Field Induced Reentrant Phase Transitions in Quasi-One-Diemnseional Random Quantum Heisenberg Chains

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1 Introduction

1.1 Quantum Magnets in the Magnetic Field

1. Magnetization Plateau

Field induced spin gap= Disordered Phase

2. Field Induced Antiferromagnetic Phase

(a) Quasi-One-Dimensional System

Magnetic Field $>$ Spin Gap$\Rightarrow$ Tomonaga-Luttinger Liquid

$+$ Weak interchain interaction

$\Downarrow$

Antiferromagnetic Long Range Order

Disorder effects on the quantum spin systems in the magnetic field

- Revived spins $\Rightarrow$ magnetic long range order
- Localized singlet pairs = plateau formation $\Rightarrow$ Suppresss the magnetic order

Competition

$\Downarrow$

Field induced reentrant transition

2 Model

Quasi-1-dimensional Random $S = 1/2$ Heisenberg model with bond alternation

$$H = \sum_{j} \left\{ \sum_{i=1}^{N/2} J \boldsymbol{S}_{2i-1,j} \boldsymbol{S}_{2i,j} + \sum_{i=1}^{N/2} J_{ij} \boldsymbol{S}_{2i,j} \boldsymbol{S}_{2i+1,j} \right\}$$

intrachain

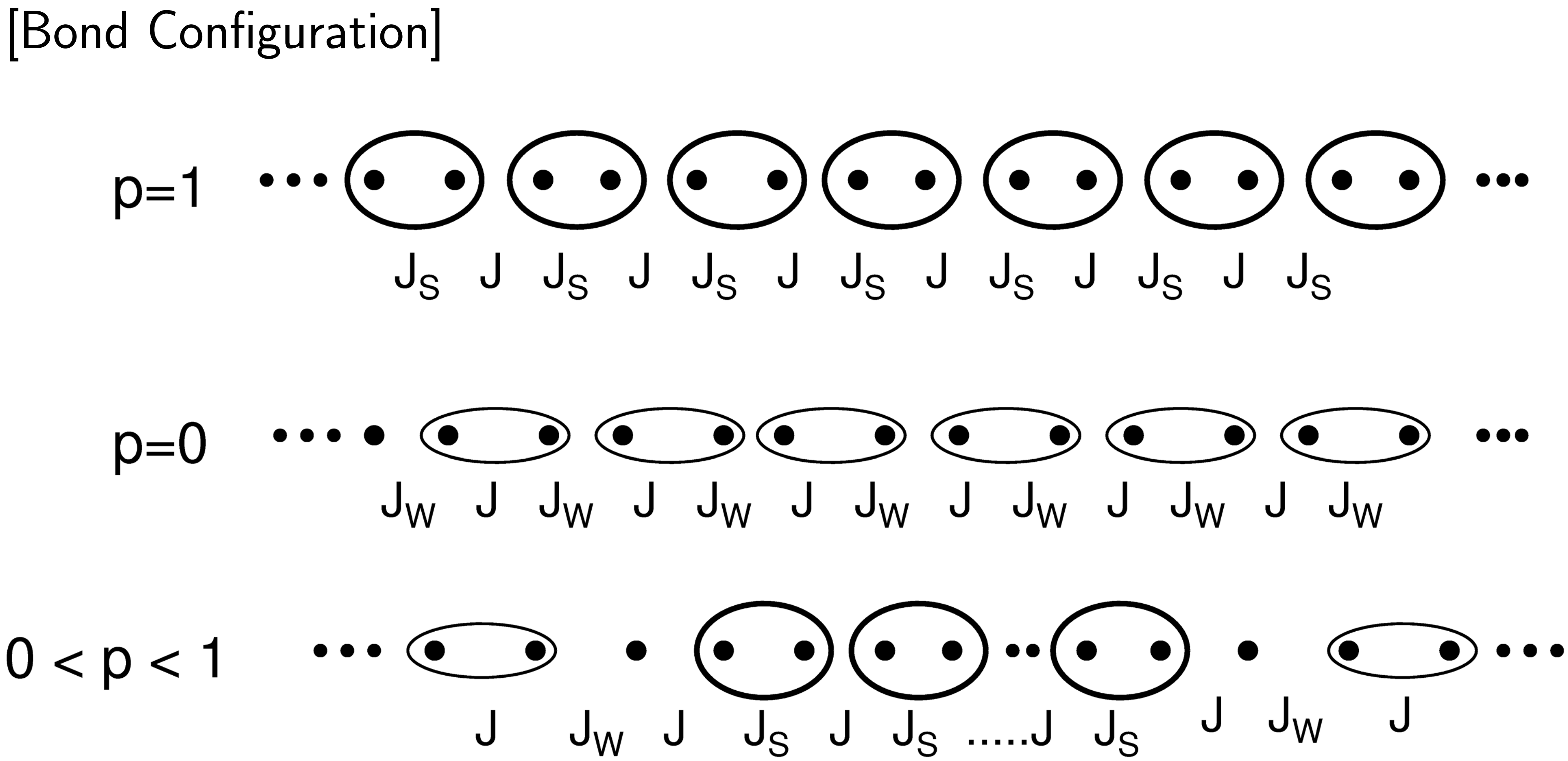
$$+ \sum_{i=1}^{N} \sum_{<j,j'>} J_{\rm int} \boldsymbol{S}_{i,j} \boldsymbol{S}_{i,j'}$$ interchain

- Intrachain Interaction:

$$J = 1 \quad J_{i,j} = \begin{cases} J_{\rm S} & \text{probability } p \\ J_{\rm W} & \text{probability } 1-p \end{cases}$$

$$J_{\rm S} > J > J_{\rm W} > 0$$

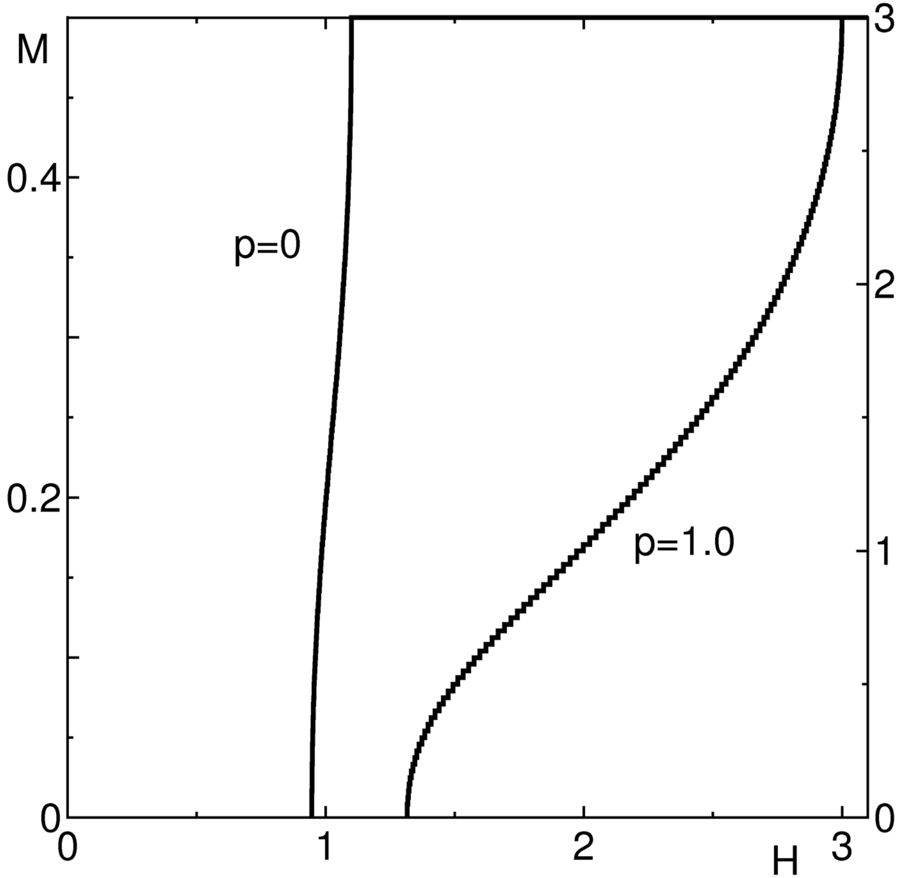
Method DMRG: Keeping 60 $\sim$ 160 states.


[Bond Configuration]
p=1
J_S J J_S J J_S J J_S J J_S J J_S J J_S
p=0
J_W J J_W J J_W J J_W J J_W J J_W J J_W
0 < p < 1
J J_W J J_S J J_S .....J J_S J J_W J

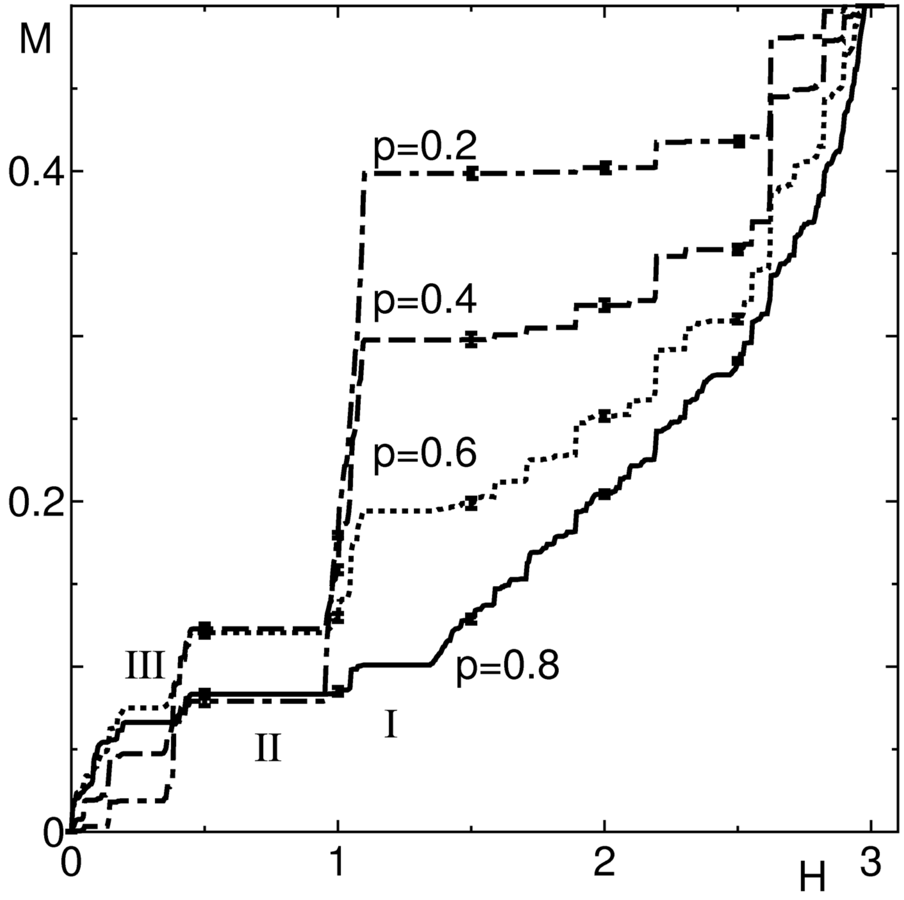
3 Magnetization Curve of an Isolated Chain at $T = 0$.

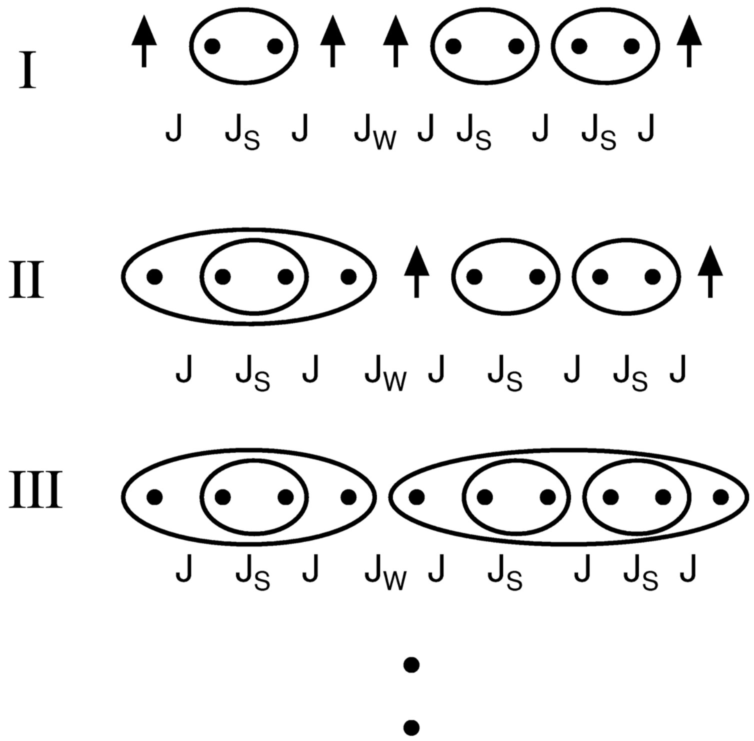
$$J_{\mathrm{S}} = 2 \; J_{\mathrm{W}} = 0.1 \; J = 1$$

1. Uniform Chain - DMRG

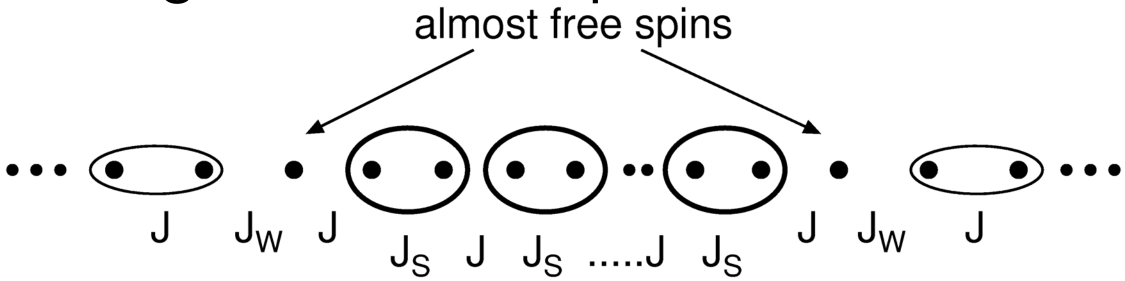


2. Magnetization Curve of Mixed Chain - Cluster picture





Averaged over 64 samples with $N = 120$.



4 Effect of Interchain Interaction

Mean Field Approximation for the Interchain Interaction

$$\left\langle S_{i,j}^x \right\rangle = \begin{cases} (-1)^i m & J_{\mathrm{int}} < 0 \quad \text{Interchain ferromagnetic interaction} \\ (-1)^i P_j m & J_{\mathrm{int}} > 0 \quad \text{Interchain antiferromagnetic interaction} \end{cases}$$

for $J_{\mathrm{int}} > 0$

$$P_j = +1 \quad j \in \text{A-sublattice}$$

$$P_j = -1 \quad j \in \text{B-sublattice}$$

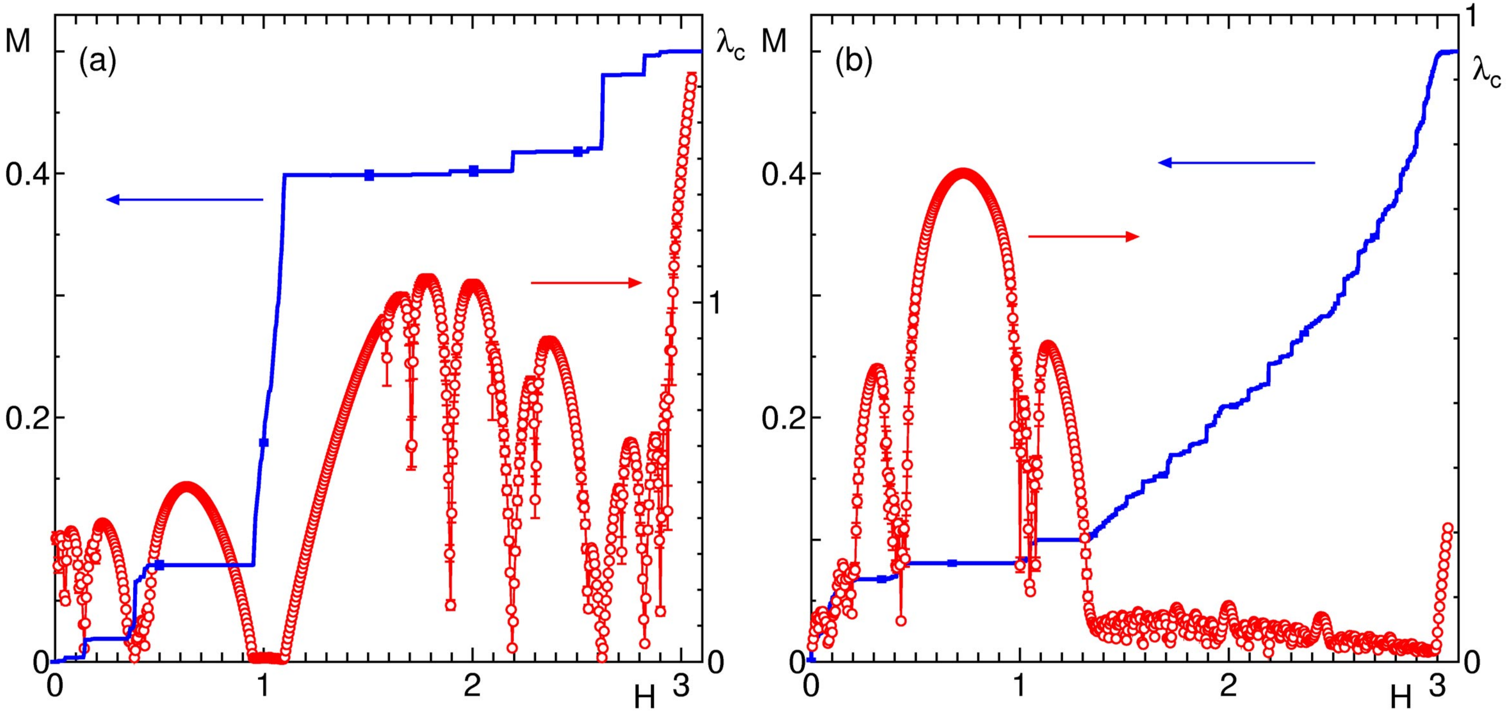
Interchain mean field Hamiltonian

$$H^{\mathrm{IMF}} = \sum_{i=1}^{N} J \boldsymbol{S}_{2i-1} \boldsymbol{S}_{2i} + \sum_{i=1}^{N} J_i \boldsymbol{S}_{2i} \boldsymbol{S}_{2i+1} - H_{\mathrm{st}} \sum_{i=1}^{N} (-1)^i S_i^x$$

$$H_{\rm st} = \lambda m(H_{\rm st})$$ Self-consistent equation $\lambda \equiv z|J_{\rm int}|$

$$\lambda_c = \lim_{H_{\rm st}\to 0} H_{\rm st}/m(H_{\rm st})$$

λ_c: critical interchain interaction λ

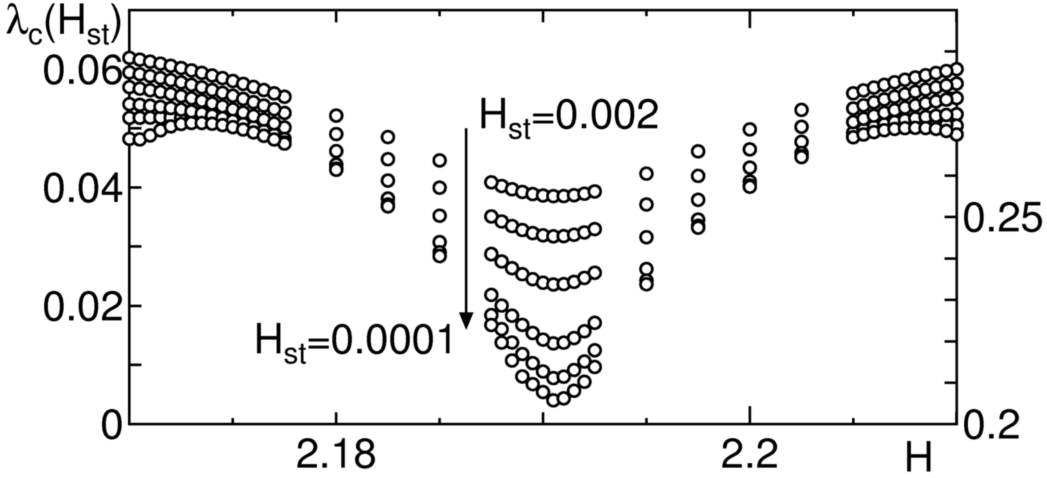


$p = 0.2$ $H_{\rm st} = 0.0005$ $p = 0.8$

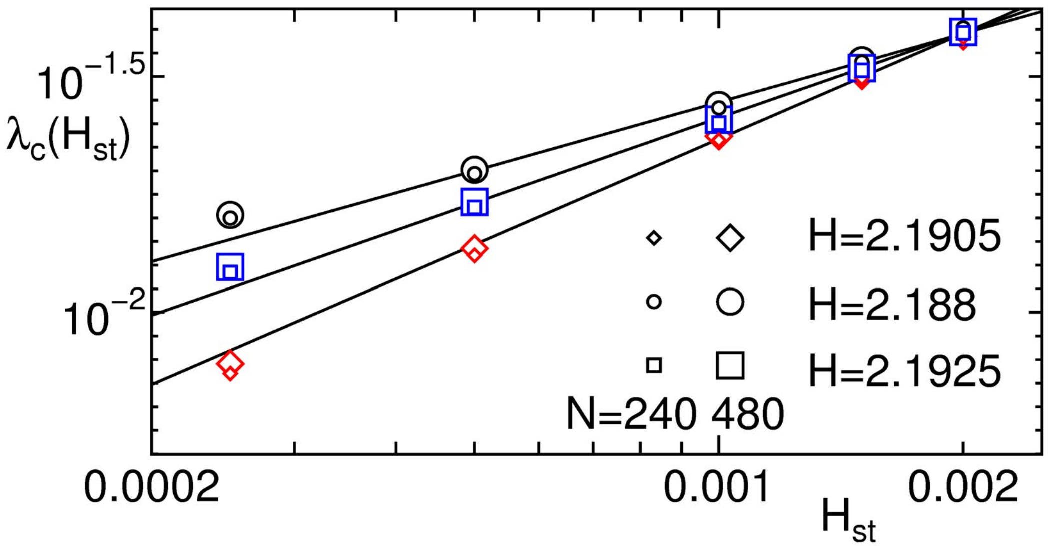
Multiple reentrant transition

$N = 120$. Averaged over 512 samples.

- Fine peak structure



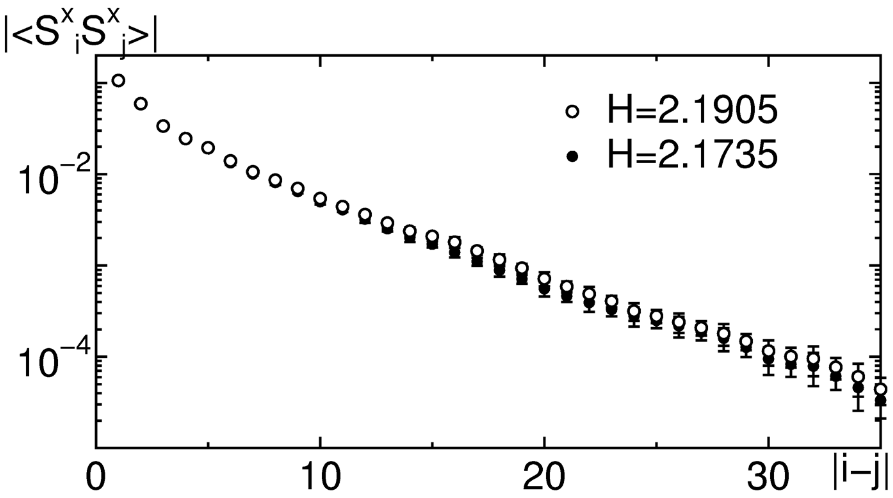
- H_c-dependence of λ_c

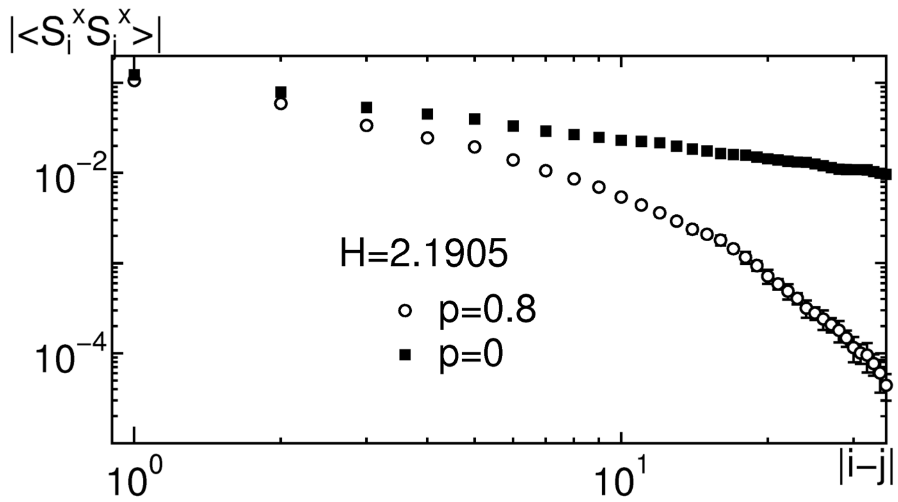


$N = 240, 480$ Averaged over 256 samples (middle 240 sites).

$\lambda_c =$0 only for discrete points?

5 Intrachain spin-spin correlation function





Averaged over 512 samples for $N = 240$

Exponential decay even for $\lambda_c = 0$

Non plateau state : Dense excited states near the ground state

Staggered mean field mixes the excited state into the ground state

$\Downarrow$

Divergence of χ_{st}

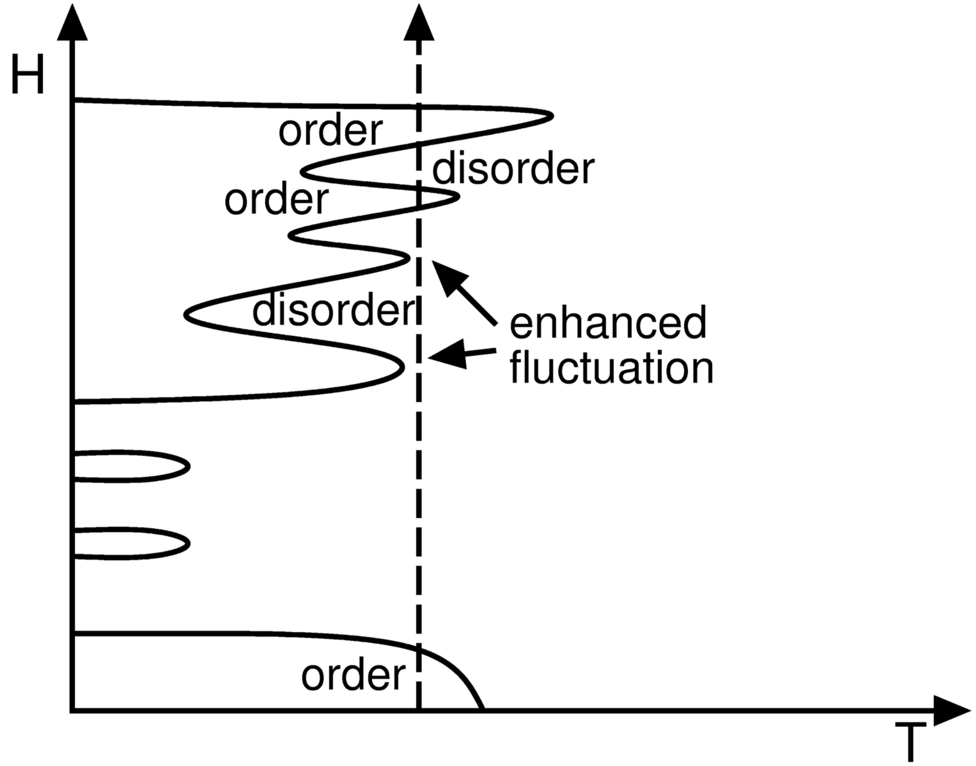
$\Downarrow$

Long range order with weak interchain interaction

6 Summary

1. Quasi-one-dimensional random alternating bond $S = 1/2$ Heisenberg model exhibits multiple reentrant transitions in the magnetic field.
   Method：DMRG+Interchain mean field approximation
2. In the absence of interchain coupling, the spin-spin correlation function decays exponentially even in the non-plateau regime.
   Mix up the low energy excited states by interchian interaction.
   ⇒Long range order
3. Bose glass phase(Nohadani *et al*) is not found
   Limitation of interchain mean field approximation
4. • Reentrant transition in 3-D random dimer system
   Random destruction of singlet dimer⇒Local moment
   • Quasi-One-dimensional random alternating bond system
   Competition of 2 types of dimer patterns⇒local moment
   More complicated features = Multiple reentrant transition

5. Speculated finite temperature phase daigram



6. Possibility of experimental observation : random substitution of anions on the superexchange path

Ref. K. Hida : J. Phys. Soc. Jpn. 75, 074709 (2006). cond-mat/0602016;