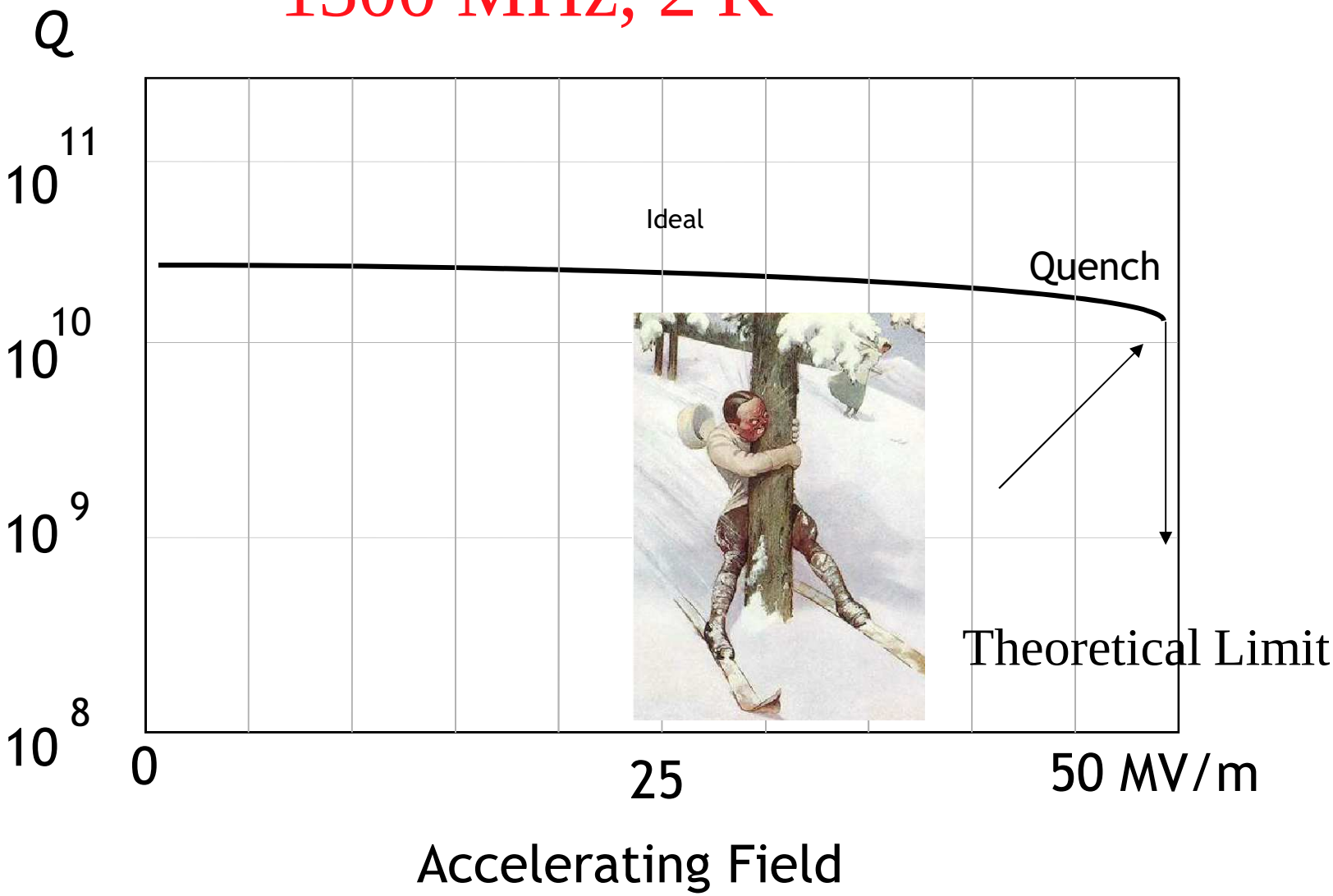
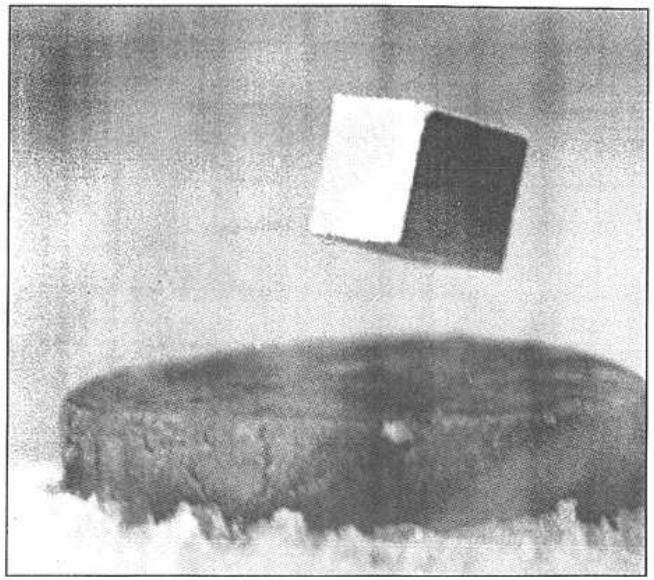
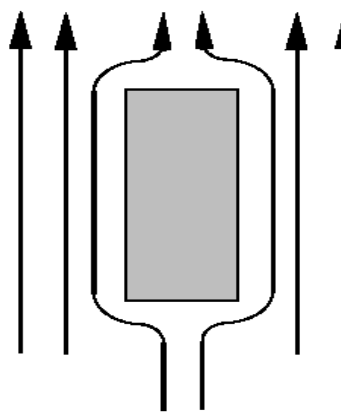
Ideal SC Cavity Behavior
1300 MHz, 2 K

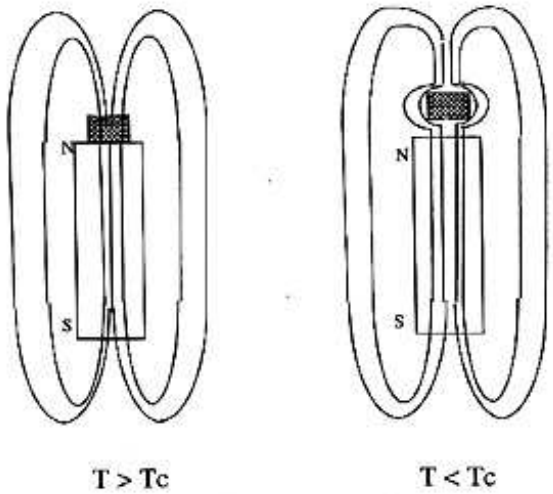


2nd Hallmark of SC - Meissner Effect

- Magnetic fields are screened by surface currents in the SC → perfect diamagnetism
- SC goes normal conducting when the energy needed for shielding exceeds that gained by being superconducting.

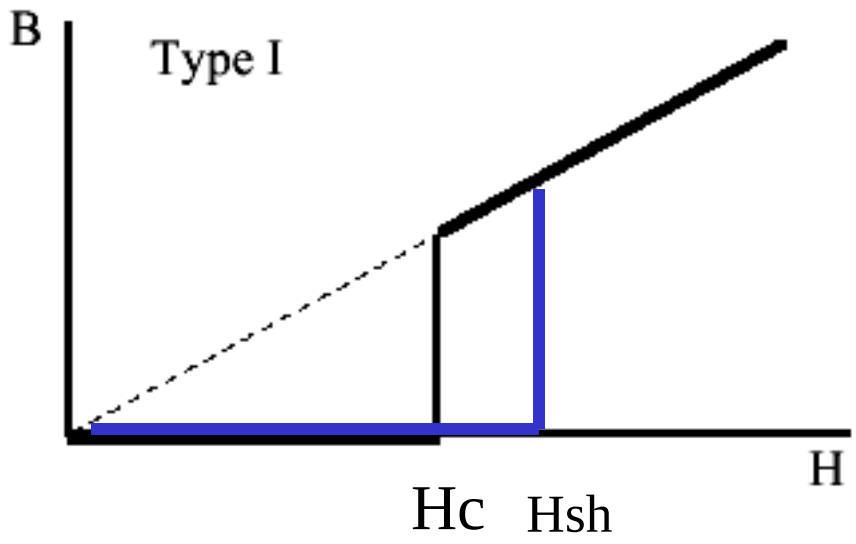


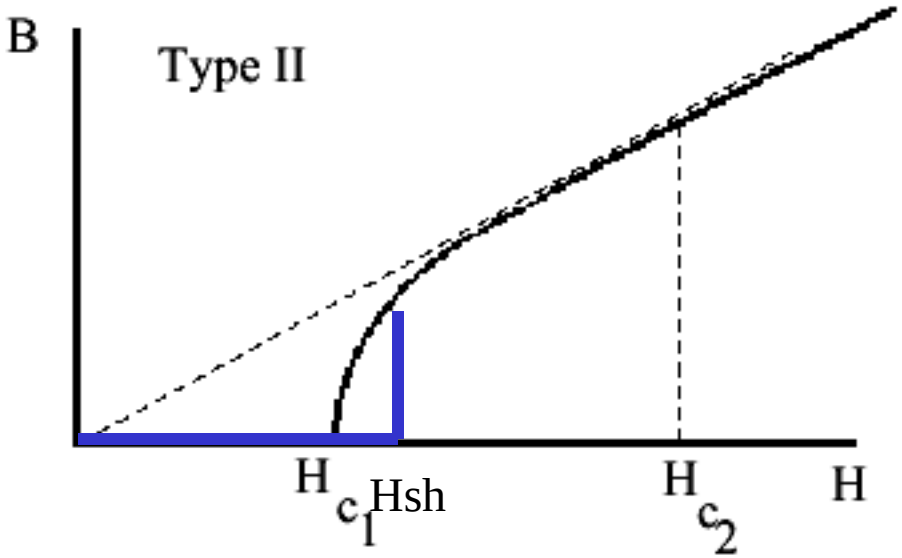


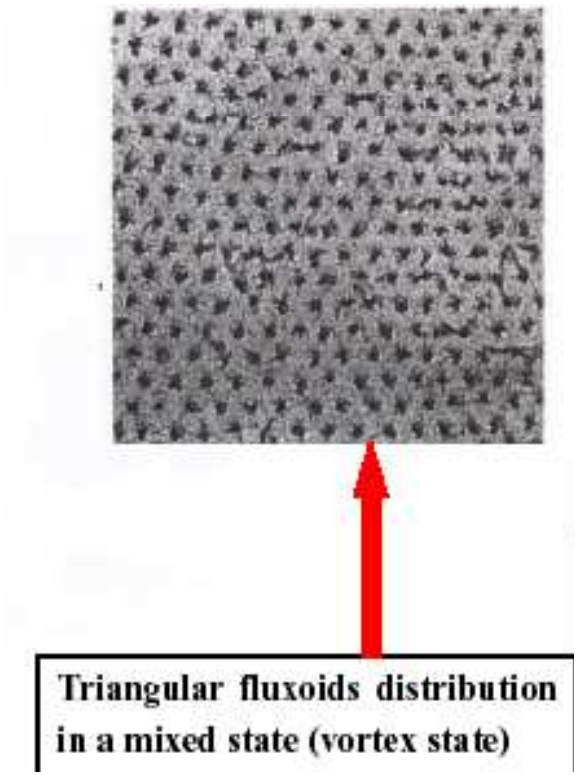


Levitation by Meissner Effect

DC Critical Magnetic fields







Critical Fields

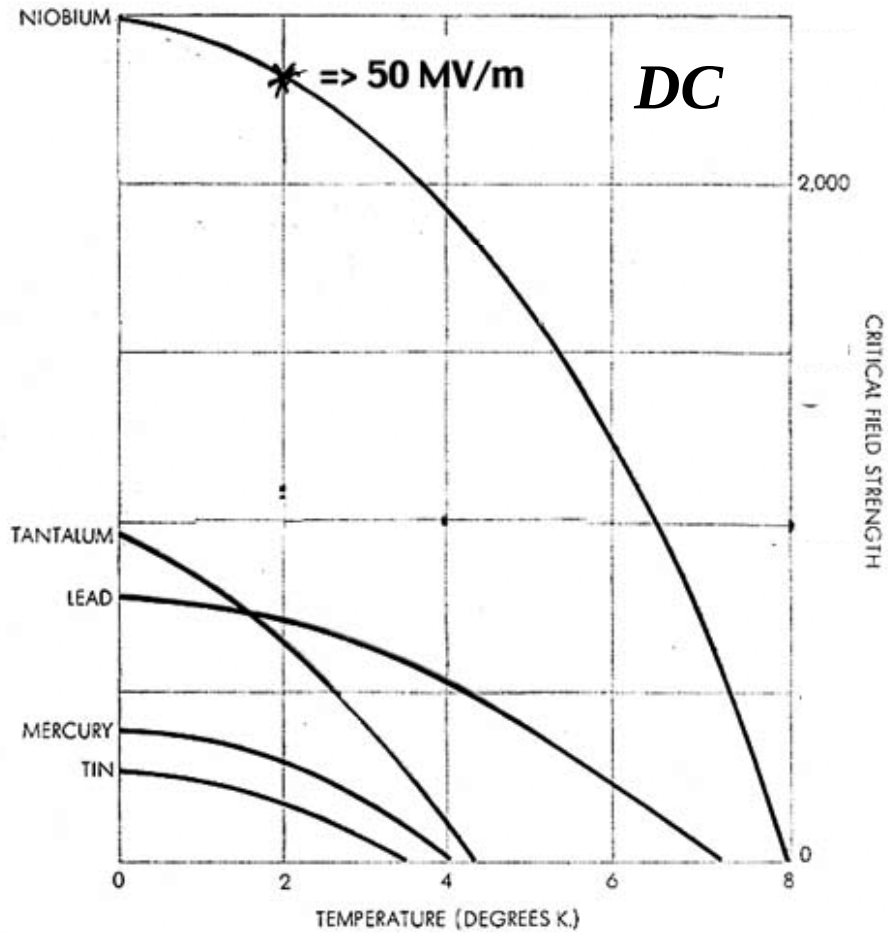
- Superconductors only remain in the superconducting state if the applied field is less than the critical magnetic field H_c (2000 Oe for Nb)
- But! Phase transition requires some time (1 μs?) to nucleate sc-nc transition.
- → For RF can exceed H_c *or Hc1* up to the superheating field.

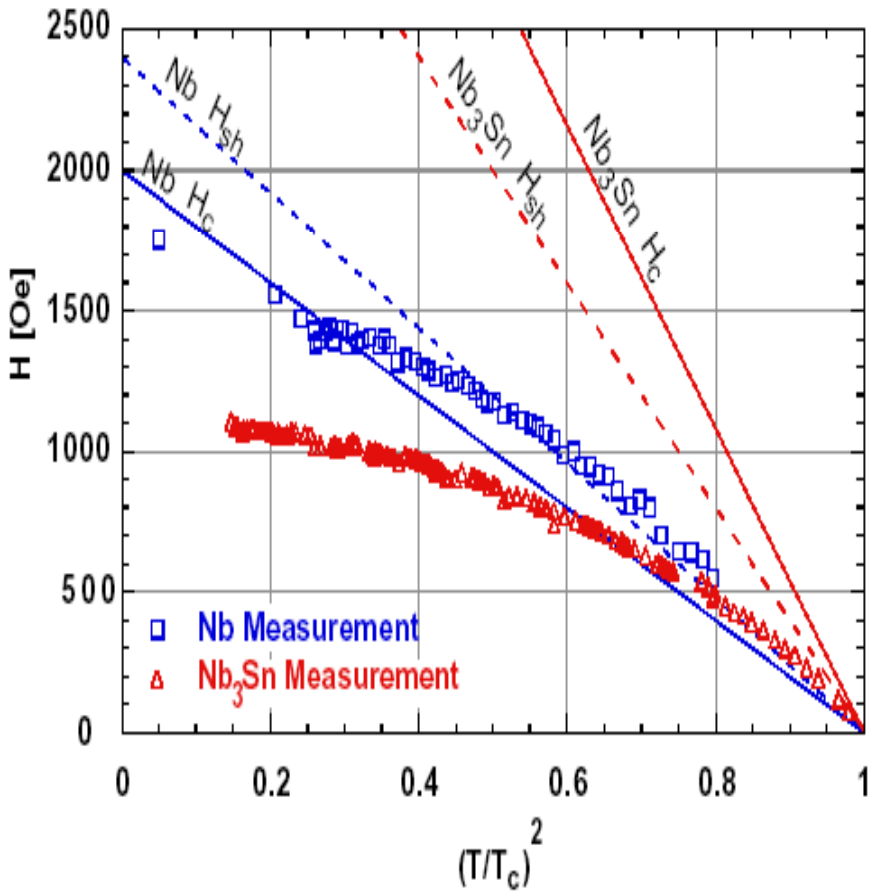
For typical $v = c$ cavities this is achieved at an accelerating field of $E_{acc} \approx 50$ MV/m.

DC/RF Critical Field for Superconductors

Superconductors only remain in the superconducting state if the applied field is less than the critical magnetic field H_c (2000 Oe for Nb)

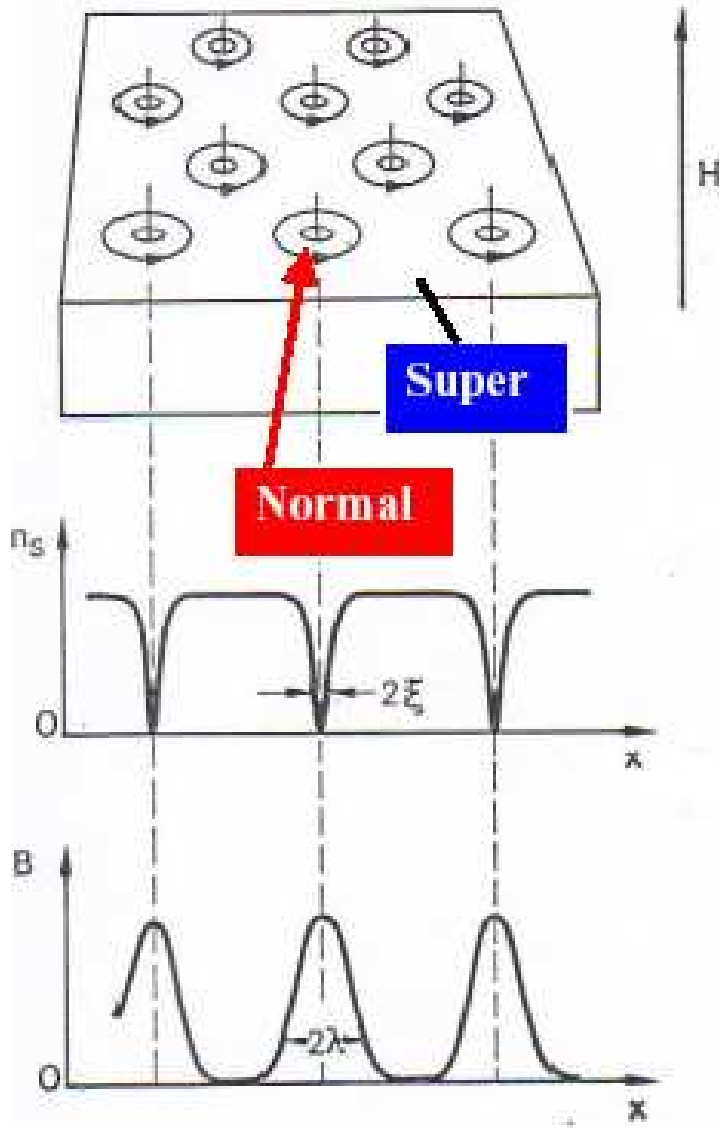
→ For RF can exceed H_c up to the superheating field.



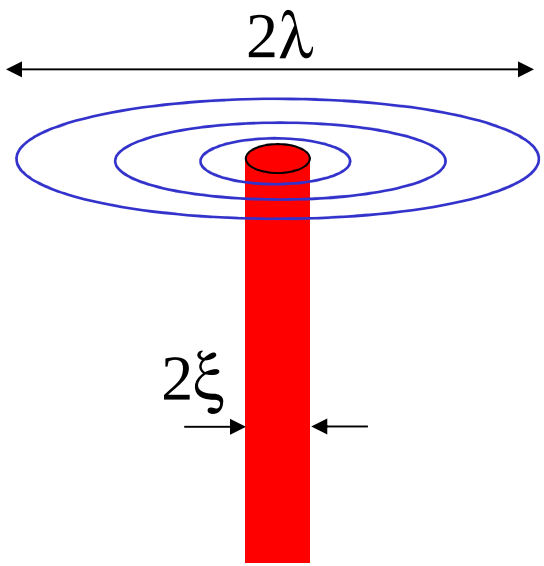


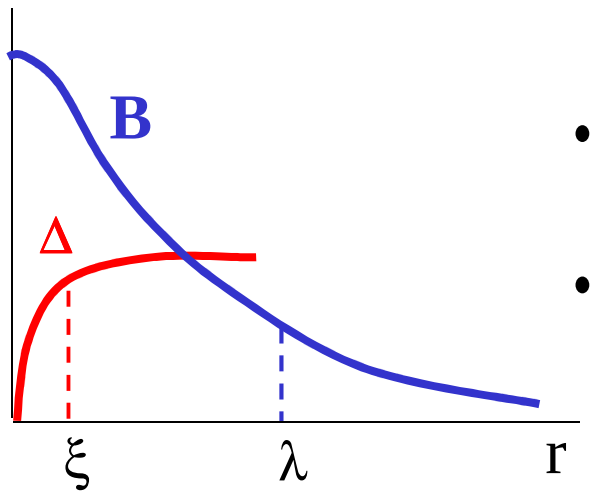
Mixed State, When Flux Enters

Triangular fluxoids distribution in a mixed state (vortex state)



Single vortex line





- Small core region $r < \xi$ where $\Delta(r)$ is suppressed
- Region of circulating supercurrents, $r < \lambda$.
- Each vortex carries the flux quantum ϕ_0

Ginzburg Landau Parameter

$$\kappa = \lambda/\xi$$

Important lengths and fields

- Coherence length ξ and magnetic (London) penetration depth λ

$$B_{c1} = \frac{\phi_0}{2\pi\lambda^2}\left(\ln\frac{\lambda}{\xi} + 0.5\right), \qquad B_c = \frac{\phi_0}{2\sqrt{2}\pi\lambda\xi}, \qquad B_{c2} = \frac{\phi_0}{2\pi\xi^2}$$

Type-II superconductors: $\lambda/\xi > 1/\sqrt{2}$: For clean Nb, $\lambda \approx 40$ nm, $\xi \approx 38$ nm

Vortex line nucleation model (VLNM)

Vacuum

$$\frac{1}{2}\mu H^2\lambda^2 - \frac{1}{2}\mu H_c^2\xi^2 = 0$$

$$H_c^{Line} = \frac{\xi}{\lambda}H_c = \frac{H_c}{\kappa}$$

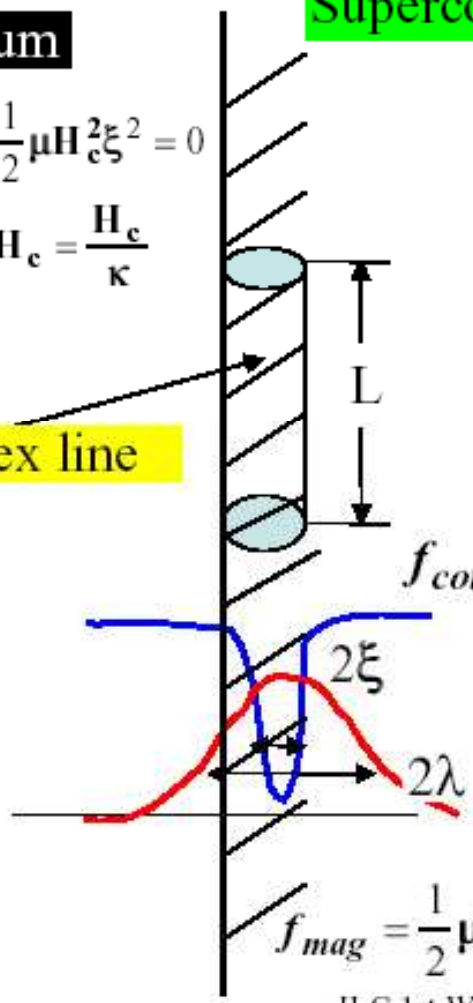
Superconductor

Effective field strength in AC application

$$H_c^{Line}(T) = \frac{\xi(T)}{\lambda(T)}\cdot\sqrt{2}H_c(T)$$

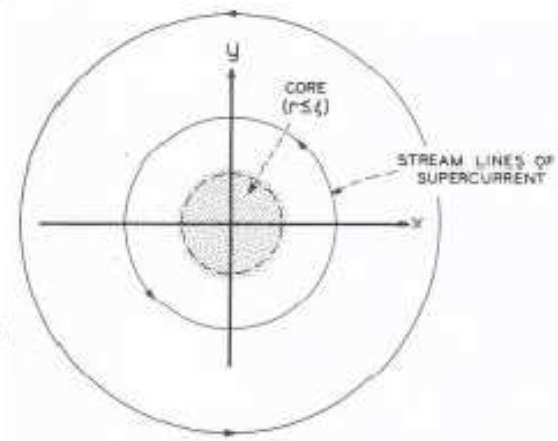
$$= \frac{\sqrt{2}H_c(T)}{\kappa(T)}$$

$$= \sqrt{2}\frac{H_c(0)}{\kappa(0)}\cdot\left[1-\left(\frac{T}{T_c}\right)^4\right]$$



$$f_{core} = -\frac{1}{2}\mu H_c^2(\pi\xi^2)\cdot L$$

$$f_{mag} = \frac{1}{2}\mu H^2(\pi\lambda)^2\cdot L$$



Theoretical RF Electric Field

- No known theoretical limit
- In SC test cavities, SC survives up to
  - Epk = Pulsed 220 MV/m
  - 145 MV/m CW over cm^2 area
- Single cell 1300 MHz accelerator cavity to Epk > 100 MV/m, CW