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MINIWORKSHOP ON STRONG CORRELATIONS
AND QUANTUM CRITICAL PHENOMENA
(4 - 22 July 1994)

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VANISHING OF GAP FUNCTION
ON THE FERMI SURFACE IN HIGH Tc SUPERCONDUCTORS

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

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VANISHING OF GAP FUNCTION ON THE FERMI SURFACE IN HIGH T_c SUPERCONDUCTORS

G. BASKARAN

★ INTRODUCTION

★ BCS THEORY & COHERENT CHARGE FLUCTUATION ON THE FERMI SURFACE

★ REAL SPACE CORRELATION ⇒ DOUBLE OCCUPANCY CONSTRAINT ON K-SPACE

★ CONSEQUENCE ON THE GAP FUNCTION

★ NUMERICAL RESULTS

★ EXPERIMENTS

Collabarators

ARJUNWADKAR — PUNE
KANHERE — PUNE
BASU — MADRAS

HIGH T_c SUPERCONDUCTORS

LARGE U-HUBBARD MODEL $\Longleftrightarrow$ t-J MODEL

ANOMALOUS NORMAL STATE PROPERTIES

$$\Longrightarrow \quad Z_{k_F} = 0 \quad (\sim N^{-\epsilon})$$

Spin-charge decoupling etc.

Is there any other consequence ?

Symmetry of order parameters (Spin Singlet)

$$\Delta(\vec{k},\omega) = \Delta(-\vec{k},\omega).$$

s-wave

$\Delta(\vec{k}) \sim f(k)$

d-wave

$\Delta(\vec{k}) \sim (k_x^2 - k_y^2)\Delta_0(k)$

Extended - S (on a lattice) $(\cos k_x + \cos k_y)$

d - on a lattice: $(\cos k_x - \cos k_y)$

$\Delta(\vec{k}) \sim (k - k_F)\Delta_0$

(odd across the F.S)

(M.L. Cohen)

ODD IN k & ω

$$\Delta(\vec{k},\omega) = -\Delta(-\vec{k},+\omega)$$

BEREZINSKI

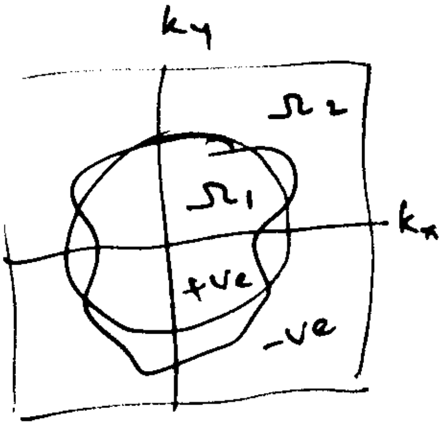
$$\Delta(\vec{k},\omega) = -\Delta(\vec{k},-\omega)$$

i.e. $\Delta(\vec{k},\omega) = \Delta(-\vec{k},-\omega)$

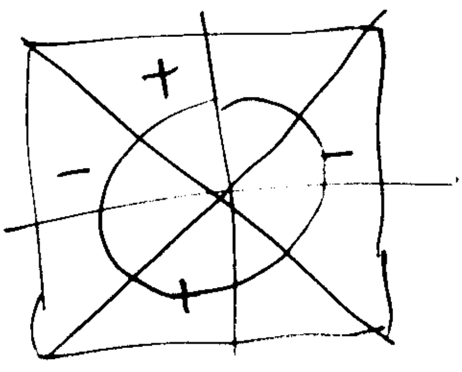
Large U or t-J Models

$$\langle C_{i\uparrow}^{+} C_{i\downarrow}^{+} \rangle = \sum_k \langle C_{k\uparrow}^{+} C_{-k\downarrow}^{+} \rangle = 0 \text{ or very sma}$$

$$= \sum_k \Delta_k = 0$$

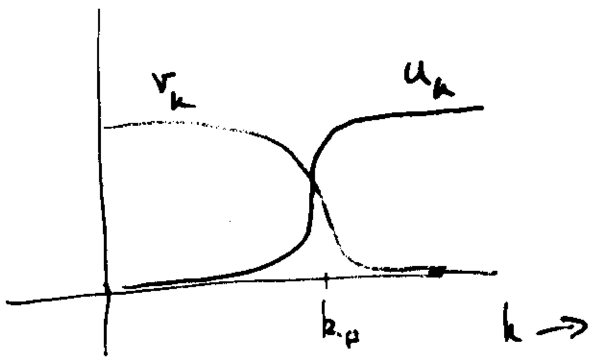


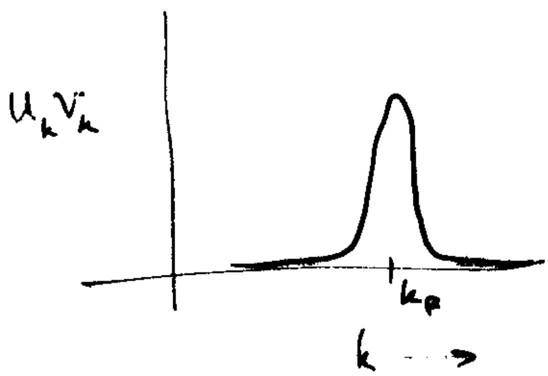
$$\sum_{k \in \Omega_1} \Delta_k = -\sum_{k \in \Omega_2} \Delta_k$$



BCS STATE

$$|BCS\rangle = \prod_k \left(u_k + v_k \, c_{k\uparrow}^{\dagger} c_{-k\downarrow}^{\dagger} \right) |0\rangle$$

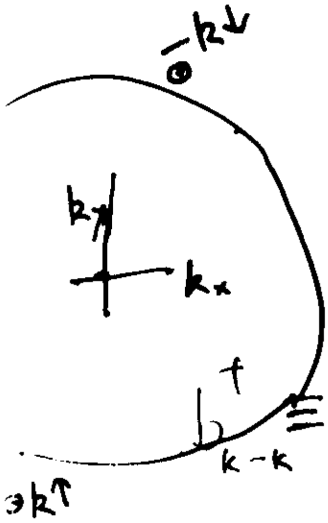




$$c_{k\uparrow}^{\dagger} c_{-k\downarrow}^{\dagger} \equiv b_k^{\dagger}$$

COHERENT
CHARGE FLUCTUATION IN K-SPACE

$$\left\langle \left(b_k^\dagger b_k\right)^2 \right\rangle - \left\langle b_k^\dagger b_k \right\rangle^2 \sim u_k^2 v_k^2$$



$$b^\dagger_{k-k} \equiv \frac{1}{\sqrt{2}}\left(c^\dagger_{k\uparrow} c^\dagger_{-k\downarrow} - c^\dagger_{k\downarrow} c^\dagger_{-k\uparrow} \right)$$

$$\left\langle b^\dagger_{k-k}\, b_{k'-k'} \right\rangle = (u_k v_k)(u_{k'} v_{k'})$$
$$= \Delta_k^* \, \Delta_{k'}$$

ODLRO IN K-SPACE !

REAL SPACE REPULSION IN 1-D & 2-D HUBBARD MODELS

1-D : finite phase shifts

$$k_i = \frac{2\pi}{L} n_i + \frac{1}{L} \sum_j \theta(k_i, k_j)$$

$$\delta k_i \sim \frac{\pi}{L} \Rightarrow \text{finite phase shift}$$

No two "fermions" $\uparrow\downarrow$ can occupy the [illegible] same k-point in k-space

$$\psi(x_1 \cdots x_N) = \sum_P A(P,Q)\, e^{i \sum_i k_{Pi} x_i}$$

$$Z_{k_F} = \left\langle {N+1 \atop k_F, \sigma} \right| C^{+}_{k_F\sigma} \left| {N \atop 0,0} \right\rangle$$

$$Z_{k_F} \sim N^{-\left(\frac{\delta}{2\pi}\right)^2}$$

$$\mathcal{L}t_{t \to \infty} \langle 0 | C_{k_F}(t) \; C^{+}_{k_F}(0) | 0 \rangle \equiv Z_{k_F}$$

VANISHING OF Z_{k_F} ALSO IMPLIES

ABSENCE OF "REAL" DOUBLE OCCUPANCY

ON THE F.S.

FINITE PHASE SHIFT ON THE FERMI SURFACE

$\Rightarrow$ Absence of "Real" double occupancy.

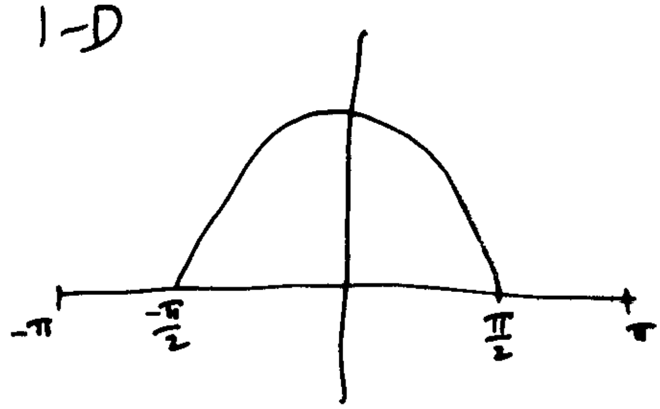
SINGLE OCCUPANCY ON THE FERMI SURFACE

& ABSENCE OF CHARGE FLUCTUATION

SPINON ZERO-MODE ON THE FERMI SURFACE

G. Baskaran

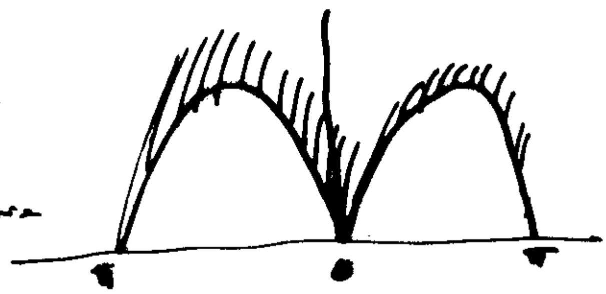
1-D



Fadeev & Takhtajan

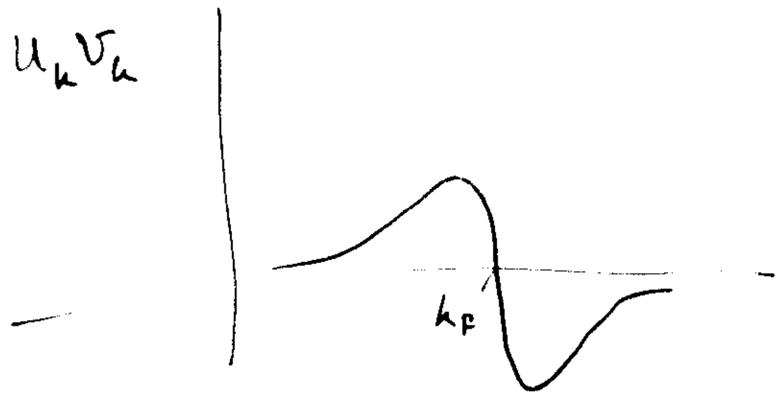
Zero mode Majorana fermion in k-space?

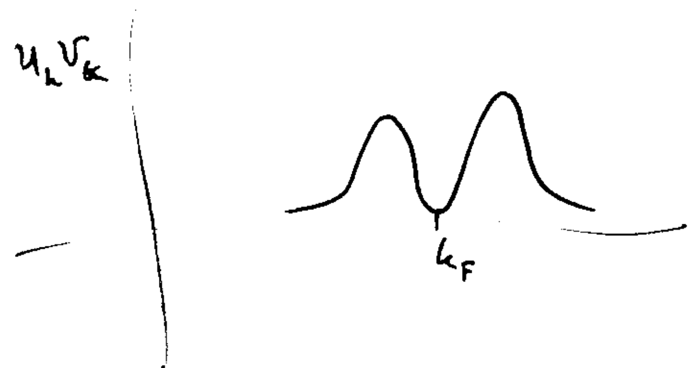
des Cloizeaux-Pearson spin-wave spectrum



BUT SIMPLE BCS SUPERCONDUCTING STATE DEMANDS COHERENT CHARGE FLUCTUATION ~~ON~~ AROUND THE FERMI SURFACE!

A WAY TO SATISFY SUPERCONDUCTING TENDENCY & THE K-SPACE REPULSION





PUT THE NODAL SURFACE OF THE GAP FUNCTION ON THE FERMI SURFACE

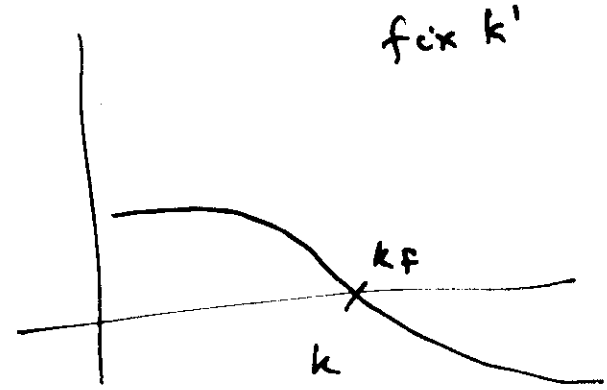
NUMERICAL STUDY OF $\langle b^\dagger_{k-k} b_{k'-k'} \rangle = A_{kk'}$

BY EXACT DIAGONALISATION

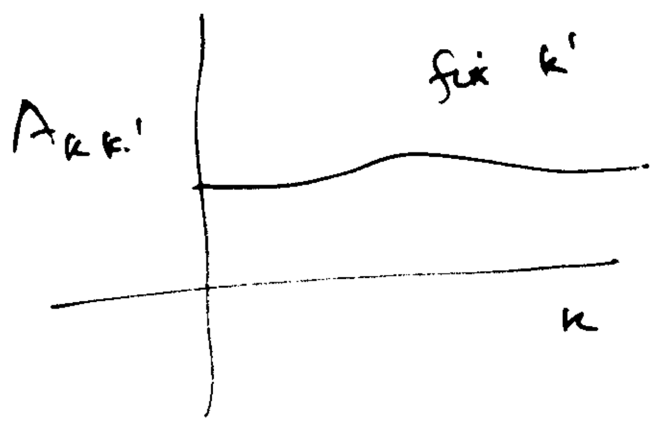
1-D CHAIN &

2-D finite clusters

1-D



t-J chain
various doping



-ve U Hubbard model

2-D 4 x 4 lattice

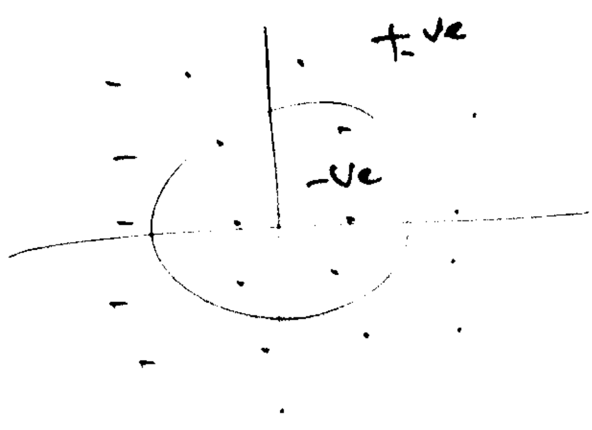
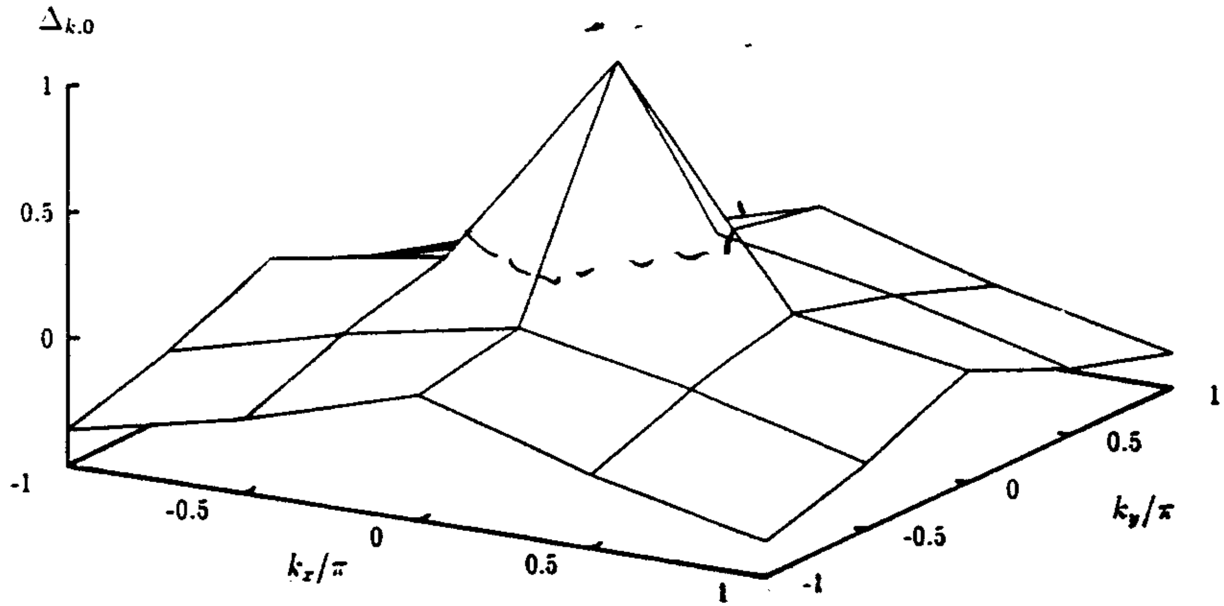
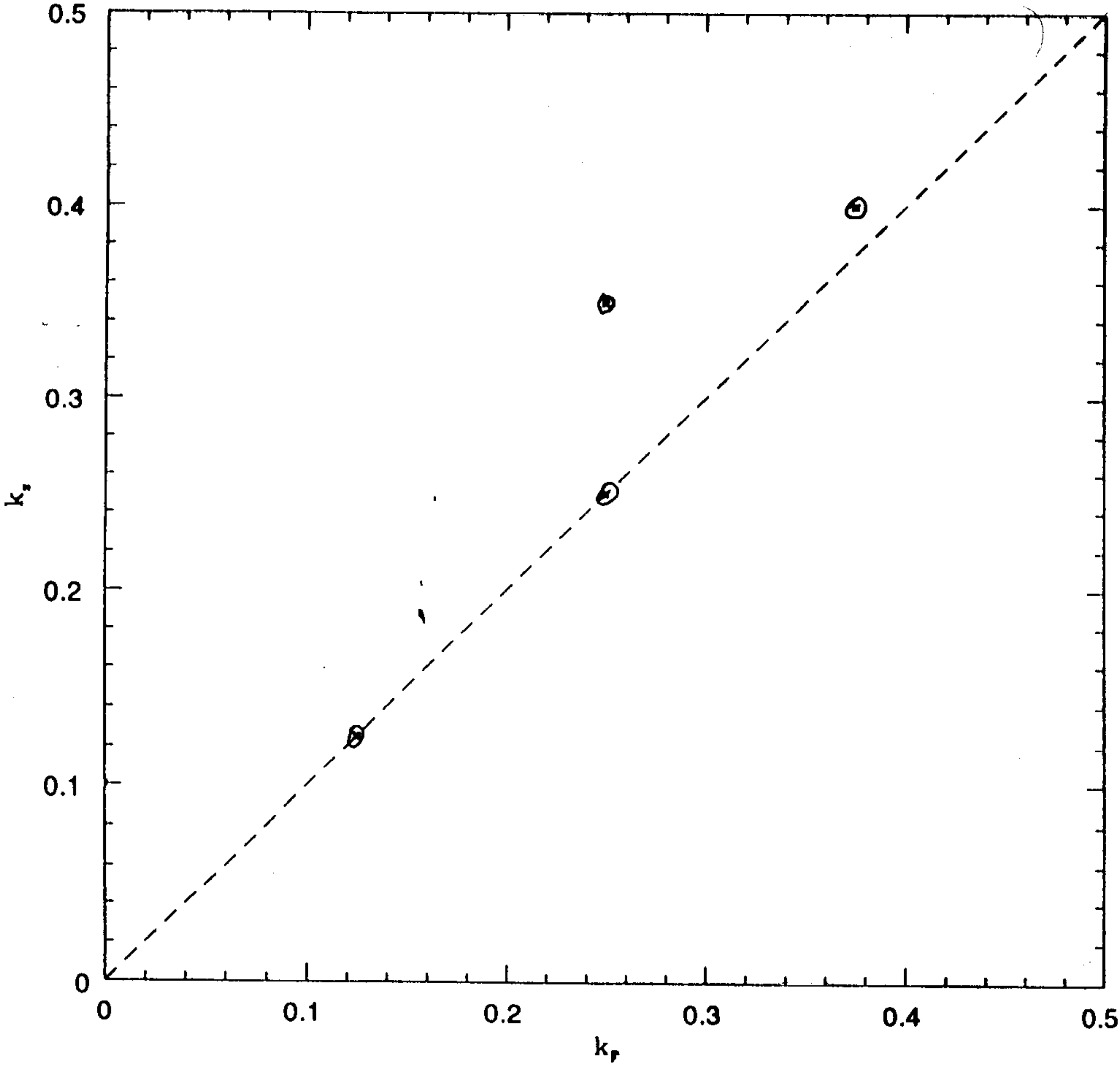


Figure 5



$\Delta(\vec{k})$ as a fn. of $\vec{k}$

Figure 3



$\Delta(k_s) = 0$ in 1-D

k_s vs k_F

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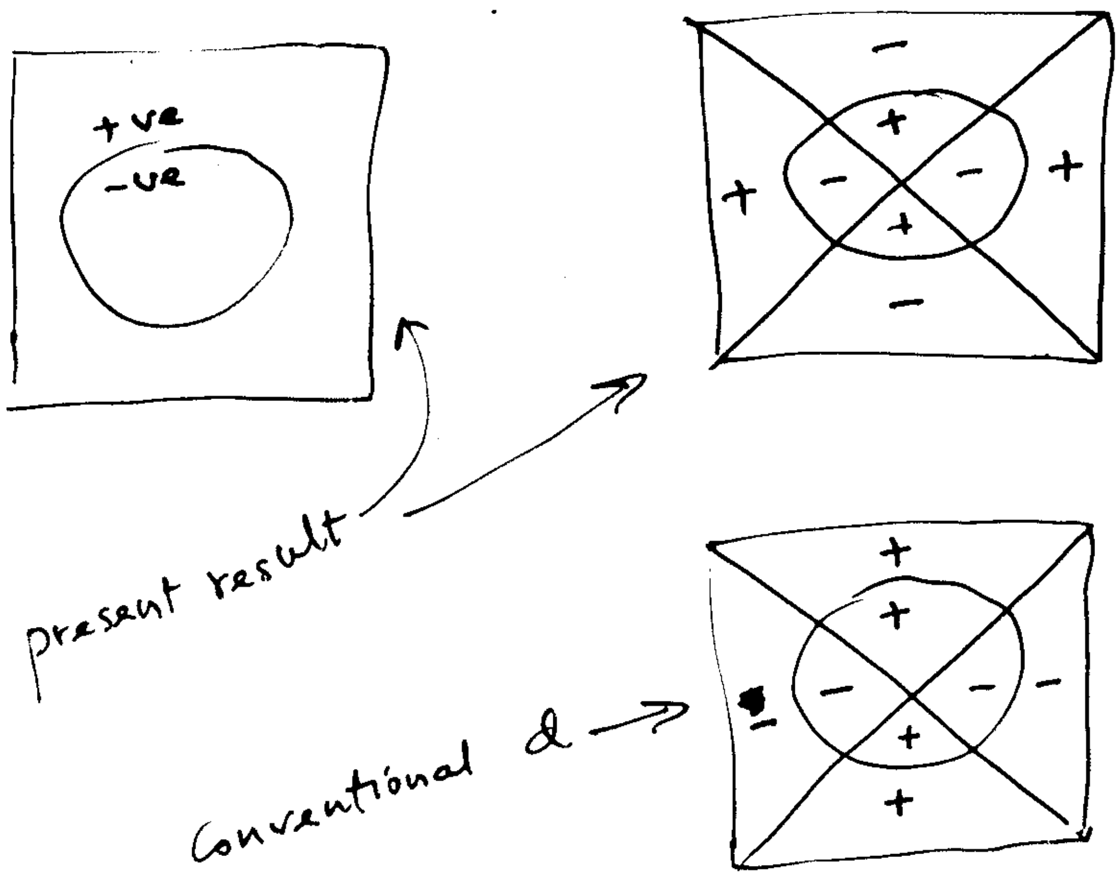
HIGH - T_c S Vs D

$$\Delta_k \sim (k_x^2 - k_y^2)(k - k_F)\Delta_0$$



$$\Delta_k \sim (k_x^2 - k_y^2)\Delta_0$$

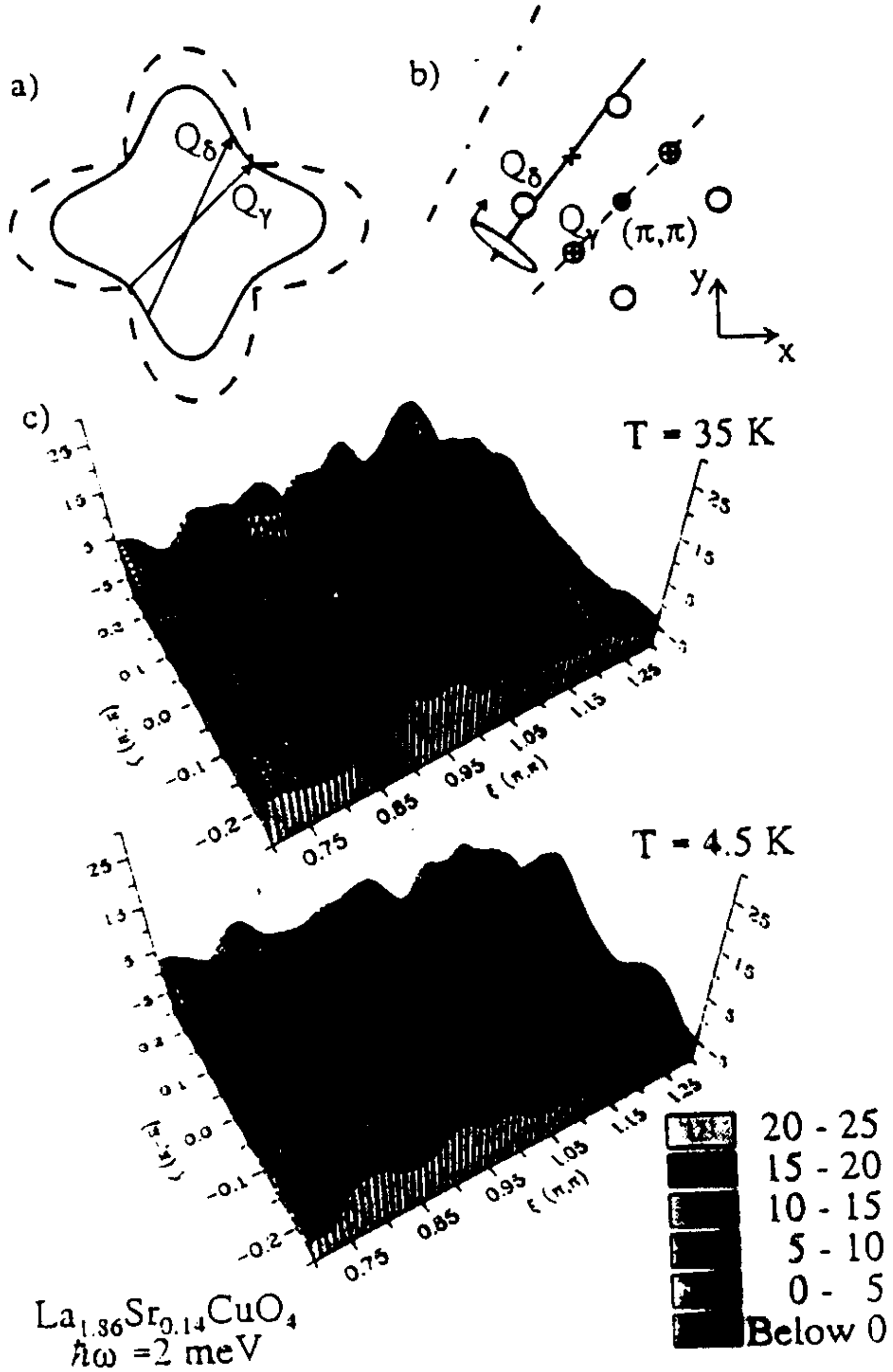


FIG. 1. (a) Schematic Fermi surface for $La_{1.86}Sr_{0.14}CuO_4$. (b) Map of reciprocal space probed in this experiment. (c) Contour plot of the magnetic intensity in the region of Q space shown in (b) for $\hbar\omega = 2$ meV for $T = 35$ K and $T = 4.5$ K.

T. E. Mason et. al.

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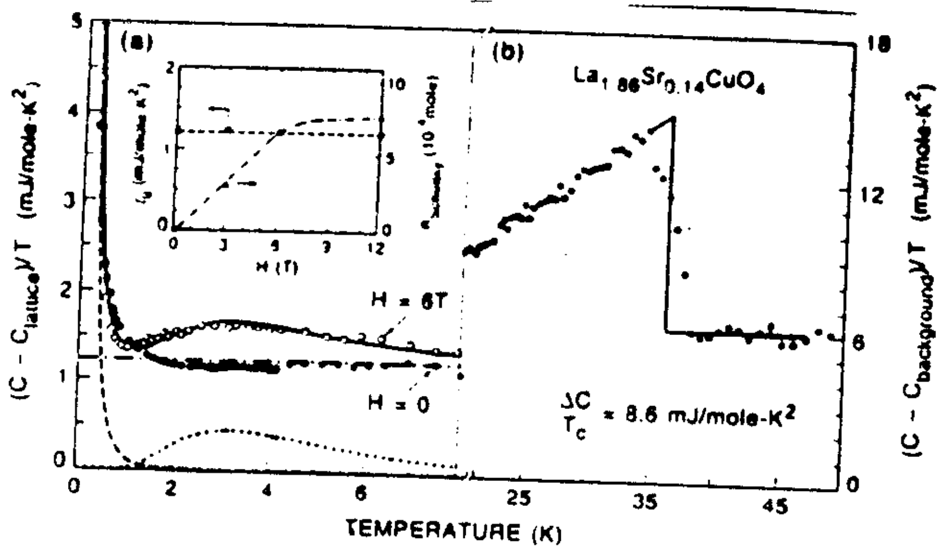

FIG. 2. Temperature dependence of the nonphonon part of the specific heat of $La_{1.86}Sr_{0.14}CuO_4$ below (left panel) and near (right panel) T_c. The concentration of impurities is found to be 0.07%/Cu from the size of the Schottky anomaly in a magnetic field (open circles); the inset shows the field dependence of this contribution, along with the estimated linear contribution.

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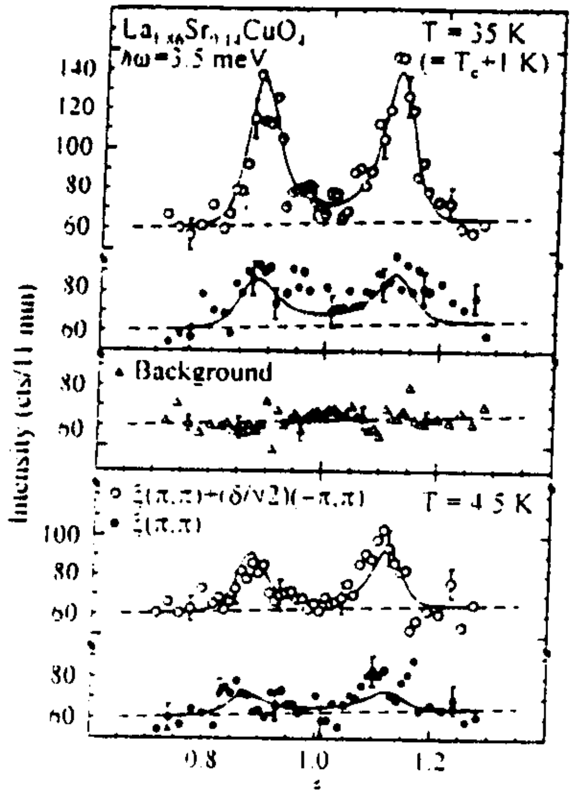

FIG. 3. The Q dependence of the neutron intensity for $La_{1.86}Sr_{0.14}CuO_4$ above (upper panel) and below (lower panel) T_c for $\hbar\omega = 3.5$ meV. The open (closed) circles correspond to the scan indicated by a solid (dashed) line in Fig. 1(b). The lines are the results of fits described in the text. The straight dashed lines indicate the measured background. shown as triangles in the middle panel.

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