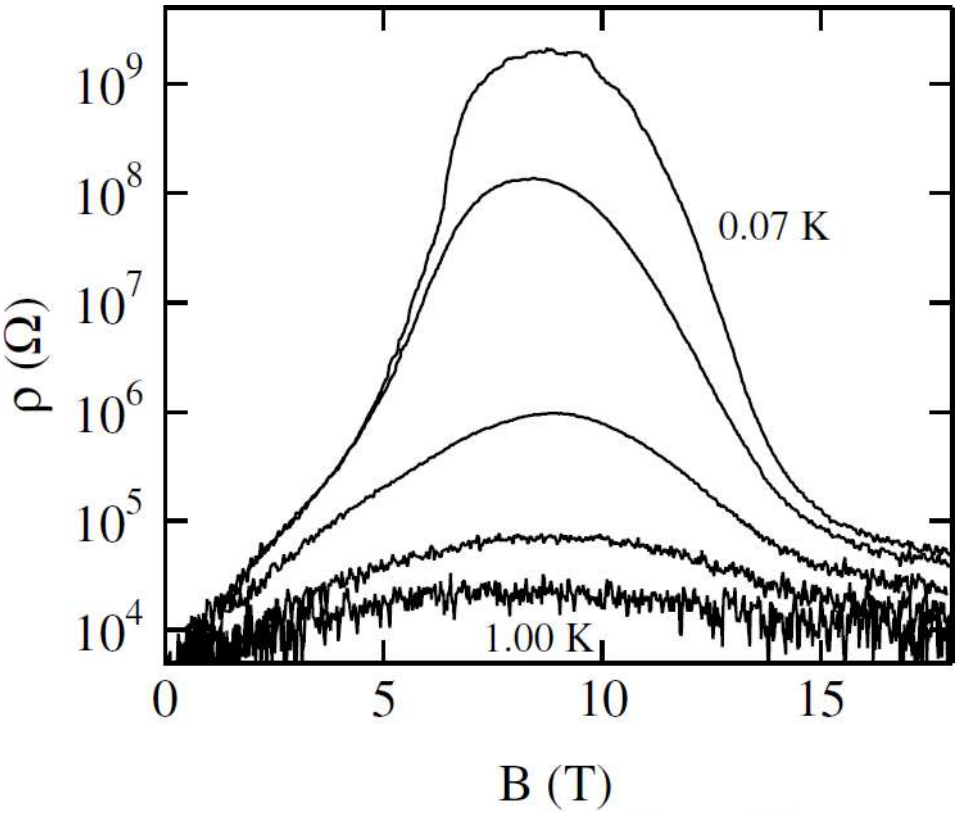
Normal current



Summary & future prospects

- Understood how normal regions emerge in a cylindrical superconductor
- Formalism can address other long-standing experimental questions:

Giant magnetoresistance
[Sambandamurthy 04]



Non-monotonic *RT* curves
[Jaeger 89, Baturina 07]