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MINIWORKSHOP ON STRONG ELECTRON CORRELATIONS
"Disorder and Interaction in Quantum Systems and Their Classical Analogs"

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"Columnar Defects as a Probe of the Vortex Liquid in YBa_2Cu_3O"

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These are preliminary lecture notes, intended only for distribution to participants.

Columnar Defects as a Probe of the Vortex Liquid in YBa_2Cu_3O

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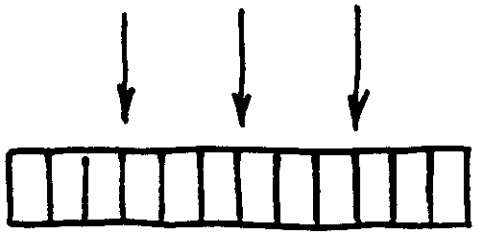
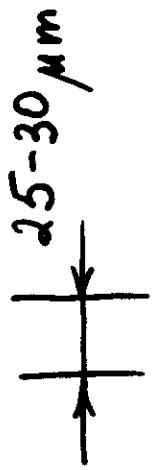
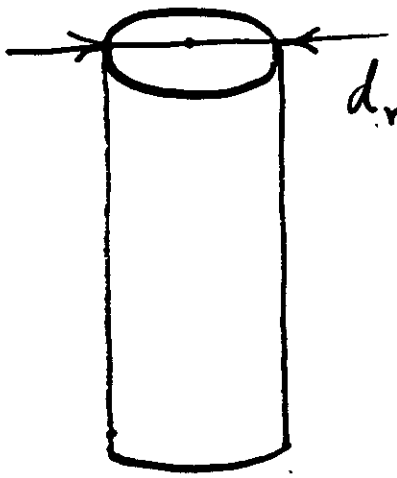
1. A. V. Samoilov and M. Konczykowski, Phys. Rev. Lett. (C) 75, 186 (1995)
2. A. V. Samoilov *et al.* , Phys. Rev. Lett. 76, 2798 (1996)

5.8 GeV Pb ions



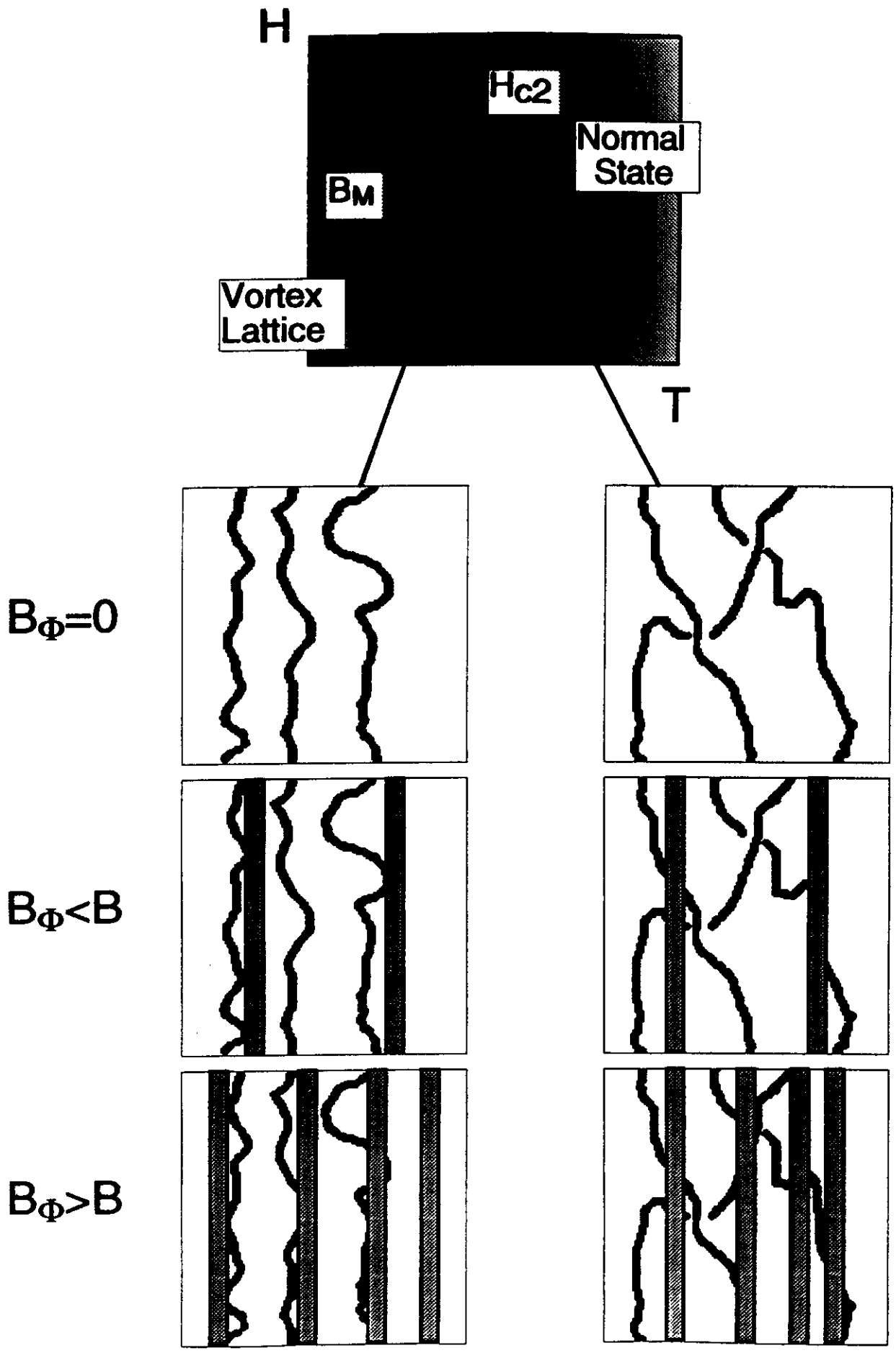


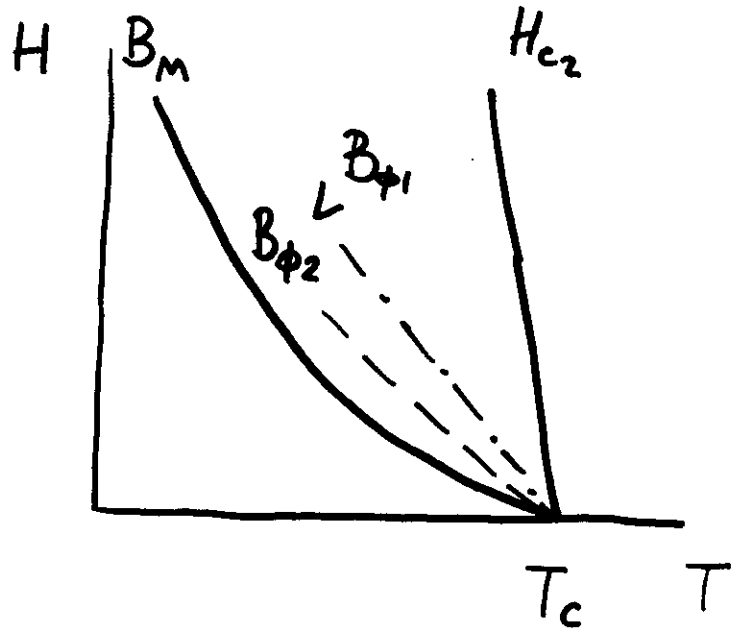


Matching field B_ϕ:

$$\boxed{B_\phi = n_d \Phi_0}$$

At $H = B_\phi$, number of vortices matches number of defects


H
Hc2
Normal State
BM
Vortex Lattice
T
BΦ=0
BΦ<B
BΦ>B



Liquid phase: $\rho_{j\to 0} \neq 0$

Solid phase: $\rho_{j\to 0} = 0$

With increasing defect concentration, the onset of nonlinearity should shift to higher H and T:

$$B_M < B_{BG}(B_\phi = 0) < H_{c_2}$$

Liquid-to-glass transition $B_{BG}(T)$

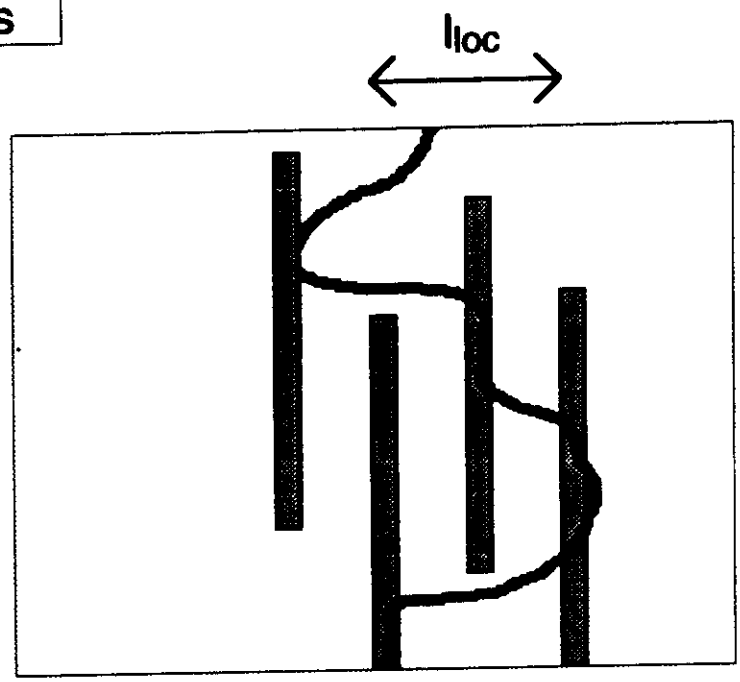
(Bose-glass)

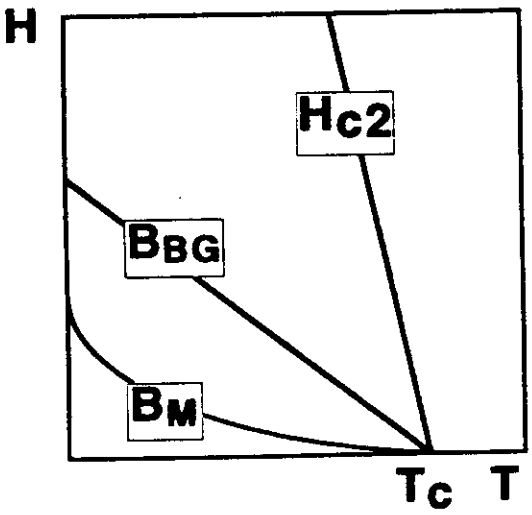
[Nelson + Vinokur]

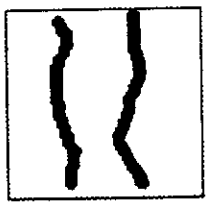
$l_{loc} \sim d_r[T\gamma/(\Phi_0/4\pi\lambda)^2 r_r]^2 >> [\Phi_0/B_{BG}(T)]^{1/2}$

amplitude of thermal fluctuations

intervortex distance a_0

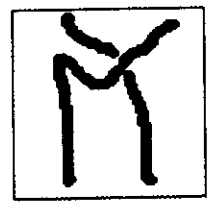






disentanglement ↔ normal Bose liquid

$Z \leftrightarrow i\tau$

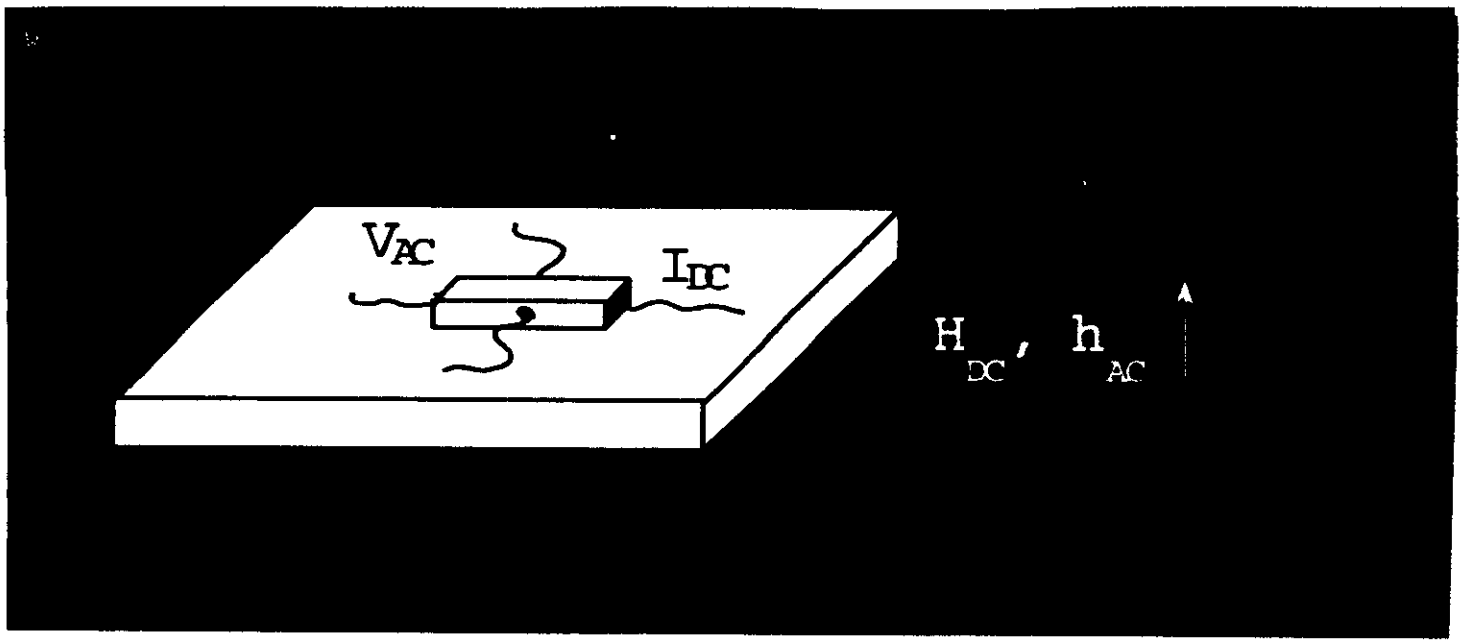


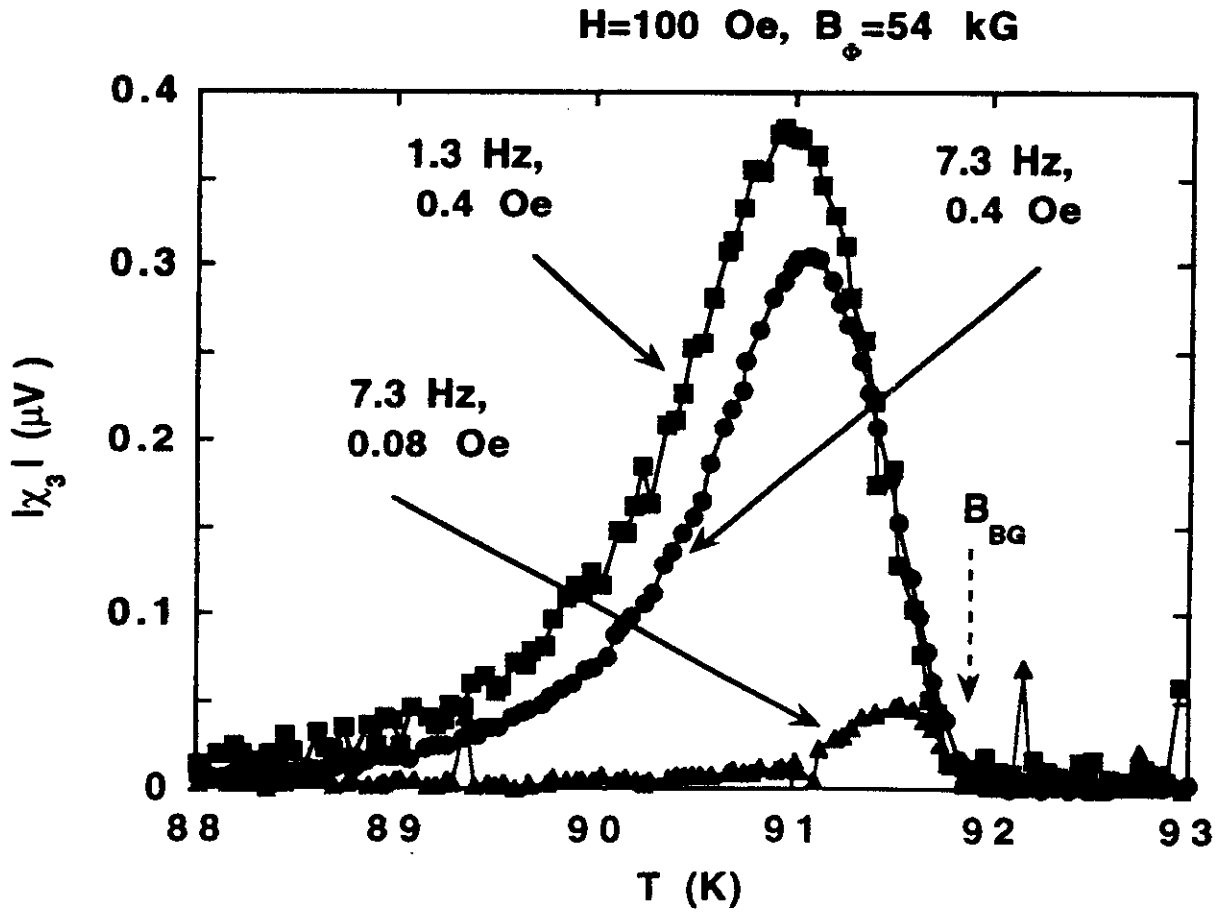
entanglement ↔ superfluid Bose liquid

$\Delta n_s = n_n/n < (E_0/10E_{rot})^{7/2}$ ↔ For $E_{rot} \sim E_0$ $\Delta n_s << 1$ ↔ $L_z \sim 1/E_{rot}$ [small entanglement length]

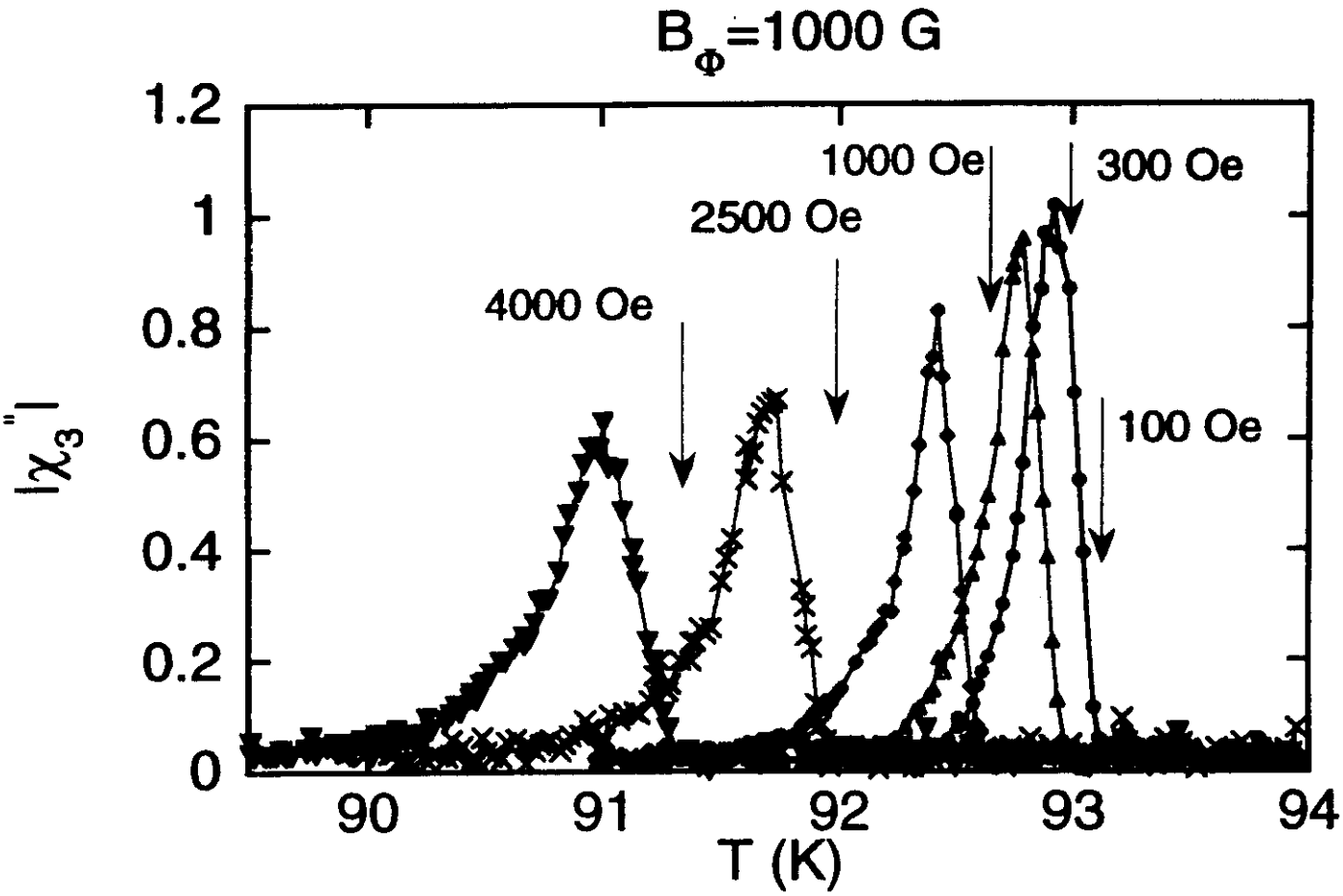
$E_0 = (\hbar K_0)^2/2m$, $K_0 = 2\pi/a_0$

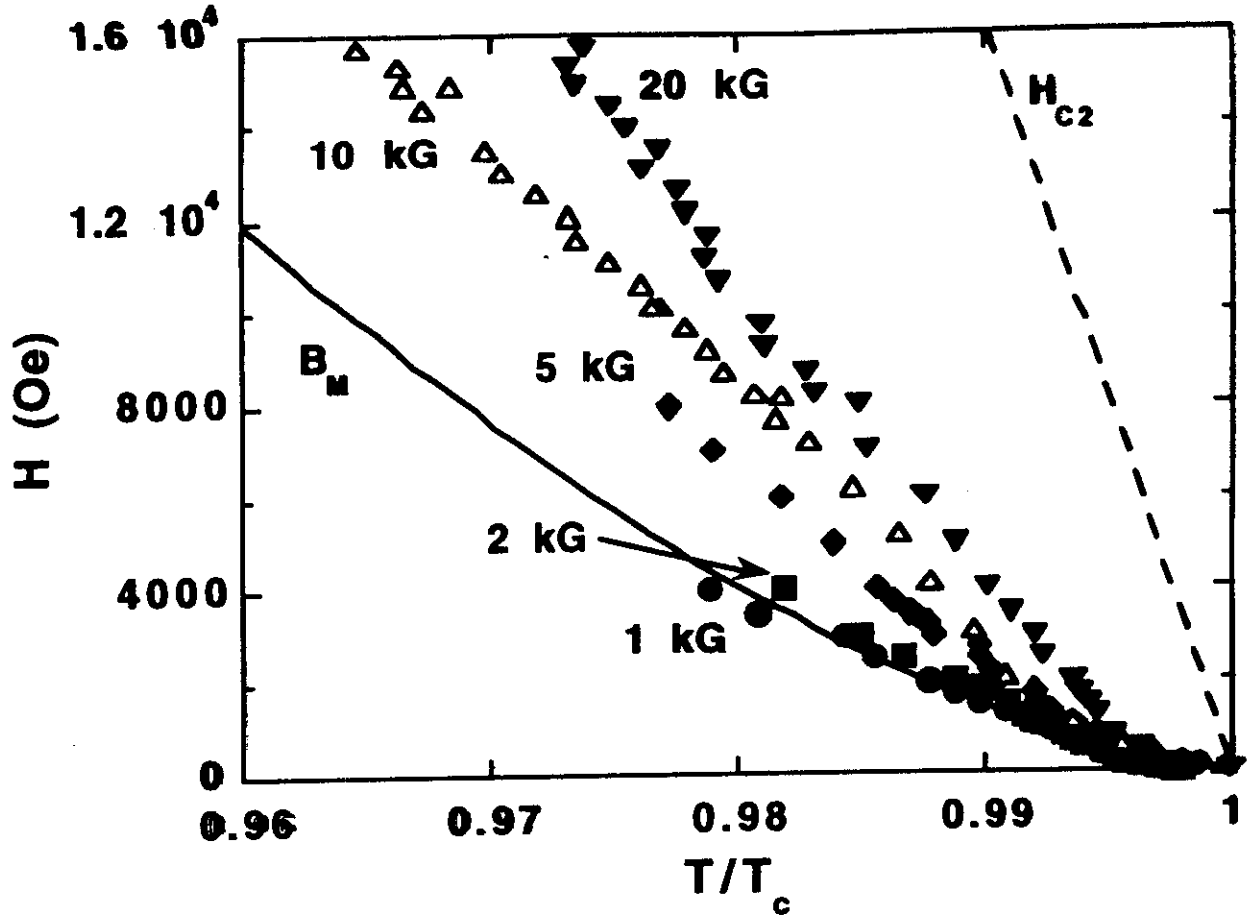
E_{rot} - roton gap

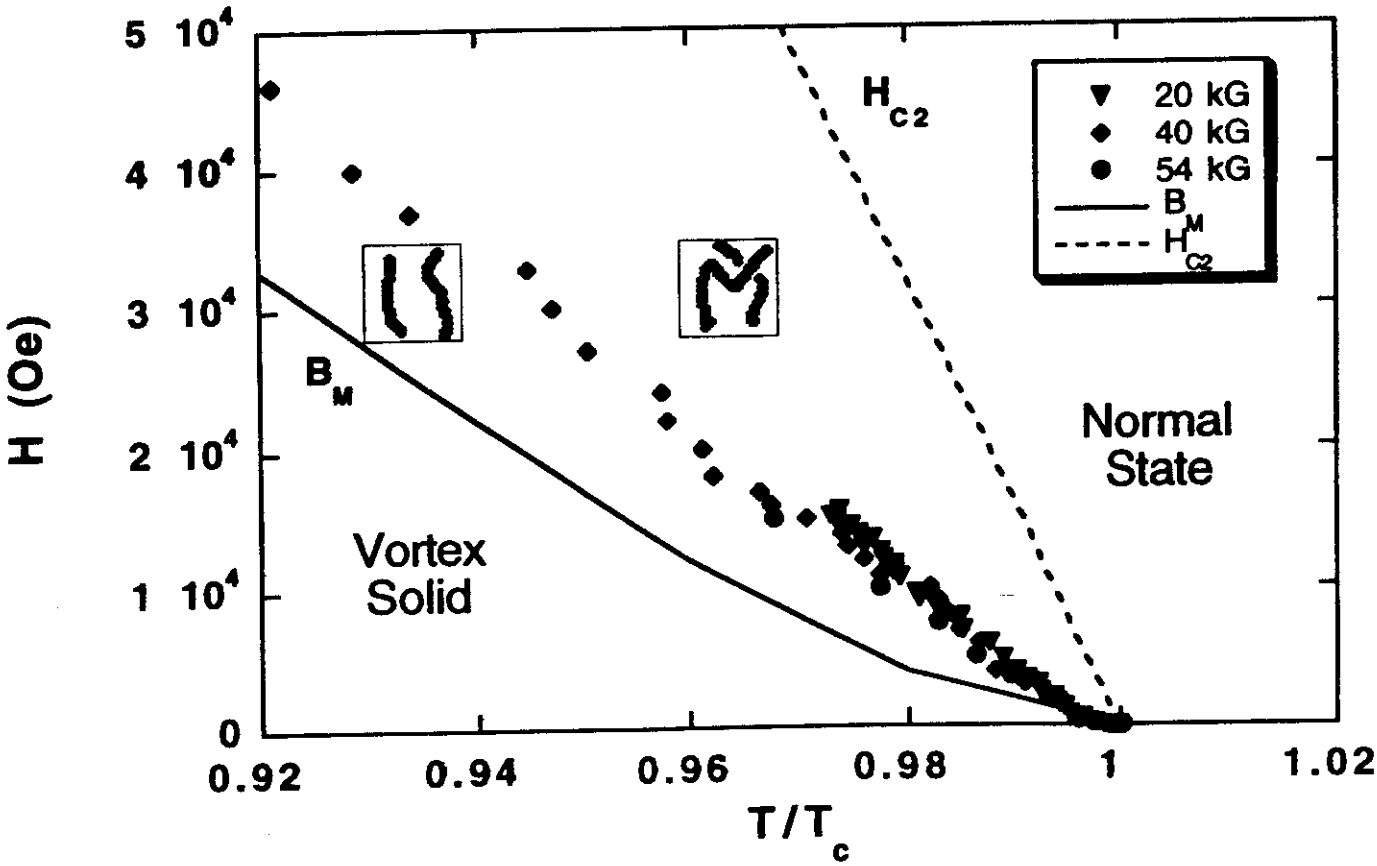




$j \sim 1\ A/M^2$ transport: $10^4\ A/cm^2$.
high-f (0.1 MHz ÷ 10 MHz): $10^4 \div 10^5\ A/M^2$


B_Φ=1000 G
1.2
1
0.8
0.6
0.4
0.2
0
|χ3"|
1000 Oe
300 Oe
2500 Oe
4000 Oe
100 Oe
90
91
92
93
94
T (K)


1.6 10^4
1.2 10^4
8000
4000
0
H (Oe)
20 kG
10 kG
5 kG
2 kG
1 kG
B_M
H_c2
0.96
0.97
0.98
0.99
1
T/T_c


5 10^4
4 10^4
3 10^4
2 10^4
1 10^4
0
H (Oe)
H_c2
20 kG
40 kG
54 kG
B_M
H_c2
B_M
Normal State
Vortex Solid
0.92
0.94
0.96
0.98
1
1.02
T/T_c

SUMMARY

1. Vortex liquid is a strongly interacting many - body system (disorder can be treated as a perturbation).

2. Disorder is able to localize disentangled vortices and to produce a Bose - glass state below $B_{BG}(T)$.

3. Disorder cannot affect the properties of the entangled vortex liquid (with large n_s and E_{rot}).

4. The uppermost position of the BG transition $B_{BG}^{max}(T)$ is well below $H_{c2}(T)$ and separates entangled and disentangled vortex liquids.

5. A finite - thickness crossover would be nontrivial because the naive estimate for the entanglement length is $L_z \sim 3$ nm<<thickness.