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IX TRIESTE WORKSHOP ON
OPEN PROBLEMS IN
STRONGLY CORRELATED SYSTEMS

14 - 25 July 1997

AC and DC TRANSPORT IN ONE-DIMENSIONAL SYSTEMS

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

AC and DC TRANSPORT IN ONE DIMENSIONAL SYSTEMS

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- G. Grüner
  L. Degiorgi

  [M. Dressel ; A. Schwartz ; V. Vescoli]

- D. Jérome

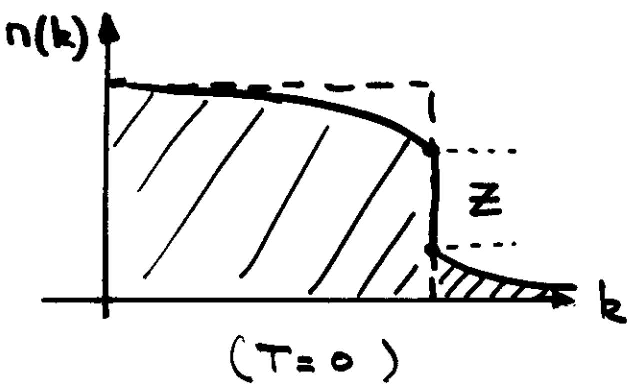
* Fermi - Liquids :

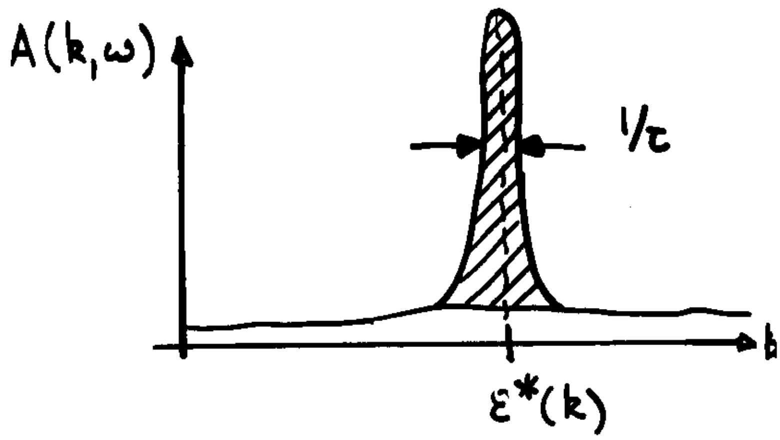
interactions not "very" important

Free Electrons ----------> Quasiparticles

- Weak residual interaction between Q.P.

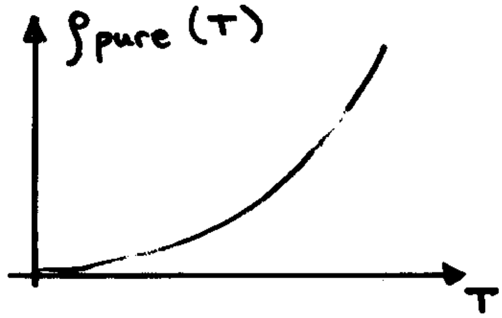
- $C_V \sim \gamma T$





- $\tau \to \infty$ when $k \to k_F$

-



$$\rho(T) \sim T^2$$

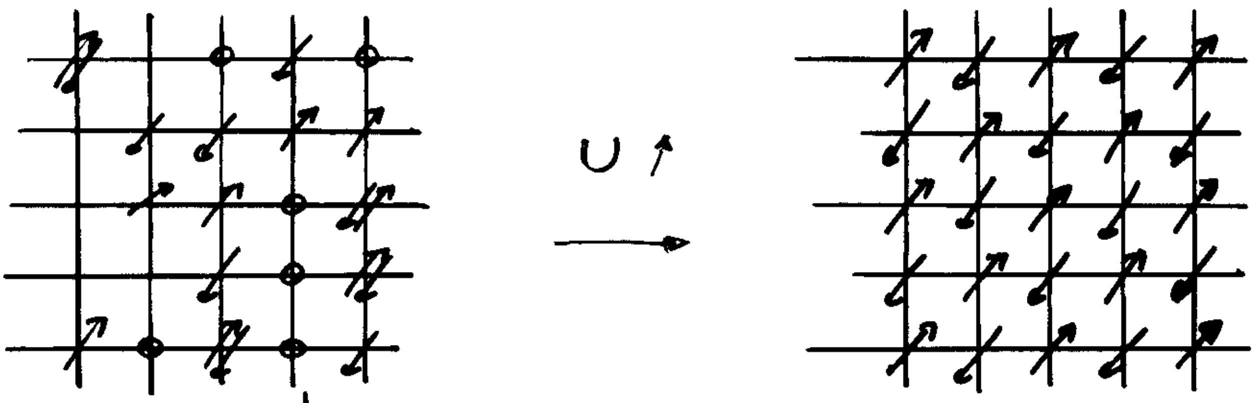
-----> [RMN, .. , BCS, ...]

- <u>Works very well !!</u>

	Nb	^3He	Heavy Fermions (UPt_3; $CeCu_2S$
m^*/m	2	6	10^2
χ/χ_{free}	< 1	20	10^2

Other Systems:

- **Strong Interactions: Mott insulators**



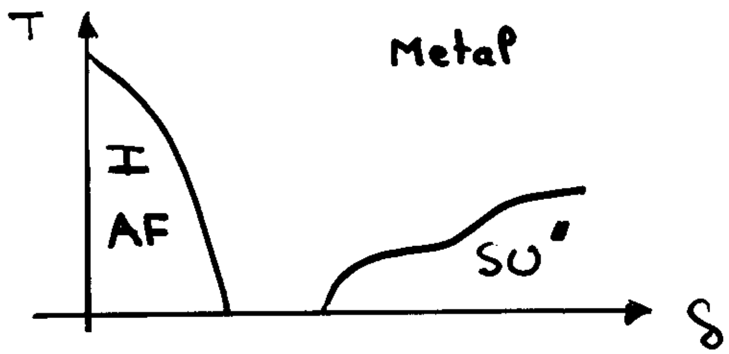
$\psi \sim e^{ikr_i}$ $\qquad\qquad$ $\psi \sim \delta(r - r_i)$

$$\left[\; H = -t \sum_{\langle ij \rangle} c^{\dagger}_{i\sigma} c_{j\sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow} \;\right] \quad \text{(Hubbard)}$$

Mott transition [metal → Insulator]

e.g. Vanadium Oxides $\qquad (U \leftrightarrow P)$

e.g. High T_c Superconductors.

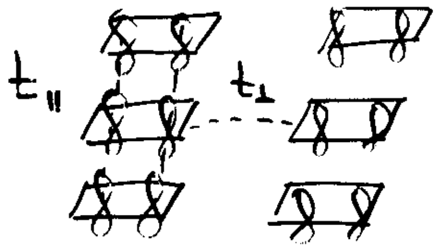


- Questions: → transition $[\, U ; \delta \,]$
  → $\rho(T)$
  → Metallic phase FL ?

- $\underline{d = 2 ; 3}$ very difficult

- Does 1D exists ??

→ Organic Conductors

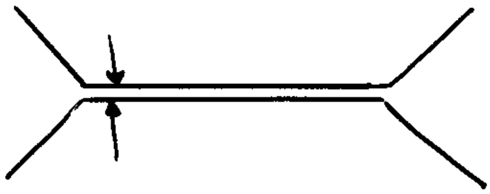


$t_{\parallel} \approx 3000\ K$

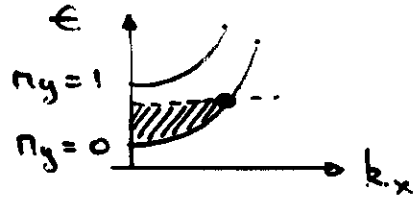
$t_{\perp} \approx 200\text{-}300\ K$

→ Ladder ; Spin Chains ; Spin Ladders

→ Quantum Wires



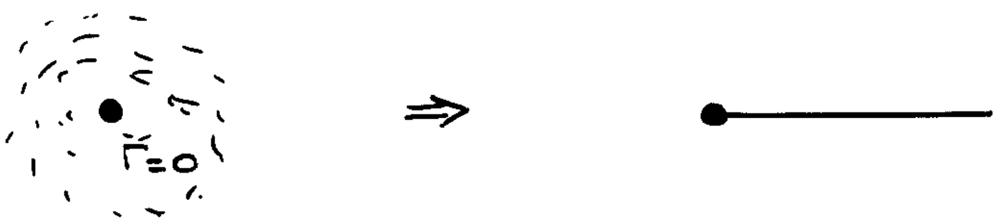
$$\epsilon = \frac{\hbar^2 k_x^2}{2m} + \frac{\hbar^2 k_y^2}{2m} \qquad k_y = \frac{2\pi n}{L_y}$$



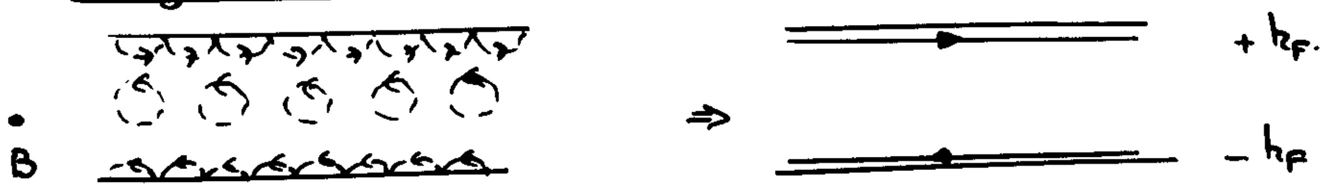
→ Josephson Junction arrays :

↳ 1D bosons + interactions

→ Impurity models



→ Edge States



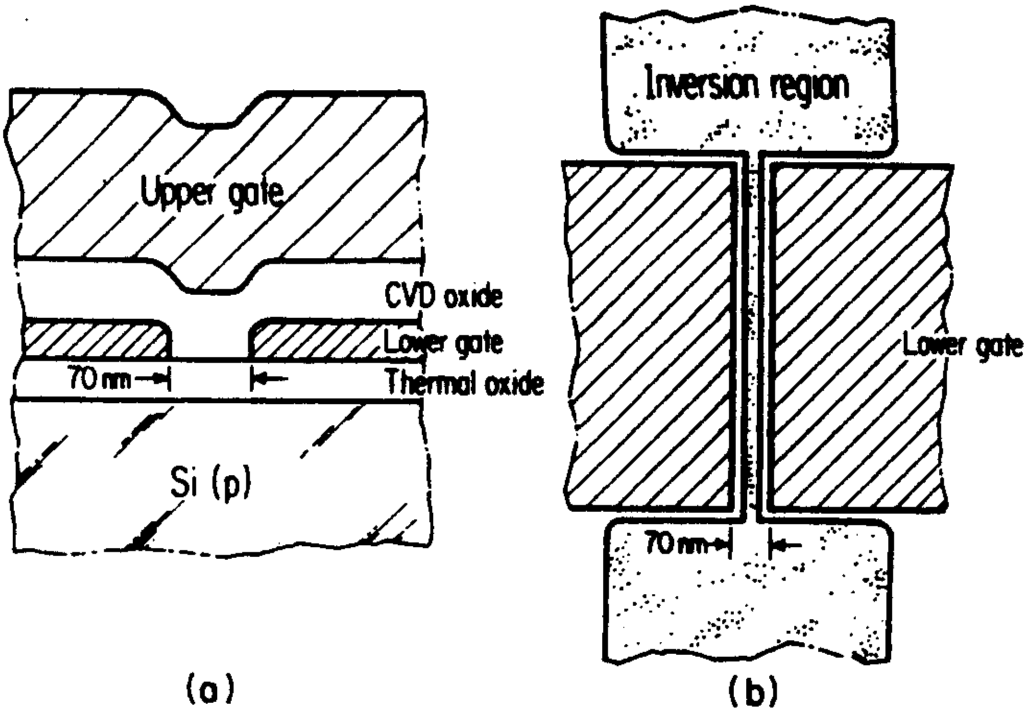


FIG. 1. Schematic (a) cross section and (b) top view of the silicon transistor with continuous upper gate and a gap in the lower gate. The electron gas, formed in the Si by the positively biased upper gate, is confined by the lower gate. The Si is *p*-type, so the surface electrons are isolated from the bulk by *p*-*n* junctions. That is why the electron-rich region is called an inversion layer. The cross section is roughly to scale, but the top view is not. The narrow channel is typically 20 nm wide by 1–10 μm long. Contact is made to the two wide inversion regions.

[S.B. Field et al. PRB 42 3523 (90)]
[J. Scott Thomas et al. PRL 62 583 (89)]
[M. Kastner Rev. Mod. Phys. 64 849 (92)]
[A.R. Goñi et al. PRL 67 3298 (91)]
[J.M. Calleja et al. Sol. St. Comm 79 911 (91)]
[S. Tarucha et al. PRB 47 4064 (93)]

One-Dimensional Mott Insulator Formed by Quantum Vortices in Josephson Junction Arrays

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The quantum transport of vortices in very long and narrow arrays of small Josephson junctions has been studied experimentally. The chemical potential of the system can be changed by an external magnetic field. When the vortex density is commensurate with the one-dimensional junction lattice, the vortex mobility vanishes for a finite window of the magnetic field. The localization of the vortices is due to the forming of a one-dimensional Mott insulator. [S0031-9007(96)00521-2]

PACS numbers: 74.50.+r, 05.30.Jp

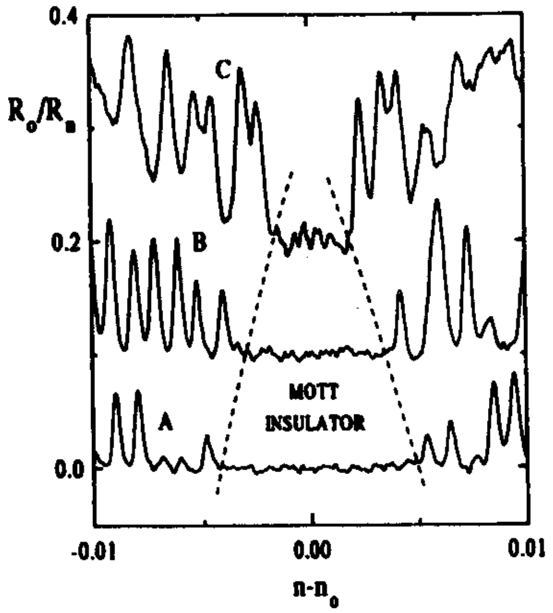
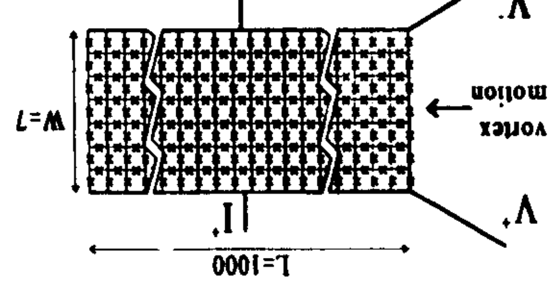


FIG. 3. The normalized resistance R_0/R_n as a function of the one-dimensional frustration n for samples A, B, and C ($T = 30$ mK) around the one-dimensional commensurate state $n_0 = 1/3$. The curves for samples B and C have an offset in R_0/R_n of 0.1 and 0.2, respectively, which is proportional to the relative increase of E_C/E_J for samples B and C. In this way the phase diagram can be constructed. The dashed lines indicate the phase boundary between the conducting phase and the Mott insulating phase.

FIG. 1. Layout of the sample. The transport properties are determined by a four-terminal measurement. The current is injected in the middle of the sample and the resulting voltage is measured at one end of the sample. The Josephson junctions are denoted by crosses.



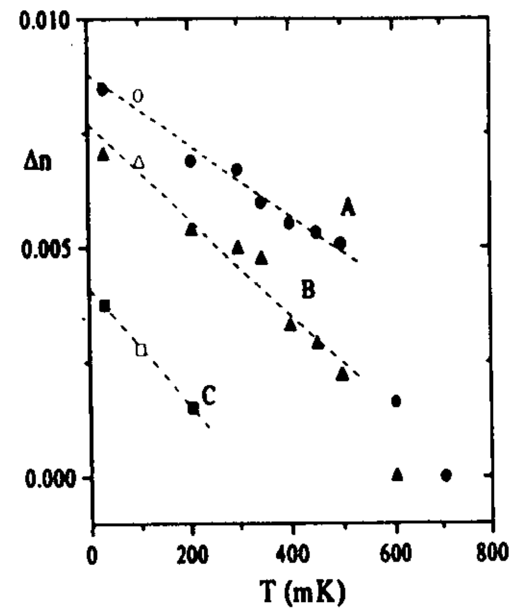


FIG. 4. The range Δn for which the vortices form a Mott insulator as a function of the temperature. Note that Δn is of the order of 10^{-2}, which corresponds to a magnetic induction B of only 10^{-2} G.

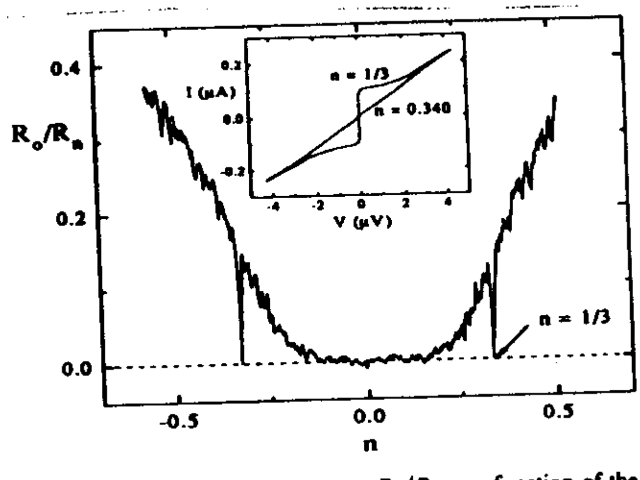
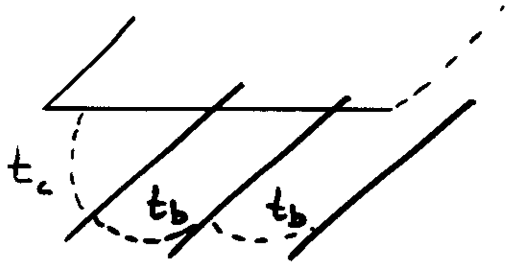


FIG. 2. The normalized resistance R_0/R_n as a function of the one-dimensional frustration n for sample C ($T = 30$ mK). The resistance drops sharply to zero at the one-dimensional commensurate state $n = 1/3$. In the inset the I-V characteristics are shown for a commensurate filling $n = 1/3$ and an incommensurate filling $n = 0.340$ for sample C.

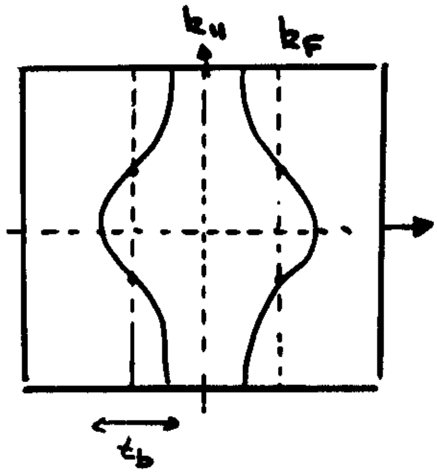
Quasi-1D :



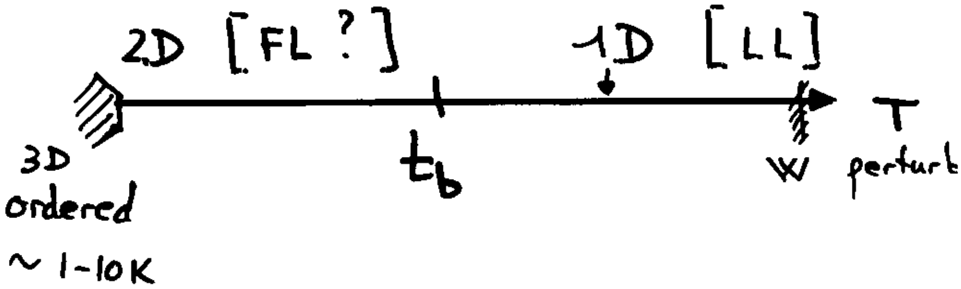
$t_a \sim 3000$ K

$t_b \sim 200 - 300$ K

$t_c \sim 10$ K



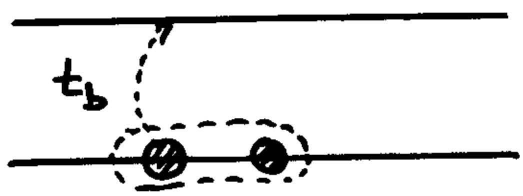
Naïf :

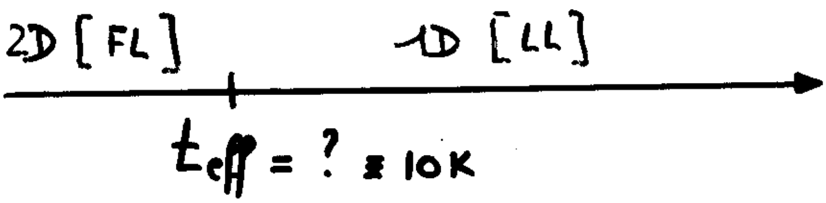


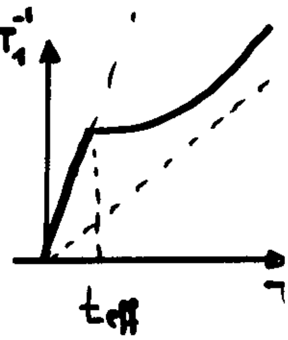
• **80's :**

$$t_{eff} = t_\parallel \left(\frac{t_b}{t_\parallel}\right)^2$$

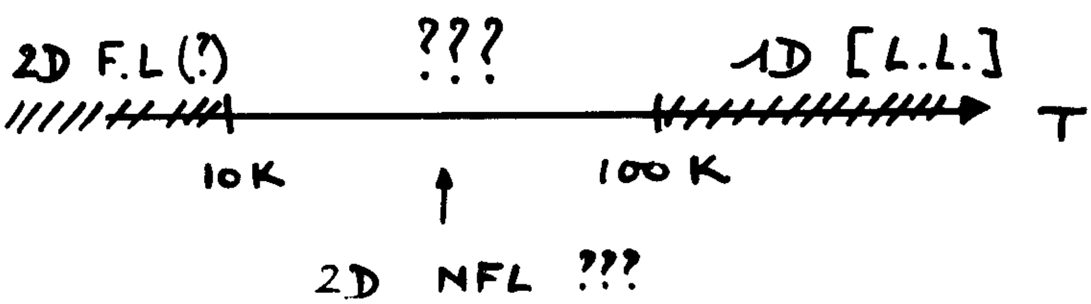
[C. Bourbonnais et al]

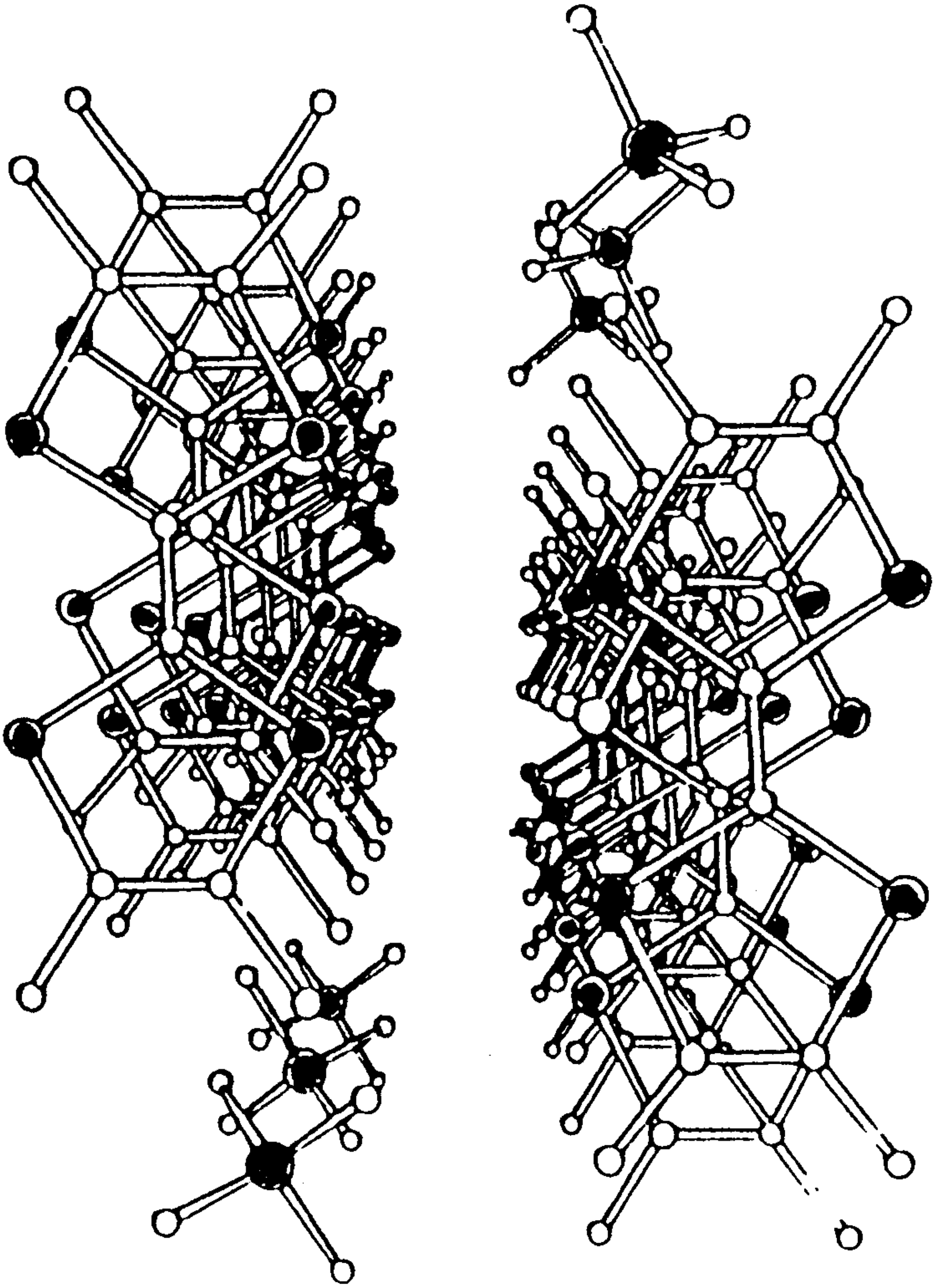


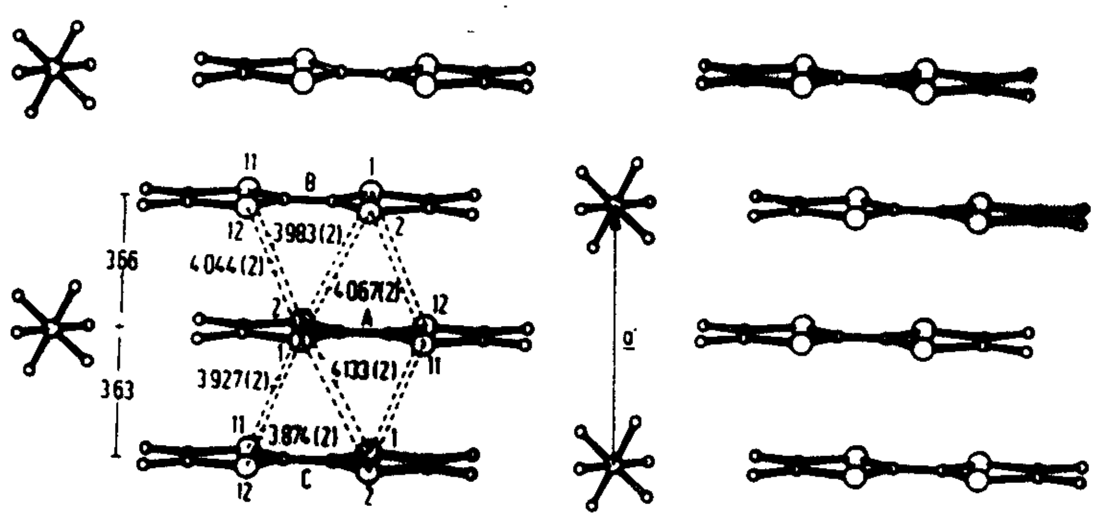




• **Transport ?**

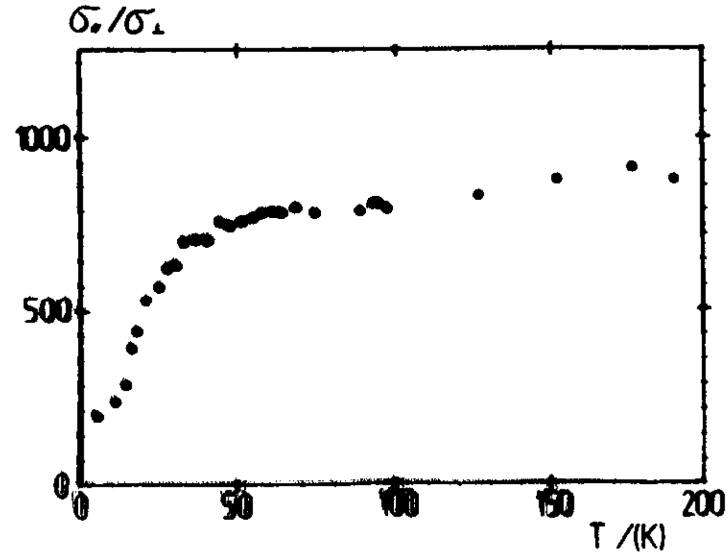


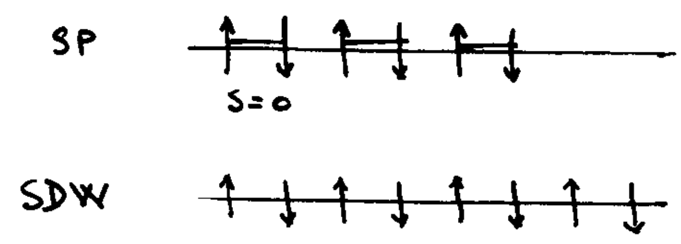




(*d*) (*continued*)

Crystal structure of some quasi one dimensional conductors. (*a*) TTF–TCNQ, a view normal to the *ac* plane of the crystal packing (top), a view down [100] of the crystal packing (bottom), (after reference [2.10]). (*b*) HMTSF–TCNQ, a view projected along the high conduction axis (top) and along the *b*-axis (bottom) (after [2.12]). (*c*) (TTF)$Br_{0.79}$ viewed down the *c*-axis (top) and down the *b*-axis (bottom) (after: La Placa, S. J., Corfield, P. W. R., Thomas, R., and Scott, B. A., 1975, *Solid St. Commun.*, **17**, 635). (*d*) $(TMTSF)_2PF_6$, viewed along the *a*-axis (top) and side-viewed tilted 10° (bottom) (after [2.11]).




SP
S=0
SDW

a) b)

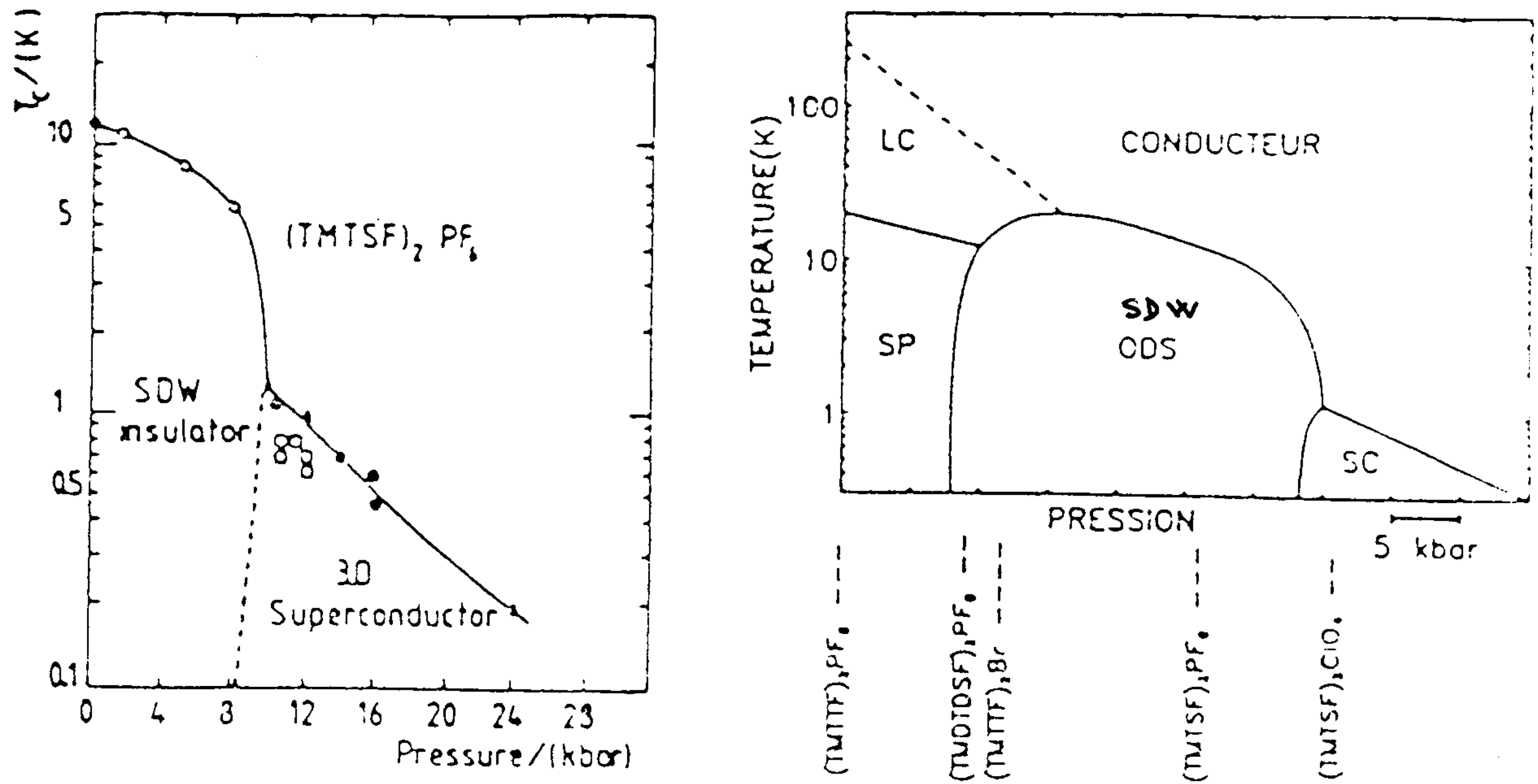
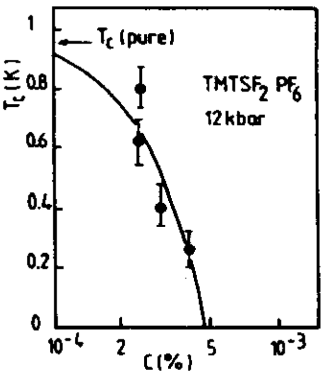
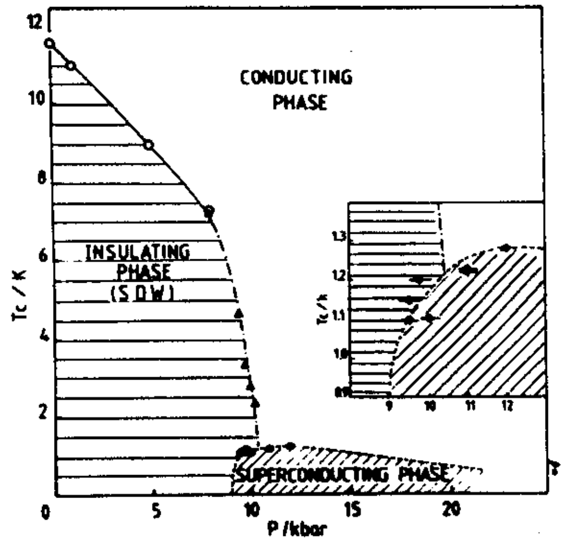

T_c/(K)
10
5
1
0.5
0.1
0
4
8
12
16
20
24
28
Pressure/(kbar)
$(TMTSF)_2PF_6$
SDW
insulator
3D
Superconductor
TEMPERATURE(K)
100
10
1
LC
CONDUCTEUR
SP
SDW
ODS
SC
PRESSION
5 kbar
$(TMTTF)_2PF_6$
$(TMDTDSF)_2PF_6$
$(TMTTF)_2Br$
$(TMTSF)_2PF_6$
$(TMTSF)_2ClO_4$

Fig. 4.14



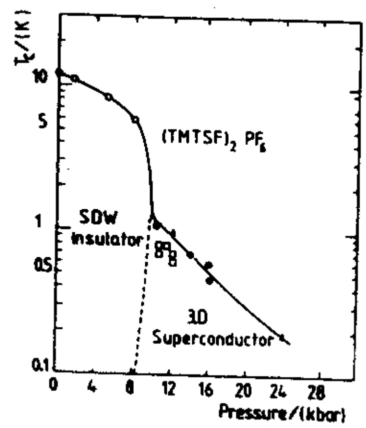
Effect of electron irradiation on the superconducting transition of $(TMTSF)_2PF_6$ (after [46]).

Fig 4.15



The phase diagram of $(TMTSF)_2AsF_6$. The inset shows the re-entrance of the superconducting state below the SDW state (after [16]).

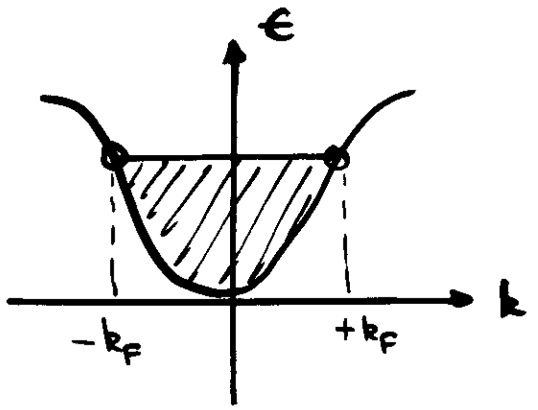
Fig. 4.8



Phase diagram of $(TMTSF)_2PF_6$ showing [illegible]

- ## One Dimension:

Very special



- **Nesting property**: $\epsilon(k+2k_F) = -\epsilon(k)$

Perturbation in interaction is divergent !!!

$$\chi(2k_F) \equiv \int dk \, \frac{1}{\epsilon_k - \epsilon_{k+2k_F}} \sim \int \frac{d\varepsilon}{2\epsilon} \sim \text{Log}(\ )$$

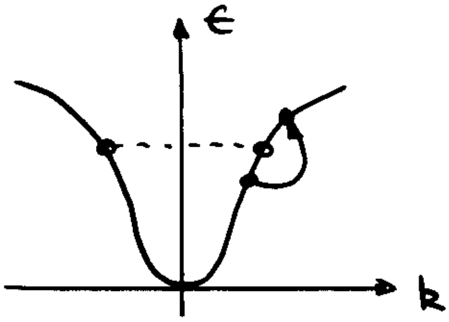
- 1D : No mean-field theory !!

↳ RG

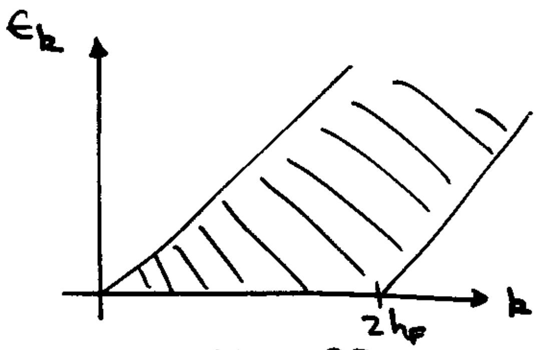
"Parquet"

$\Rightarrow$ IN 1D free fermions are a bad starting point !!

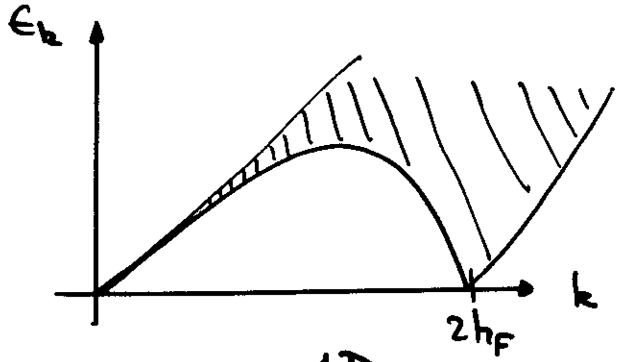
- **What is a good Starting point ?**



particle - hole
excitations



2D - 3D



1D

$$E_{q,k} \equiv \epsilon(k+q) - \epsilon_k \approx v_F(k+q) - v_F k \approx v_F q$$

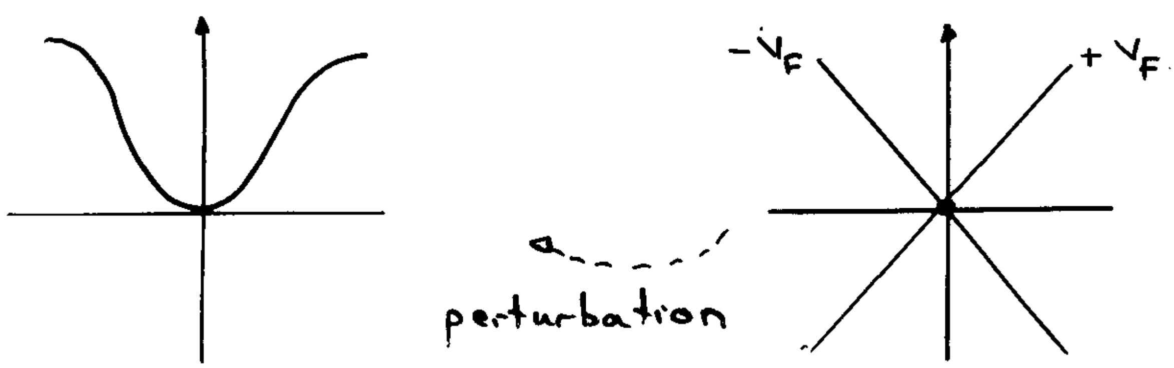
$\delta E \ll E_q \Rightarrow$ Quasiparticles !

- **Useful ?**

interaction : $H = \epsilon \psi^\dagger \psi + \int\int \longrightarrow \psi^\dagger \psi \psi^\dagger \psi$

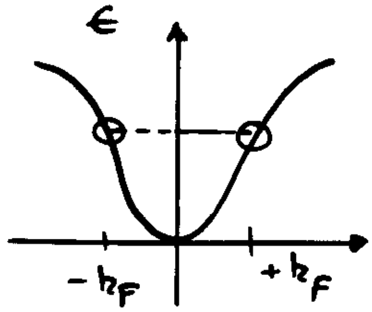
$\rho(q) \equiv \sum_k c^\dagger_{k+q} c_k \longrightarrow b^{(\dagger)}$

$H_{int} = b^\dagger b$ good basis !!



* Pure System :

$$H = -t \sum_{\langle ij \rangle} c^{+}_{i\sigma} c_{j\sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow} + V\, n_i n_{i+1} + W \ldots$$



$$\begin{cases} +k_F & \longrightarrow \\ -k_F & \dashrightarrow \end{cases}$$

[Bosonization] [A. Luther]

$$\rho(x) = \nabla \phi(x) \qquad \phi_\rho = \phi_\uparrow + \phi_\downarrow \qquad \phi_\sigma = \phi_\uparrow - \phi_\downarrow$$

$$\begin{cases} H = H_\rho + H_\sigma \\ H_\nu = \dfrac{1}{2\pi} \displaystyle\int dx \quad u_\nu K_\nu \, (\pi \Pi_\nu)^2 + \dfrac{u_\nu}{K_\nu} (\nabla\phi)^2 \end{cases}$$

Valid for All interactions (Haldane) if one uses the correct u_ρ, u_σ, K_ρ, K_σ

Hubbard:
$$\begin{cases} K_\rho = 1 - \dfrac{U}{\pi v_F} \qquad K_\sigma = 1 + \dfrac{U}{\pi v_F} \\ K_\rho \, (U \to \infty) \to 1/2 \end{cases}$$
Longer range $K_\rho \searrow$

$$\theta(x) = \int_{-\infty}^{x} dy \, \Pi(y) \qquad \psi_r(x) = e^{i[r\phi - \theta]}$$

$$\langle \rho(r) \rho(0) \rangle = \frac{1}{r^2} + \cos(2k_F r) \left(\frac{1}{r}\right)^{K_\rho + K_\sigma}$$
$$+ \cos(4k_F r) \left(\frac{1}{r}\right)^{4K_\rho}$$
$$+ \ldots$$

- All Low energy properties depend only on these modes even if interactions are strong !!! $\Rightarrow$ Luttinger Liquid

[F.D.M. Haldane J. of. Phys. C 4 2585 (81)]

Luttinger Liquid properties :

$$(u_\rho \,,\, K_\rho) \qquad\qquad (u_\sigma \,,\, K_\sigma)$$

- $(q \approx 0)$ Properties : "FL" like

$$C_V \sim \gamma T \qquad \kappa \sim \text{Cste} \qquad \chi_{q\approx 0} \sim \text{Cste}$$

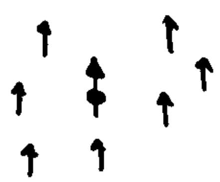
- $q \approx 2k_F$: Non FL

$$\langle \rho(r)\,\rho(0)\rangle \sim \frac{\text{Cste}}{r^2} + \cos(2k_F r)\left(\frac{1}{r}\right)^{1+K_\rho} + \dots$$

$$\chi\,(Q = 2k_F\,;\,T) \sim T^{K_\rho - 1}$$

- Repulsion : AF $\uparrow\downarrow\uparrow\downarrow\uparrow\downarrow$ "instability"

- RMN :



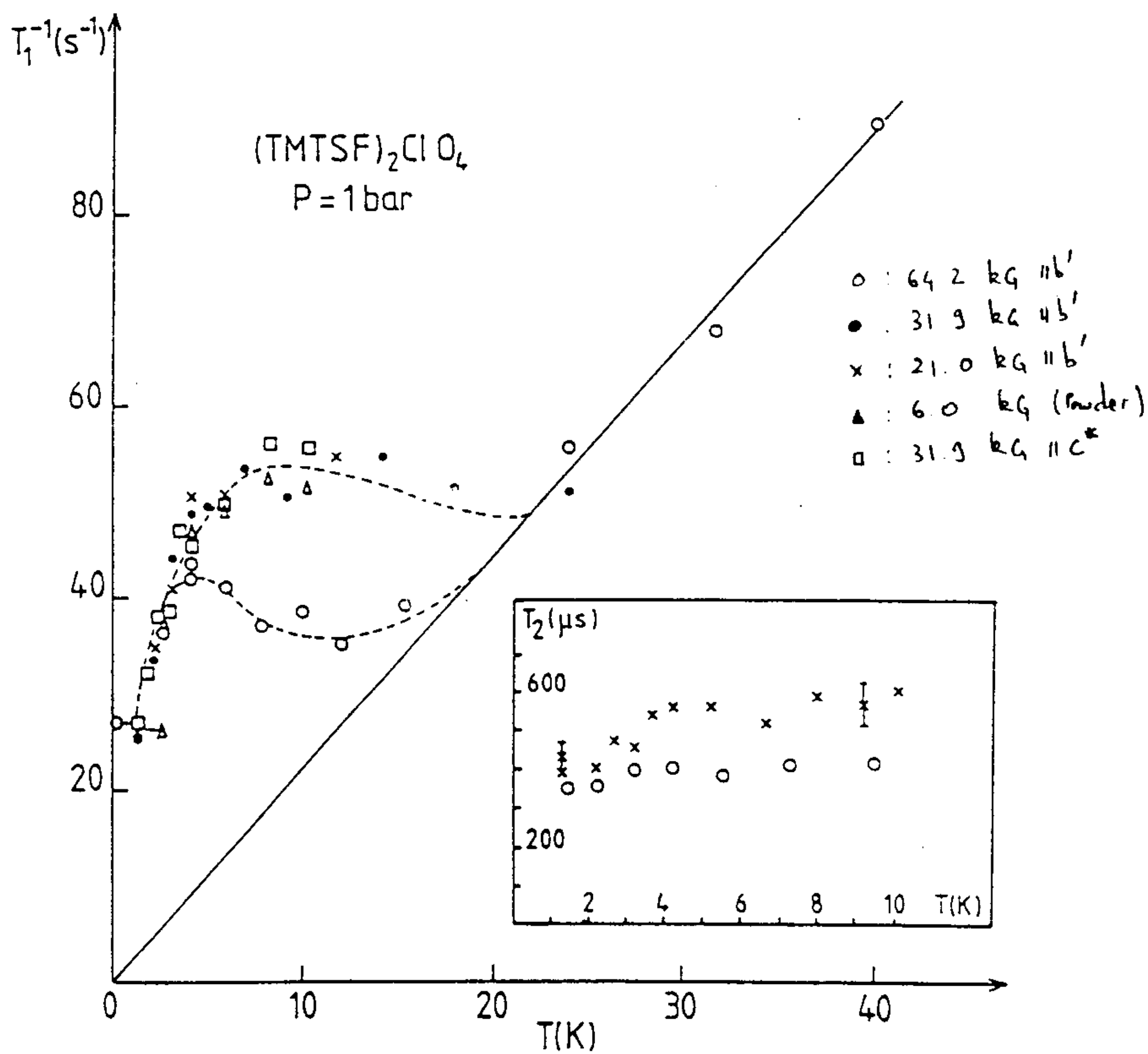
$$\frac{1}{T_1 T} \approx \sum_q \chi(q) \sim \chi(q\approx 0) + \chi(q \approx 2k_F)$$
$$\sim \text{Cste} + T^{K_\rho - 1}$$

Fermi Liquid : $\dfrac{1}{T_1 T} = \text{Cste}$ (Korringa)

Gives : $\begin{cases} K_\rho \approx 0.2 - 0.3 \\ T^*_{3D} \approx 10\ \text{K} \end{cases}$

$$T_1^{-1} = T \left[\chi(q=0) + \chi(q=2k_F) \right]$$

[F. Creuzet
P. Wzietek
C. Bourbonnais
et al.]



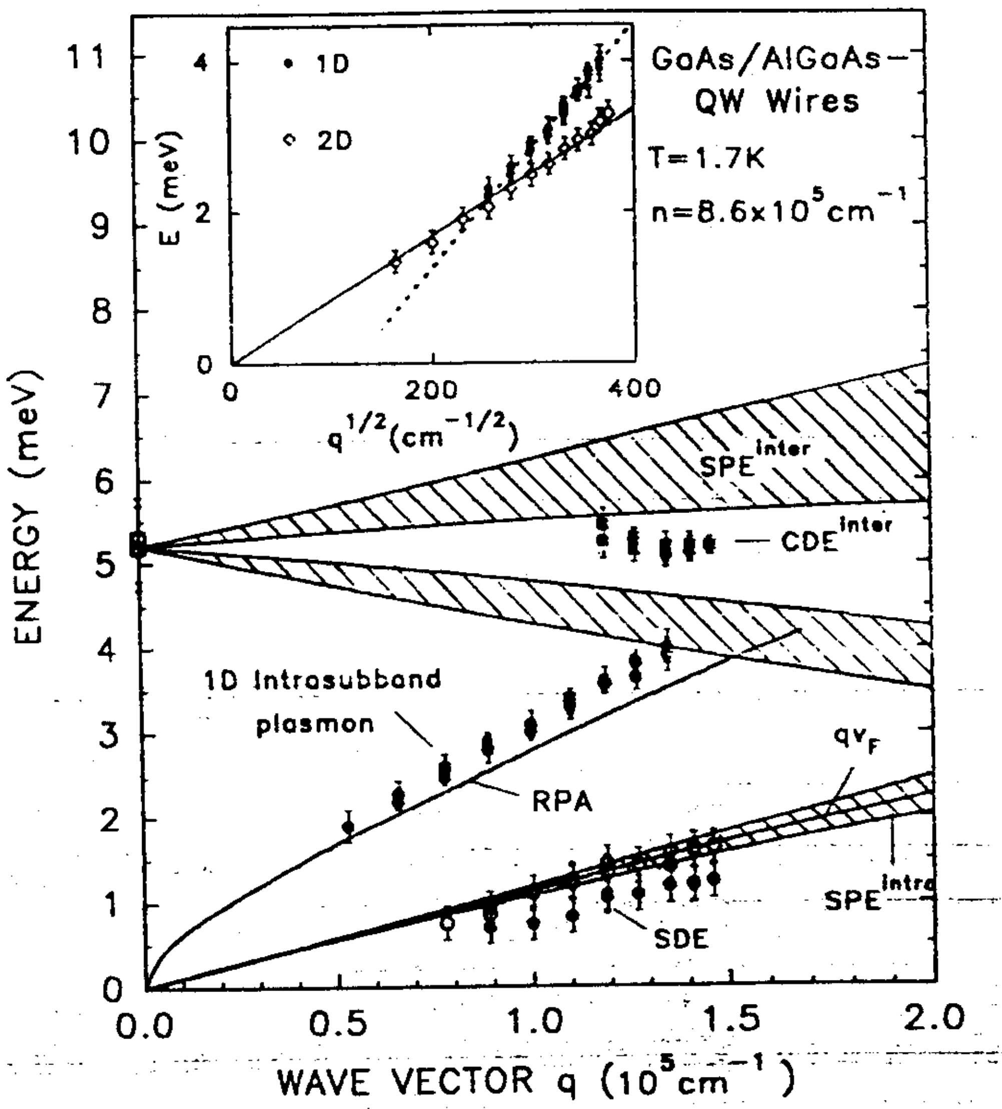


FIG. 3. Wave-vector dispersions of intrasubband and intersubband excitations of a 1D electron gas in the quantum limit. Solid dots represent intrasubband collective CDE's and SDE's. Open circles display the position of the peak at $\hbar q v_F$ of intrasubband SPE's. Squares correspond to data of 1D intersubband CDE's measured in VV polarization. The shaded areas indicate ranges of electron-hole pair excitations (SPE) given by the condition $\mathrm{Im}\chi(\omega,q)\neq 0$. Inset: Comparison of the 1D intrasubband plasmon frequencies with those of a 2D electron gas with $E_F = 3.8$ meV as a function of $q^{1/2}$.

Goni et al. PRL 67 3298 (91)

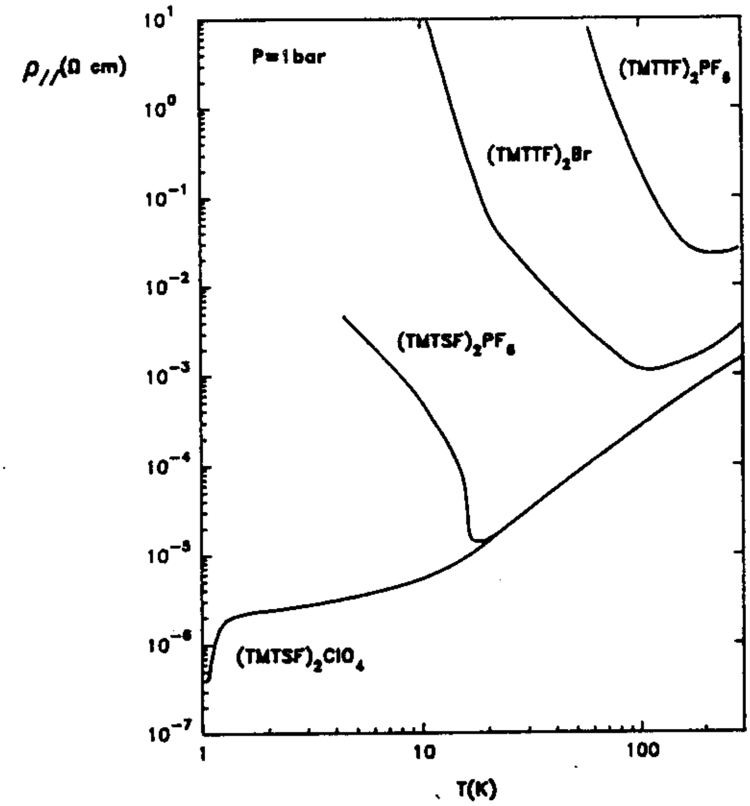
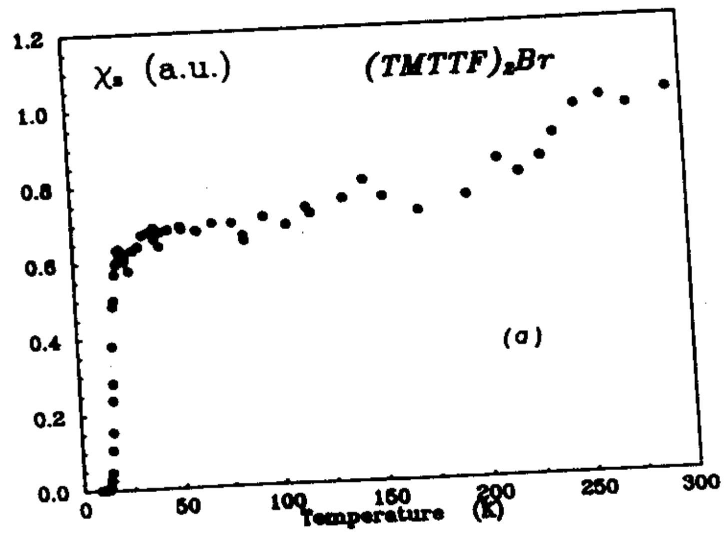
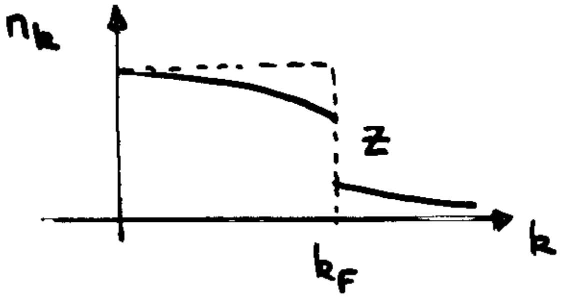


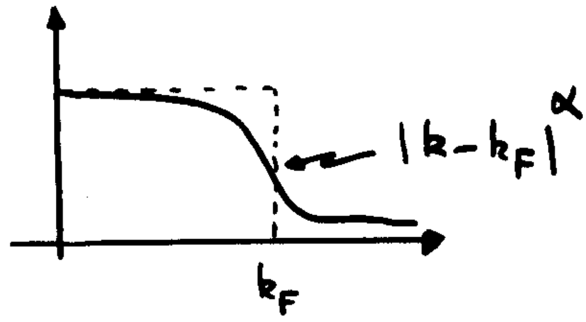
Fig. 1. — Resistivity *vs.* temperature for representatives of (TMTTF)$_2$X and (TMTSF)$_2$X series. After [3] and [11].



Photoemission

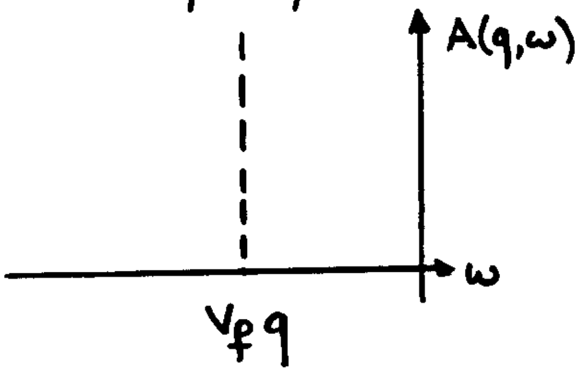


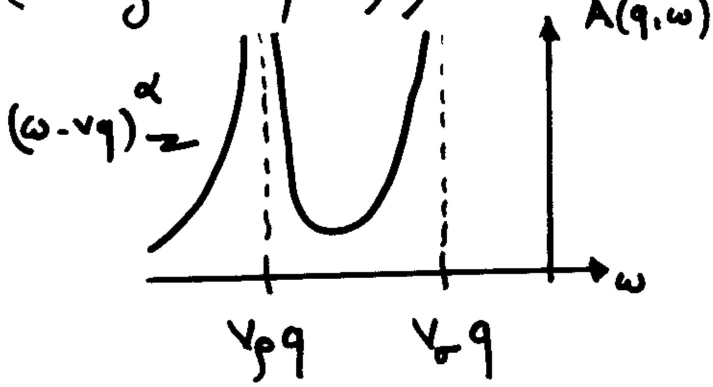
FL



L.L. $(Z=0)$

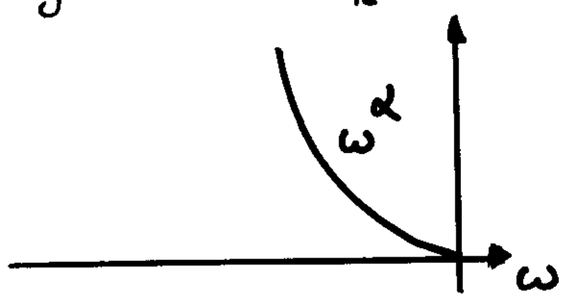
(Pas de quasiparticules (charge + Spin))





[J. Voit PRB 47 6740 (93)]

integrated $\sum_k A(k,\omega) \sim \omega^{\alpha}$ $(\alpha > 0)$



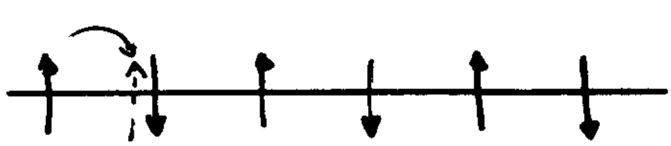
$$\alpha = \frac{1}{4}\left[K_\rho + K_\rho^{-1} - 2 \right]$$

[B. Dardel et al. EPL 24 687 (93)]

Transport :

1/2 filled band (1 part / site)

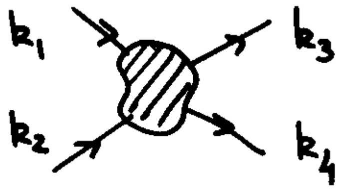
→ Mott Insulator



Charge gap Δ_ρ

Lattice Effects

→ Umklapp process

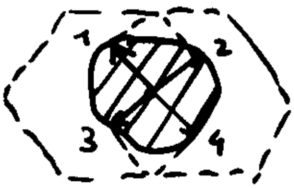


$$k_1 + k_2 = k_3 + k_4$$

$$J = \sum_i k_i / m \qquad \text{Conserved !}$$

Need $\quad k_1 + k_2 - k_3 - k_4 = G$

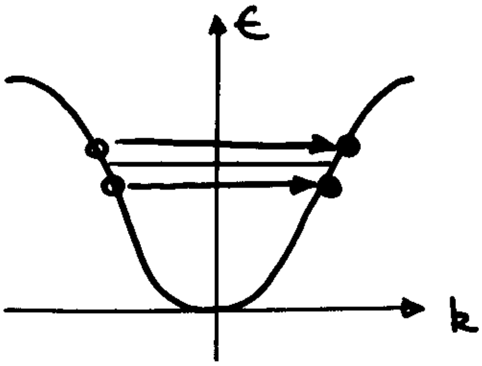
- More than 1D : easy !



BZ

$$\Rightarrow \quad \rho(T) \sim T^2$$

- 1D : Conservation of Energy and momentum



$$4k_F = G = 2\pi$$

$k_F = \pi/2 \quad \to$ half filling

"Naive Boltzmann" $\longrightarrow \rho(T) \sim T$

→ Umklapp also responsible for Mott transition

[Lieb + Wu ; Gorkov + Dzialoshinskii , Luther + Emery]

Hubbard: insulator $(\delta = 0)$ for all $U > 0$

$$\sum_i n_{i\uparrow} n_{i\downarrow} \equiv \sum_i \left(e^{ik_F r_i} \psi_+^\dagger(r_i) + e^{-ik_F r_i} \psi_-^\dagger(r_i) \right)_\uparrow \text{h.c} \left(\qquad \right)_\downarrow \text{h.c}$$

$$\equiv \sum_i \underbrace{e^{i 4k_F R_i}}_{1 \text{ if } 4k_F = 2\pi} \psi_+^\dagger(r_i) \psi_+^\dagger(r_i) \psi_-(r_i) \psi_-(r_i)$$

$$\rightarrow \int dx \quad \cos\left(\sqrt{8}\, \phi_\rho(x) + \delta x\right)$$

$$H_\rho = \frac{1}{2\pi} \int dx \; (u_\rho K_\rho)(\pi \Pi_\rho)^2 + \frac{u_\rho}{K_\rho} (\nabla \phi)_\rho^2$$

$$+ \frac{2 g_3}{(2\pi\alpha)^2} \int dx \quad \cos\left(\sqrt{8}\, \phi + \delta x\right)$$

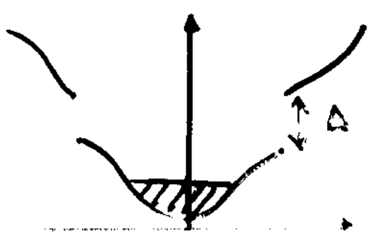
Current:

$\rho = \nabla \phi \qquad \frac{\partial \rho}{\partial t} + \frac{\partial j}{\partial x} = 0 \qquad \rightarrow \quad j \equiv \partial_t \phi$

$g_3 = ?$

Hubbard $\quad g_3 = U$

Organics "1/4" filled

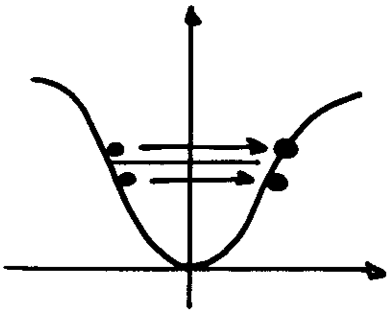


$g_3 \sim U \frac{\Delta}{W}$

- More general (Higher commensurabilities!)

[TG + A.J. Millis (92); H.J. Schulz (93)]

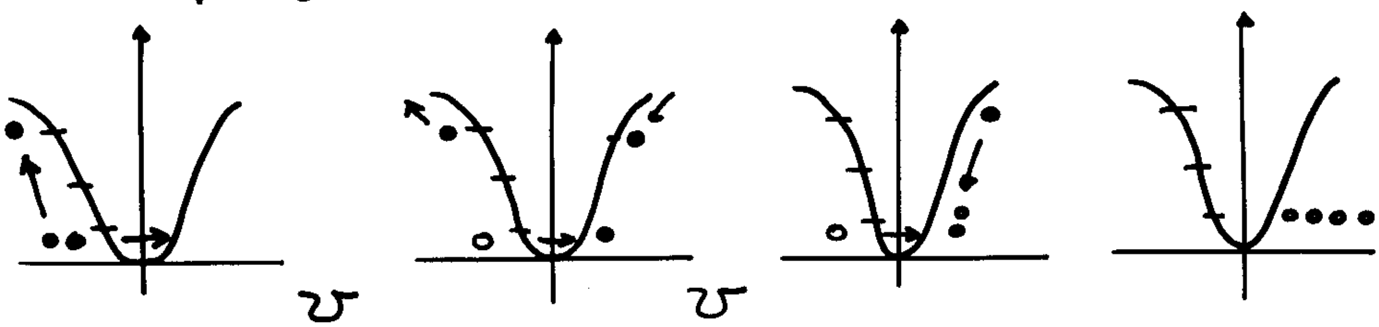
- 1/2 filling



$$H_{1/2} = g_{1/2} \cos(\sqrt{2}\, 2\, \phi_\rho)$$

$$g_{1/2} \sim v$$

- 1/4 filling



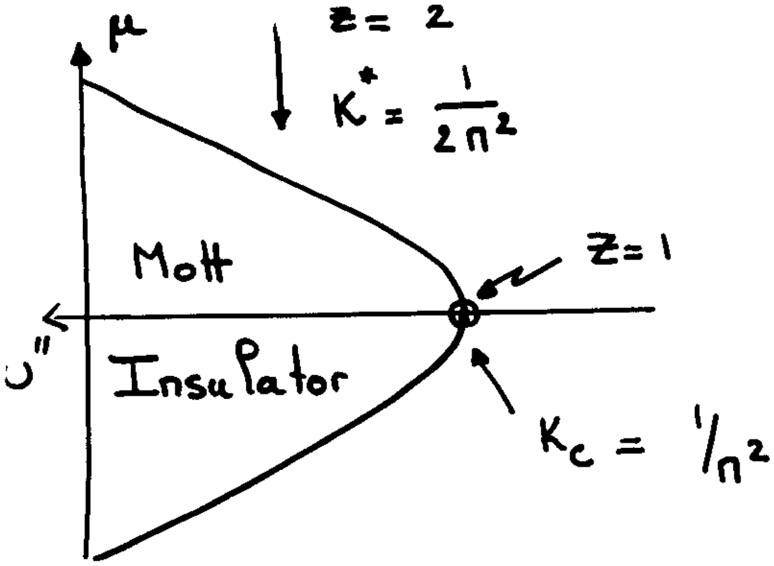
$$H_{1/4} = g_{1/4} \cos(4\sqrt{2}\, \phi_\rho)$$

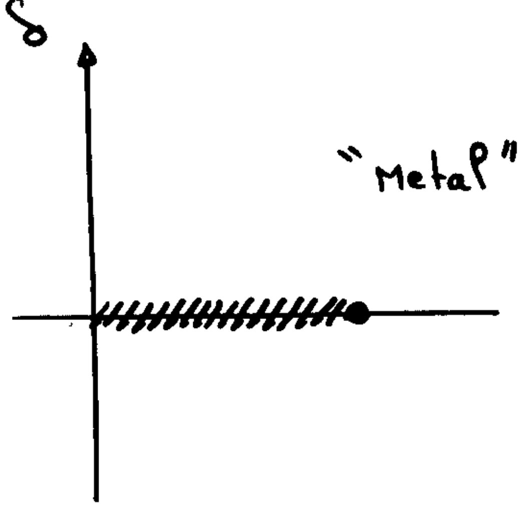
$$g_{1/4} \sim v \left(\frac{U}{E_F}\right)^2$$

Commensurability of order n

$$H_v = g \cos(n\sqrt{8}\, \phi_\rho + \delta x)$$

$$H = \frac{1}{2\pi} \int dx \; uK (\pi\Pi)^2 + \frac{u}{K} (\nabla\phi)^2 + H_v$$





(All 1D systems : Fermions, bosons, ...)

[TG PRB 44 2905 (91), PRB 46 343 (92)]
Physica B 230-232 975 (97)

• $\underline{\delta = 0}$

$\cos(n\phi) \approx m\phi^2$ Gap Δ_ρ

[1/2 Filling: Lieb + Wu ; Luther + Emery]

1/2 filling : $K_c = 1$ (non interacting)

1/4 filling : $K_c = 1/4$ (strong repulsion)

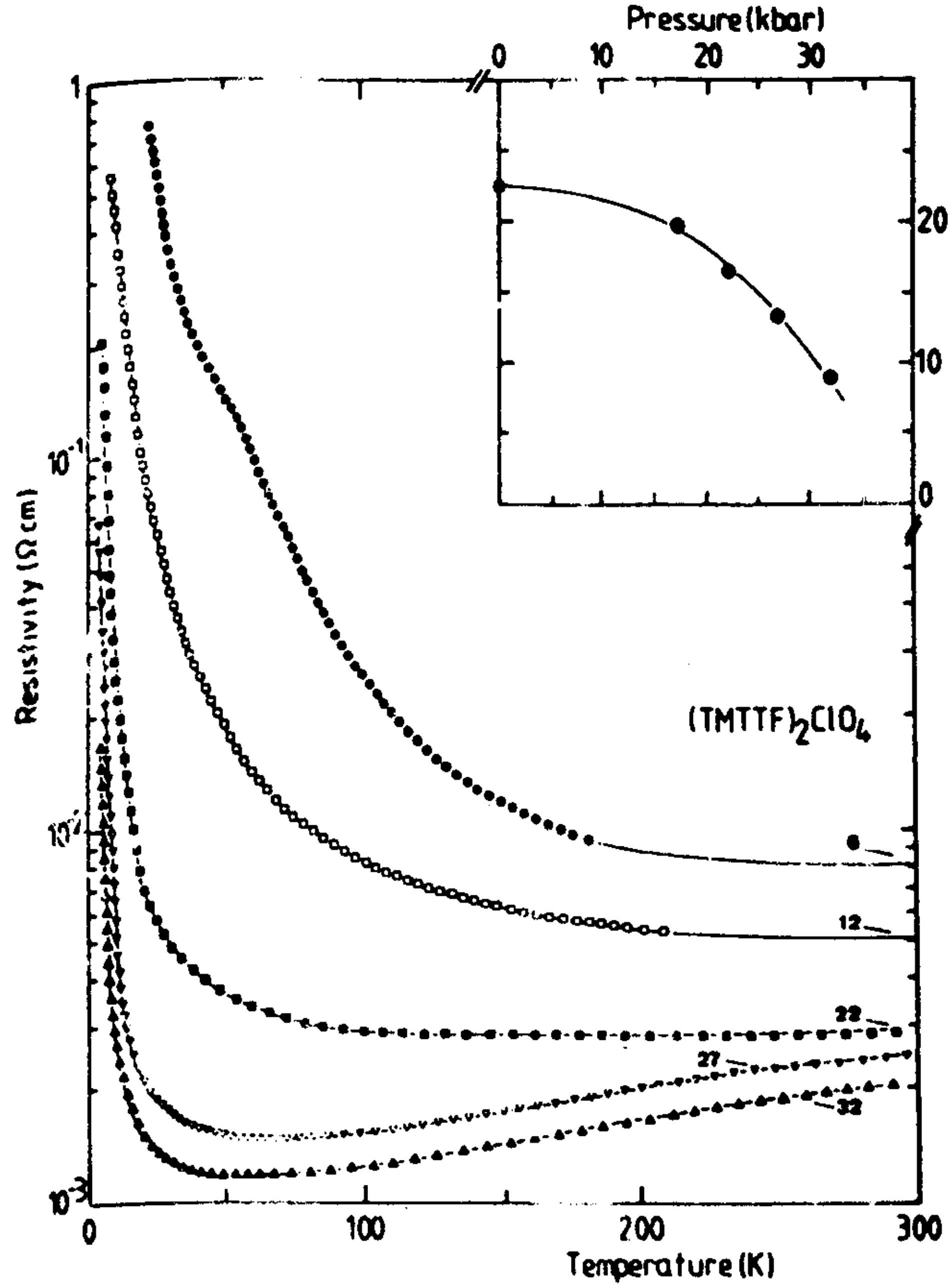
• Transport:

$$\sigma(\omega) = D\,\delta(\omega) + \sigma_{reg}$$

Hubbard : $D \sim \delta$ [Schulz; Shastry + Sutherland; Stafford + Millis]

$\sigma(T)$ etc.... ?

$1/\tau_{ee}$ [Gorkov + Dzialoshinskii] but | perturbative in int
1/2 filling

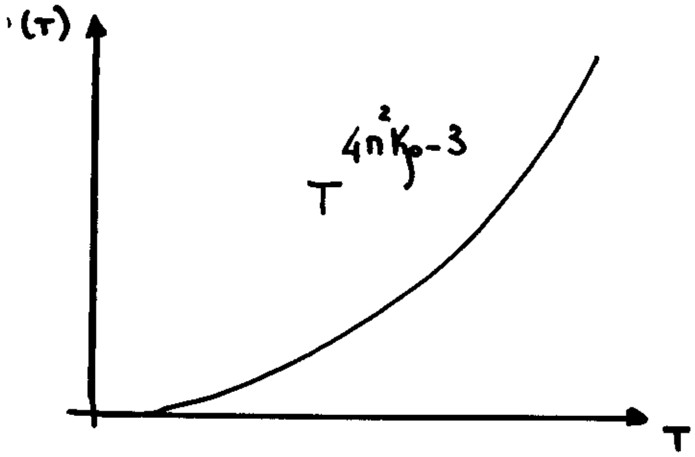


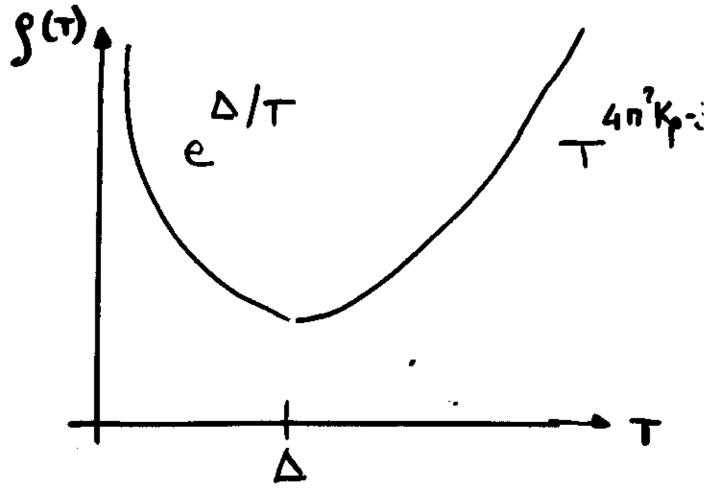
$(TMTTF)_2\ ClO_4$

[F. Creuzet et al.
J de Phys C3 - 1099 (83)]

$\rho(T)$ $[\omega = 0]$:

- $\delta = 0$:





$K > K_c = 1/n^2$ — "Metallic state"

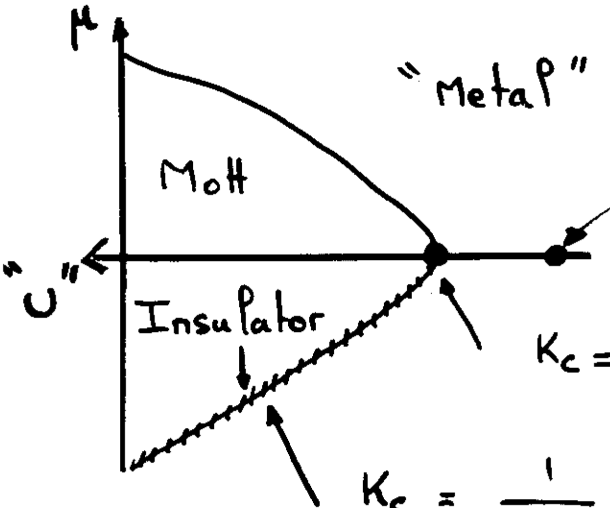
$K < K_c$ — "Mott Insulator"

- At K_c :

$$\rho(T) \sim T \quad \text{universal}$$

$$\sigma(\omega) \sim \frac{1}{\omega \, \mathrm{Log}^2 \omega}$$

- When $\delta \neq 0$ $[\delta \simeq 0]$: $\rho(T) \sim 1/T$



$\rho(T) \sim T^{n^2 4K_\rho - 3}$

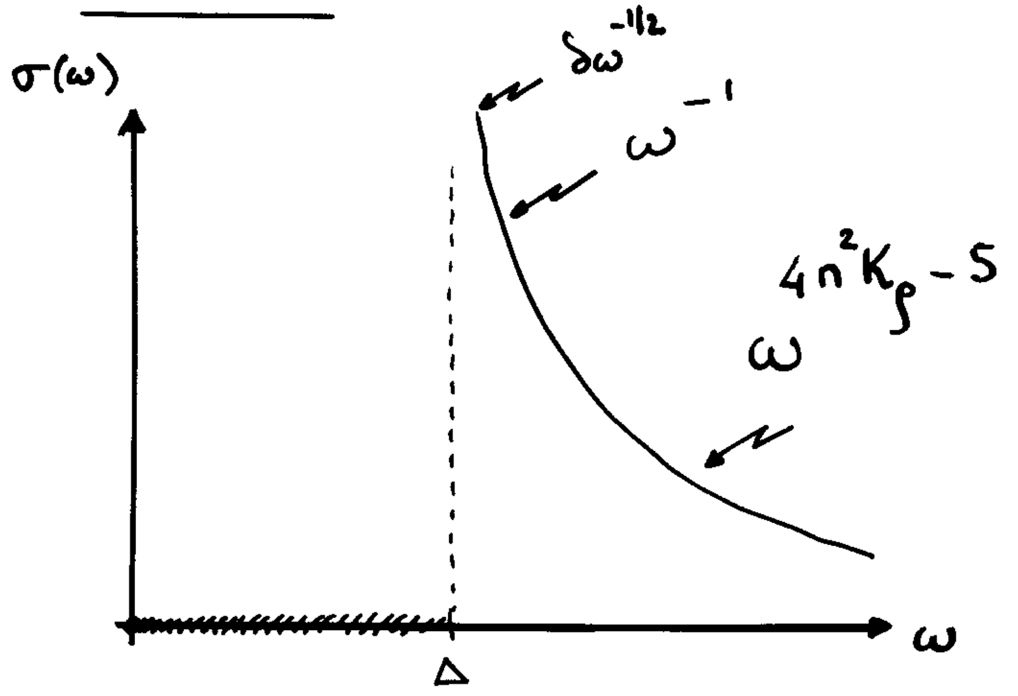
$\sigma(\omega) \sim \mathbb{D}\,\delta(\omega) + \omega^{n^2 4K_\rho - 5}$

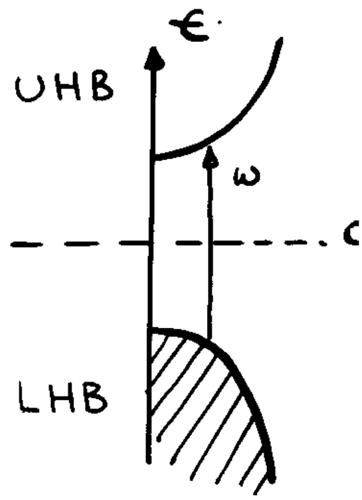
$K_c = 1/n^2$ $\rho(T) \sim T$ $\sigma(\omega) \sim 1/\omega$

$K_c = \frac{1}{2n^2}$ $\rho(T) \sim 1/T$

* $\sigma(\omega)$: $[T = 0]$ [TG PRB 44 2905 (91); PRB 46 345(
[Physica B 230-232 975 (97)]

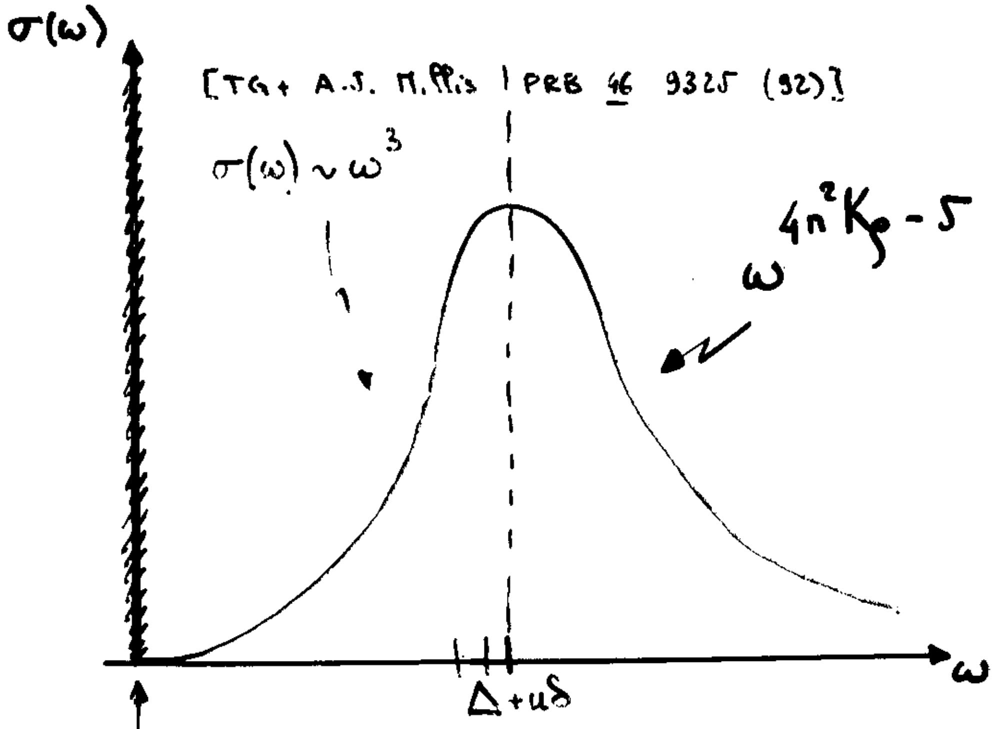
• $\delta = 0$:

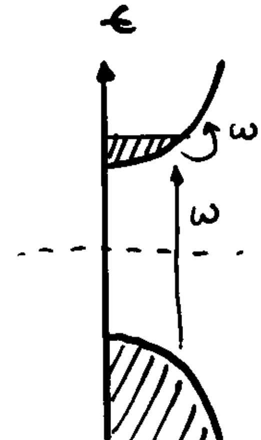




$n=1$ (1/2 filling) $\sigma(\omega) \sim \omega^{4K_\rho - 5}$ $[\Delta \neq 0$ if $K > K_c]$

• $\delta \neq 0$

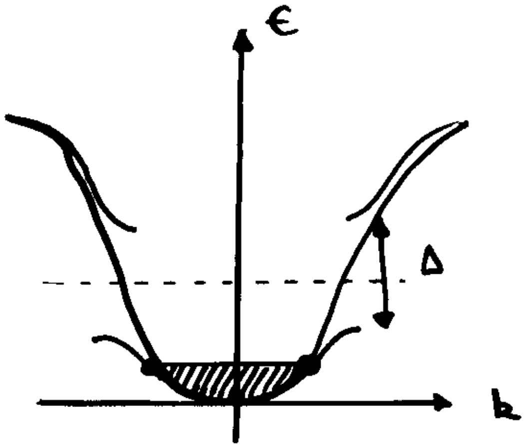




$\mathbb{D}\,\delta(\omega)$ $\mathbb{D} \sim \delta/\Delta$ [generic in 1D]

Organics :

TMTTF or TMTSF → 1/4 filled



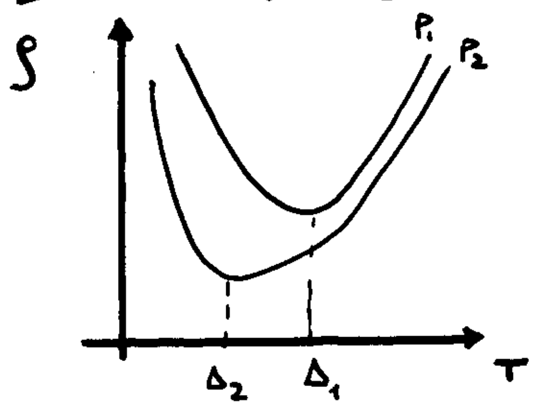
- dimerization gap Δ
- Interactions "v"
- Umklapp $g_{1/2} \sim v \left(\frac{\Delta}{E_F}\right)$

▸ ≠ Hubbard (where $g_{1/2} \sim v$)

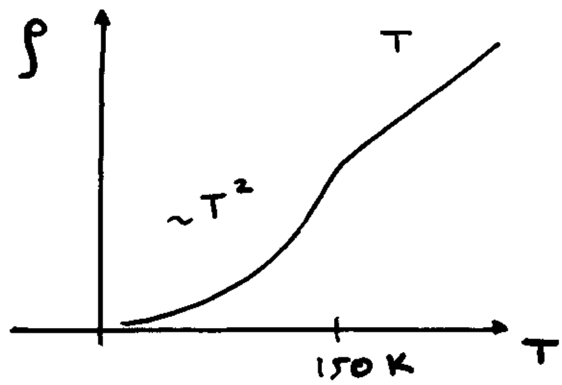
▸ $g_{1/2}$ can change [pressure]

- but also $g_{1/4} \sim v \left(\frac{v}{E_F}\right)^2$

→ Should be Mott Insulators



TMTTF



TMTSF

TMTTF OK but ! ↓

$K_\rho^{tr} = 0.8$ $K_\rho^{NMR} \sim 0.2 - 0.3$!!

$$\rho \sim g_{1/2}^2\, T^{4K_\rho - 3} + g_{1/4}^2\, T^{16 K_\rho - 3}$$

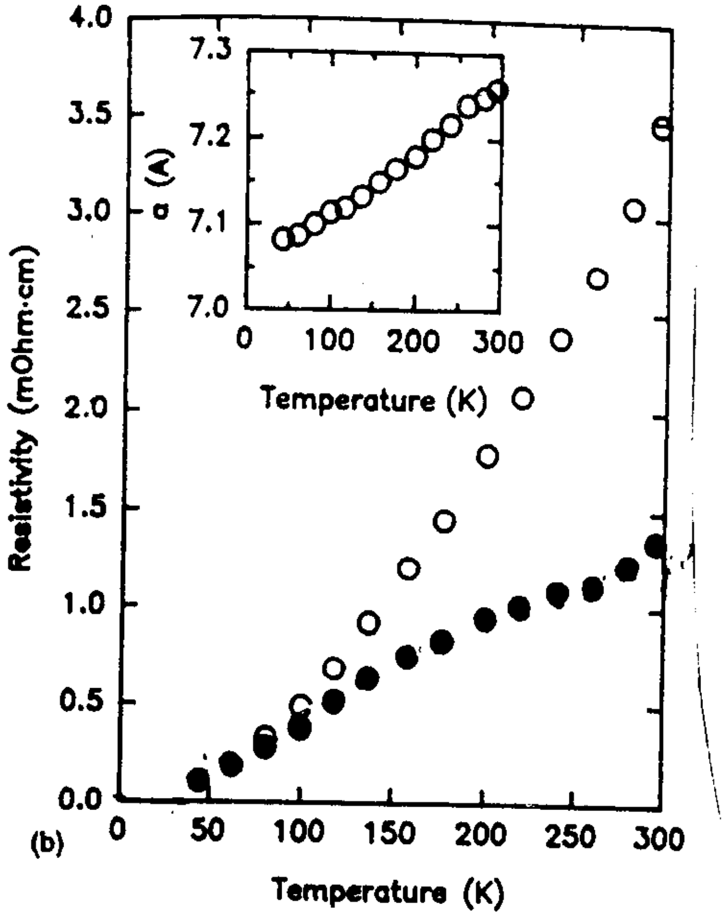


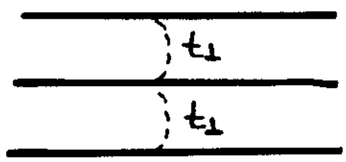
Figure 14 (a) Pressure dependence of the spin susceptibility $\chi \sim (T_1T)^{-1/2}$ from NMR data. (From Ref. 41b.) (b) Constant-pressure and constant-volume temperature dependences of the resistivity of $(TMTSF)_2AsF_6$ derived point by point from the constant-pressure data of Fig. 12. The lattice parameters are from Ref. 33 and the pressure coefficient of the conductivity from Ref. 57.

[D. Jerome "Organic Superconductors" ed. J.P. Farges]

→ $\sigma(\omega)$ also gives K_ρ

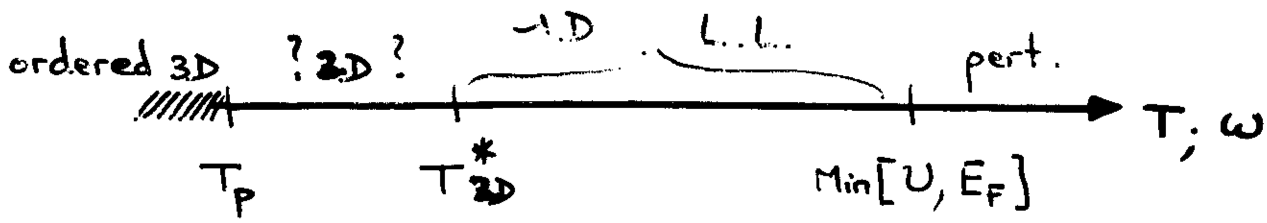
[No thermal expansion problem !]

Quasi - one dimensional systems :



$t_\parallel \sim$ 3000 K

$t_\perp \sim$ 300 K

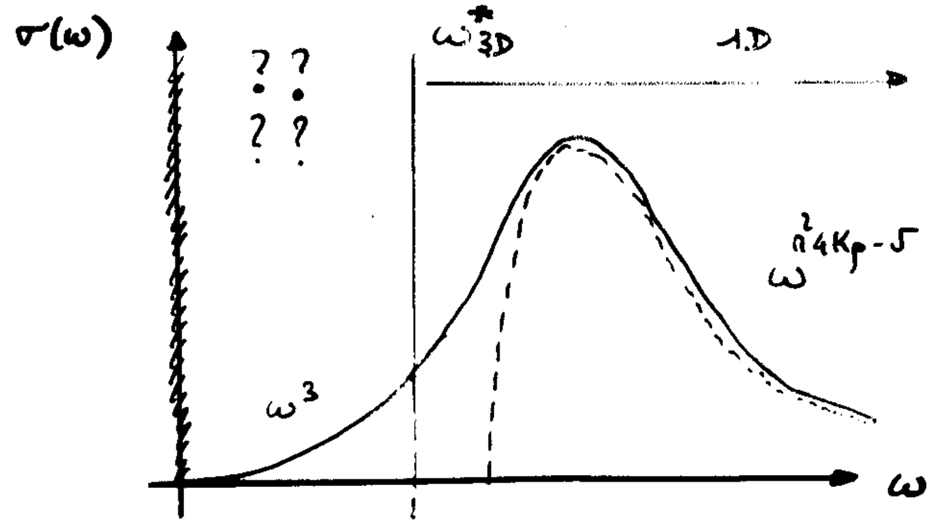


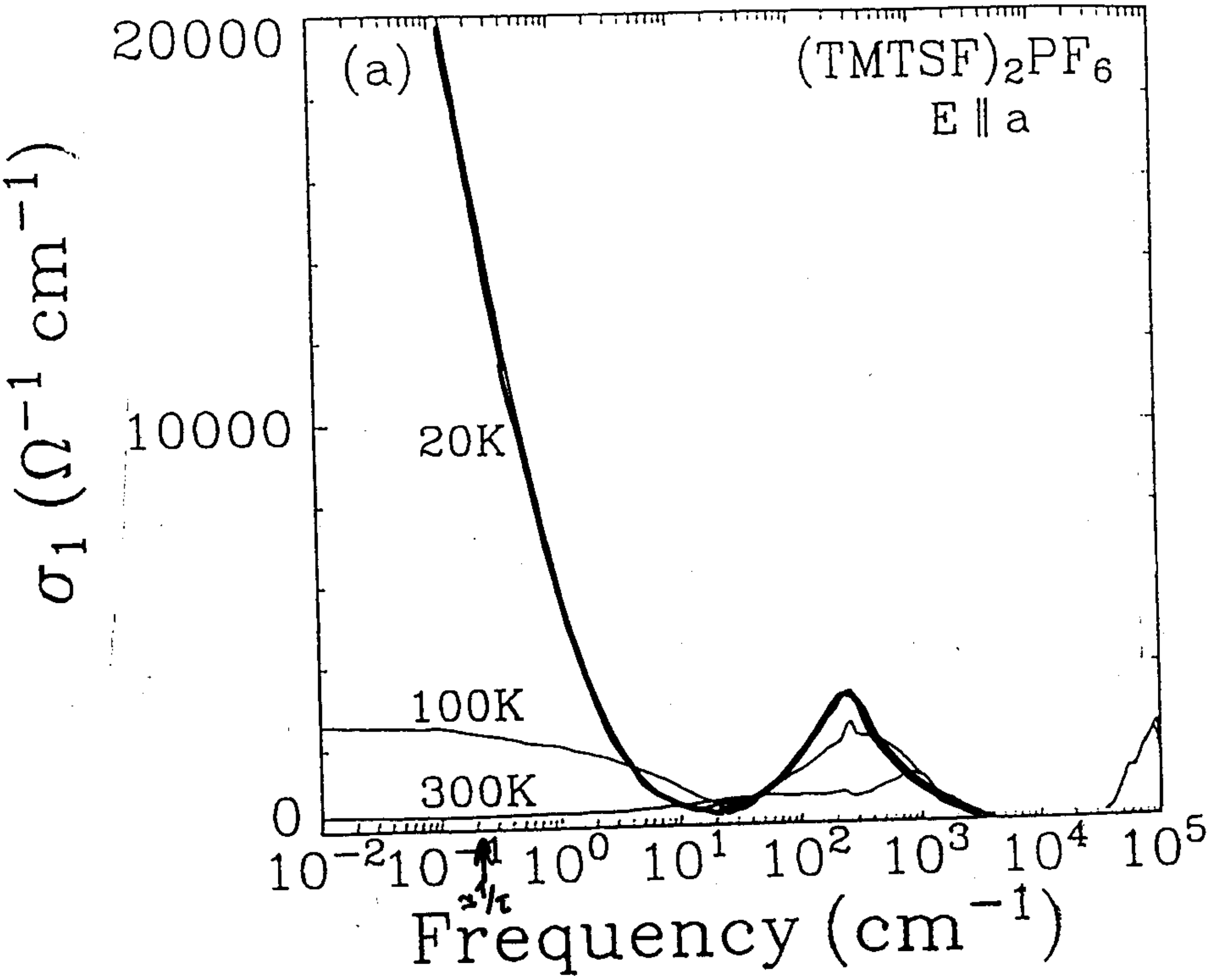
$= t_\perp$

$=^? t_\perp^\nu$

T^*_{2D} : 100K → 10K $\qquad$ T_p : 10K - 1K

- $\underline{\Delta_\rho > T^*_{3D}}$: $t_\perp$ irrelevant
- $\underline{\Delta_\rho < T^*_{3D}}$:





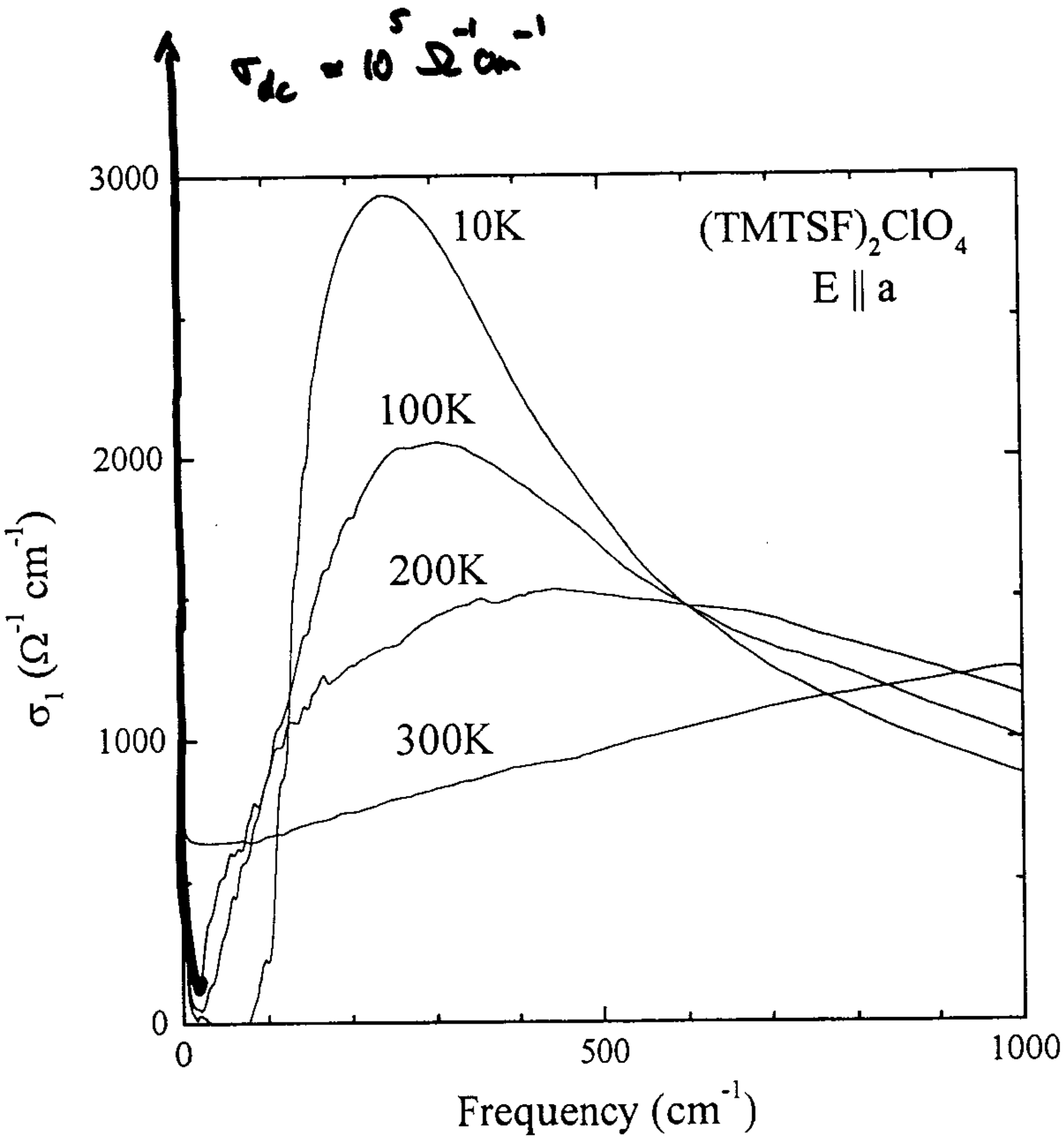
— $\omega = 0$ MODE :

DRUDE LIKE WITH :

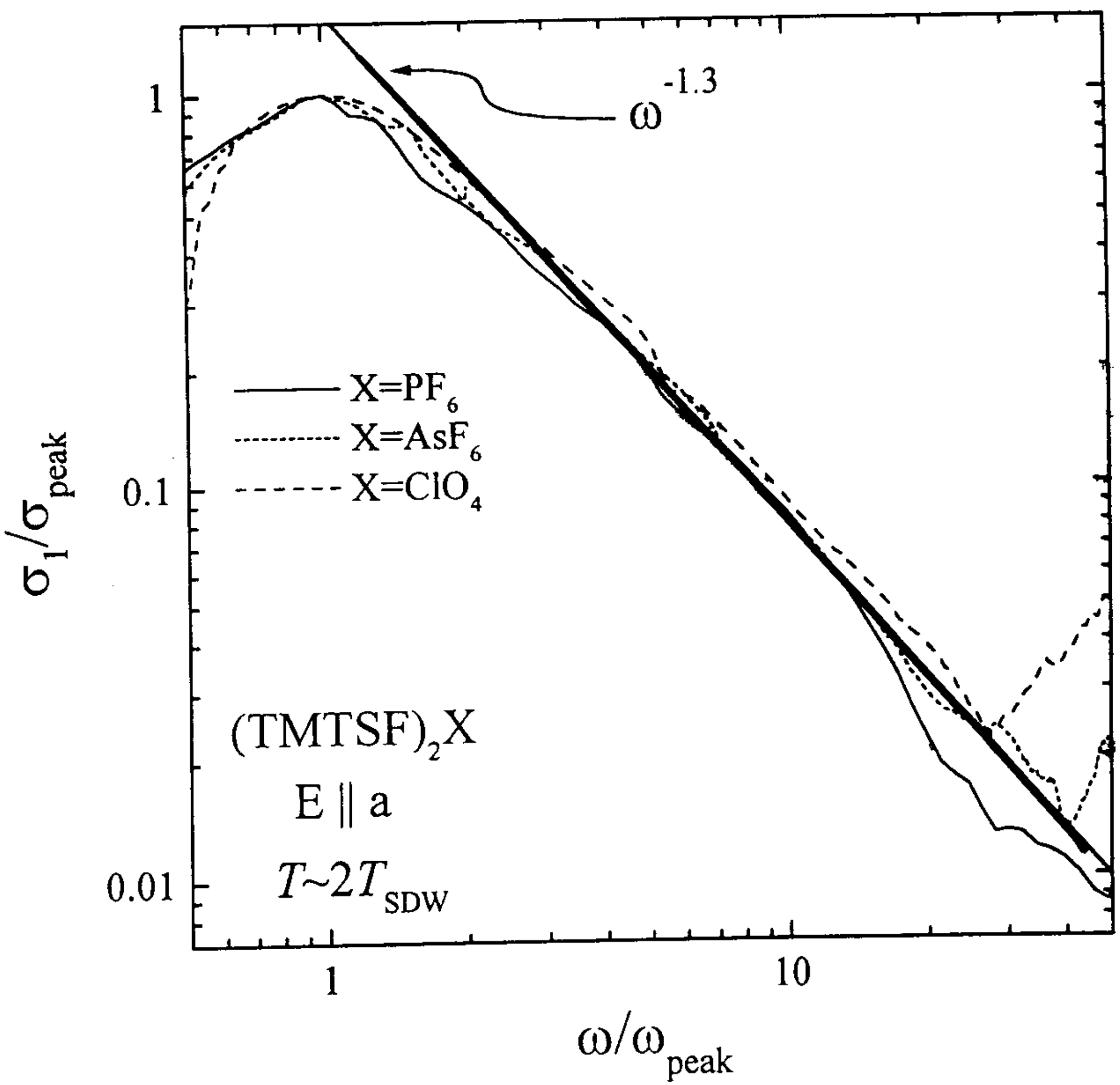
- SMALL $\omega_p = \left(\frac{4\pi n e^2}{m^*}\right)^{1/2}$

- ω DEP. $1/\tau$ (SMALL)

M. Dressel et al.
PRL 76 3838 (96)

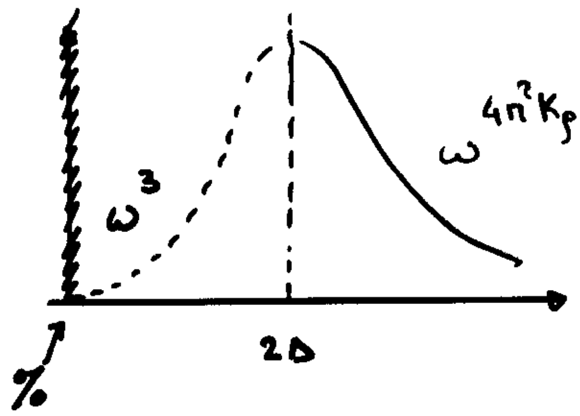


A. Schwartz et al. PRB



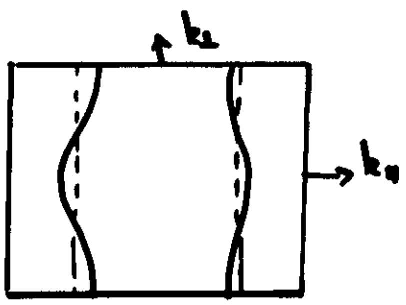
$\sigma(\omega)$

[TG Physica B (1997) 230-232 975]



$\Delta \gg t_b \quad \rightarrow \quad t_b^* \rightarrow 0 \quad$ 1D physics

$\Delta \lesssim t_b \quad \rightarrow \quad$ Crossover $\quad \omega^*_{3D} \quad (T^*_{3D})$



$k_\parallel^F \neq \pi/4$ "doping"

- $\underline{\text{Exp.}}$:

$\omega^{-1.2}$ $\rightarrow$ K_ρ : 0.8-0.9 (1/2 f.f. Umk.)

$\phantom{\omega^{-1.2}}$ $\rightarrow$ K_ρ : 0.2 0.25 (1/4 f.f. Umk.)

and. $\underline{\text{No}}$ ω^3

→ Not 1D below 100 - 200 K.

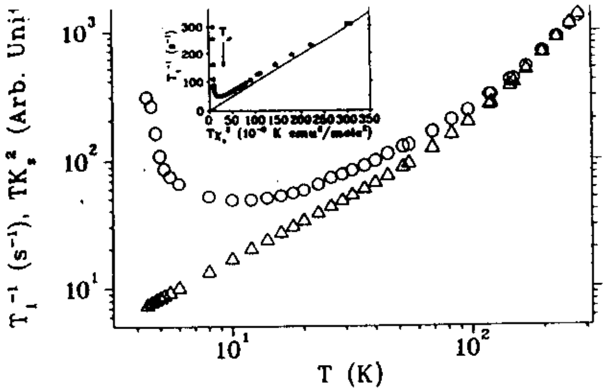


FIG. 3. Temperature dependence of ^{77}Se T_1^{-1} for $H = 15$ T along c^*. TK_s^2 is scaled in order to fit the T_1^{-1} value at high temperature where the uniform contribution dominates. In the inset T_1^{-1} vs $T\chi_s^2$ is reported (the solid line passing through the origin shows the extrapolation of the high temperature regime).

TMTSF$_2$ (ClO$_4$)

K. Behnia et al. PRL 74 5272 (95)

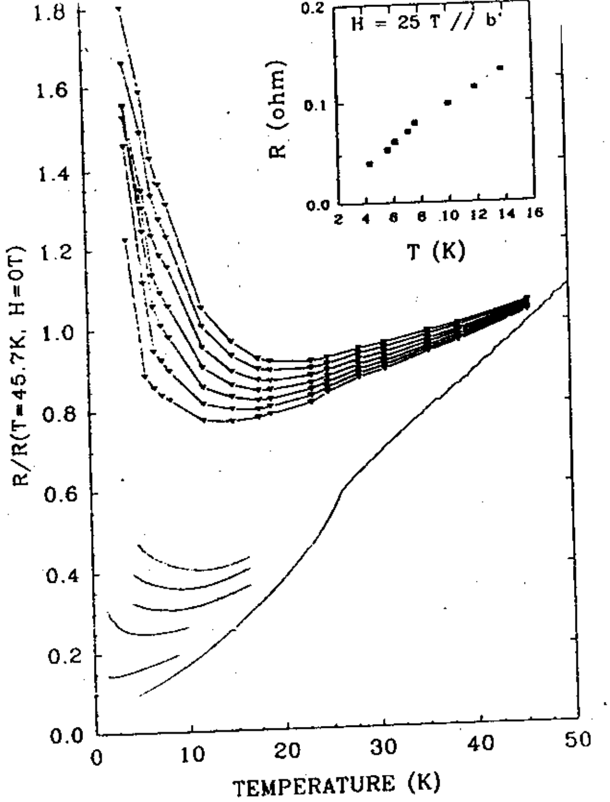
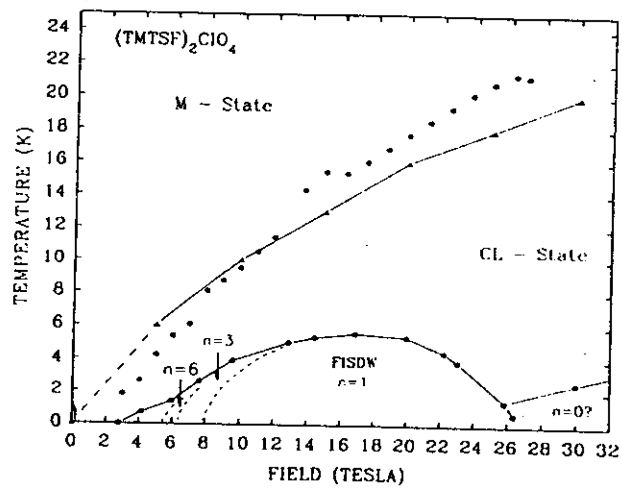


FIG. 1. Resistivity results for two different samples. The continuous lines are the measurements performed at low fields 12.3, 10, 8, 6, 3, and 0 T, respectively. The high field points 27, 25, 22.5, 20, 17.5, 15, and 12.5 T were taken from the field sweeps at fixed temperatures. It clearly shows that resistance minima are shifted towards higher temperatures at higher magnetic fields. Inset: Resistance vs temperature at 25 T along the b' direction. No minimum is observed down to 4.2 K.



'IG. 2. Temperature vs magnetic field phase diagram of TMTSF)$_2$ClO$_4$ displaying the various phases, metallic (M), harge-localized (CL), and the field-induced spin-density-wave hases (FISDW). Triangles show the field dependence of $_n(H)$ from the theory with the set of parameters given in ie text.

Speculations :

- Which Umklapp ?

$$\Delta \sim g_{1/2}^{\frac{1}{2(1-K_\rho)}} \sim g_{1/2}^{2} \qquad (K_\rho \approx 0.8)$$

Seems very small ??

↳ 1/2 filled Umklapp <u>and</u> $K_\rho \approx 0.2 - 0.25$ [?]

- <u>Question</u>:

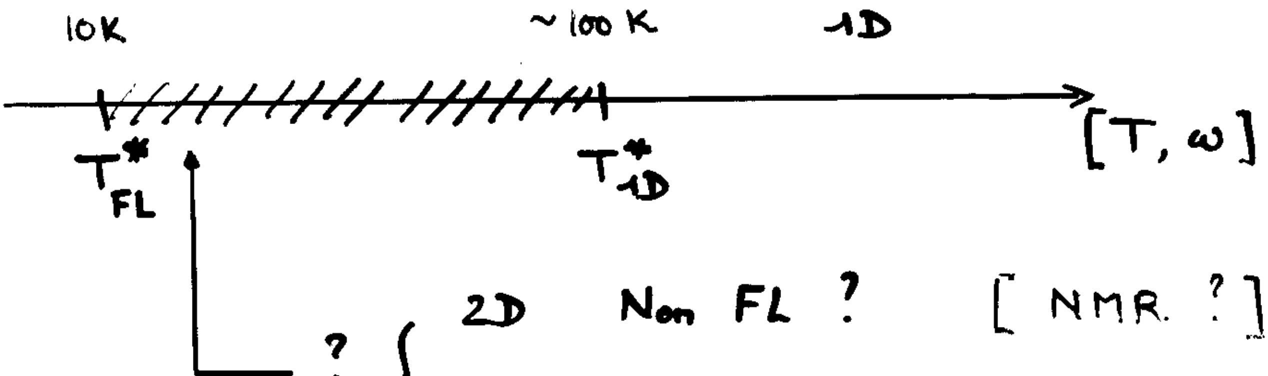
→ TMTTF ???

$$\Delta \sim g_{1/4}^{\frac{1}{2(1-4K_\rho)}} \qquad ???$$

→ why $T^*_{1D} \sim 100$ K

$$t_\perp \left(\frac{t_\perp}{t_\parallel}\right)^{\frac{\alpha}{1-\alpha}} \sim \frac{t_\perp^2}{t_\parallel} \qquad \leftarrow 30\text{ K } !$$

-



? { 2D Non FL ? [NMR ?]
2D FL ? [$\rho(T) \sim T^2$]
Crossover ?

- Conclusions:

  - Complete study of Transport and Mott transition in 1D [Fermion / bosons ; all filling, T, ω
  - 2 different transitions:
    Mott-ν Mott-δ
  - Non-universal power laws in Transport

$$\begin{cases} \rho(T) \sim T^{4n^2K-3} \\ \sigma(\omega) \sim \omega^{4n^2K-5} \end{cases}$$

Organics:

- $\sigma(\omega)$ o.k with 1D

$K_\rho \approx 0.8 - 0.9$ or $K_\rho \approx 0.2 - 0.25$

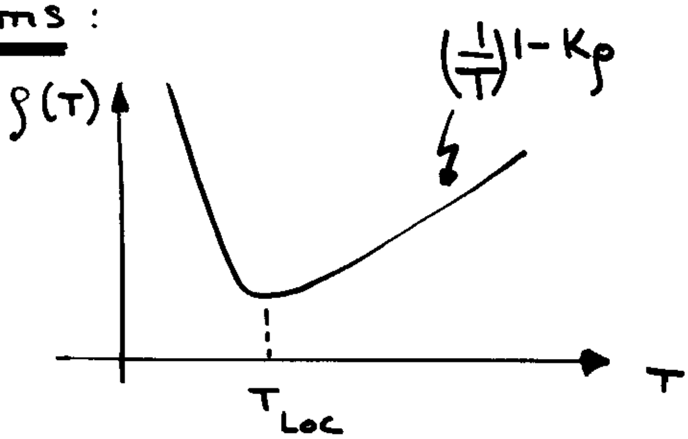
$\omega^*_{1D} \sim 100\,K - 200\,K$ $\Delta \approx 100\,K$

- ok with d.c.

- which Umklapp ?
- Role and renormalization of t_b ?
- What happens $10K \leq T \leq 100K$?

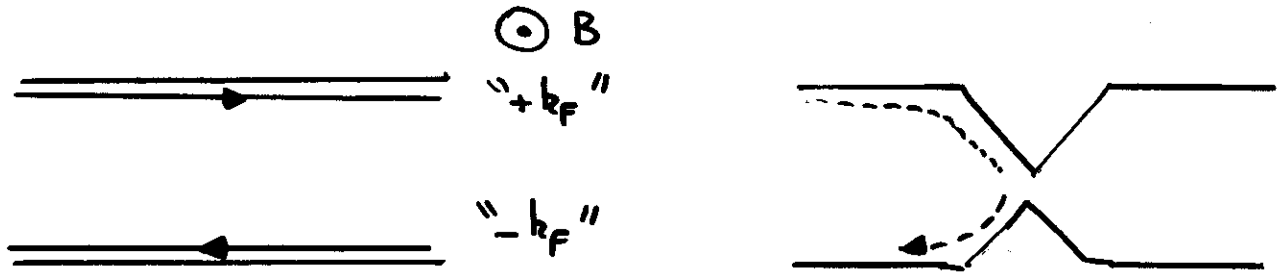
Other 1D Systems :

Disorder !!



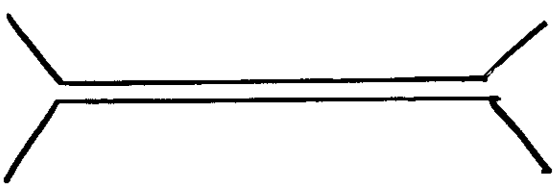
[TG + H.J. Schulz PRB 37 325 (88) ; TG + P. Le Doussal PRB (96)]

Hall Systems :



[C. Kane + M.P.A. Fisher PRB 46 15233 (92)]

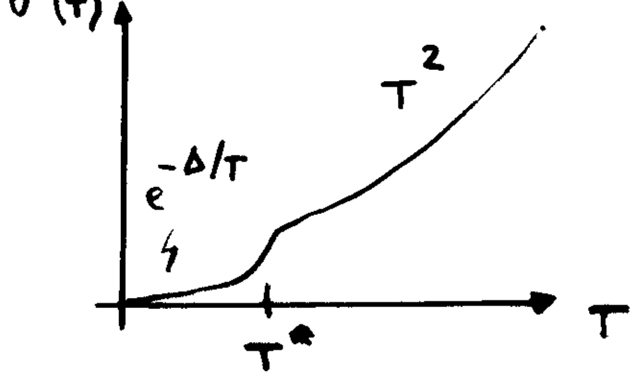
Quantum Wires



Coulomb not Screened !

Wigner Crystal (!)

$$\langle \rho(r)\,\rho(0)\rangle_{WC} \sim \cos(4k_F r)\, e^{-\mathrm{Log}^{1/2}(r)}$$



[H. + Maurey + T.G. PRB 51 10833 (95)]

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J. Voit — Phys. Rep (1996)

H.J. Schulz + TG — Rev. Mod. Phys. (1997)

- Mott Transition in d=1

TG — Physica B 230-232 975 (97)

- Disorder in d=1 / Link with classical Systems

TG + H.J. Schulz — PRB 37 325 (88)

C. Kane + M.P.A. Fisher — PRB 46 15233 (91)

TG + P. Le Doussal — PRB 53 15206 (96)