Science & Technology Facilities Council
ISIS

Muons in superconductors

- What are superconductors
- Measuring magnetic fields
- Extracting key length scales
- Understanding new physics

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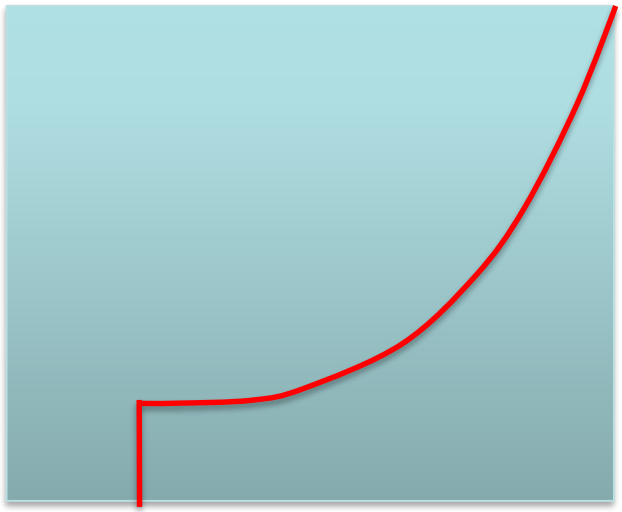
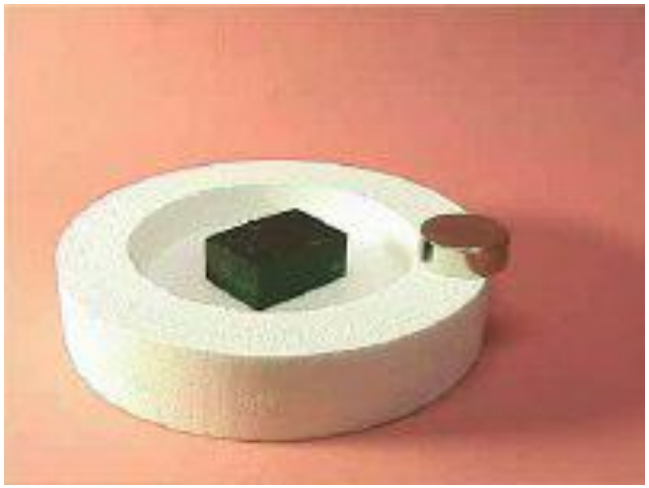
Superconductors

Zero resistance state

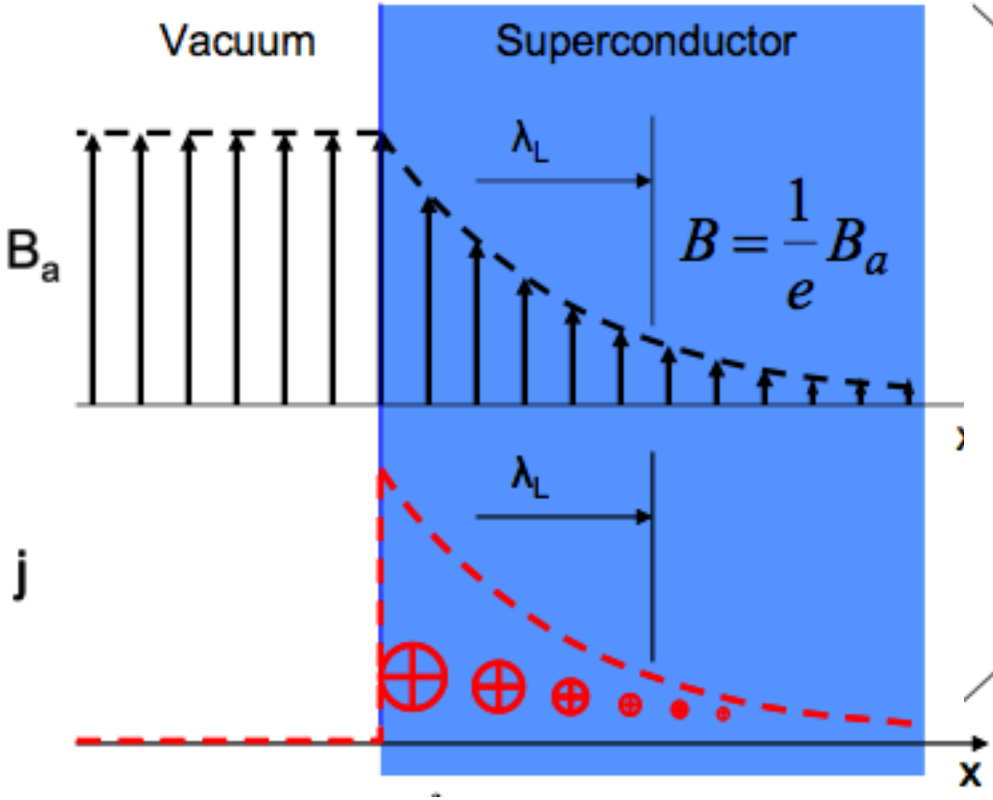


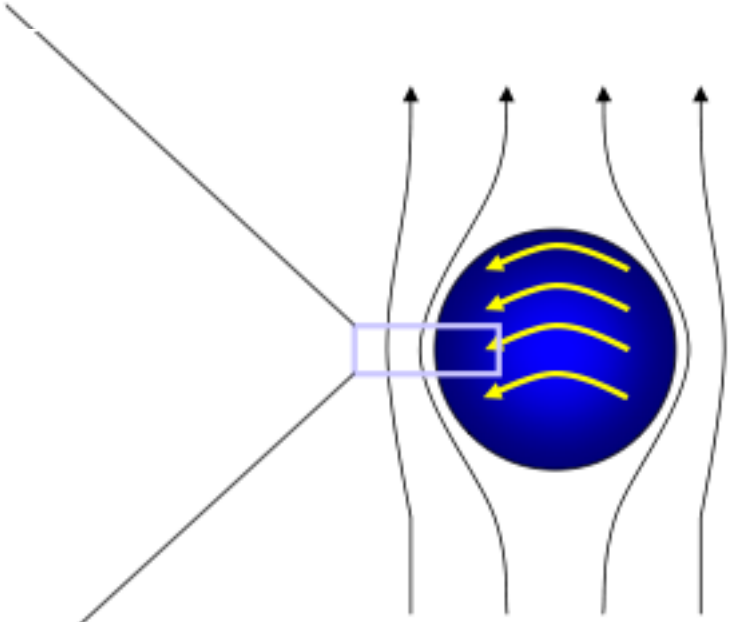
Expels magnetic fields



More than just a perfect conductor

Magnetic Penetration



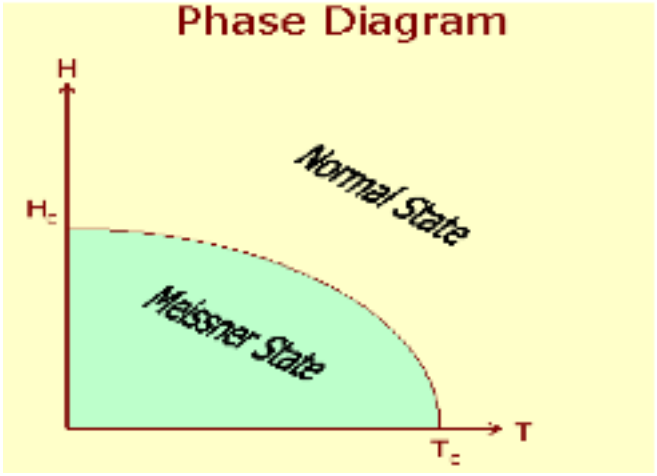


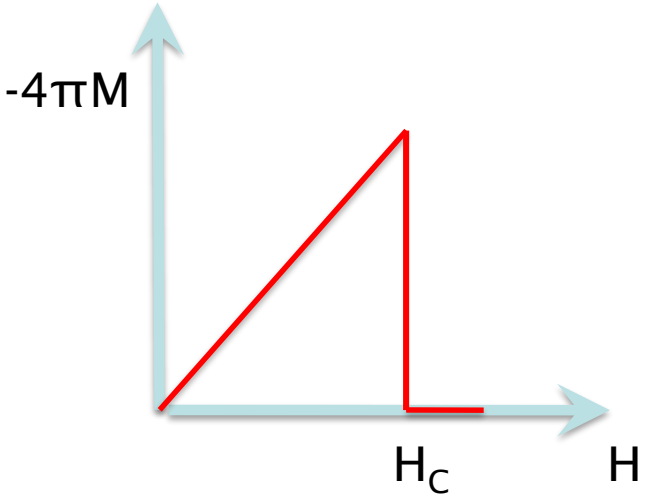
$$\lambda_L^2 \propto \frac{1}{n_s} \qquad B = B_a e^{-x/\lambda_L}$$

Can probe this directly using low energy muon implantation at different depths

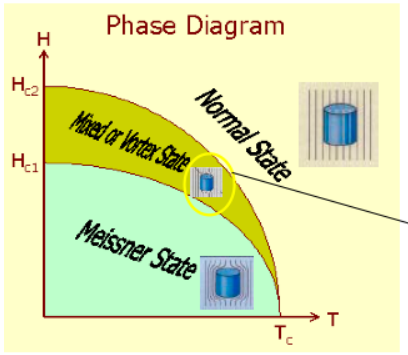
Two Types of Superconductor

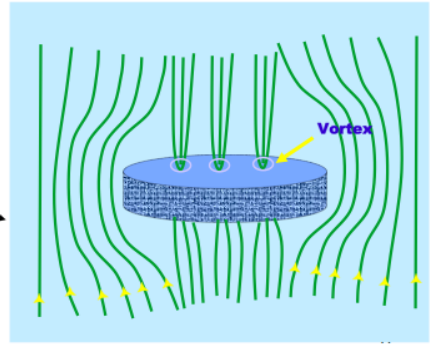
Type I

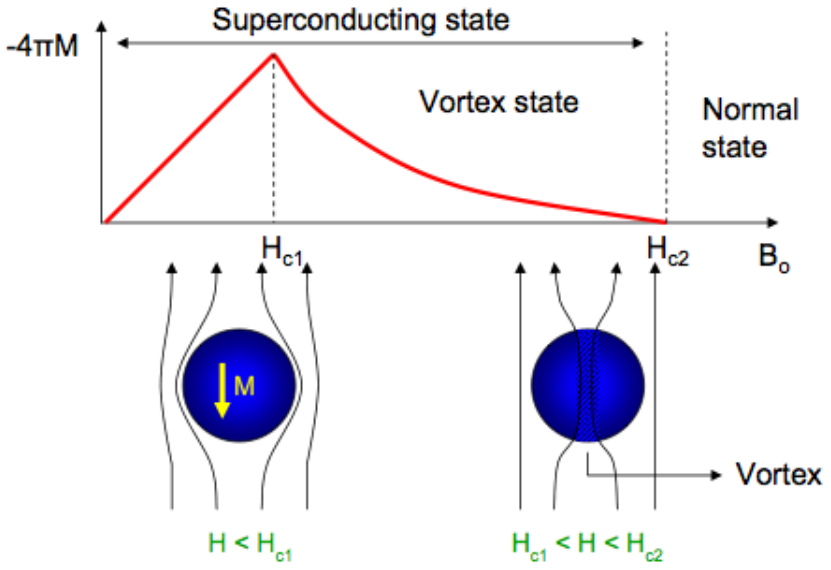




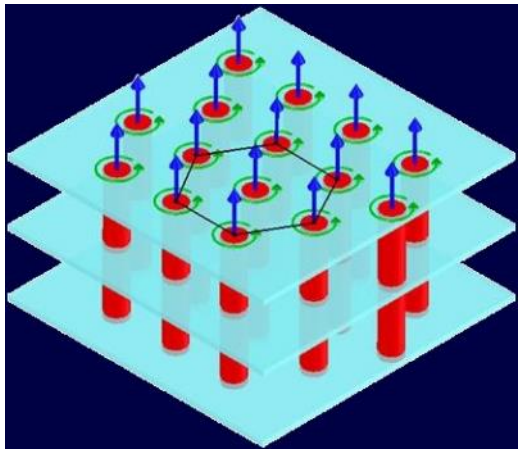
Type II

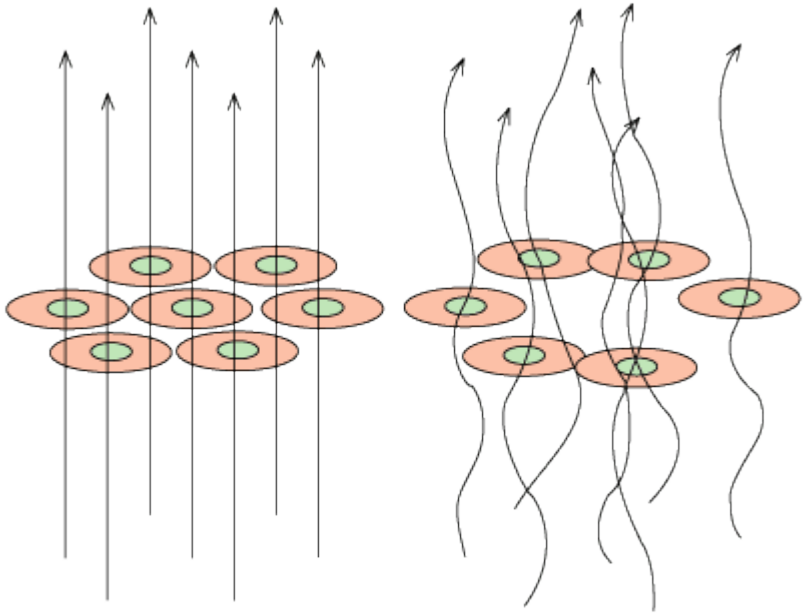


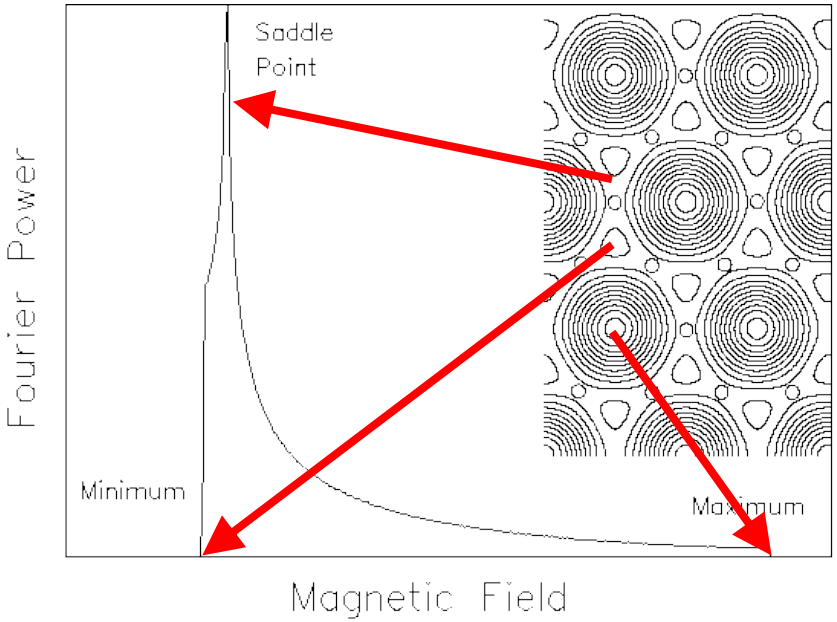




Vortex lattice measurement

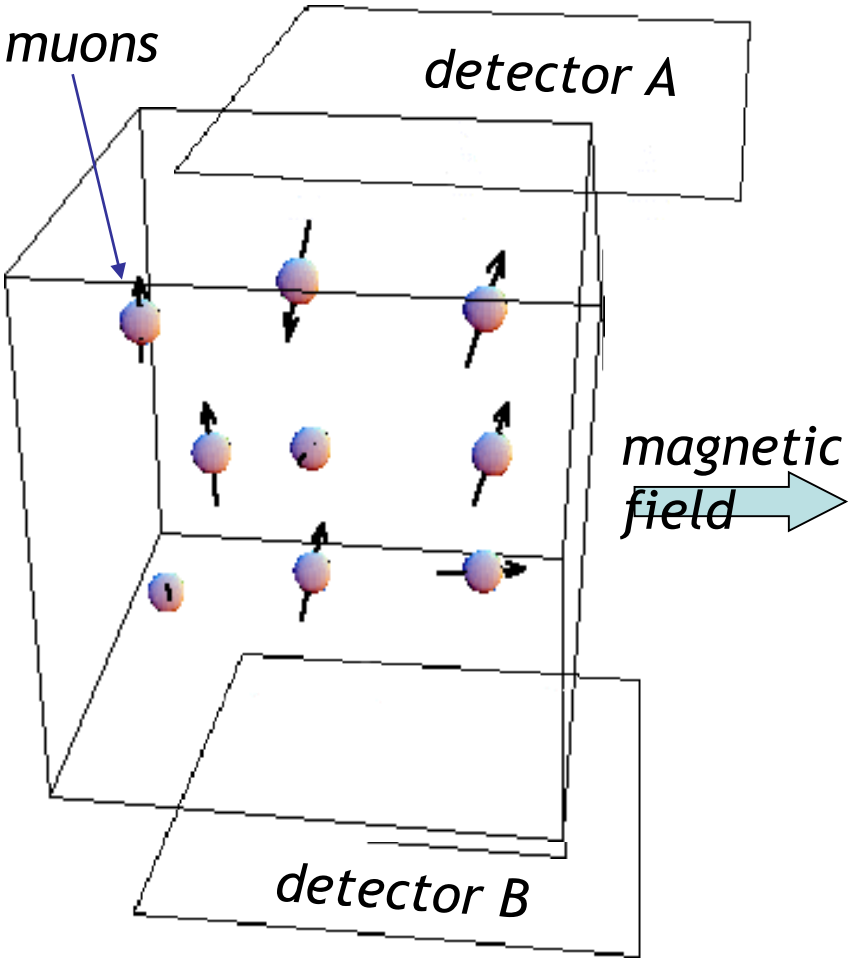




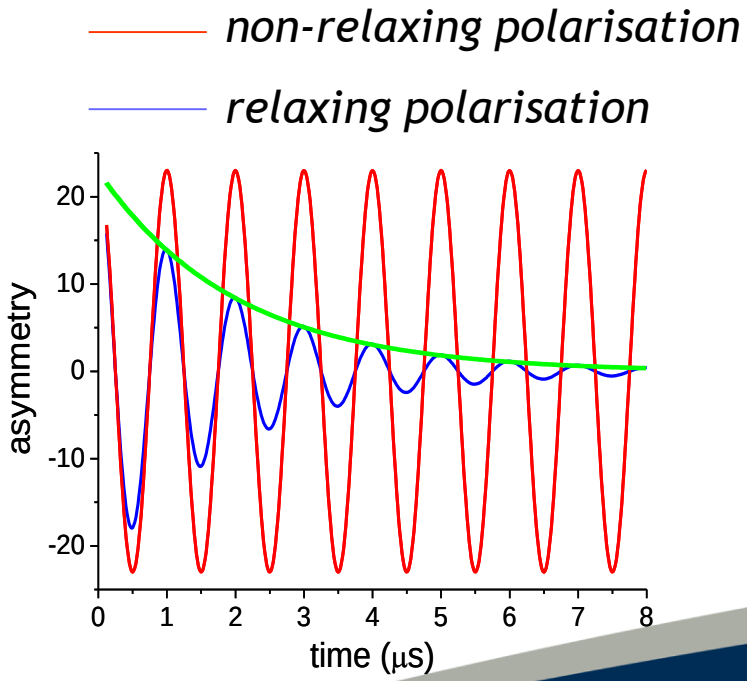


Muons measure a distribution of fields that depends on the penetration depth λ and the coherence length ξ.

How the measurement works

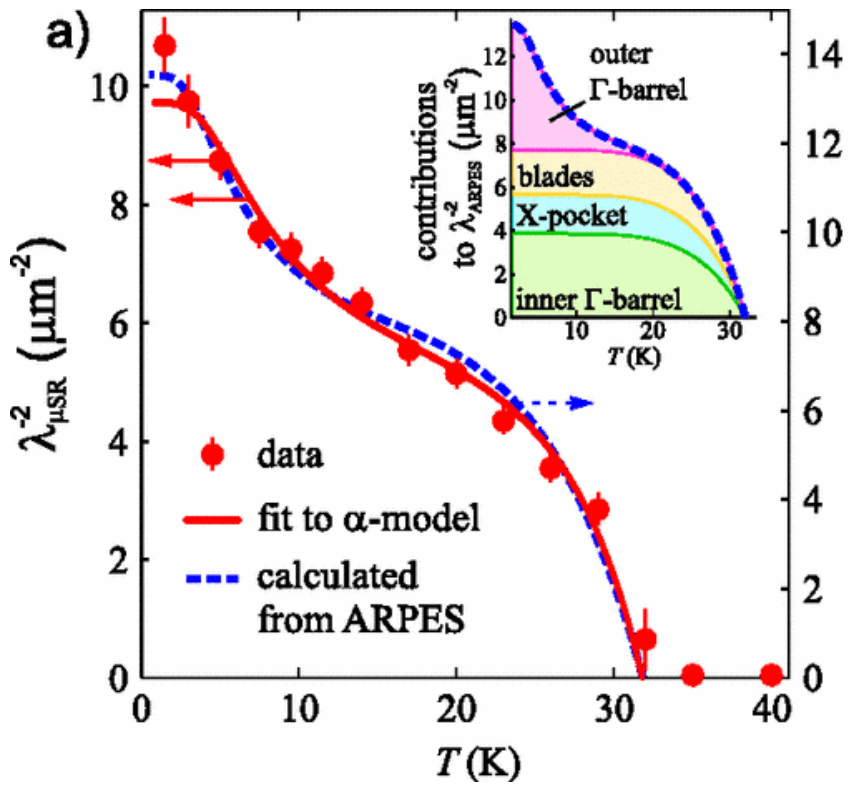


- Compare the field distribution above and below superconducting transition
- Difference is from the vortex lattice field distribution

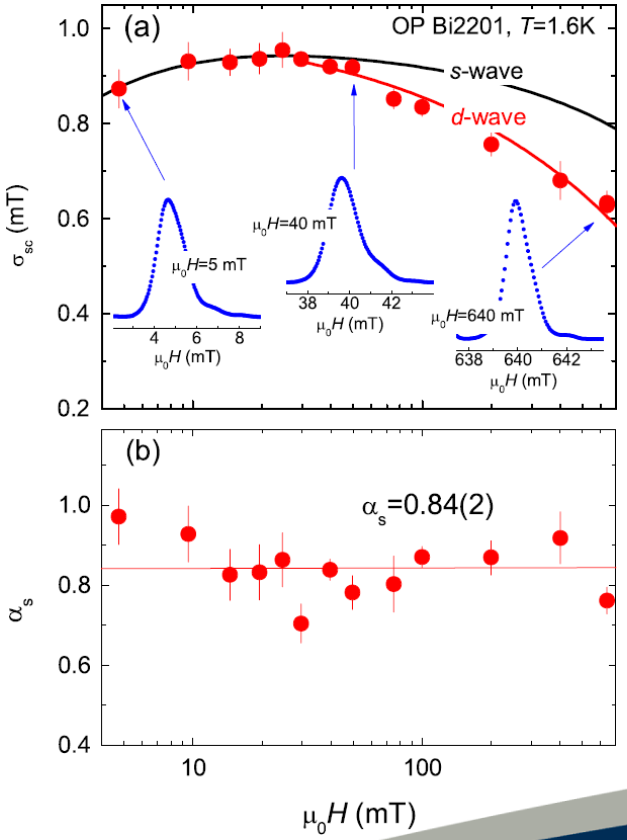


What data do you get?

Temperature dependence



Field dependence



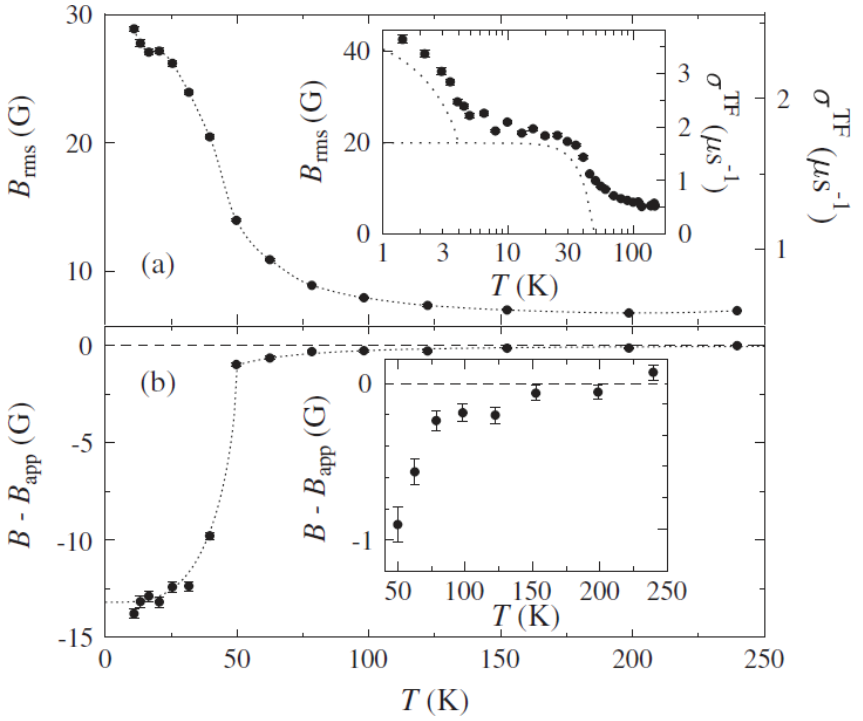
(Ba,K)Fe_2As_2 gives quantitative agreement with electronic band structure

Applications – I

Determining properties of superconductors

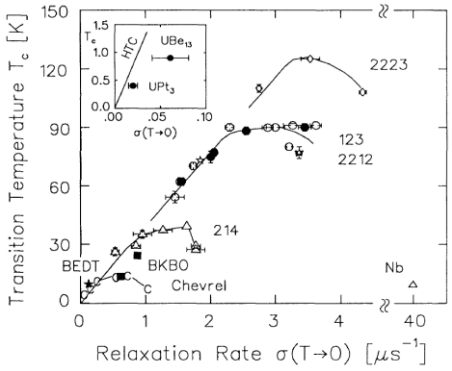
- Penetration depth λ
  - Related to critical current
  - Maximum field without vortex penetration (H_{c1})
- Coherence length ξ
  - Related to maximum superconducting field (H_{c2})
- Structure/symmetry of the superconducting energy gap
  - Gives clues about the interactions driving superconductivity

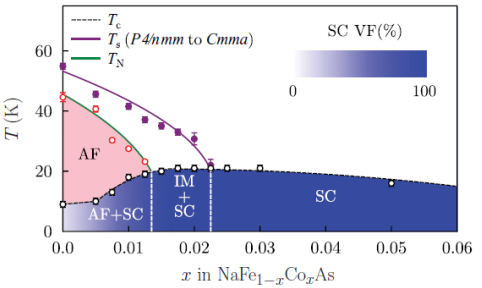
$SmFeAsO_{1-x}F_x$

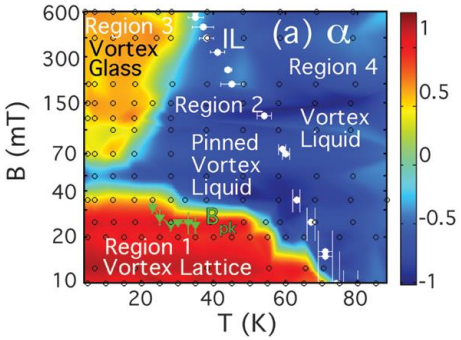


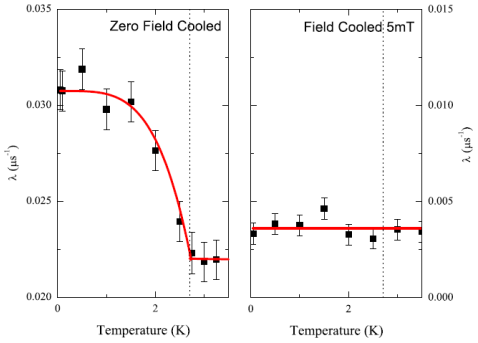
Applications – II

- Finding trends in families of superconductors
  - Uemura plot
  - Phase diagrams for materials
- Understanding the physics of the vortex lattice
  - Vortex liquid and glass states
  - Pancake vortices
- Time-reversal symmetry breaking
  - Measure in zero applied field compensating any external fields
  - Tiny magnetic signal emerges
  - Very hard to measure otherwise









Practicalities

- Measure a sample in 1-2 days
- Field range: 0-60mT (ISIS), <9.5T (PSI)
- Temperature range: Above 0.02K
- Powders or crystals, 20mg < m < 3g