Correlated lattice fermions in a spin-dependent random potential

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INNOVATIVE ECONOMY NATIONAL COHESION STRATEGY

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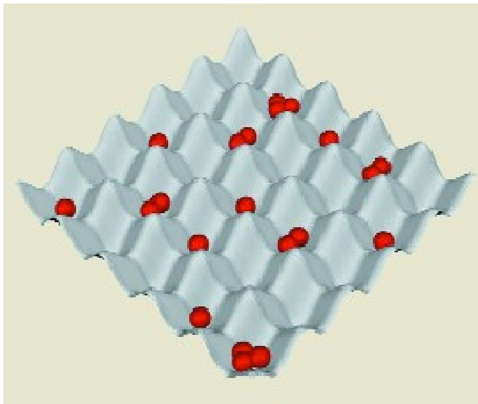
Introduction

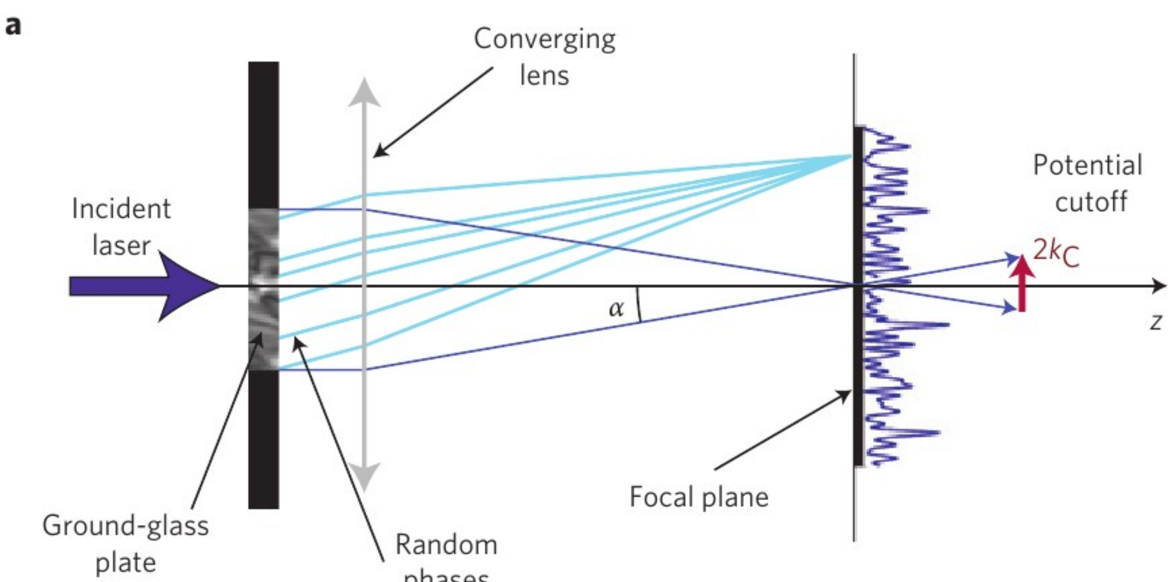
Neutral particles in optical lattice

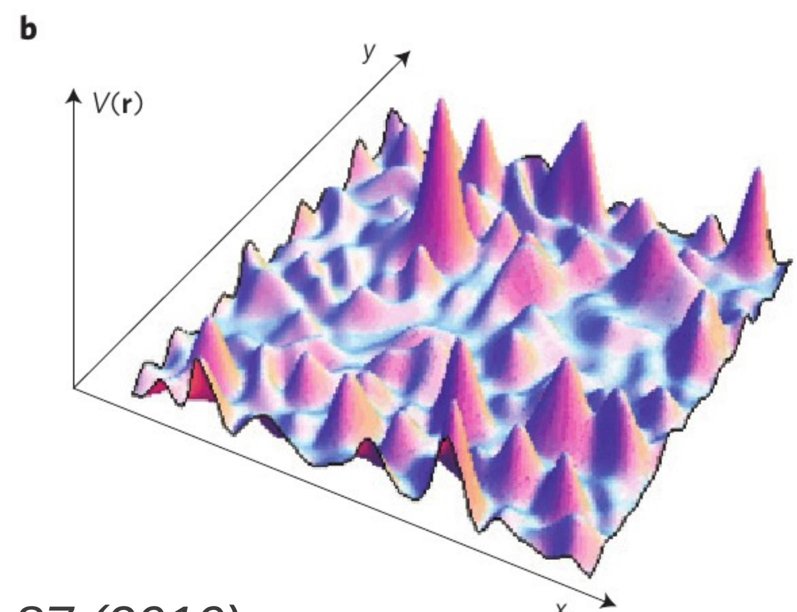


I. Bloch, Phys. World 17, 25 (2004)

Interacting electrons in materials

Disorder





L. Sanchez-Palencia, M. Lewenstein, Nature Phys. 6, 87 (2010)

Motivations and aims of our work

Apart from disorder in optical lattices:

Spin-dependent lattices first proposed:

D. Jaksch, H. Briegel, J. Cirac, C. Gardiner, and P. Zoller, Phys. Rev. Lett. 82, 1975 (1999)

Spin-dependent lattices first implemented:

O. Mandel, M. Greiner, A. Widera, T. Rom, T. Hänsch, and I. Bloch, Nature (London) 425, 937 (2003)

P. Soltan-Panahi, J. Struck, P. Hauke, A. Bick, W. Plenkers, G. Meineke, C. Becker, P. Windpassinger, M. Lewenstein, and K. Sengstock, Nat. Phys. 7, 434 (2011)

- disorder in lattice realized
- spin-dependent lattice realized

Spin-dependent disorder in optical lattice possible to realize
(beyond standard solid state physics)

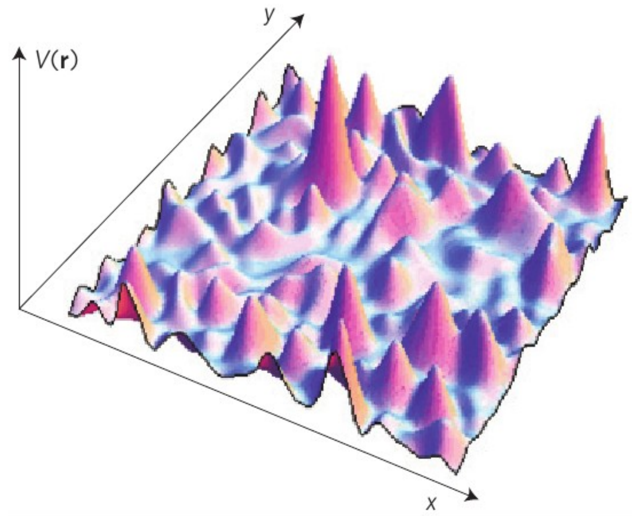
Comprehensive thermodynamics?

Hubbard model with spin-dependent disorder

$$H = t \sum_{(i,j)} \sum_{\sigma=\uparrow,\downarrow} \hat{c}^{\dagger}_{i\sigma} \hat{c}_{j\sigma} + \sum_{i} \sum_{\sigma=\uparrow,\downarrow} \epsilon_{i\sigma} \hat{n}_{i\sigma} + \sum_{i} U \hat{n}_{i\uparrow} \hat{n}_{i\downarrow}$$

$$\hat{n}_{i\sigma} \equiv \hat{c}^{\dagger}_{i\sigma} \hat{c}_{i\sigma}$$

Disorder in the model:
- comes through diagonal terms
- quenched disorder



Similar model: *R. Nanguneri, M. Jiang, T. Cary, G.G. Batrouni, and R.T. Scalettar, Phys. Rev. B 85, 134506 (2012)*

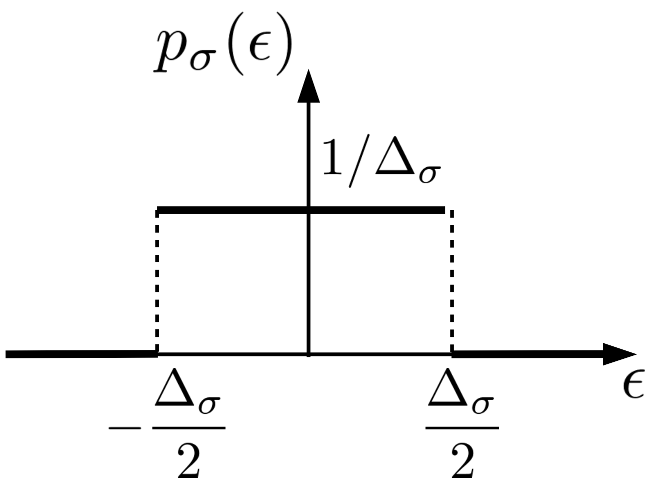
but: U<0, Bogolubov de Gennes mean field theory

More about disorder in the model

$$H = \ldots + \sum_i \sum_{\sigma=\uparrow,\downarrow} \epsilon_{i\sigma} \hat{n}_{i\sigma} + \ldots$$

We assume uncorrelated rectangular probability distribution function:

$$P(\epsilon_{1\uparrow}, \epsilon_{1\downarrow}, \ldots) = \prod_i p_\uparrow(\epsilon_{i\uparrow}) p_\downarrow(\epsilon_{i\downarrow})$$



Two cases compared:

Spin-dependent disorder:	$p_\uparrow(\epsilon) \neq p_\downarrow(\epsilon)$	$\Delta_\uparrow = 0; \quad \Delta_\downarrow \equiv \Delta$
Spin-independent disorder:	$p_\uparrow(\epsilon) = p_\downarrow(\epsilon)$	$\Delta_\uparrow = \Delta_\downarrow \equiv \Delta$

Thermodynamic properties

Magnetization:

$$m \equiv \lim_{N_L \to \infty} \langle \langle \sum_i \hat{m}_i \rangle \rangle_{\mathrm{dis}} / N_L$$

Double occupation:

$$d \equiv \lim_{N_L \to \infty} \langle \langle \sum_i \hat{n}_{i\uparrow} \hat{n}_{i\downarrow} \rangle \rangle_{\mathrm{dis}} / N_L$$

Also:

$$N_\sigma(\mu), \left(\frac{\partial n}{\partial \mu} \right)_T, \left(\frac{\partial m}{\partial h} \right)_{T,\mu}, \ldots$$

Method of solution

- Dynamical mean field theory

  W. Metzner, D. Vollhardt, Phys. Rev. Lett. 59, 121 (1987)
  A. Georges, G. Kotliar, W. Krauth, M. J. Rozenberg, Rev. Mod. Phys. 68, 13 (1996)
  M. Ulmke, V. Janis, D. Vollhardt, Phys. Rev. B 51, 10411 (1995)

- Hirsh-Fye quantum Monte-Carlo algorithm

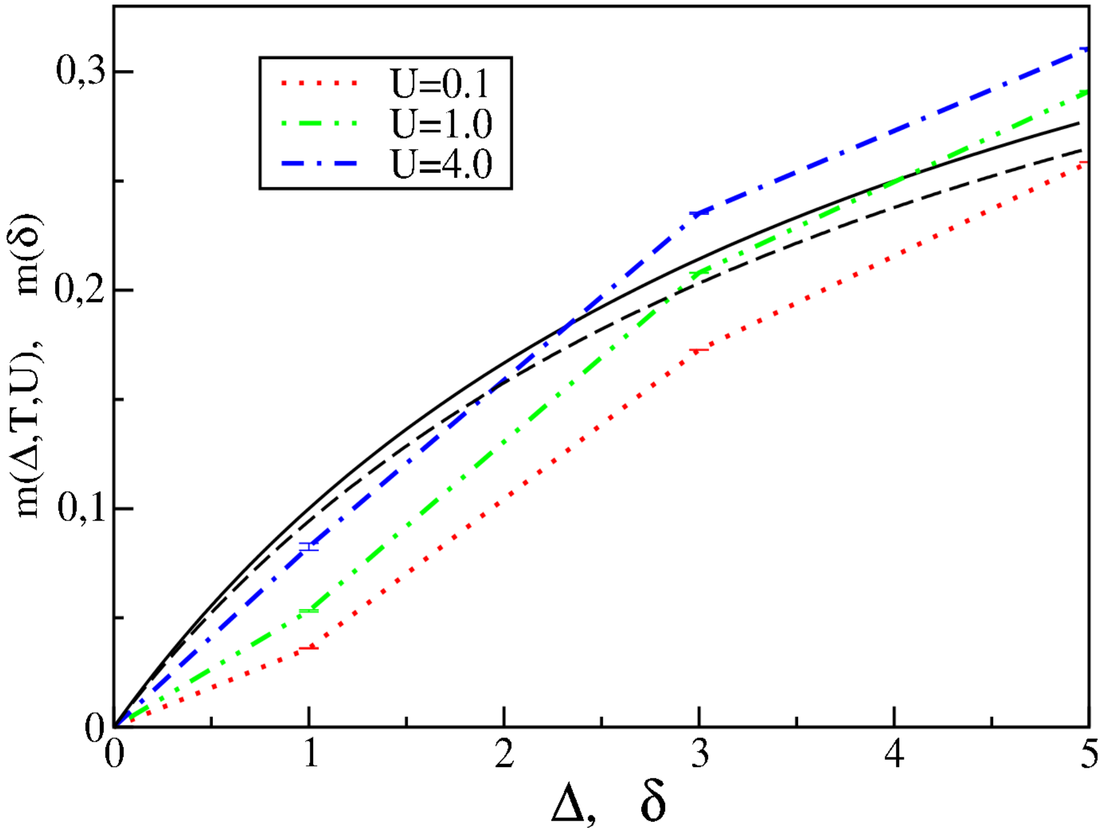
- Arithmetic average over (quenched) disorder

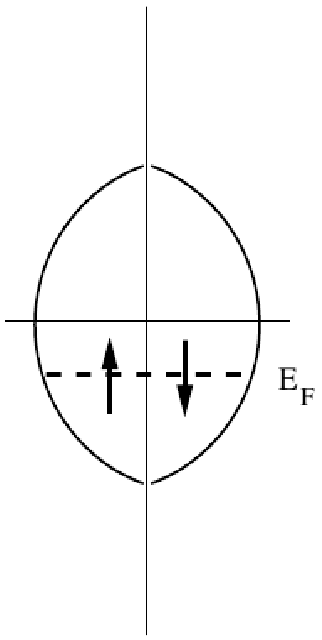
- Semi-elliptic density of states

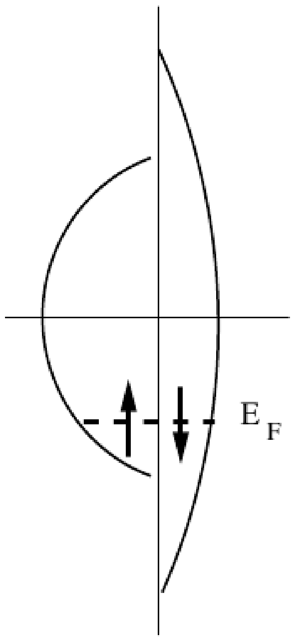
Results - magnetization

Spin-independent disorder: $m = 0$

Spin-dependent disorder: $m \neq 0$



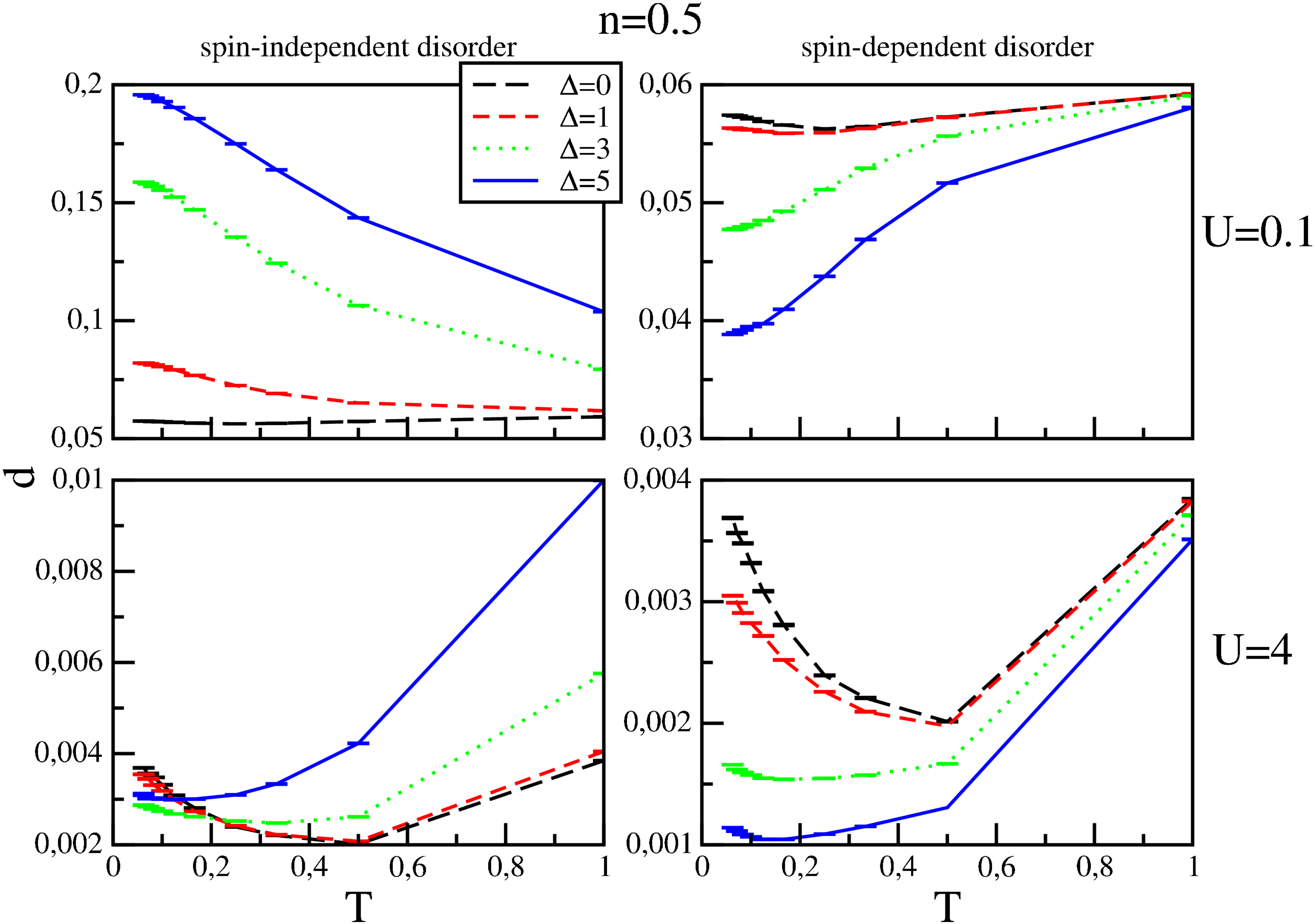




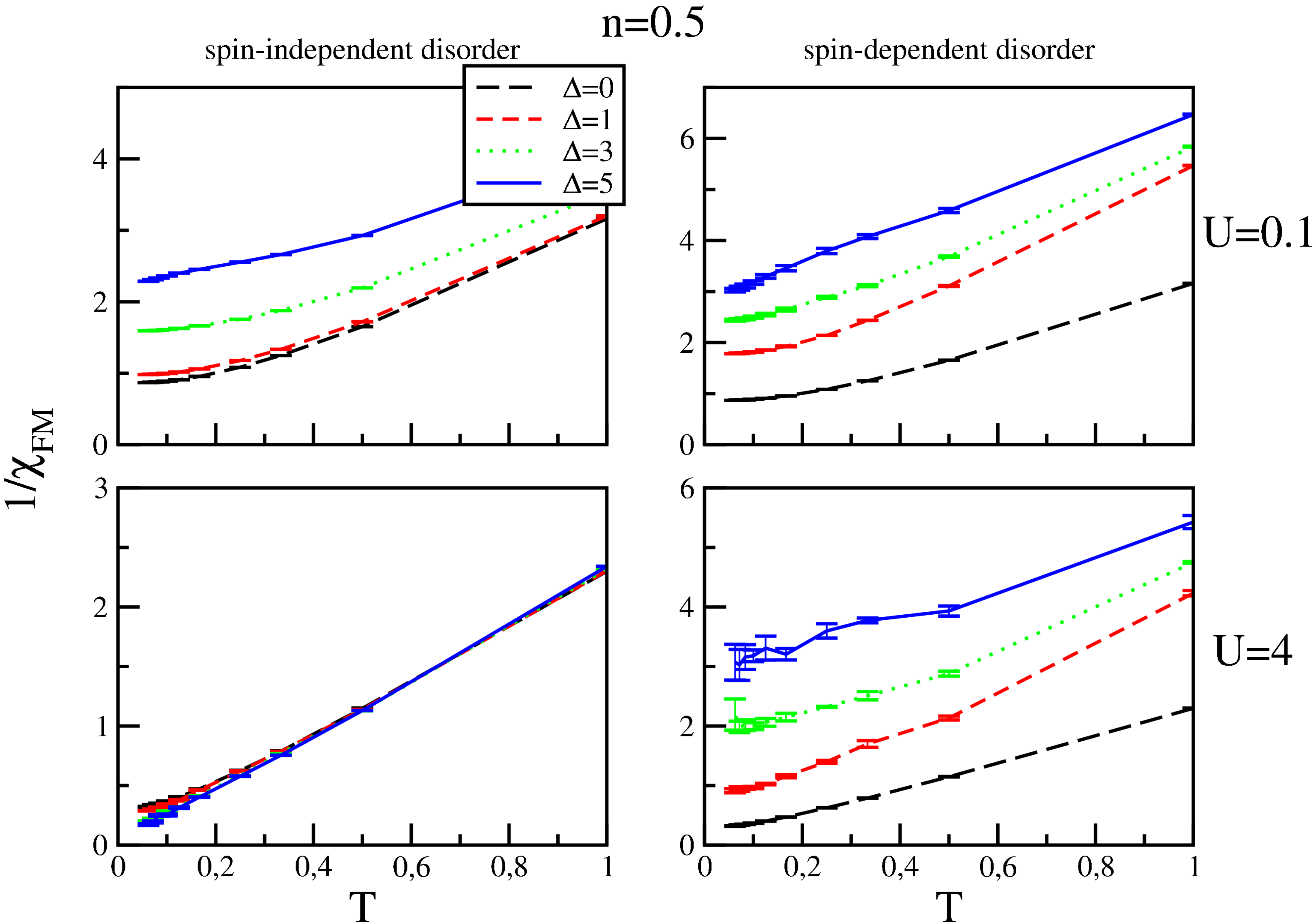
n=0.5 ; T=1/16

not so significant U dependence
- magnetization by noninteracting system

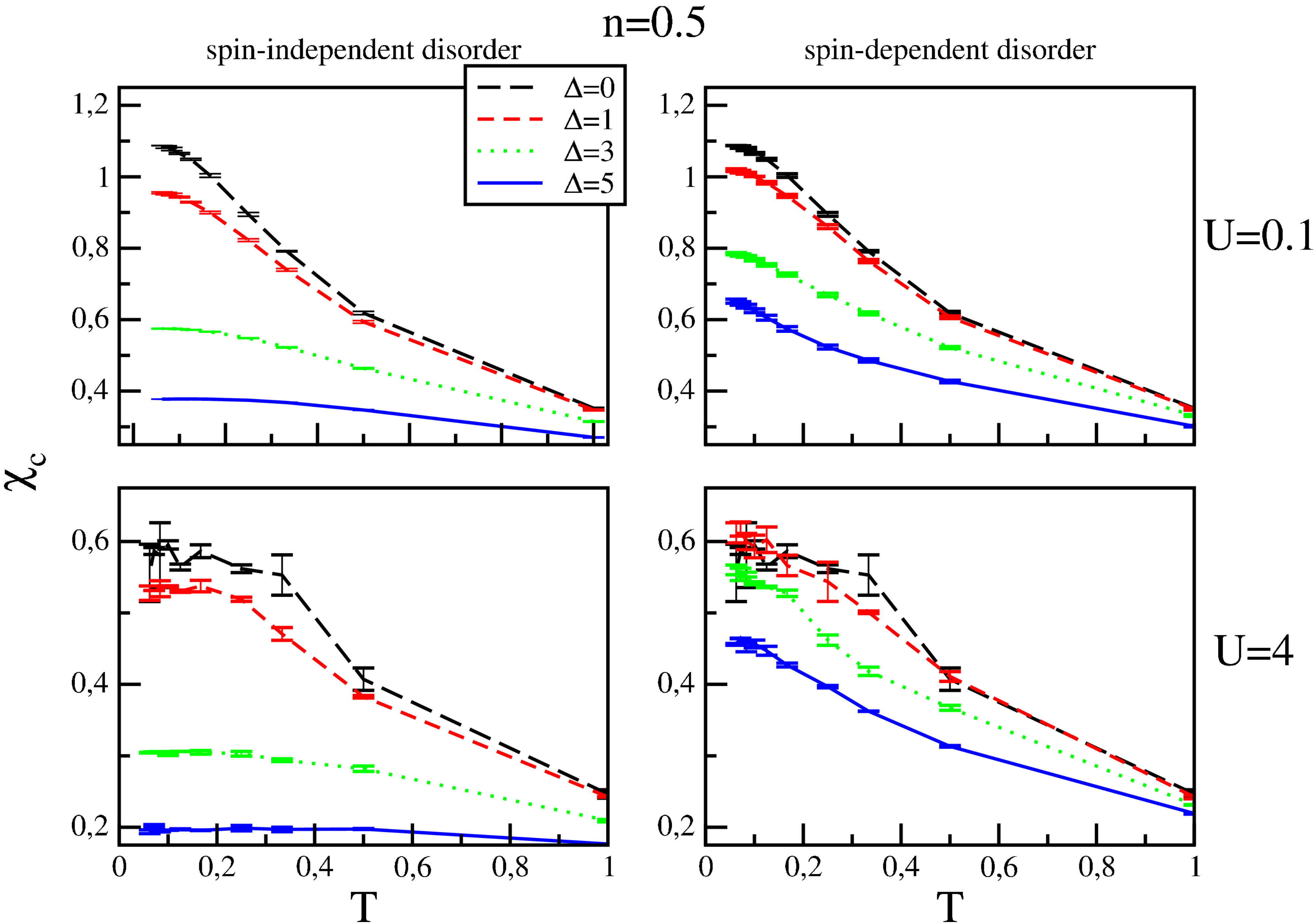
Results – double occupation



Results – ferromagnetic susceptibility



Results – charge susceptibility



Results – other physical properties

Other thermodynamical properties can be found in:

K. M, J. Skolimowski, P. B. Chakraborty, K. Byczuk, D. Vollhardt, 2013, arXiv:1302.3395

There also:

consideration for spin-imbalanced system – fixed $n_\uparrow, n_\downarrow$