Small-Angle Scattering from Flux Line Lattices

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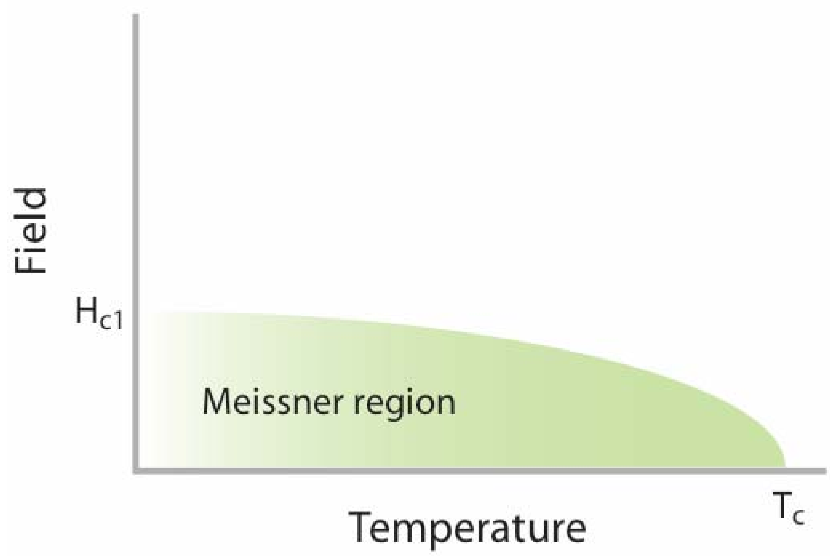
Superconductivity - type I

Phenomenon:

- the existence of a by zero resistance at critical temperature T_c

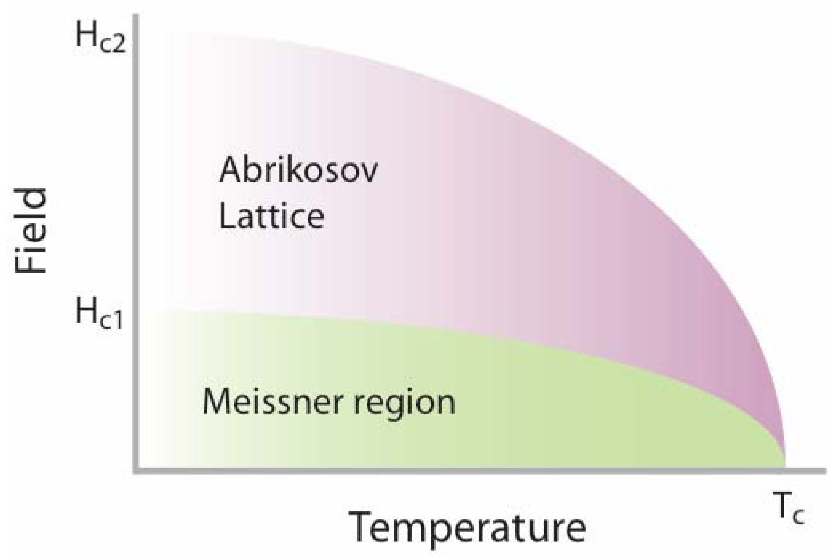
Type-I

- Surface currents exclude applied magnetic field upto a critical field - then becomes normal

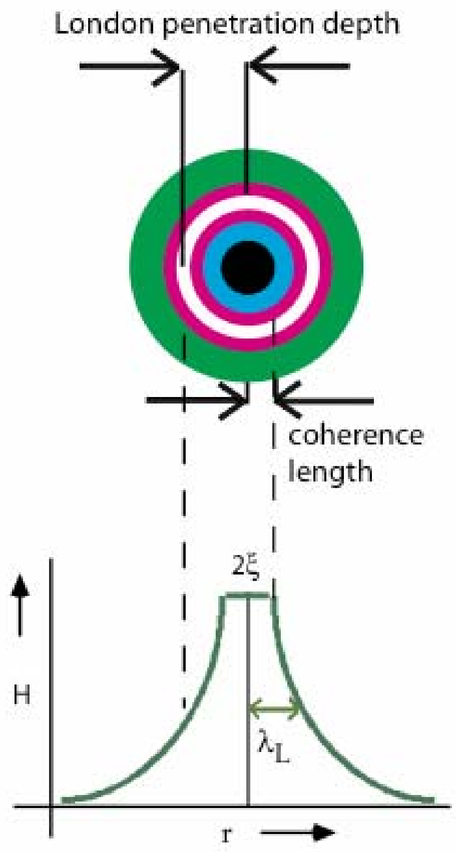


Superconductivity - type II

- Abrikosov predicted
  - the existence of a "mixed" phase where lines of flux penetrate the material above H_{c1}
- Type-II
  - Quantized vortices - each flux quantum has 2.07×10^{-7} Gauss-cm^2



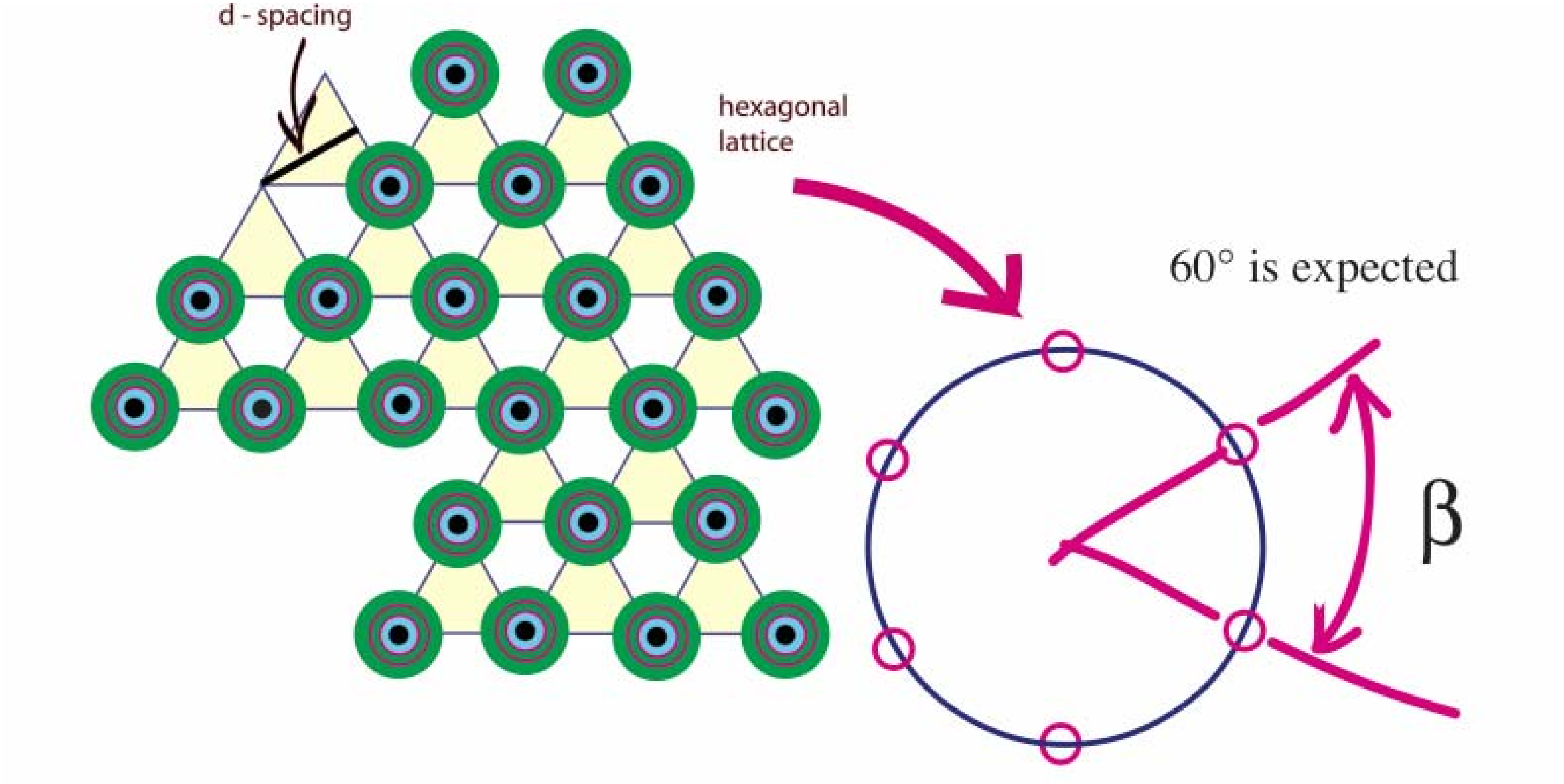
A single flux line



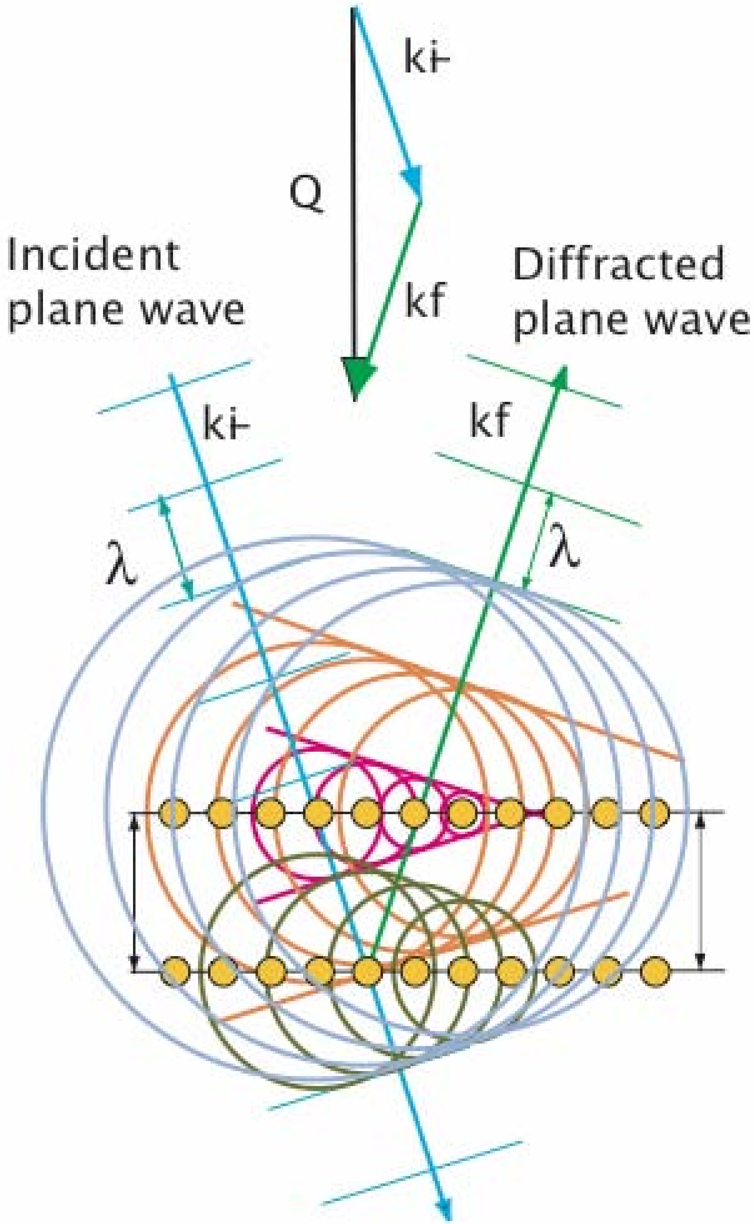
- Magnetic field modulation
- Normal core
- Supercurrents around this core
- Length scales of interest

  λ and ξ

Vortices repel each other - repulsion causes them to form arrays to maximize the distance between the vortices



alignment - vortex lattices or Abrikosov lattices => Bragg diffraction!



Bragg Scattering

For periodic arrays of nuclei, coherent scattering is reinforced only in specific directions corresponding to the Bragg condition:

$$2d \sin \theta = n \lambda$$

How to measure this…

- At a field of 1Tesla, vortices are roughly 450Å apart
- $d^2 = \Phi_0/B$ since each flux line carries one quantum of flux

  Φ_0 is the flux quantum

  B is the applied field

  d=lattice spacing (square arrangement)

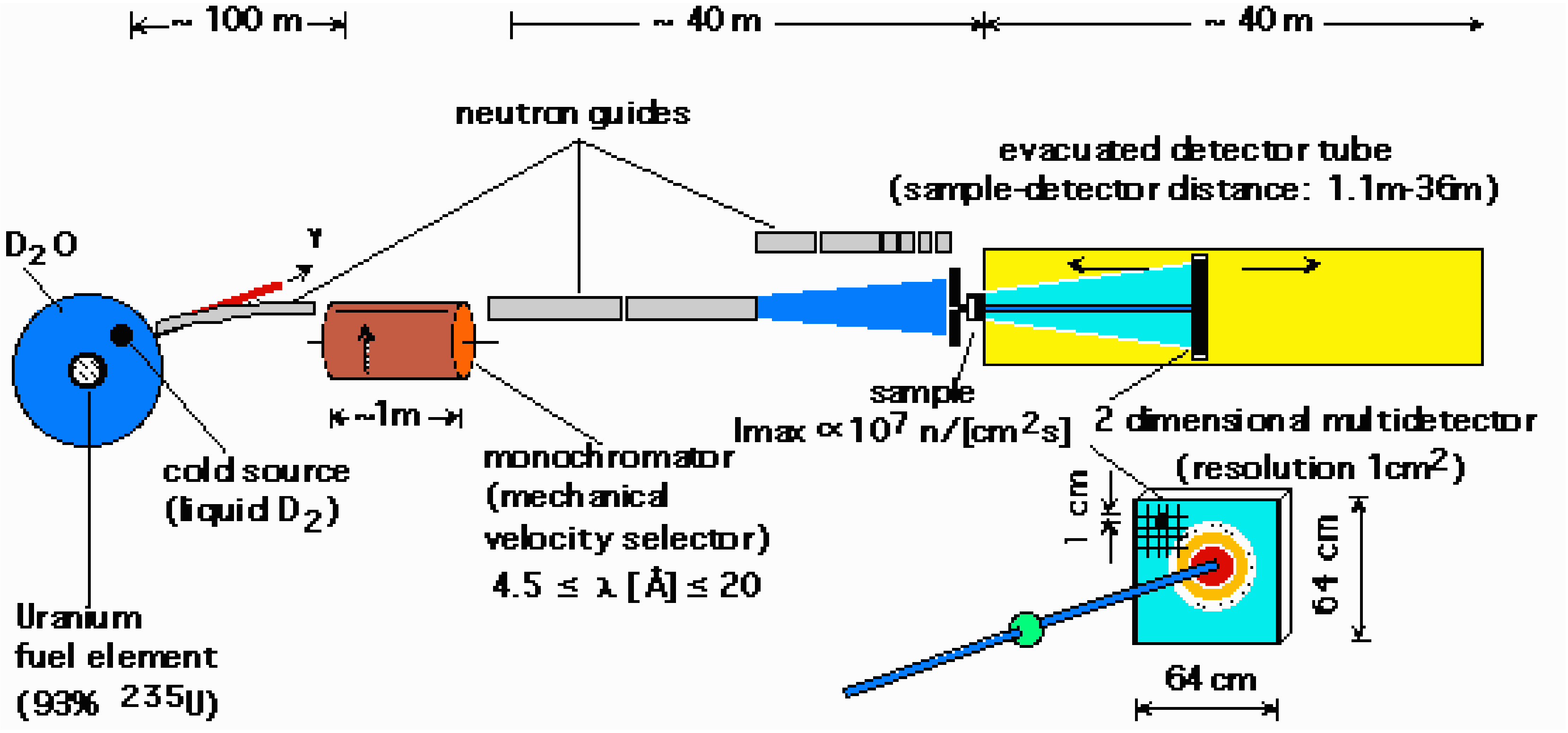
- Bragg's law $2d \sin \theta = \lambda$

  (θ = Bragg angle; λ=neutron wavelength)

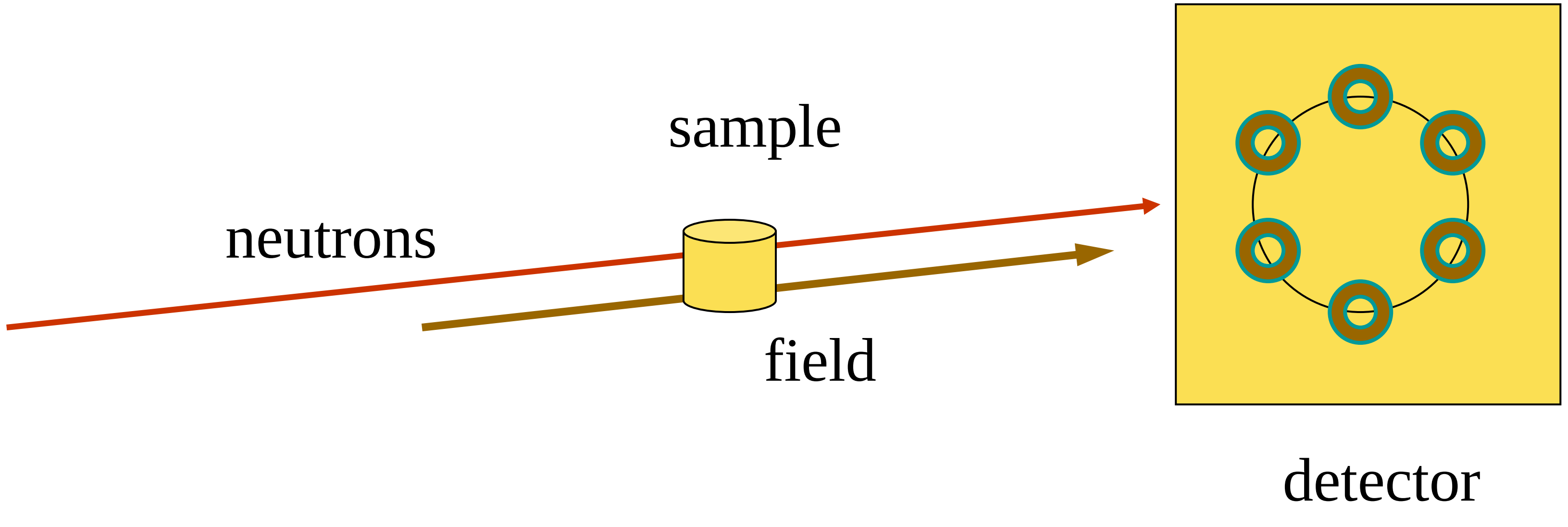
- Bragg scattering observed at small angles - SANS!

- PS Neutrons can see magnetic contrast

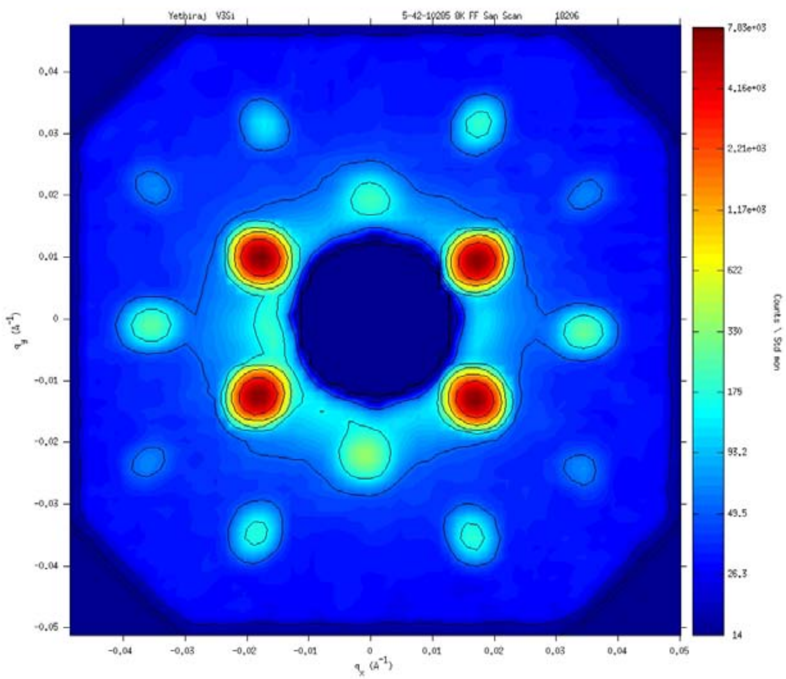
SANS instrument schematic



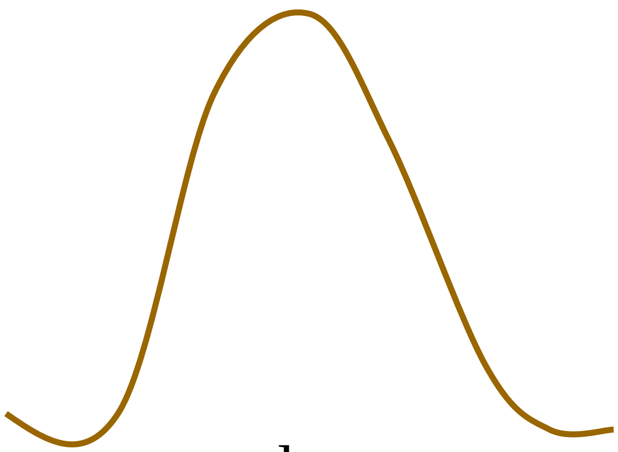
Field parallel to neutrons



Observed flux lattice with B (=2T) parallel to 110 in V_3Si



Sum over rocking curve

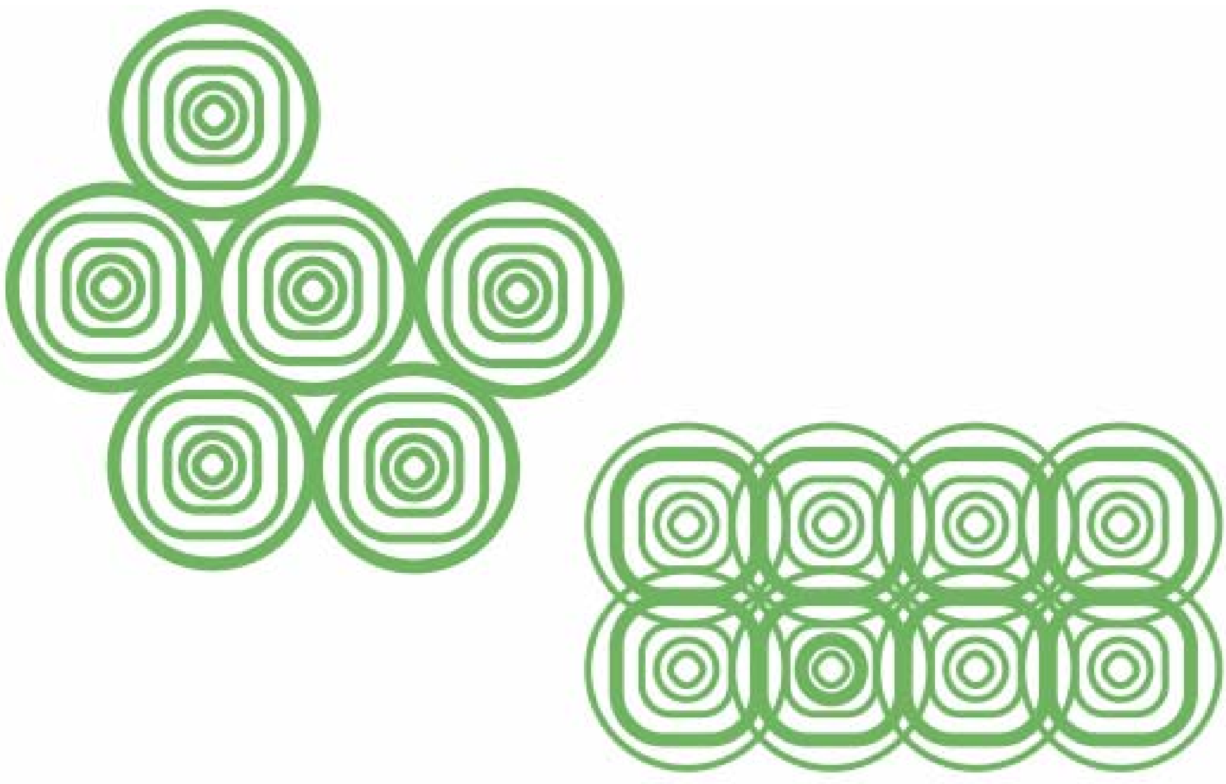


angle →

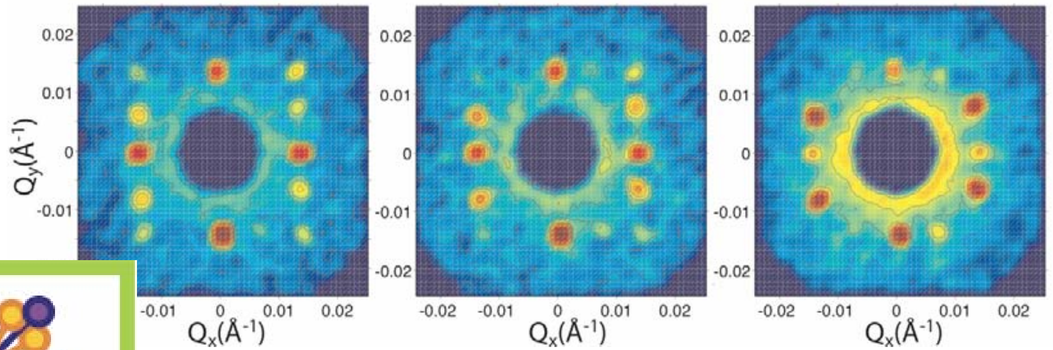
Long flux lines => no width to the bragg spot in q_z

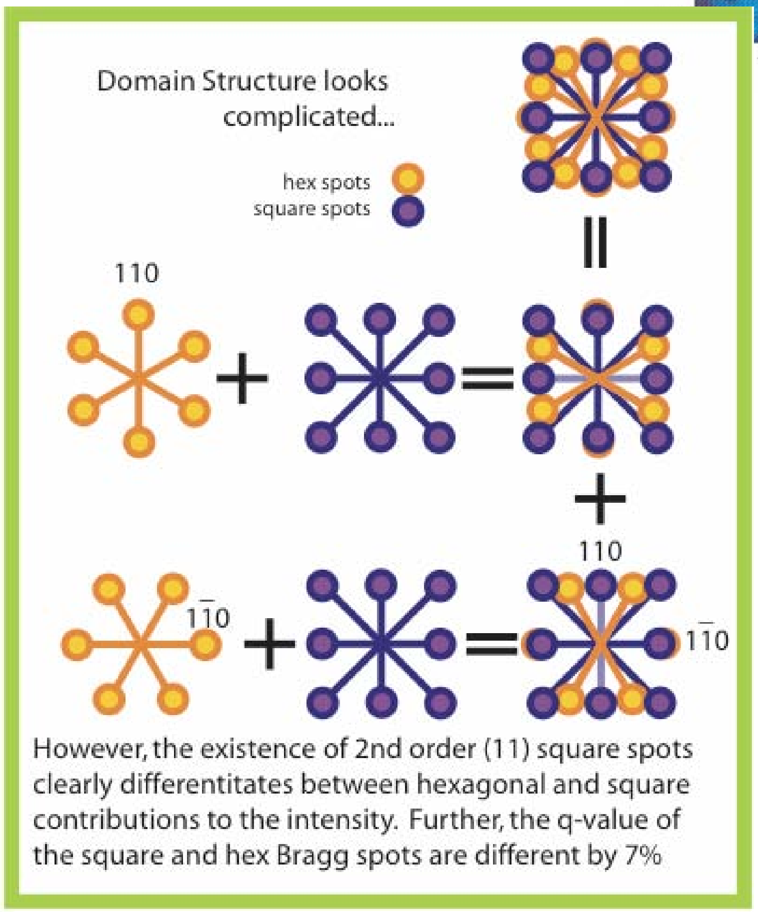
Why do square flux lattices exist?

The lattice symmetry can change as a function of field (and hence distance between vortices)



V3Si: B//001

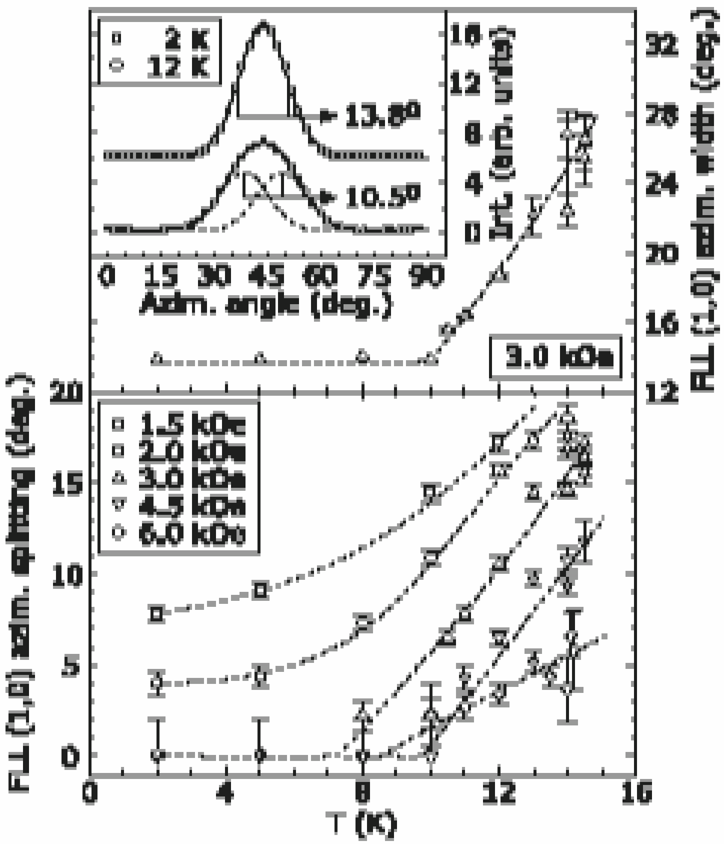


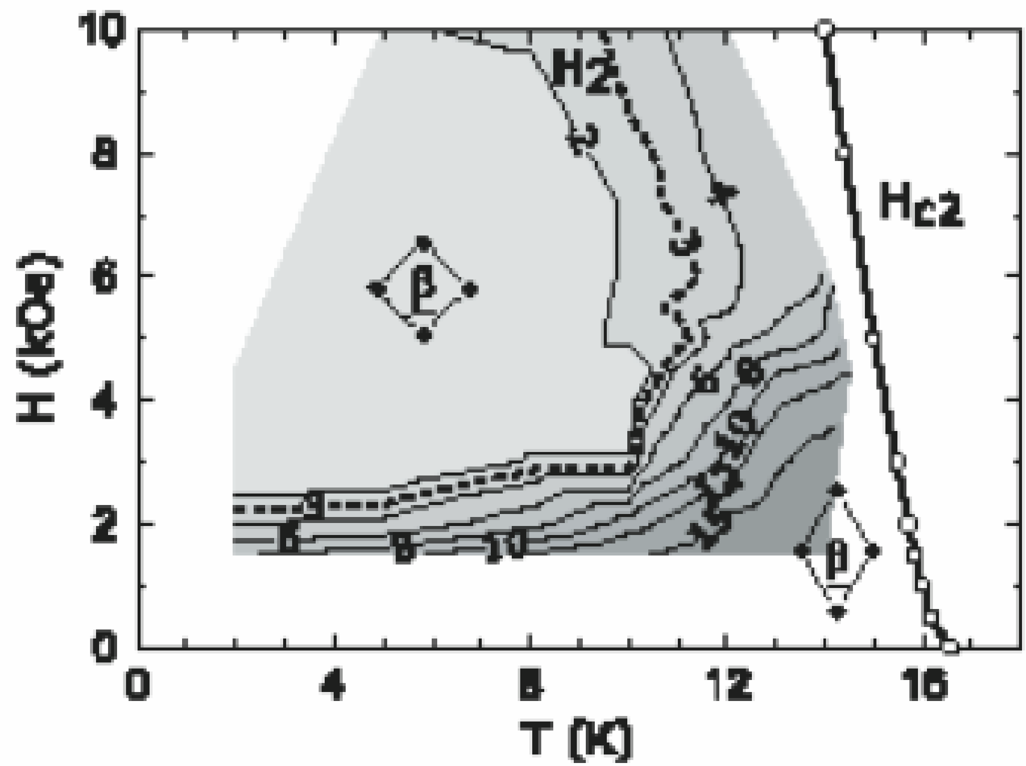


The square lattice at low temperature transforms to a triangular lattice as the sample is warmed at constant field.

2nd order spots have 1/5 the intensity as the 1st order (square lattice)

In $LuBi_2B_2C$, a possible broadening was observed - Eskildsen et. al, PRL 86, 5148 (2001)



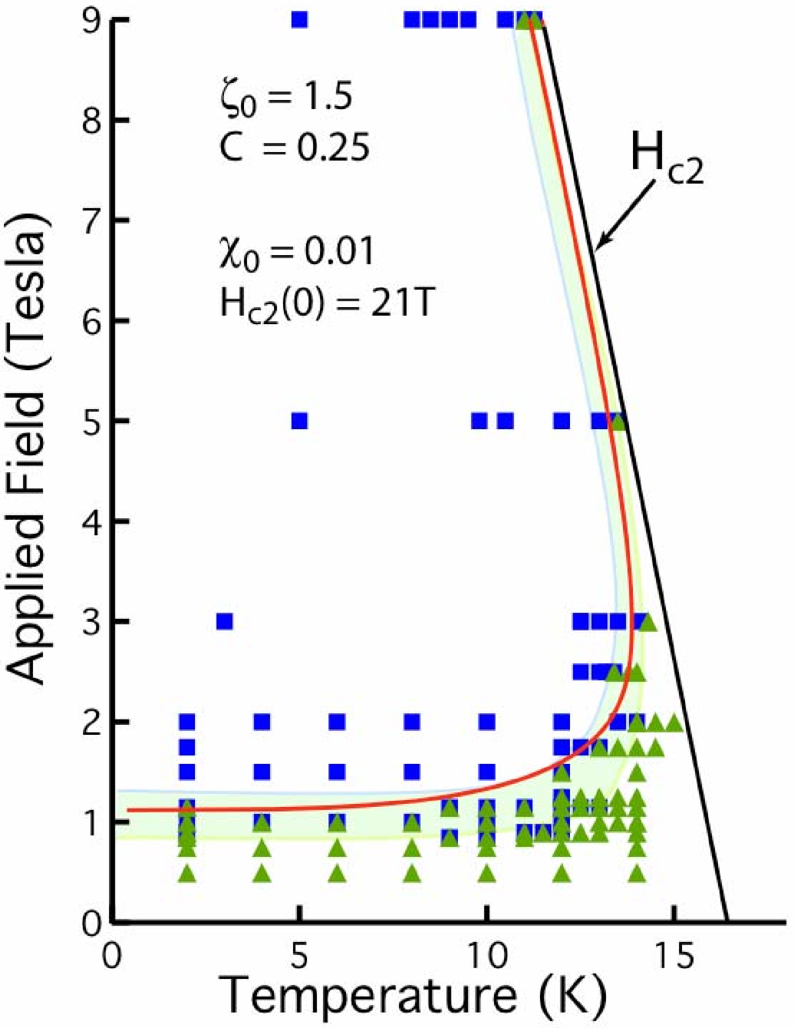


Phase Diagram with B//001

At low fields, the FLL has 6-fold symmetry. As the field is increased the lattice transforms to a square one.

As the temperature (hence coherence length) is increased, the square symmetry reverts back to hexagonal.

Gurevich and Kogan PRL 87 177009 (2001) - Thermal vortex fluctuations



Conclusions

- SANS is the best way to study bulk properties of a vortex lattice – μSR; STM, decoration surface probes

- Flux Lattice Symmetry always reflects underlying lattice symmetry

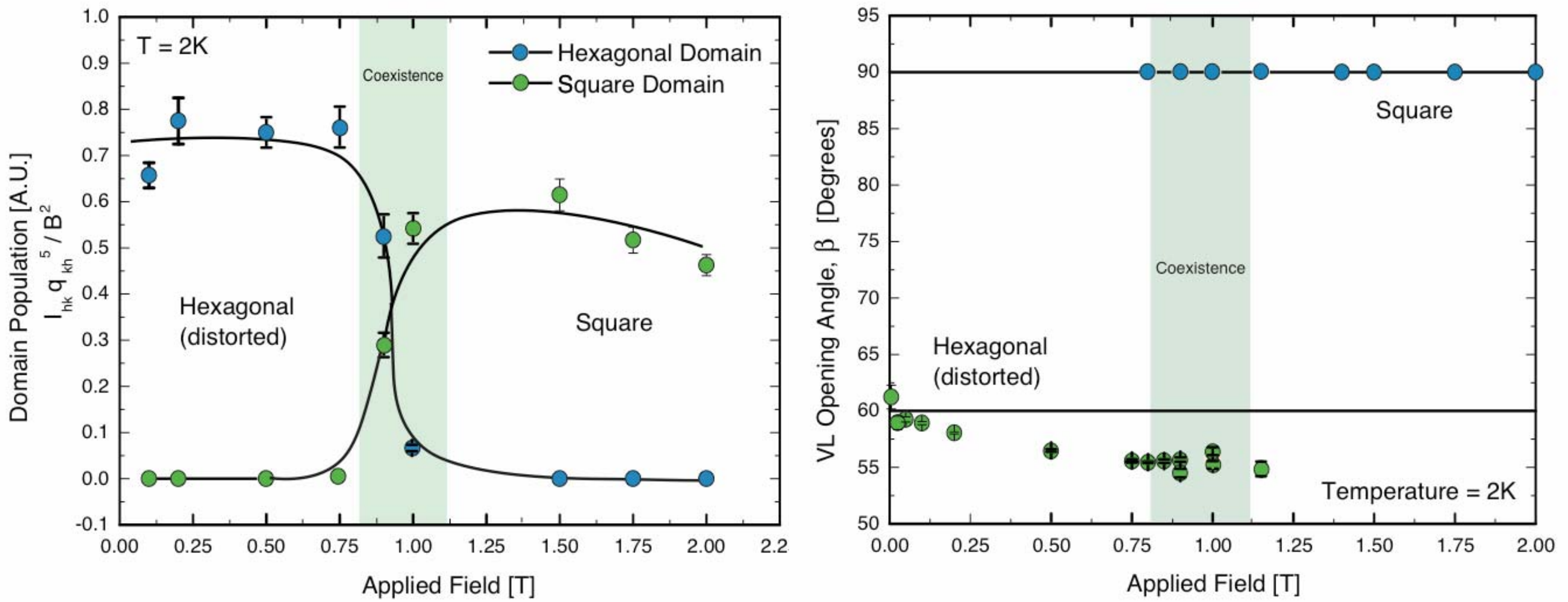
- Mass Anisotropy
  - Temperature-independent
  - Field-independent

- Fermi Surface Anisotropy

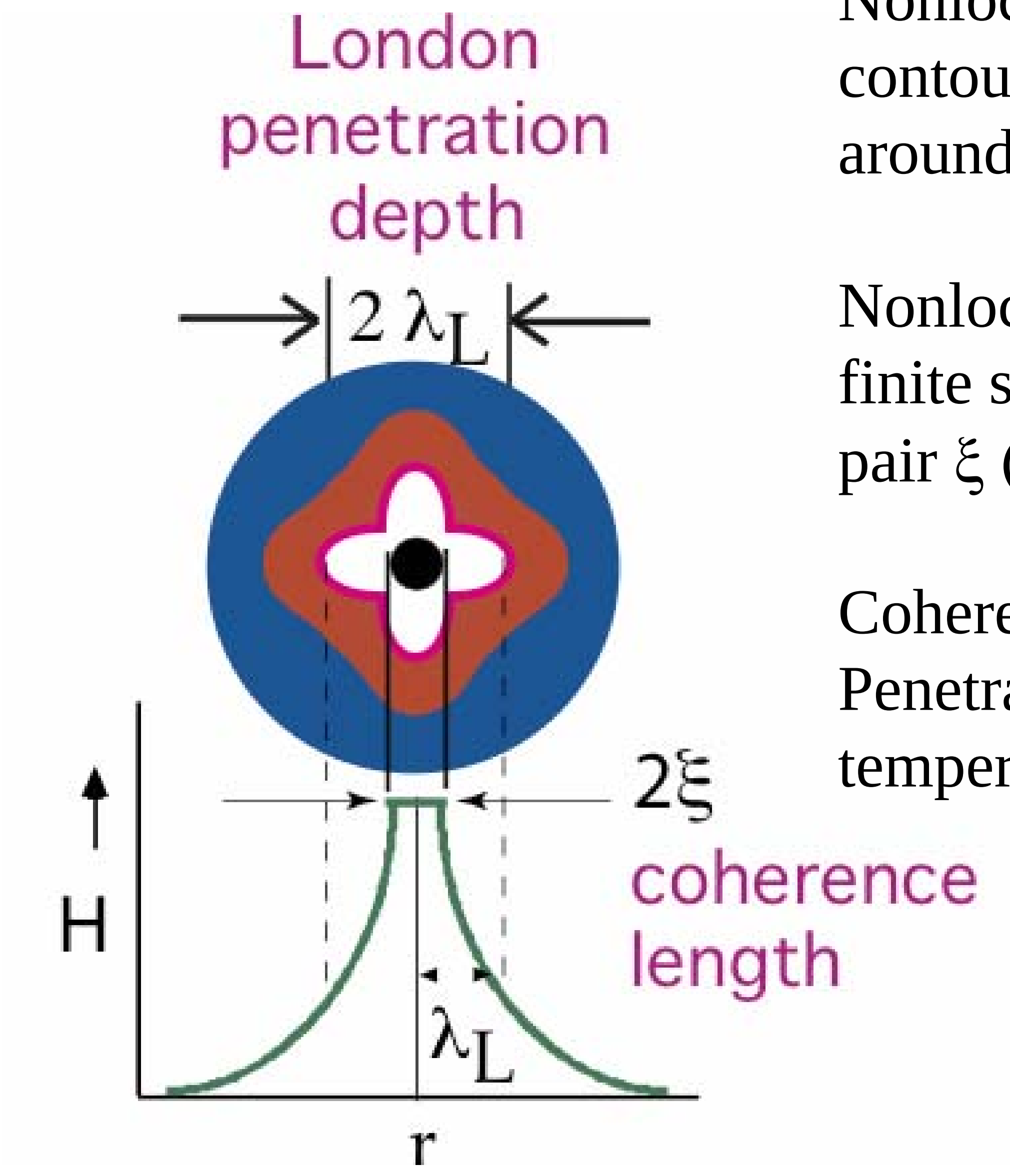
  Temperature-dependent

  Field-dependent

Field and Temperature Dependence



The opening angle departs from 60° as the field is increased till the lattice transforms to one with square symmetry. The region of coexistence and lack of any continuous structural evolution suggests a first order transition.



Nonlocal case: equal field contours are not circular around the core of the flux line

Nonlocality: Effects of the finite spatial extent of a Cooper pair ξ (coherence length)

Coherence length and Penetration depth diverge as temperature approaches T_c