The Role of the Van Hove Singularity in the Quantum Criticality of the Hubbard Model?

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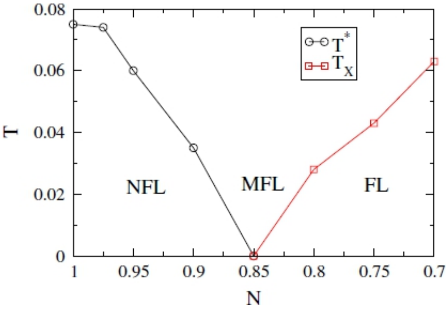


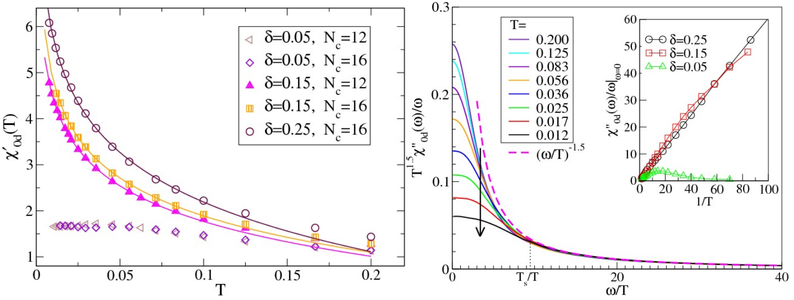
Vidhyadhiraja *et. al* PRL 102, 206407 (2009)

- Hubbard model on square lattice

$$\mathcal{H} = -\sum_{ij} t_{ij} c^{\dagger}_{i\sigma} c_{j\sigma} + U \sum_{i} n_{i\uparrow} n_{i\downarrow}$$

- A quantum critical point exist in the Hubbard model
- Characterized by quasi-particle weight going to zero
- At finite temperatures, MFL separates a NFL phase from FL phase

Scaling behavior of d-wave susceptibility



Yang *et. al* PRL, 106, 047004 (2011)

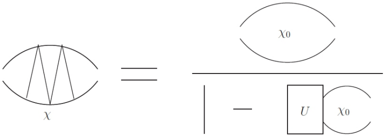
- At QCP, pairing polarization decays algebraically $\chi'_{0d}(T) \propto \frac{1}{\sqrt{T}}$
- *Scaling* - $T^{1.5}\chi''_{0d}(\omega)/\omega$ curves for different T fall on top of each other

$$T^{1.5}\chi''_{0d}(\omega)/\omega = H(\omega/T) = (\omega/T)^{-1.5}$$

Kramers-Krönig -
$\chi'_{0d}(T) = \frac{1}{\pi}\int d\omega\chi''_{0d}(\omega)/\omega = \frac{1}{\pi}\int dxH(x) \times \frac{1}{\sqrt{T}} \propto \frac{1}{\sqrt{T}}$

Motivation

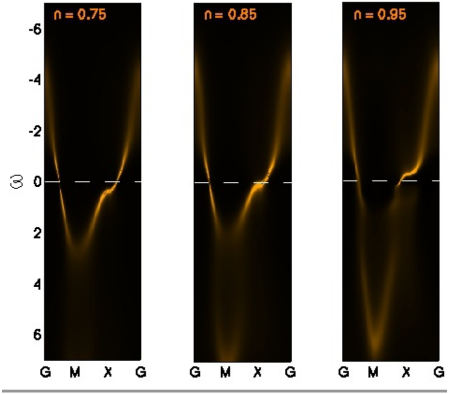
- Bethe-Salpeter equation for χ



- BCS equation for transition temperature T_c

- $\chi'_{0d}(T) \propto \frac{1}{\sqrt{T}} \Rightarrow T_c \sim U^2$

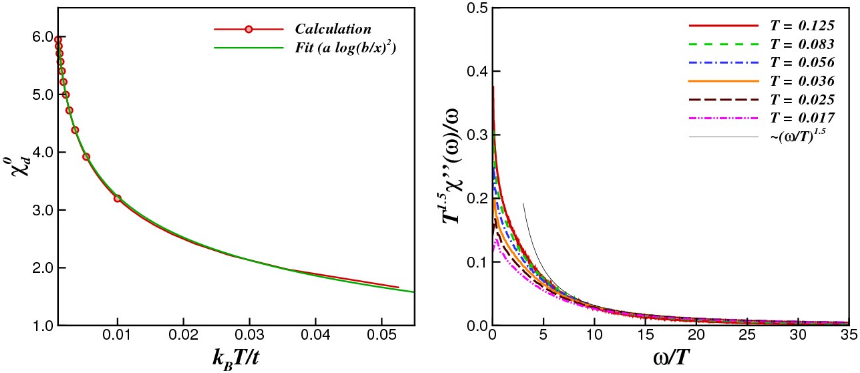
Energy Dispersion



- vHS is pinned to the Fermi level near anti-nodal point X $(\pi, 0)$ at the QCP!
- New result - pinning at *finite* filling

Role of vHS in the quantum criticality of Hubbard model?

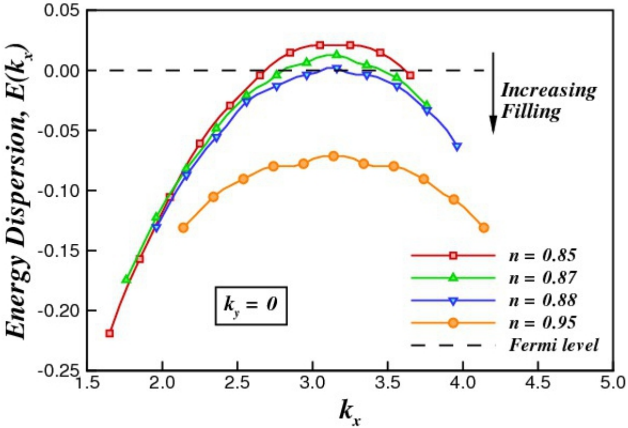
Bare d-wave susceptibility does not show good scaling!



$$\chi'_{0d}(T) = \frac{1}{\beta}\sum_{\mathbf{k},i\omega_n} g_d^2(\mathbf{k}) G(\mathbf{k}, i\omega_n) G(-\mathbf{k}, -i\omega_n) = \sum_{\mathbf{k}} g_d^2(\mathbf{k}) \left(\frac{1-2n_F(\epsilon_{\mathbf{k}})}{2\epsilon_{\mathbf{k}}}\right)$$

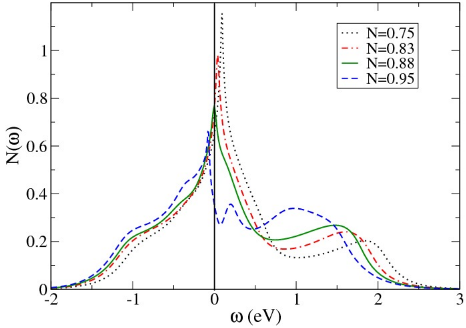
- For standard dispersion $\epsilon(\mathbf{k}) = -2t(\cos k_x + \cos k_y)$, DOS $N(\omega) \sim \log|\omega|$
- By converting sum to integral cutoff by T, we get $\chi'_{0d} \sim -(\log T)^2$

Closer look at dispersion shows that vHS is flatter than quadratic!



- Dispersion around the Fermi vector along the anti-nodal direction

Critical DOS is ALGEBRAICALLY singular, not logarithmic!



- Peaks in DOS are algebraic near $\omega = 0$ (Using analytic continuation of self energy, Wang *et. al* PRB 80, 045101 (2009))

$$N(\omega) \sim \frac{1}{(\omega - \omega_p)^{\alpha}},$$

where, $0 < \alpha < 0.5$ and ω_p is location of maximum of peak

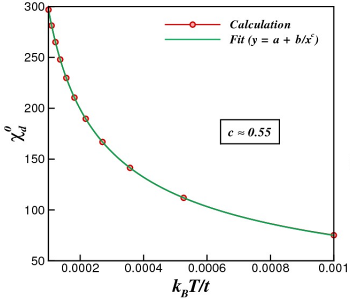
- Peaks moves through $\omega = 0$ at quantum critical filling
- Quantum critical $N(\omega)$ shows low ω particle-hole symmetry

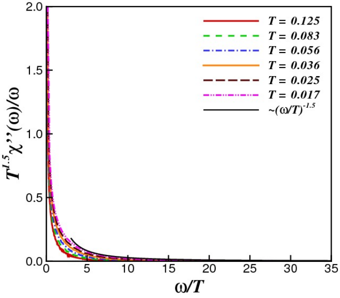
Quartic dispersion show algebraic decay!

- Toy Model with Quartic Dispersion

$$\epsilon(\mathbf{k}) = -\frac{4}{\pi^4}\left((|k_x| - \pi)^4 - k_y^4\right)$$

- Similar argument shows that for $N(\omega) \sim \frac{1}{\sqrt{\omega}}$, $\chi_d^0 \sim \frac{1}{\sqrt{T}}$

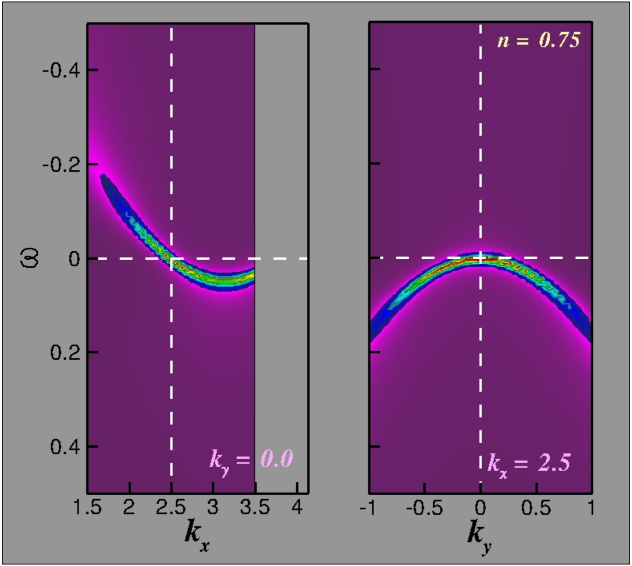




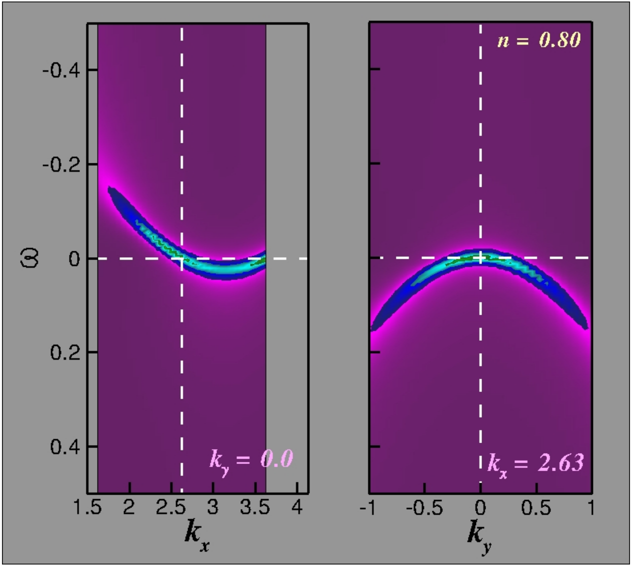
Effect of t' ($t' = -0.1$)

- vHS pinned to Fermi level for larger range of doping
- Affects transport properties like linear T resistivity, etc. for larger doping range

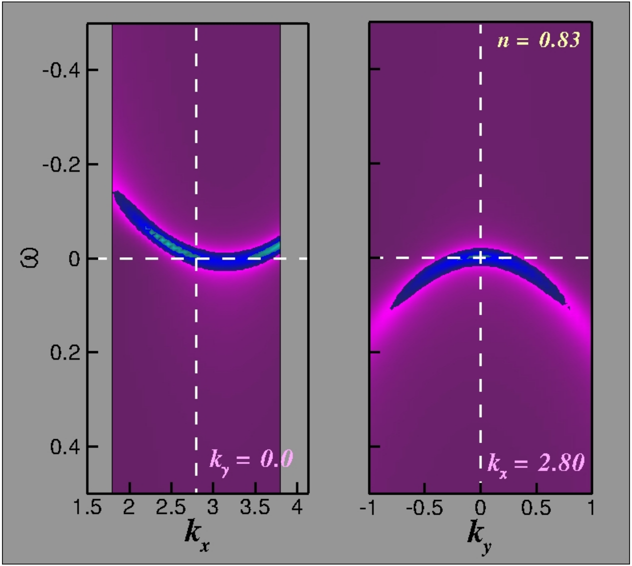
$n = 0.75$



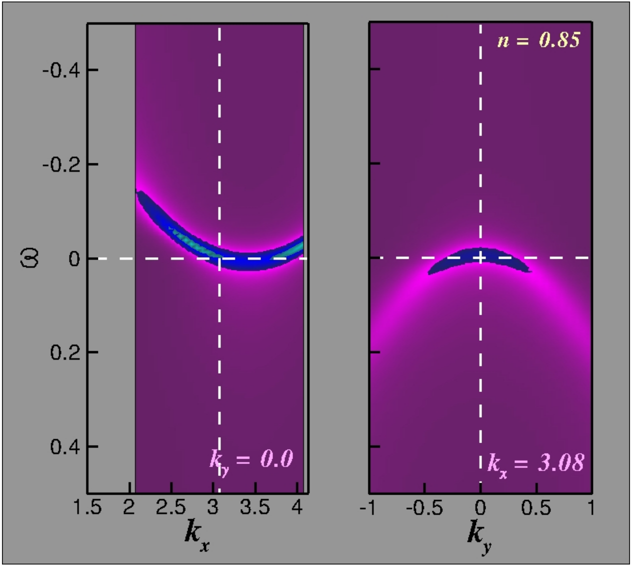
$n = 0.80$



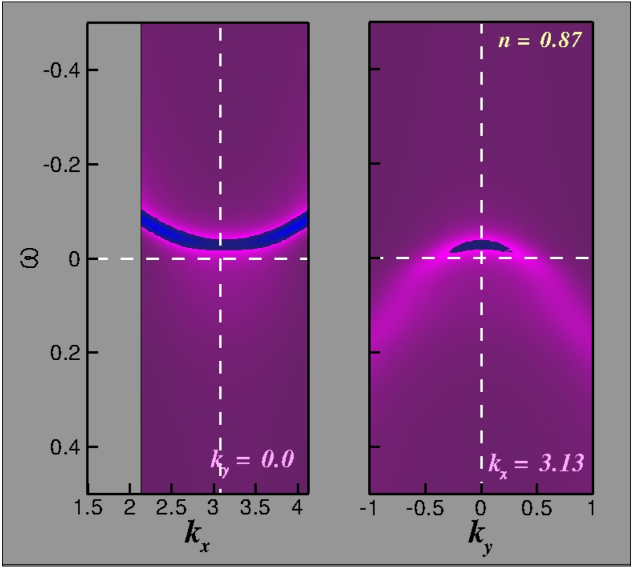
$n = 0.83$



$n = 0.85$

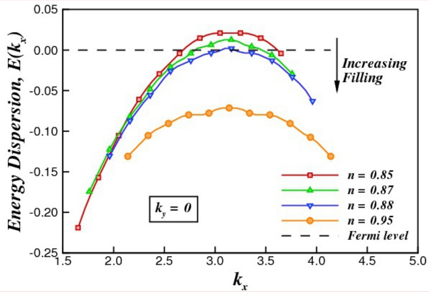


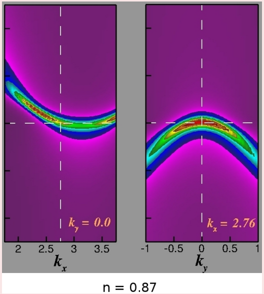
$n = 0.87$



Summary

- The algebraic decay of χ'_{0d} cannot be understood simply from vHS at Fermi level picture

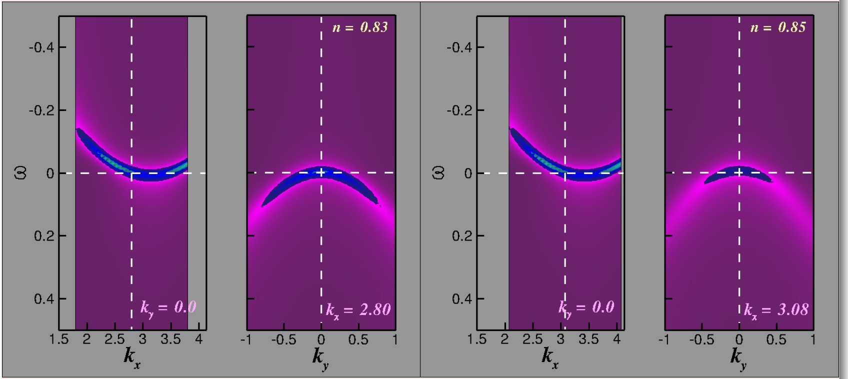




- Combined effect of vHS at Fermi level, extendedness of the singularity and thermal broadening of the quasi-particle peaks

Summary

For negative t', vHS pinned to Fermi level for larger range of doping



- leads to larger range of doping where MFL behavior is observed

Phase Diagram