Extended Hubbard Model

Results with DCA and Lanczos

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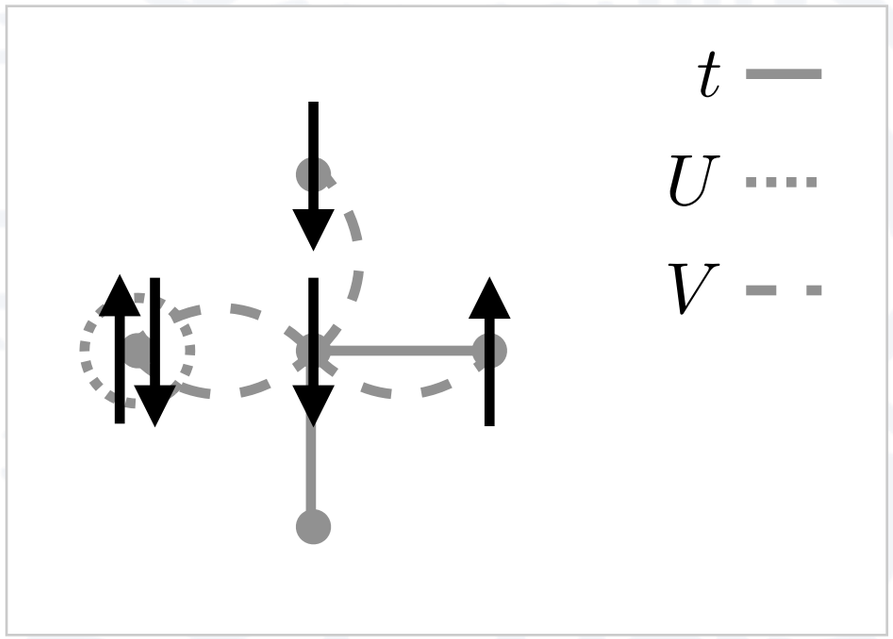
The Extended Hubbard Model

$$H = -t \sum_{\sigma} \sum_{\langle i,j \rangle} (c^{\dagger}_{i\sigma} c_{j\sigma} + c^{\dagger}_{j\sigma} c_{i\sigma}) + U \sum_{i} n_{i\uparrow} n_{i\downarrow}$$

$$+ V \sum_{\sigma} \sum_{\langle i,j \rangle} (n_{i\sigma} n_{j\sigma} + n_{i\sigma} n_{j-\sigma})$$

Physical Properties

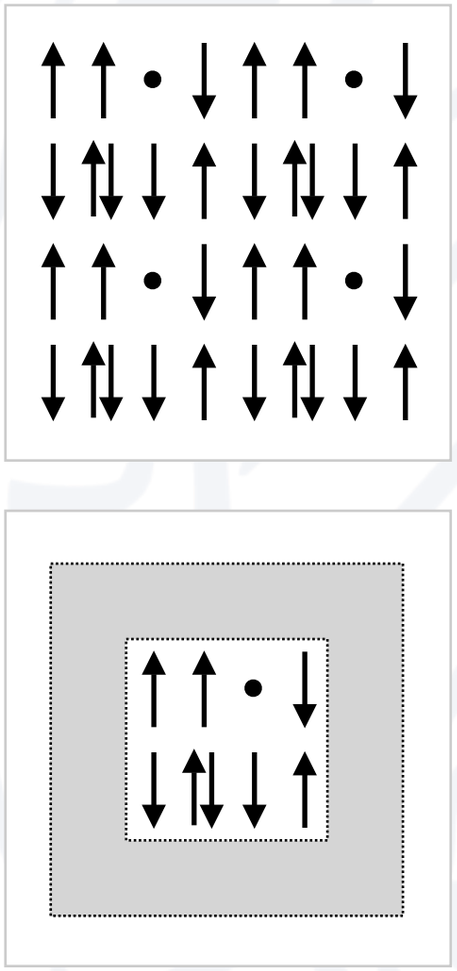
- Spin Density Wave Phase Driven by On-Site Interaction U
- Charge Density Wave Phase Drive by Inter-Site Interaction V
- Super-Conducting and Bond-Ordered Wave Phases



Analyzation Techniques

Dynamical Cluster Approximation

Exact in the Large Cluster Limit
(Accounts for Fluctuations)
Fully Causal



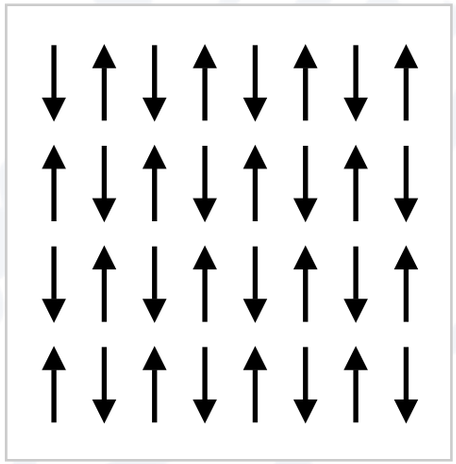
Lanczos

Exact Hamiltonian Diagonalization
Produces T=0 Results

$$\begin{pmatrix} h_{1,1} & h_{1,2} & & & & 0 \\ h_{1,2}^* & h_{2,2} & h_{2,3} & & & \\ & h_{2,3}^* & h_{3,3} & h_{3,4} & & \\ & & \ddots & \ddots & \ddots & \\ & & & & & h_{stp-1,stp} \\ 0 & & & & h_{stp-1,stp}^* & h_{stp,stp} \end{pmatrix}$$

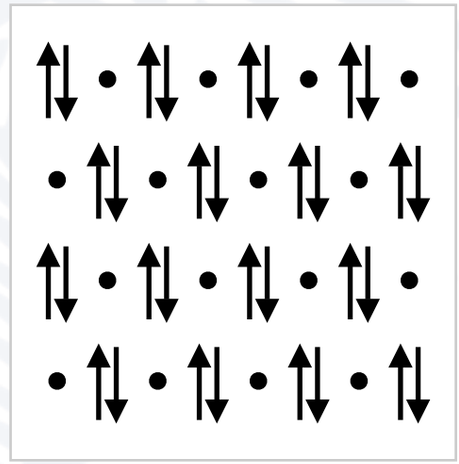
M. Jarrel, T. Maier, C. Huscroft, & S. Moukouri (Phys. Rev. B 64)

Spin & Charge Density Wave Phases



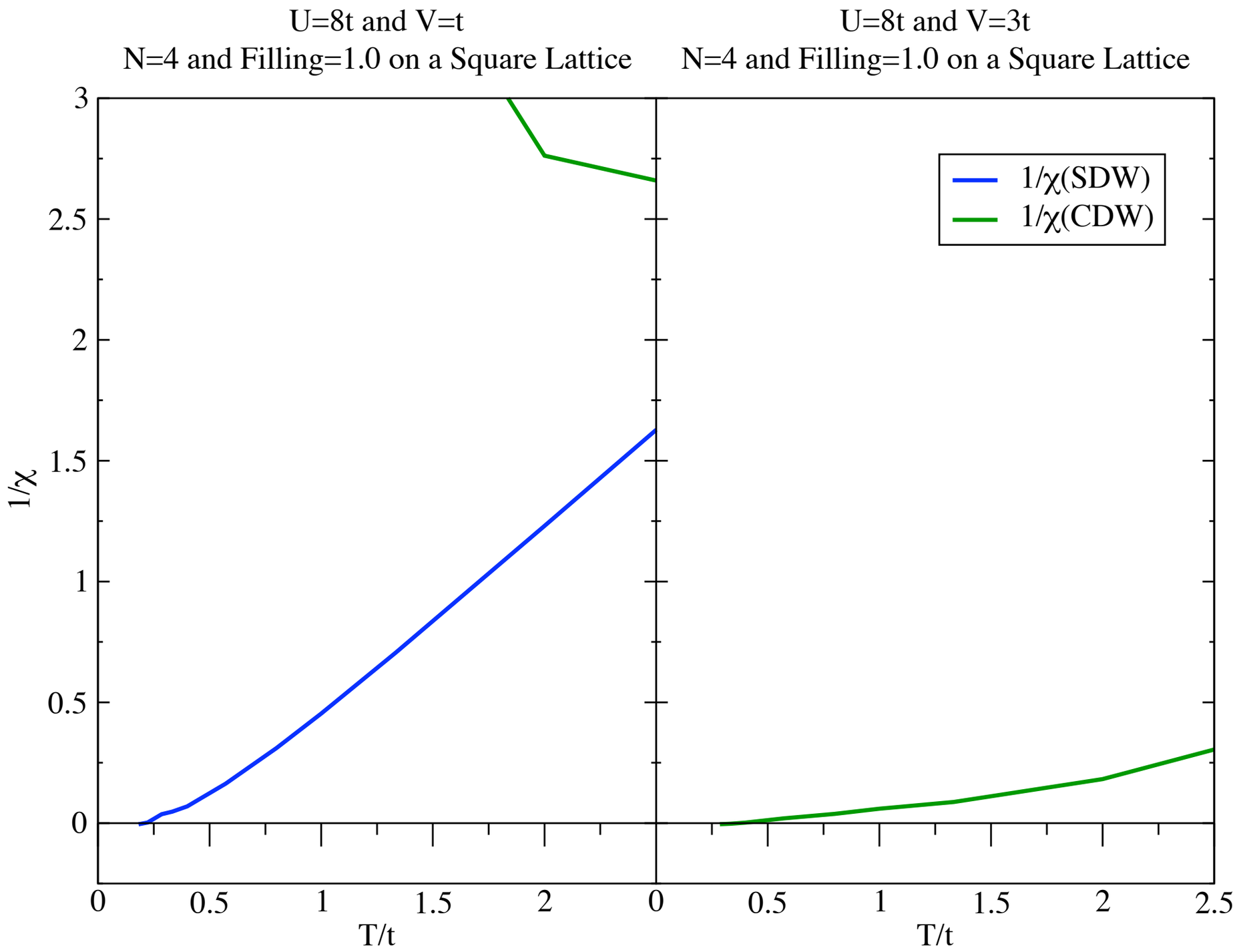
Spin Density Wave (SDW)
Present for U ≫ 4V in 2D

$$< (n_{i+r\uparrow} - n_{i+r\downarrow})(n_{i\uparrow} - n_{i\downarrow}) >$$



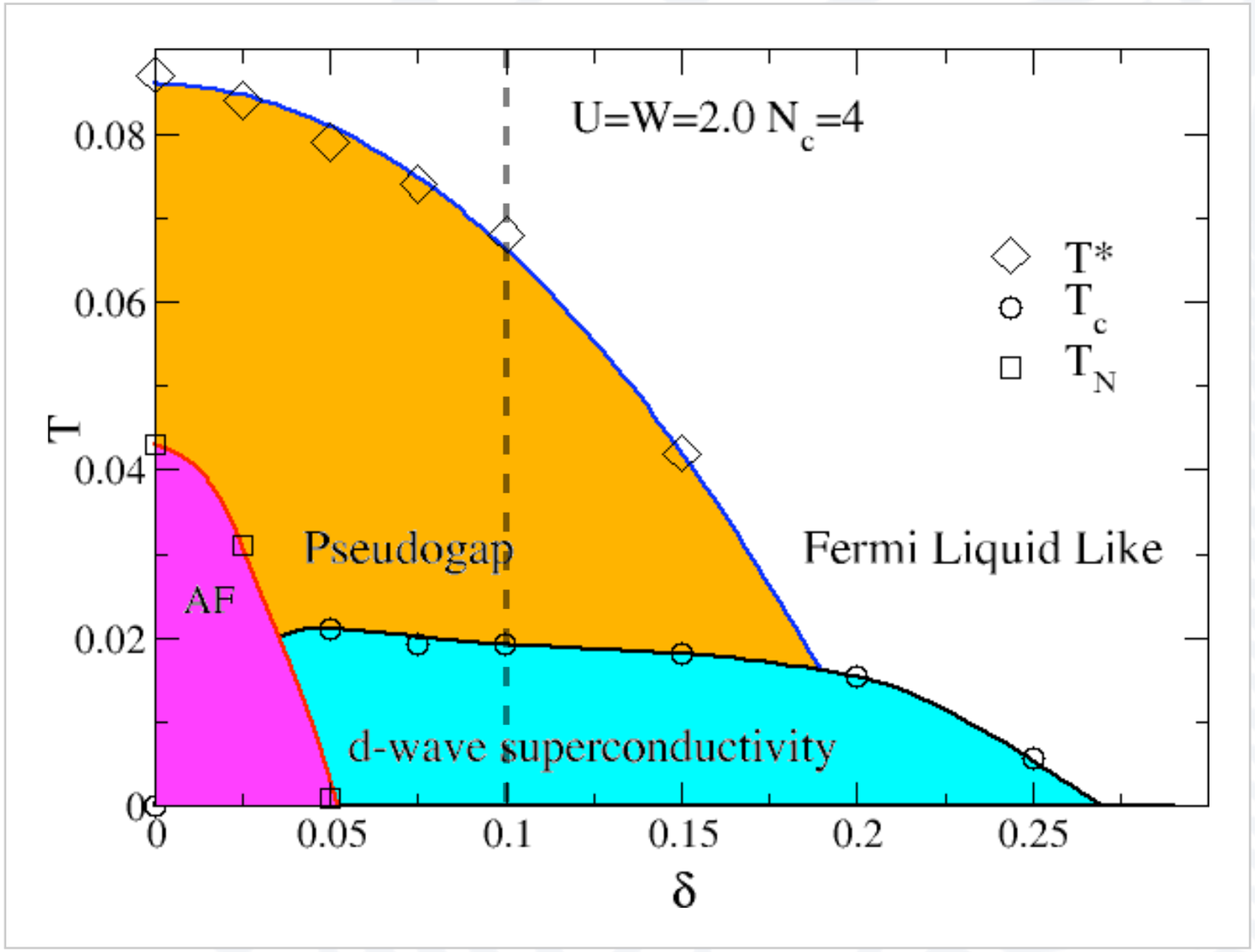
Charge Density Wave (CDW)
Present for U ≪ 4V in 2D

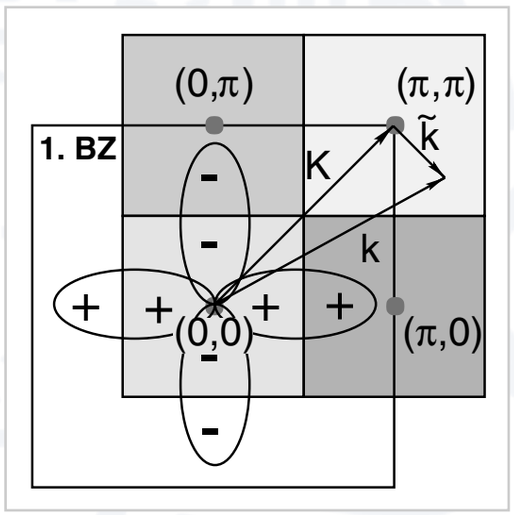
$$< (n_{i+r\uparrow} + n_{i+r\downarrow} - 1)(n_{i\uparrow} + n_{i\downarrow} - 1) >$$

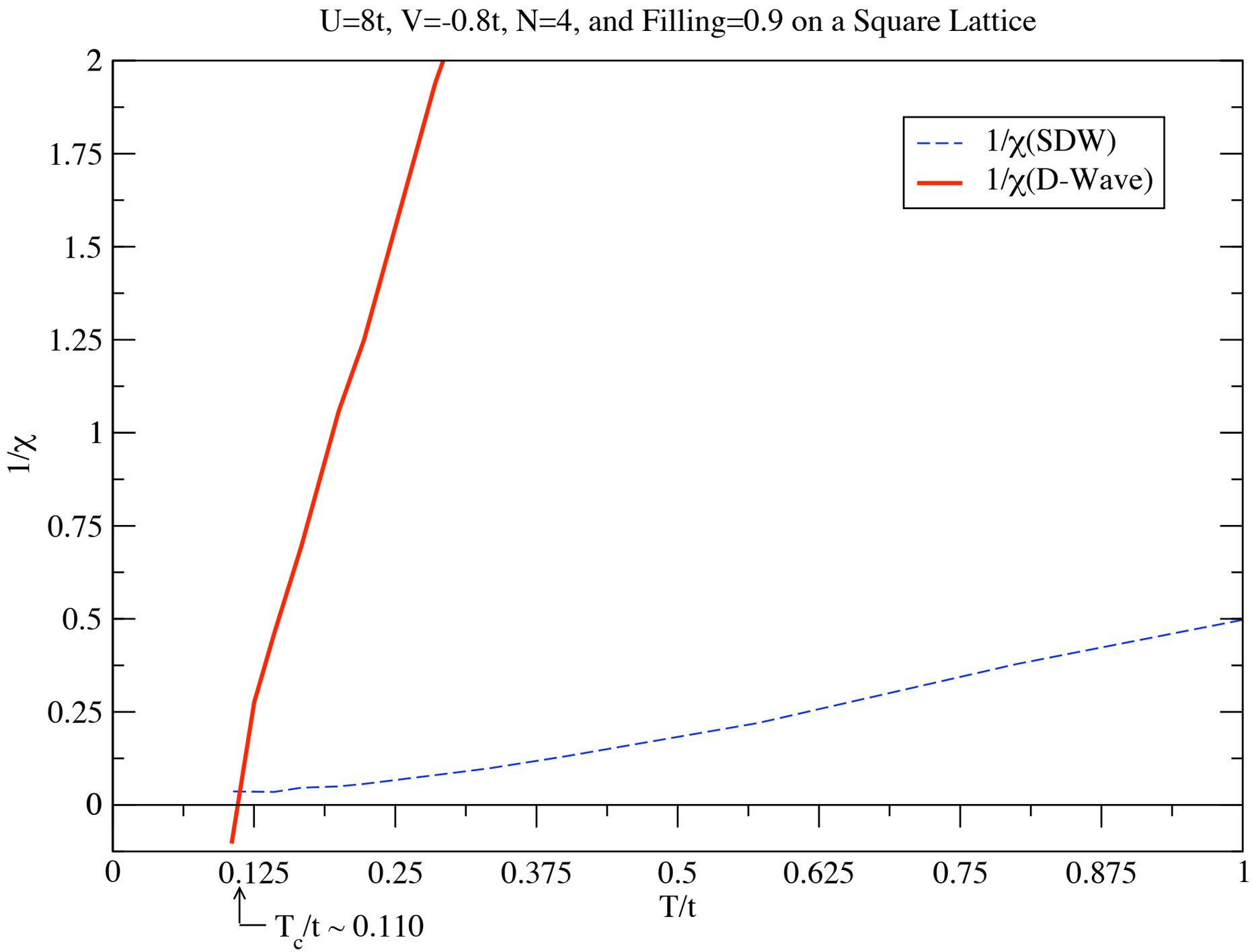

U=8t and V=t
N=4 and Filling=1.0 on a Square Lattice
U=8t and V=3t
N=4 and Filling=1.0 on a Square Lattice
1/χ(SDW)
1/χ(CDW)
1/χ
T/t
T/t
0
0.5
1
1.5
2
2.5
3

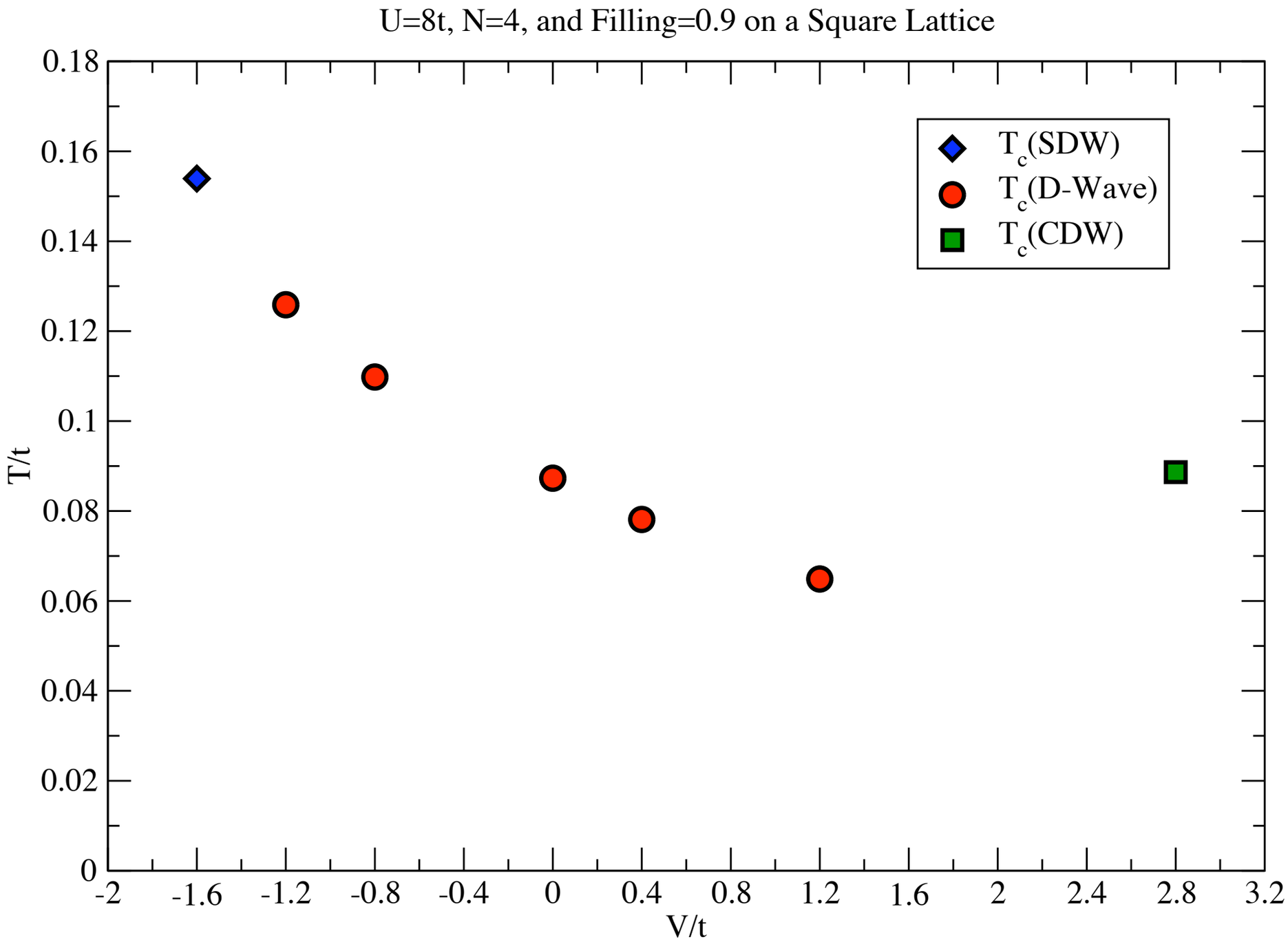
2D Hubbard Model Phase Diagram

Motivation for the Search for D-Wave Superconductivity

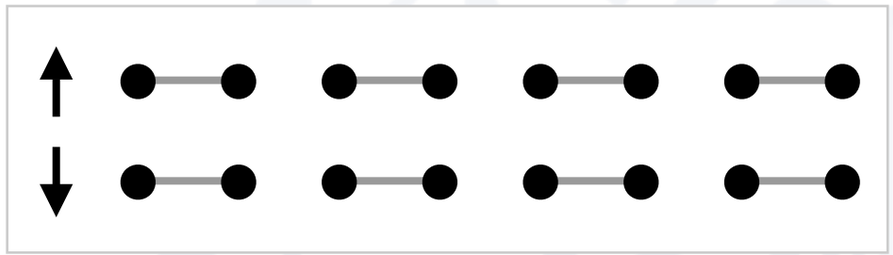





U=8t, V=-0.8t, N=4, and Filling=0.9 on a Square Lattice
1/χ(SDW)
1/χ(D-Wave)
1/χ
T/t
T_c/t ~ 0.110
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0
0.125
0.25
0.375
0.5
0.625
0.75
0.875
1


U=8t, N=4, and Filling=0.9 on a Square Lattice
T_c(SDW)
T_c(D-Wave)
T_c(CDW)
T/t
V/t
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-2
-1.6
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2

Bond-Ordered & S-Wave Superconductivity Phases

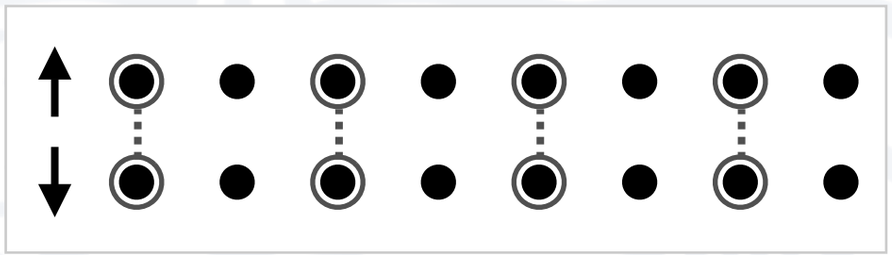


Bond Ordered Wave (BOW)

$$\bar{c} = < \sum_{\sigma} (c^{\dagger}_{i+1\sigma} c_{i\sigma} + h.c.) >$$

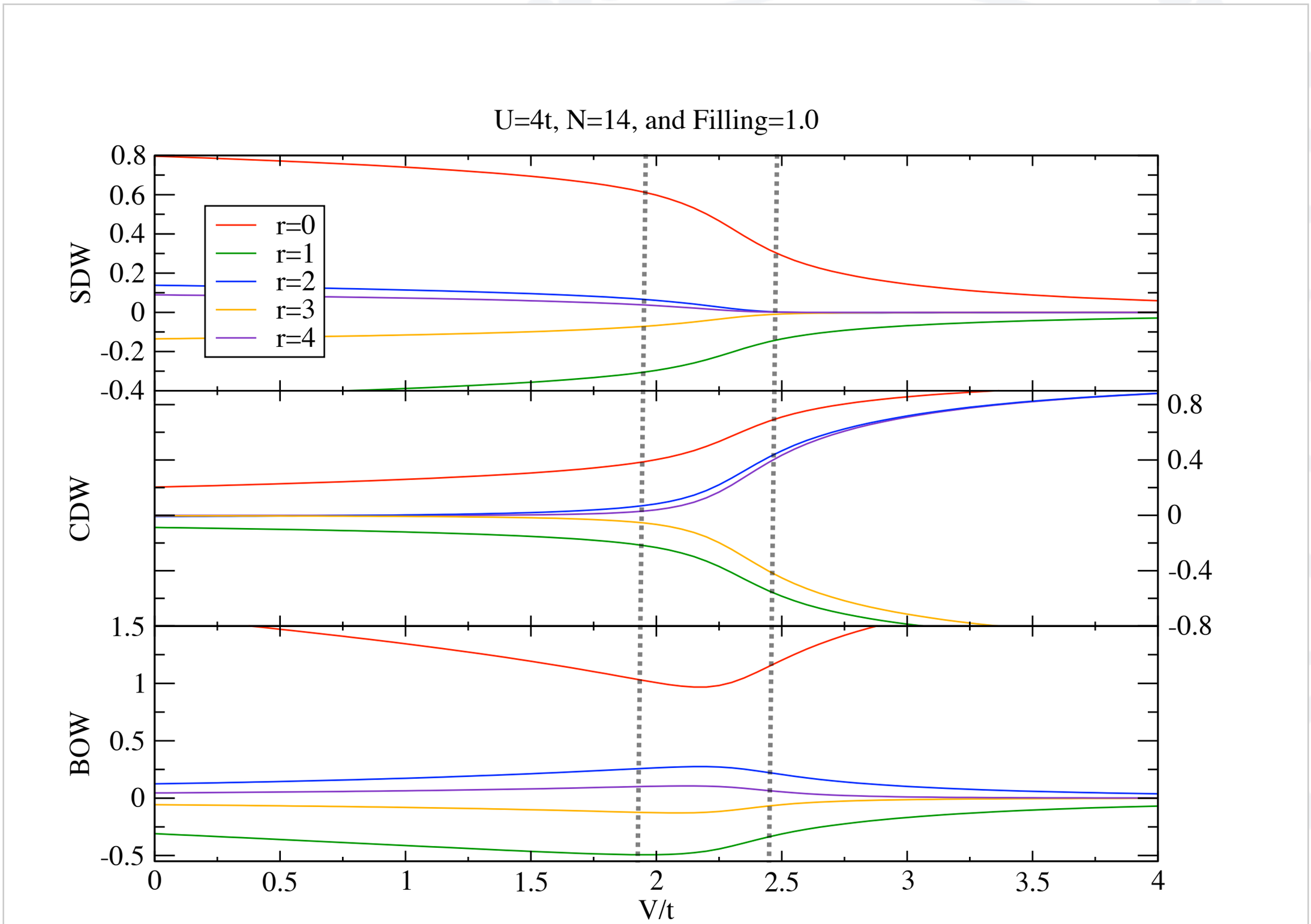
$$< (\sum_{\sigma} [c^{\dagger}_{i+r+1\sigma} c_{i+r\sigma} + h.c.] - \bar{c})$$

$$(\sum_{\sigma} [c^{\dagger}_{i+1\sigma} c_{i\sigma} + h.c.] - \bar{c}) >$$

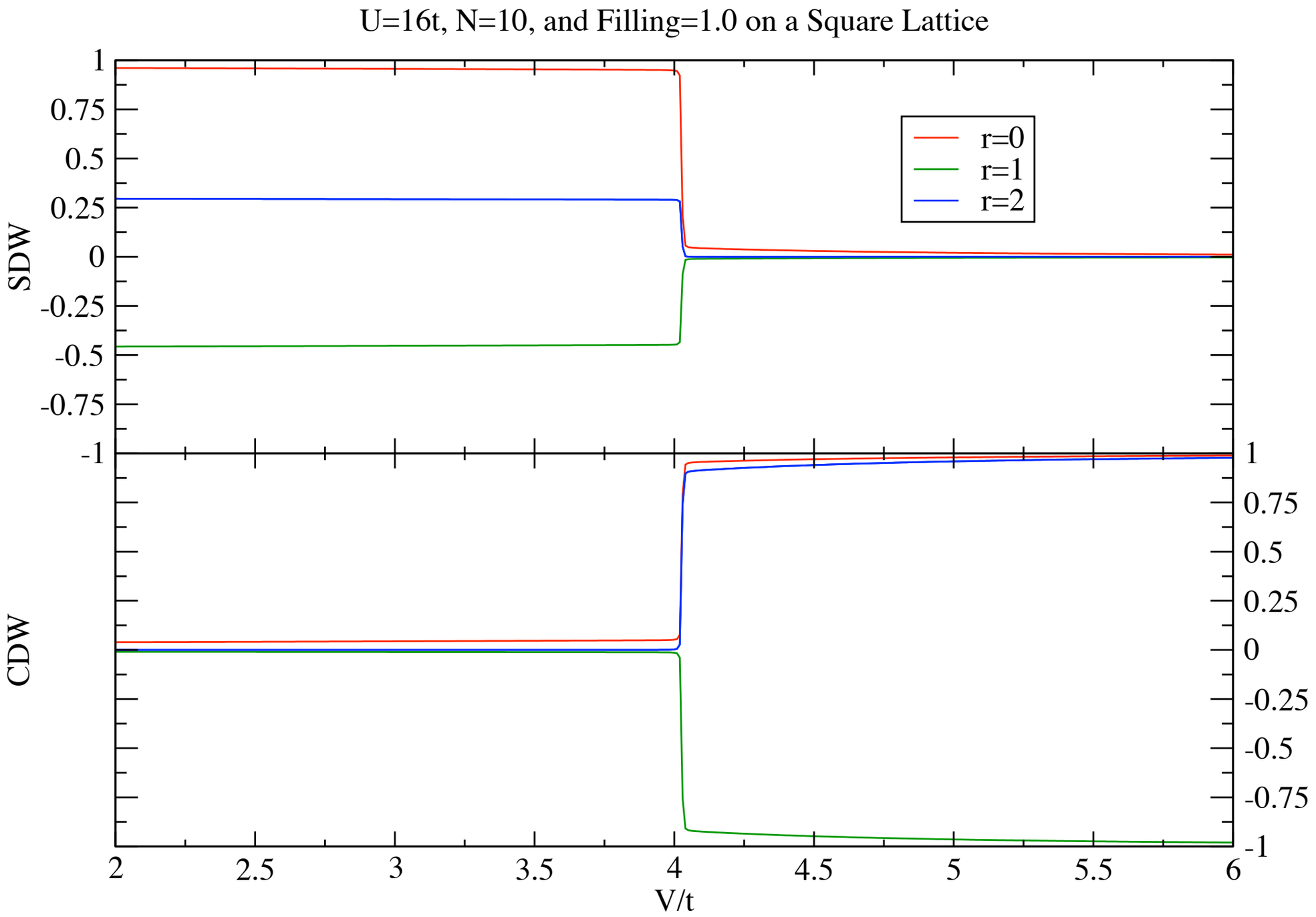


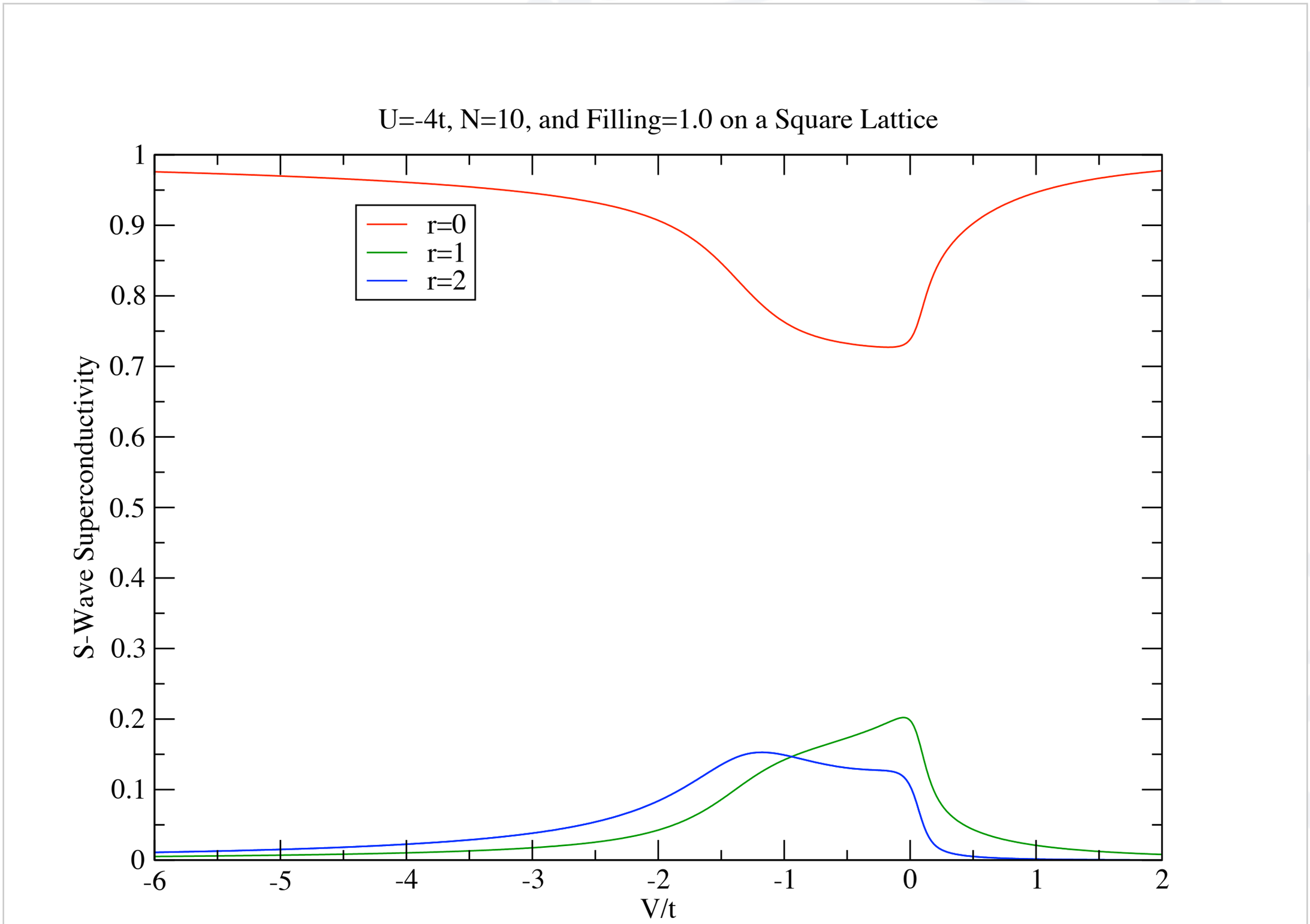
S-Wave Superconductivity

$$< c^{\dagger}_{i+r\uparrow} c^{\dagger}_{i+r\downarrow} c_{i\uparrow} c_{i\downarrow} >$$



M. Nakamura (Phys. Rev. B 61); P. Sengupta, A. Sandvik, & D. Campbell (Phys. Rev. Lett. 96)


U=16t, N=10, and Filling=1.0 on a Square Lattice
SDW
CDW
V/t
r=0
r=1
r=2
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
2
2.5
3
3.5
4
4.5
5
5.5
6


U=-4t, N=10, and Filling=1.0 on a Square Lattice
S-Wave Superconductivity
V/t
r=0
r=1
r=2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-6
-5
-4
-3
-2
-1
0
1
2

The End

Conclusions

- Confirmed Existence via. DCA
  - D-Wave Superconductivity in 2D with a Significant V Dependence
- Confirmed Existence via. Lanczos
  - Bond-Ordered Wave in 1D
  - S-Wave Superconductivity in 2D

Future Plans

- Increase Cluster Size to Study Finite Size Effects
- Explore D-Wave Superconductivity via. Lanczos
- Investigate Possible Circulating Current Phase