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SUMMER SCHOOL
on
LOW-DIMENSIONAL QUANTUM SYSTEMS:
Theory and Experiment
(16 - 27 JULY 2001)

PLUS

PRE-TUTORIAL SESSIONS
(11 - 13 JULY 2001)

TRANSPORT AND DIMENSIONAL CROSSOVER IN QUASI-ONE DIMENSIONAL CONDUCTORS

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Transport and dimensional crossover in quasi-one dimensional conductors

G. Gruner, L. DeGiorgi
A. Schwarz, V. Vescoli, M. Dressel

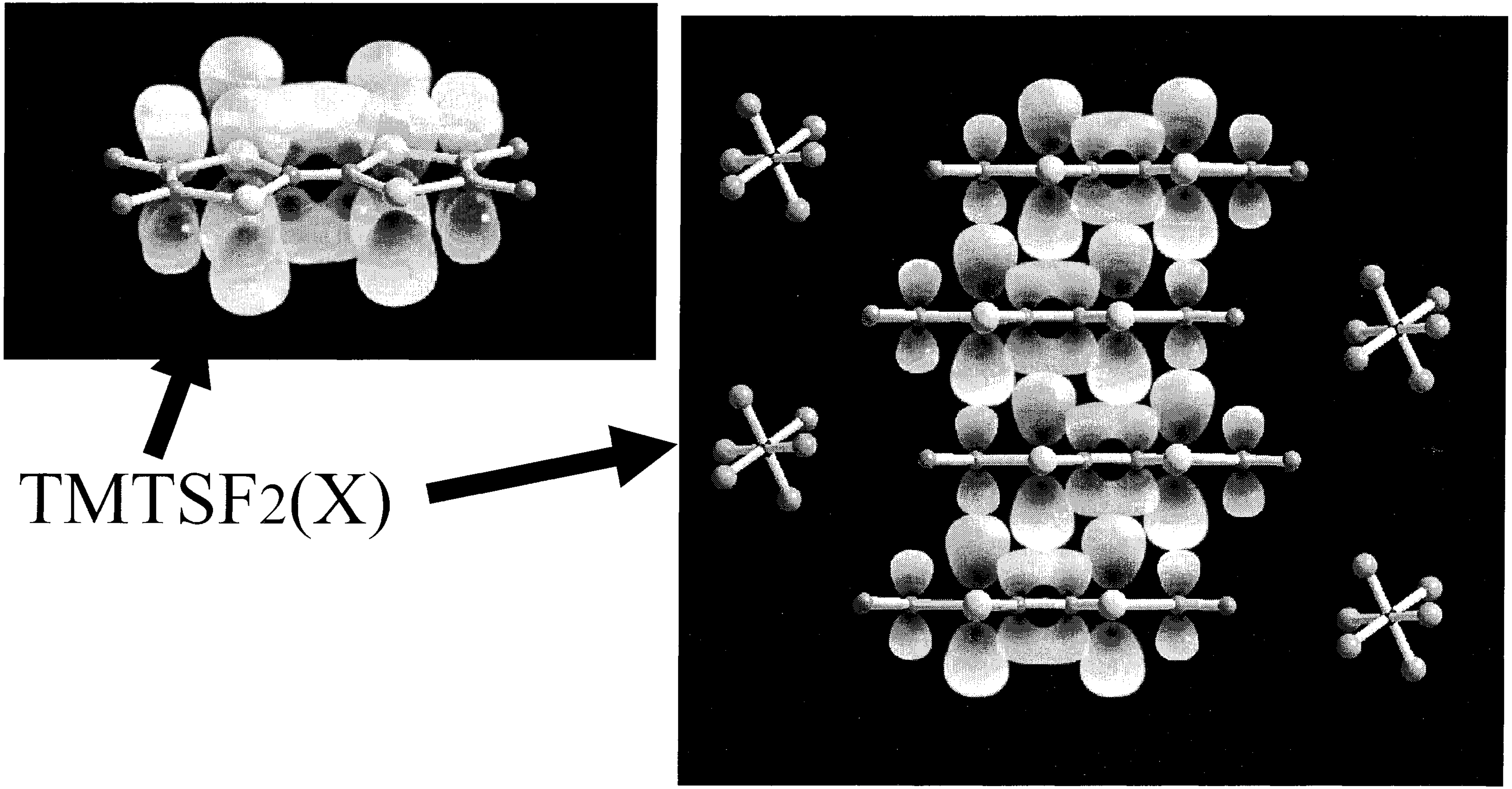
A. Georges, N. Sandler

S. Biermann, A. Lichtenstein

- Organic Superconductors: quasi-one dimensional systems (Bechgaard salts)

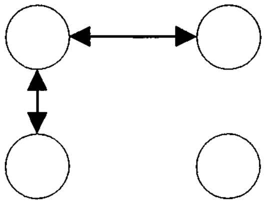
- TMTTF and TMTSF molecules

- Remarquable properties :
    - Non Fermi liquid behavior
    - Quantum Hall effect
    - Superconductivity and Frohlich conductivity



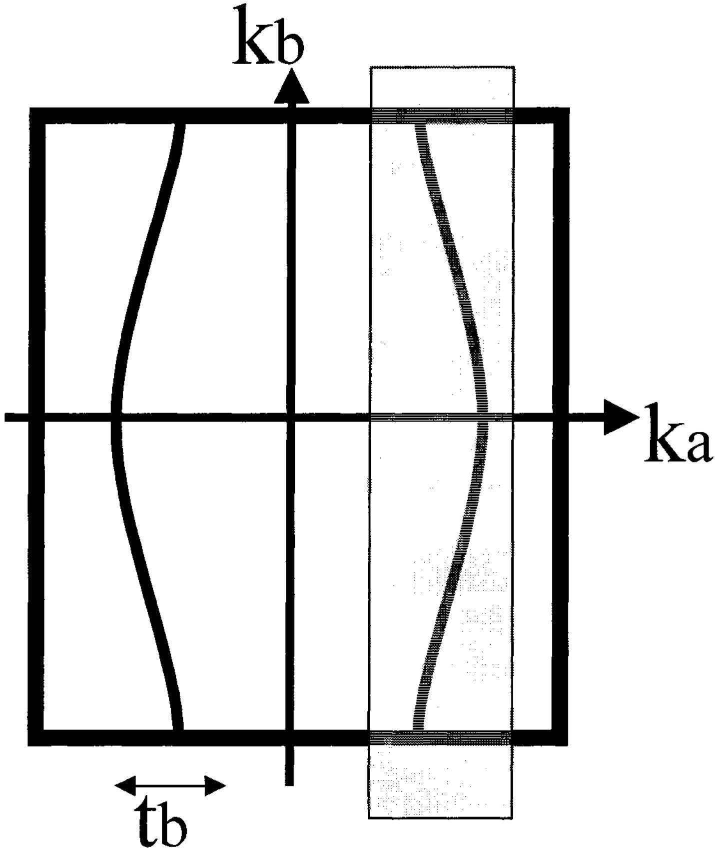
TMTSF$_2$(X)

- Propagation of electrons along the chains
- Commensurate filling (1/4 filling)



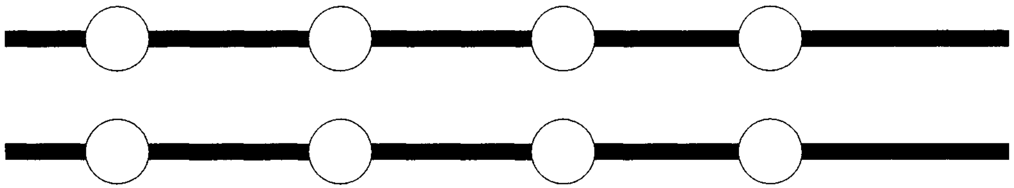
$$t_a > t_b > t_c$$

$$3000K, 300K, 20K$$

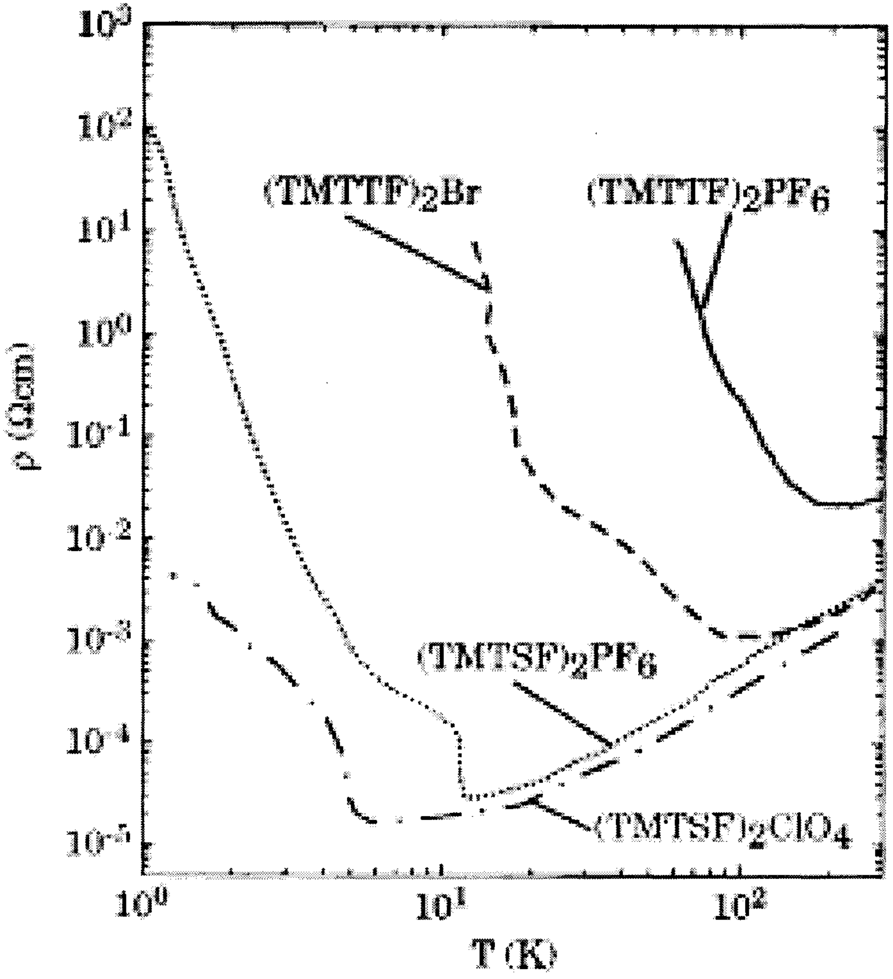


- High Energy (T,ω): 1D
- Low Energy (T,ω) : 2D,3D

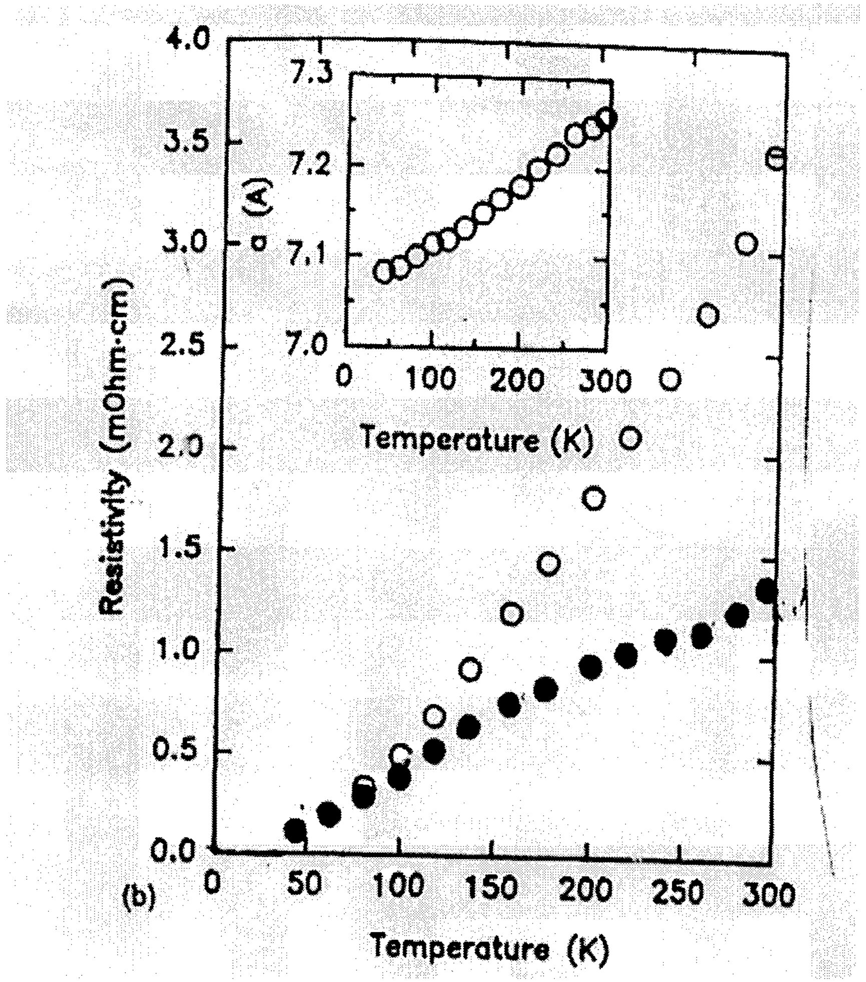
Dimensional crossover



Competition Mott insulator/Interchain hopping



V. Vescoli et al.
Euro Phys J B 13
503 (2000)



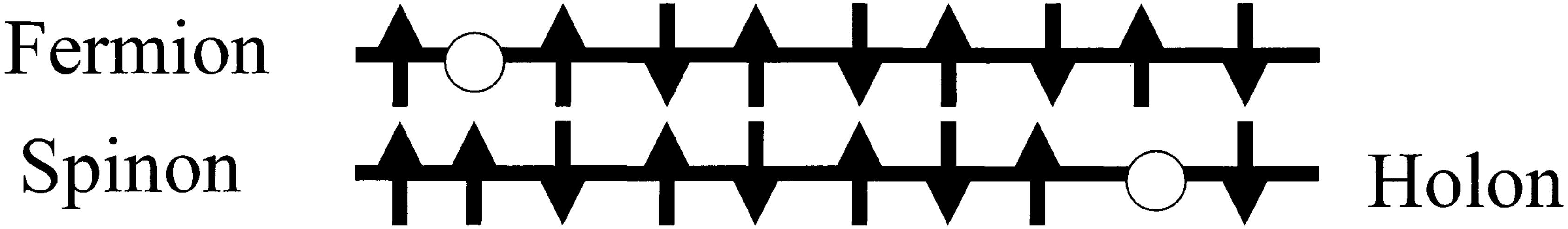
D. Jérome in ``Organic superconductors'', ed. J.P. Farges

Questions

- Are TMTSF strongly correlated systems ?
- What is the strength of interactions ?
- What causes the difference between TF and SF (weak vs strong dimerization ?) ?
- At what scale does the dimensional crossover takes place ? tb renormalized by interactions (C. Bourbonnais). 300K vs 20 K !

Luttinger liquid

- Spin charge separation



Fermion

Spinon

Holon

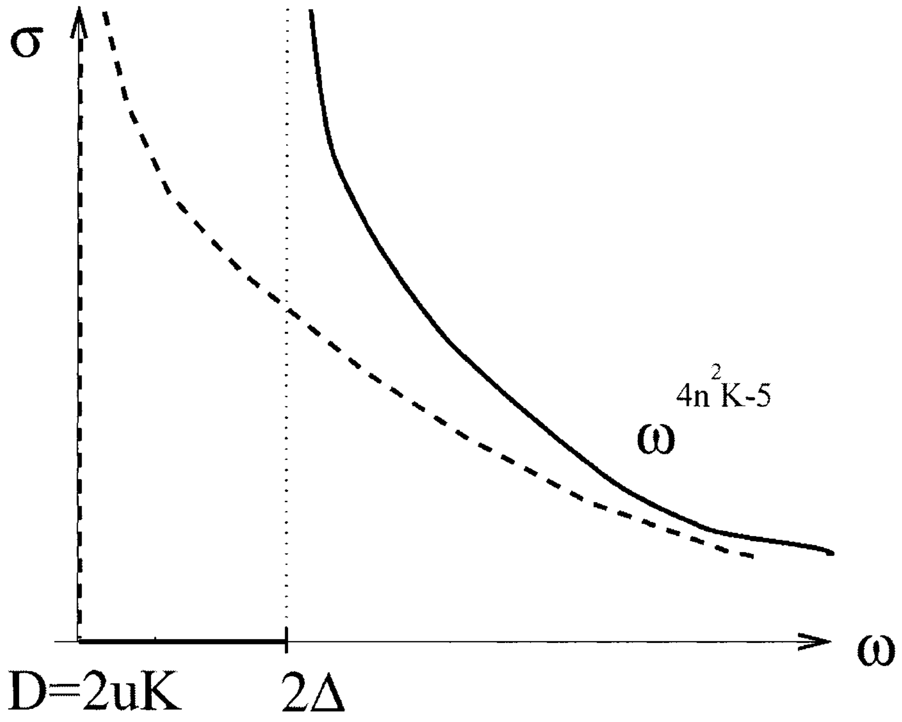
- No fermionic quasiparticles
- Power law decay of correlation functions

$$\left\langle S(x)S(0)\right\rangle = \frac{1}{x^2} + \cos(2k_F x)\left(\frac{1}{x}\right)^{1+K_\rho} + \dots$$

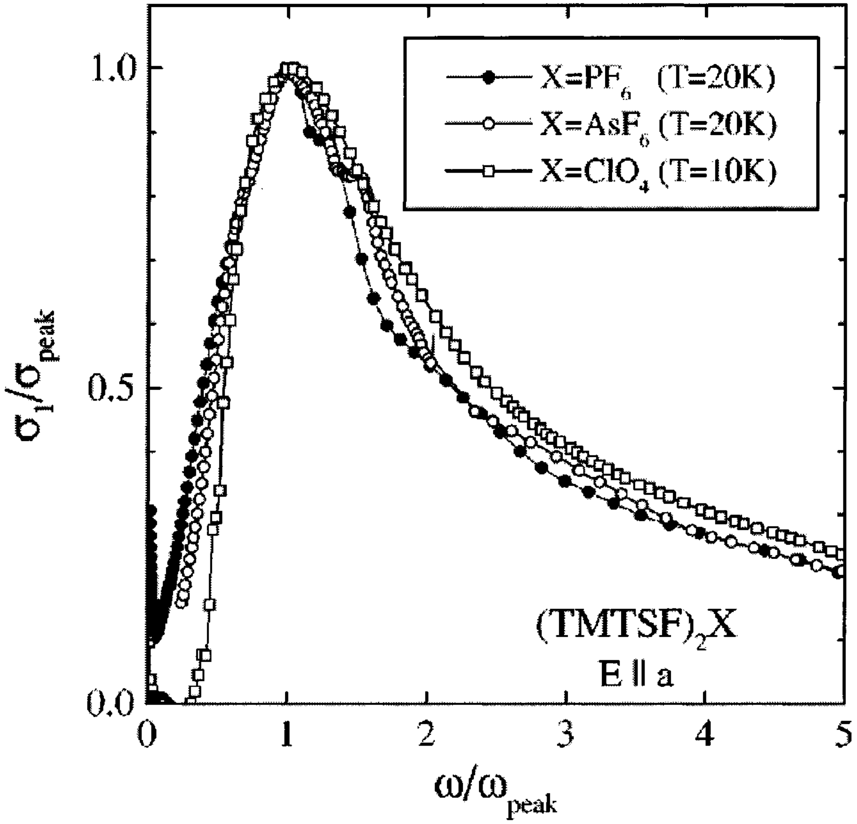
Kρ contains all information about interactions

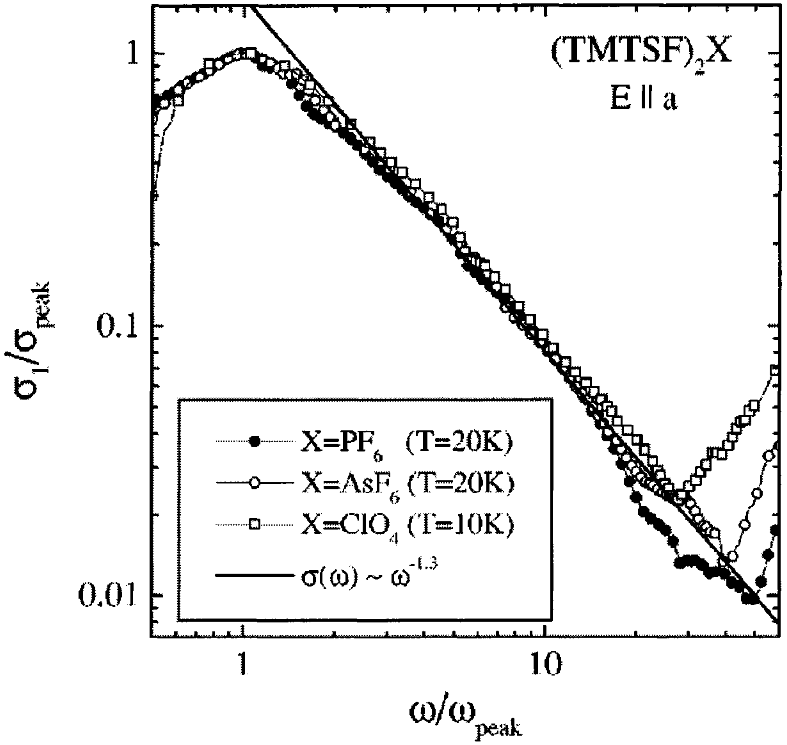
Transport in a LL

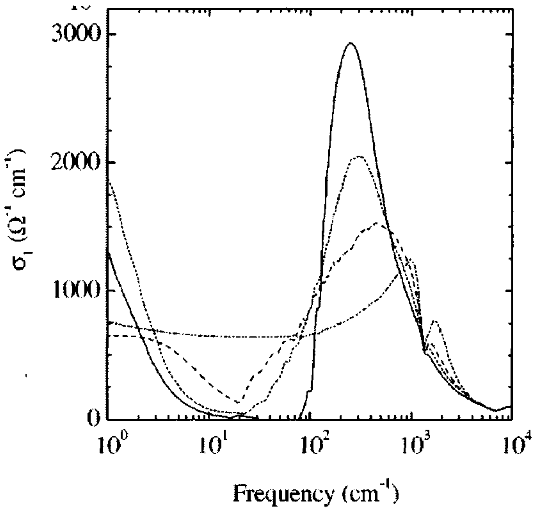
TG PRB 44 2905 (91); Physica B 230 975 (97)



- Mott insulator for _ filling also !
- Power law in σ(ω) determines Kρ
- Deviations from 1D law gives Ec







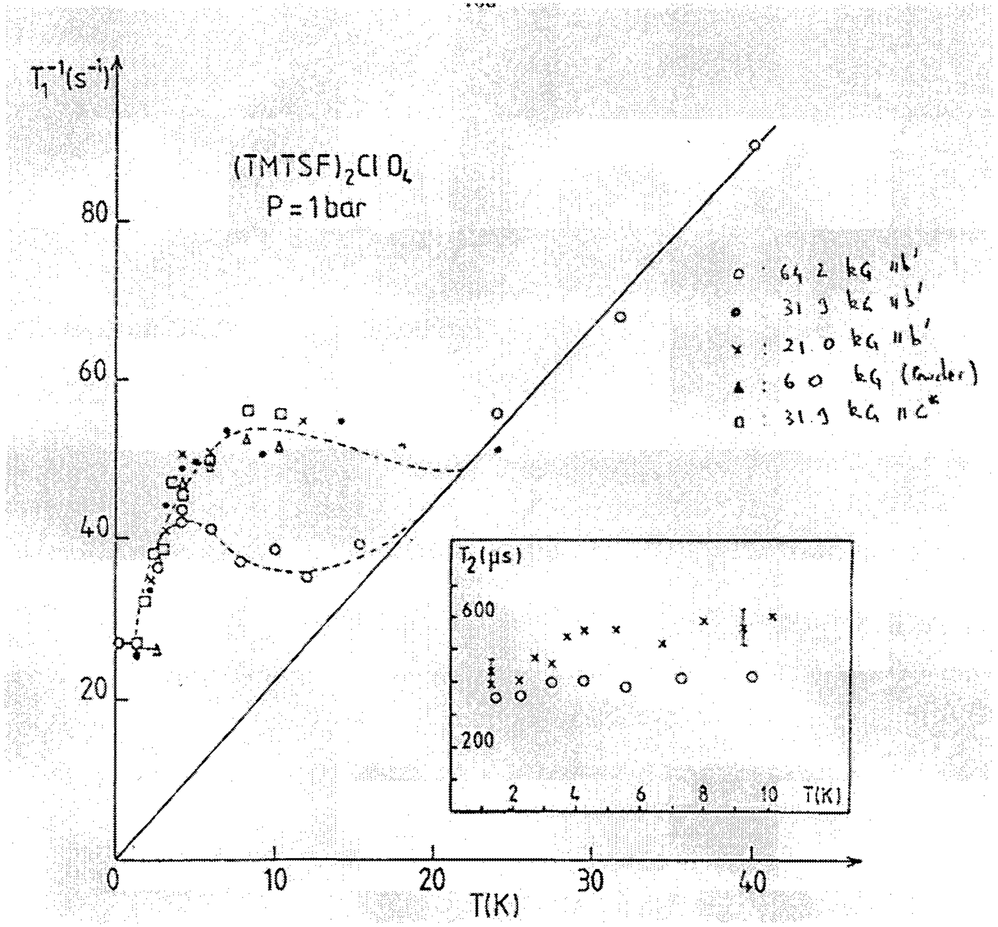
A. Schwartz et al. PRB 58 1261 (1998)

Consequences

- Luttinger Liquid !
- $K_\rho = 0.23$ very strong interactions
- Dimerization not important (1/4 filled Mott insulator) [confirmed in new non-dimerized compound]
- TF vs SF likely to be due to change of interactions (quantum critical point)

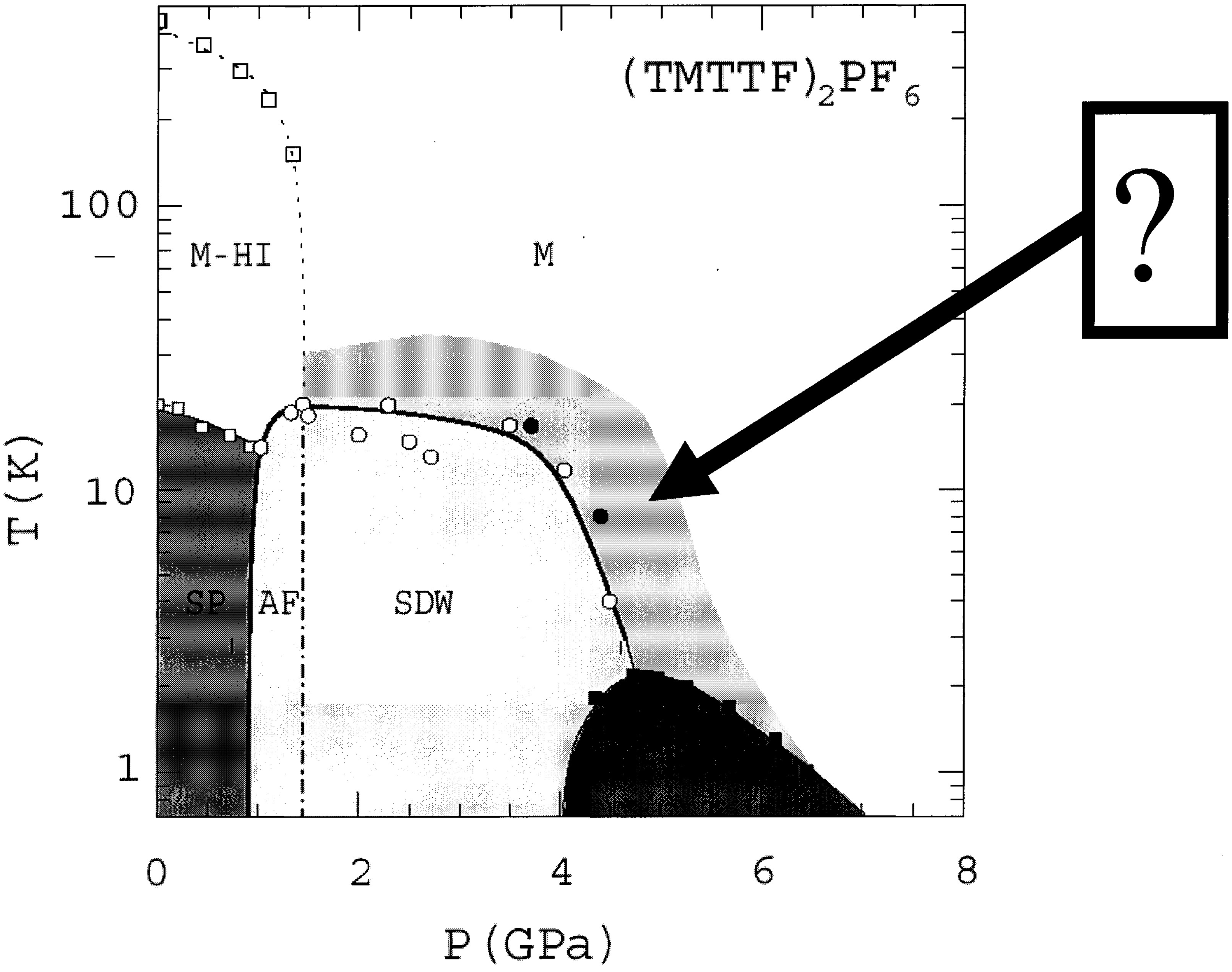
- Dimensional crossover at E=100K !

Puzzle from NMR



F. Creuzet et al., J. Phys. Lett 45 L755 (84)

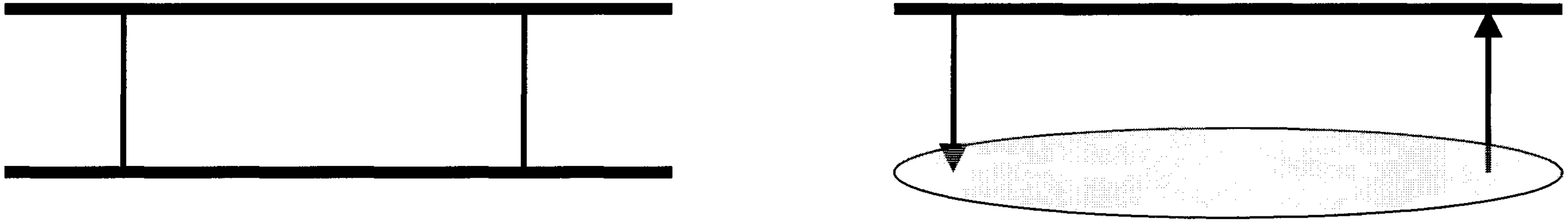
Non fermi liquid below Ec ?



After D. Jérome

Dimensional Crossover

A. Georges, TG, N. Sandlers PRB 61 16393 (00)



- d = ∞ + 1 (cDMFT)
- Effective one dimensional theory

$$S_{\mathrm{eff}} = -\int\int_0^{\beta} d\tau d\tau' \sum_{ij,\sigma} c_{i\sigma}^{+}(\tau)\mathcal{G}_0^{-1}(i-j,\tau-\tau')c_{j\sigma}(\tau')$$

$$+\int_0^{\beta} d\tau H_{\mathrm{1D}}^{\mathrm{int}}[\{c_{i\sigma},c_{i\sigma}^{+}\}], \qquad (4)$$

$$G(k,i\omega_n) = \int d\epsilon_{\perp} \frac{D(\epsilon_{\perp})}{i\omega_n+\mu-\epsilon_k-\Sigma(i\omega_n,k)-\epsilon_{\perp}}.$$

$$\mathrm{Re}\,\sigma_{\perp}(\omega,T) \propto t_{\perp}^2 \int d\epsilon_{\perp} D(\epsilon_{\perp}) \int \frac{dk}{2\pi} \int d\omega' A(\epsilon_{\perp},k,\omega')$$

$$\times A(\epsilon_{\perp},k,\omega+\omega') \frac{f(\omega')-f(\omega'+\omega)}{\omega}.$$

- Self consistent theory for Σ

- Feedback of $t_\perp$ in Σ (a priori important for deconfinement)

- Different from RPA

$$G(k,k_\perp,i\omega_n)=\frac{1}{i\omega_n-\varepsilon_k-\varepsilon_\perp(k_\perp)-\Sigma_{1D}(k,i\omega_n)}$$

- Difficult to solve the equations analytically

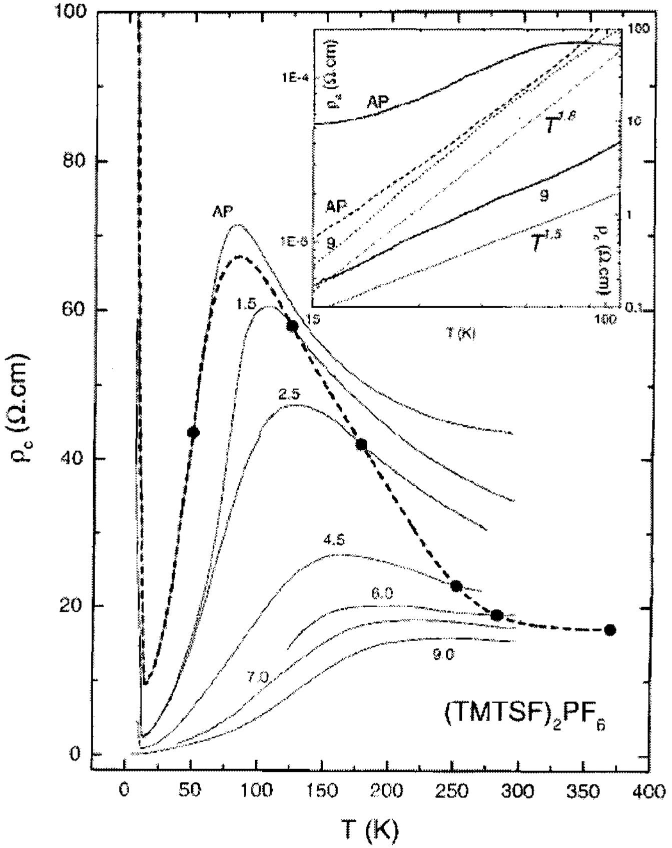
Transverse transport

$$\sigma(\omega, T) \propto (\omega, T)^{2\alpha - 1}$$

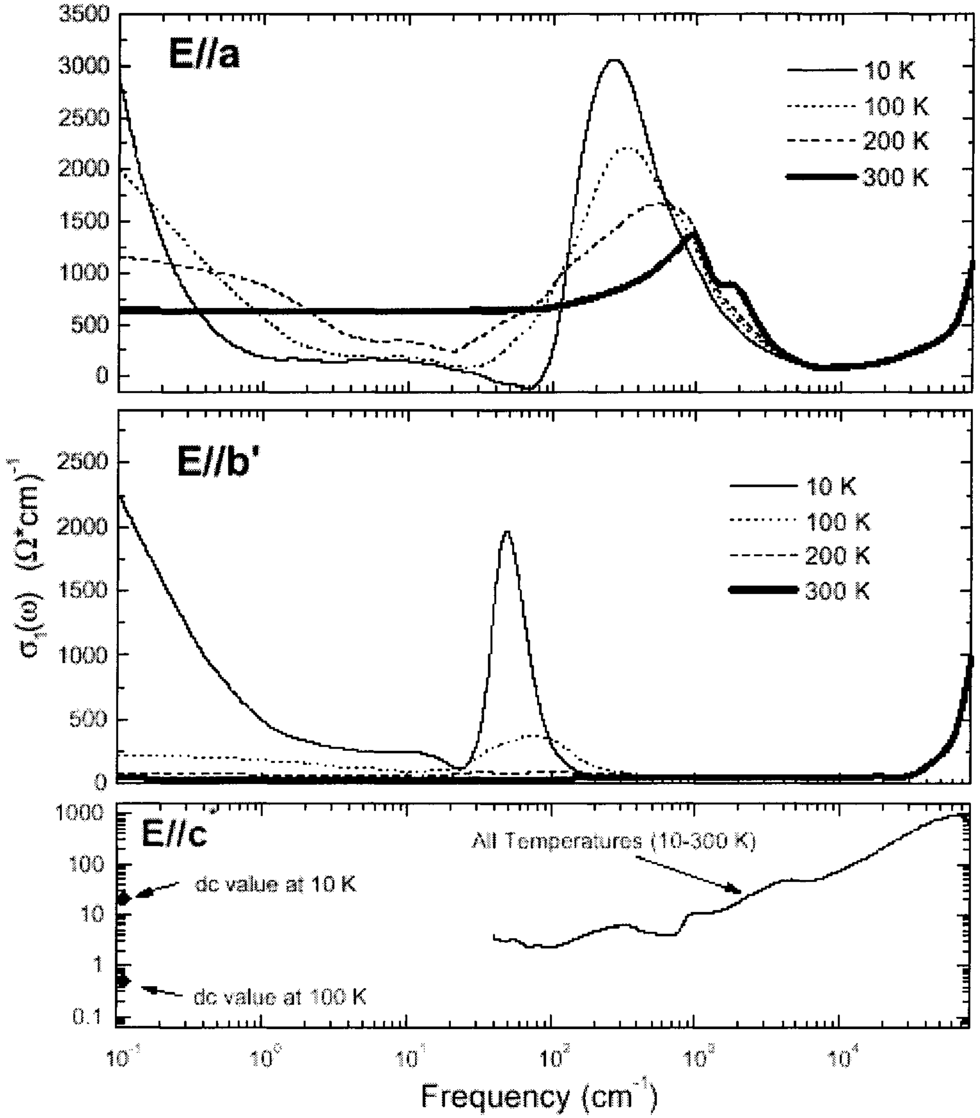
$$\alpha = \tfrac{1}{4}(K + K^{-1}) - \tfrac{1}{2}$$

$$\alpha \cup 0.6$$

$$\omega_{D\perp}^{2} / \omega_{P\perp}^{2} \propto (t_{\perp} / t)^{2\alpha/(1-\alpha)} = Z^{2}$$



J. Moser et al. Euro Phys. J. B 1 39 (1998)



V. Vescoli et al. Euro Phys J B 11 365 (1999)

Numerical Solution

S. Biermann, A. Georges, A. Lichtenstein, TG

- Hubbard Model
- QMC (16 – 32 sites)
- 32 time slices (T/W = 1/50)

Incommensurate case

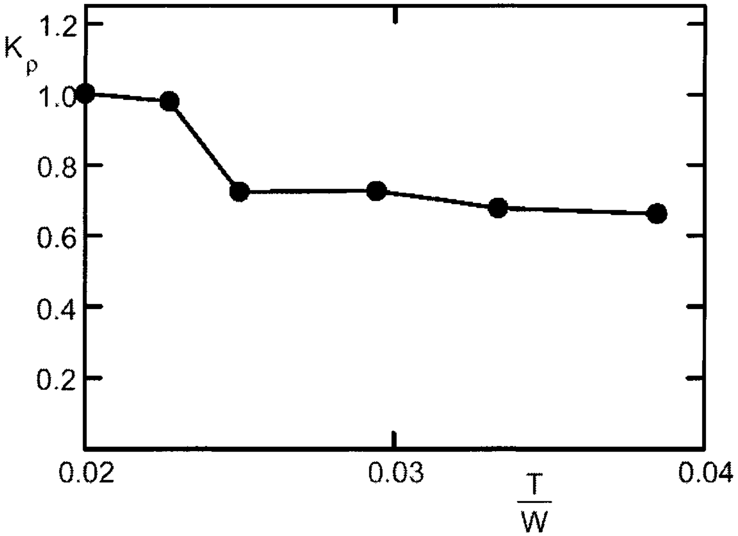


FIG. 2: Effective K_ρ *vs.* temperature in the doped case (filling $n \simeq 0.8$) for $U/W = 1.0$, $t_\perp/W = 0.14$.

$$T^* \cup \frac{t_\perp}{\pi}\left(\frac{t_\perp}{t}\right)^{\frac{\theta}{1-\theta}}$$

$$T^* \cup 0.5\frac{t_\perp}{\pi}$$

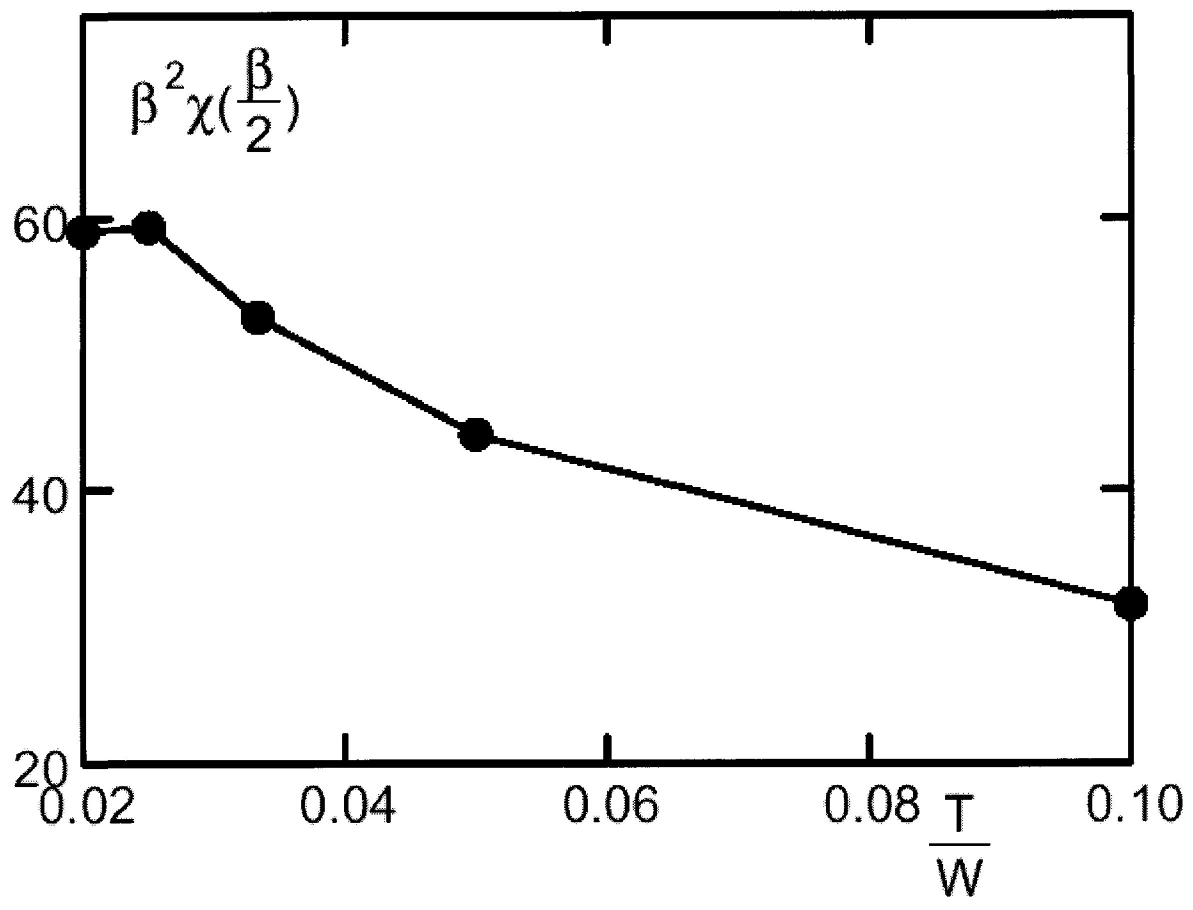
Commensurate case

TABLE II: Effective K_ρ at half-filling, as a function of $t_\perp/W$ for $U/W = 0.65$ and $T/W = 1/40$.

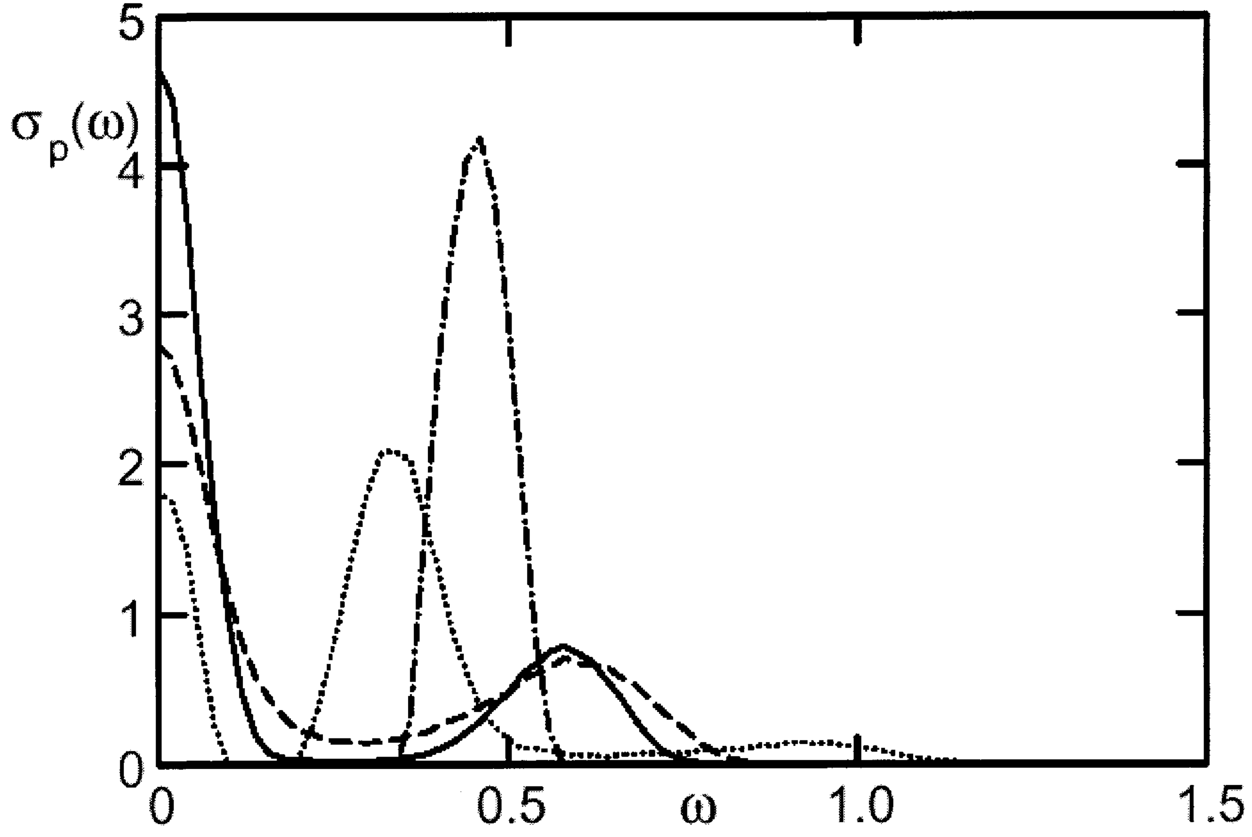
$t_\perp/W$	0.00	0.04	0.07	0.11	0.14	0.16	0.18
K_ρ	0.00	0.02	1.01	1.09	1.07	1.06	1.04

$$t_\perp^* \cup \Delta_{1D}$$

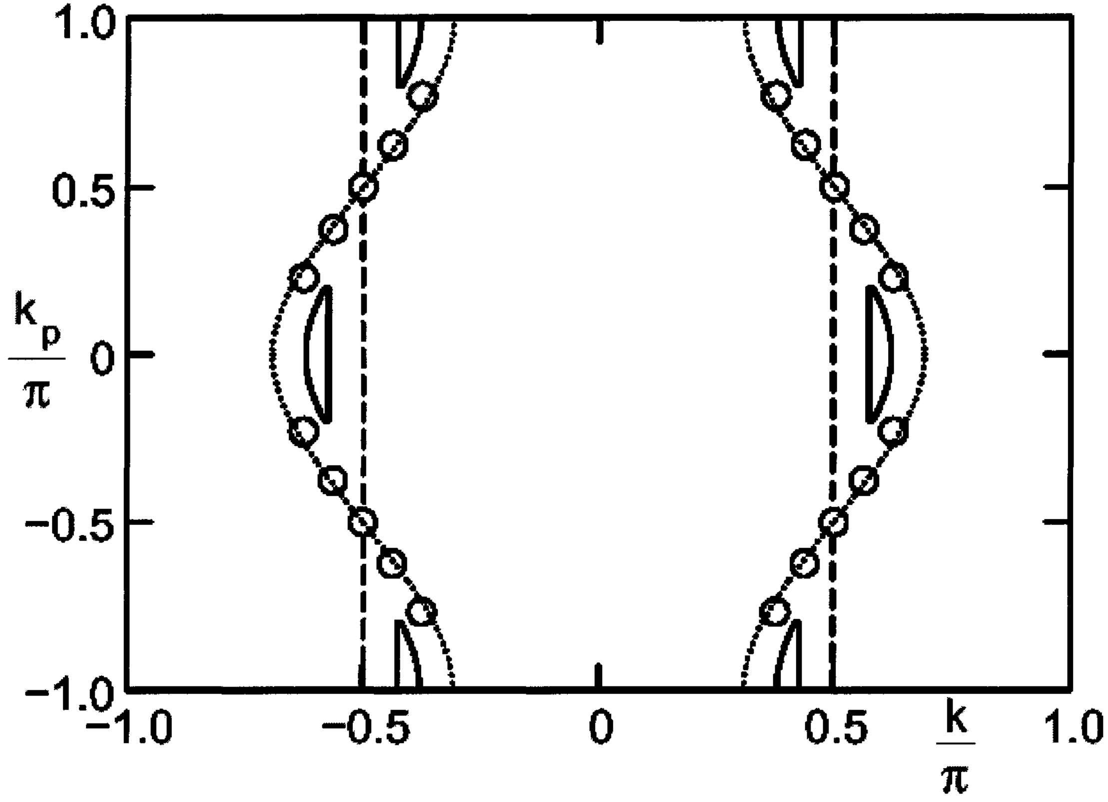
NMR



Transverse conductivity



Fermi Surface



Z

$k_\perp/\pi$	0.23	0.38	0.50	0.62	0.77
$Z(k_\perp)$	0.78	0.77	0.76	0.77	0.79

Conclusions

- Transport proves LL nature of high enery phase
- K=0.23, _ filled Mott insulators
- Ec = 100K much higher than expected
- Nature of the 2D phase ? 2D non Fermi liquid ?
- cDMFT Good method to tackle the dimensional crossover

- _ Filling with cDMFT
- Other physical quantities : Hall effect
- Ordered phases (superconductivity)