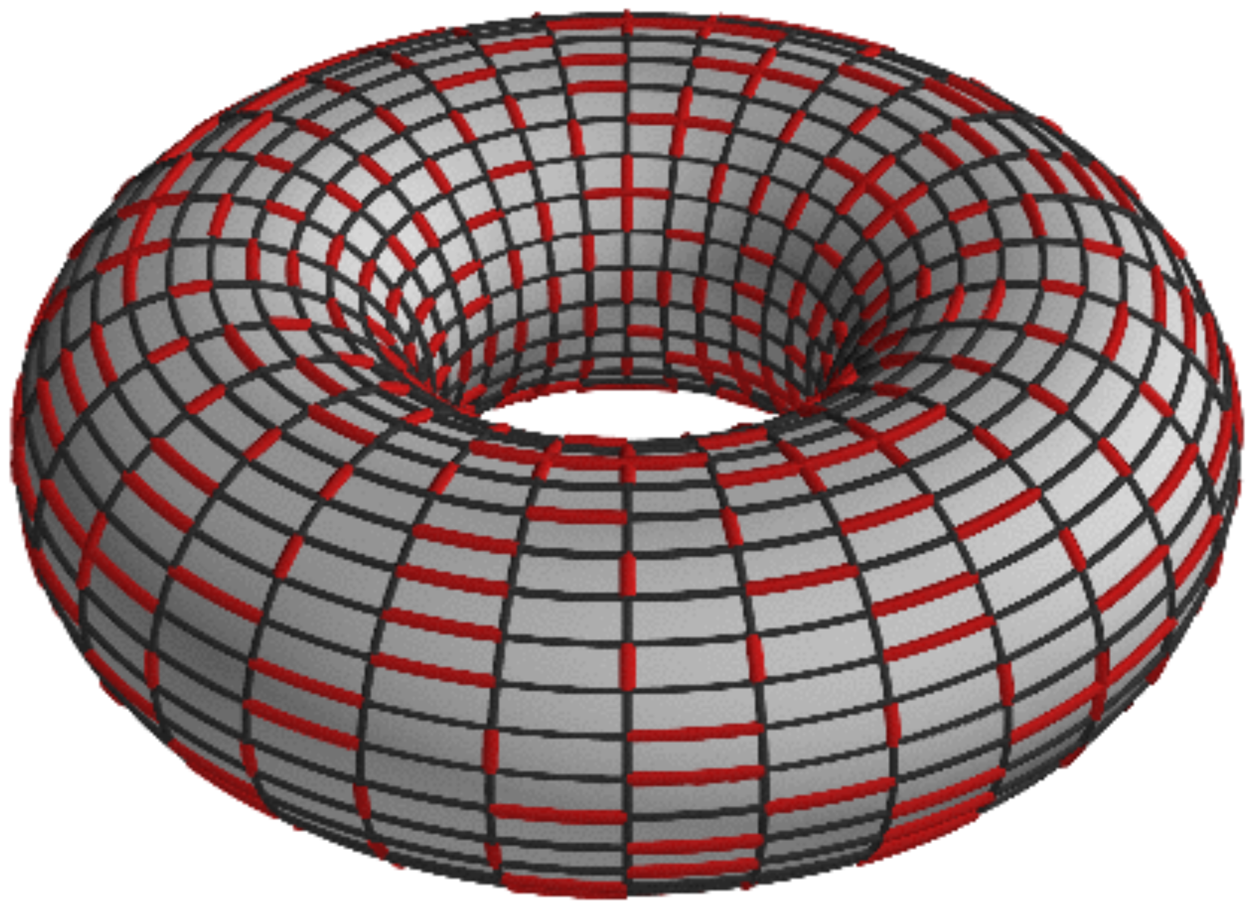
Dimer Liquid State in the Quantum Dimer-Pentamer Model on the Square Lattice



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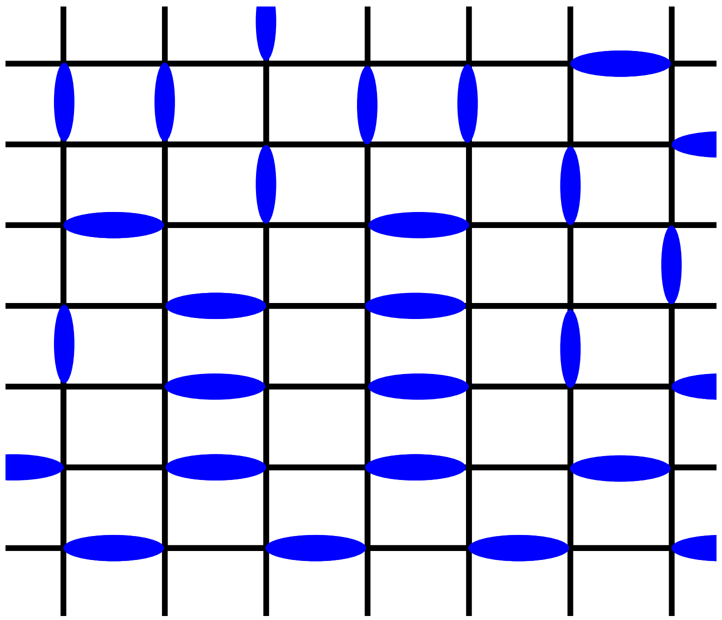
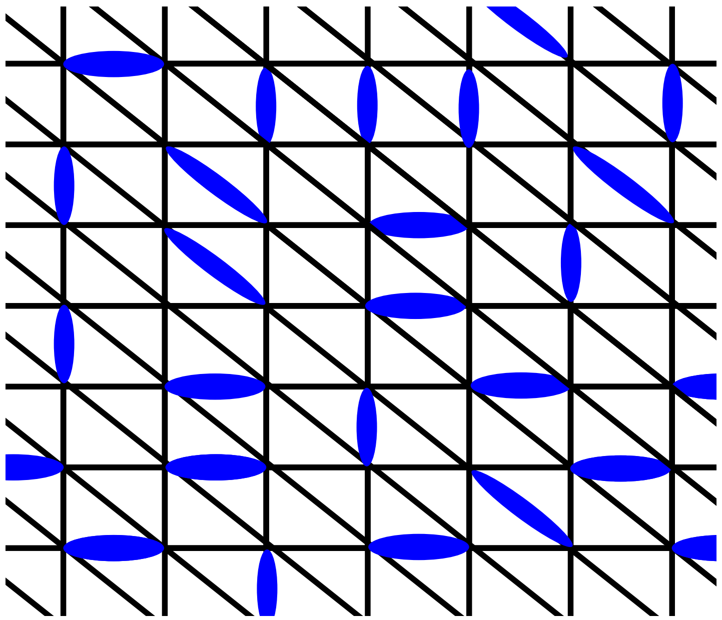
Square Lattice Quantum Dimer Model (QDM)



(At the RK Point)

- Gapless
- Power law decay of dimer correlations in liquid state
- Extensive topological degeneracy
- Log confined monomers

Triangular Lattice QDM



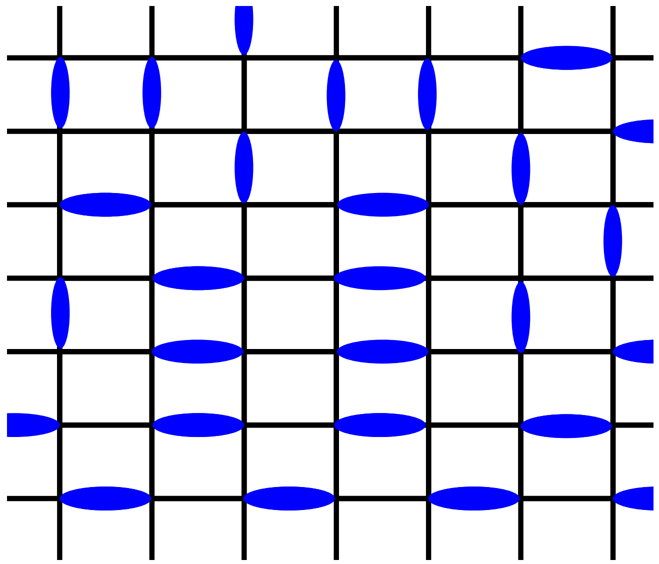
(At the RK Point)

- Gapped
- Exponential decay of dimer correlations in liquid state
- Finite topological degeneracy
- Deconfined monomers

Rokhsar, Kivelson, Phys. Rev. Lett. 1988.
Moessner, Sondhi, Phys. Rev. Lett. 2001.

Local Constraints

QDM



One dimer touching each vertex

$$e^{i\alpha(n_v - 1)}|\psi\rangle = |\psi\rangle$$

For $n_v = 1$, α can be anything

→ $U(1)$ Local gauge symmetry

Relax constraints:

E.g. Toric Code Even Parity

$n_v \to 0, 2, 4$ $\alpha = \{0, \pi\}$ satisfies $e^{i\pi n_v}|\psi\rangle = |\psi\rangle$

Moessner, Sondhi, Fradkin, Physical Review B, 2001.

$$U(1) \to Z_2$$

Possibilities on the square lattice

Dimers at vertex	Corresponding Model	Exact Local Gauge Symmetry
$n_v = 0$ $(n_v = 4)$	Trivial Case	
$n_v = 1$ $(n_v = 3)$	QDM	$U(1)$
$n_v = 2$	Fully Packed Loop Model	$U(1)$
$n_v = 1, 3$	Toric Code Odd Parity	Z_2
$n_v = 0, 2, 4$	Toric Code Even Parity	Z_2

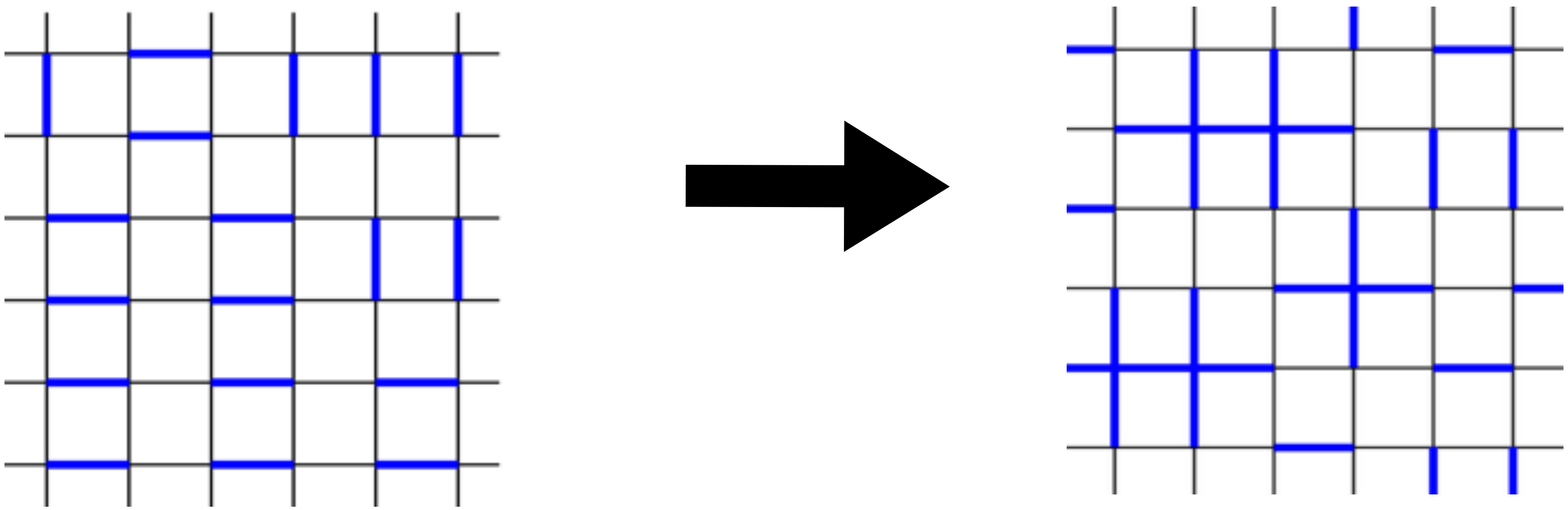
What else is possible?

$n_v = 1, 4$	Quantum Dimer Pentamer Model (QDPM)

$$e^{i\alpha(n_v - 1)} \qquad \alpha = \{0, 2\pi/3, -2\pi/3\}$$

Z_3

QDM → QDPM



$$H_{QDM} = -t_0 \sum_{\square} \Big(|=\rangle\langle \| | + \text{h.c.} \Big) + v_0 \sum_{\square} \Big(|=\rangle\langle = | + |\|\rangle\langle \| | \Big)$$

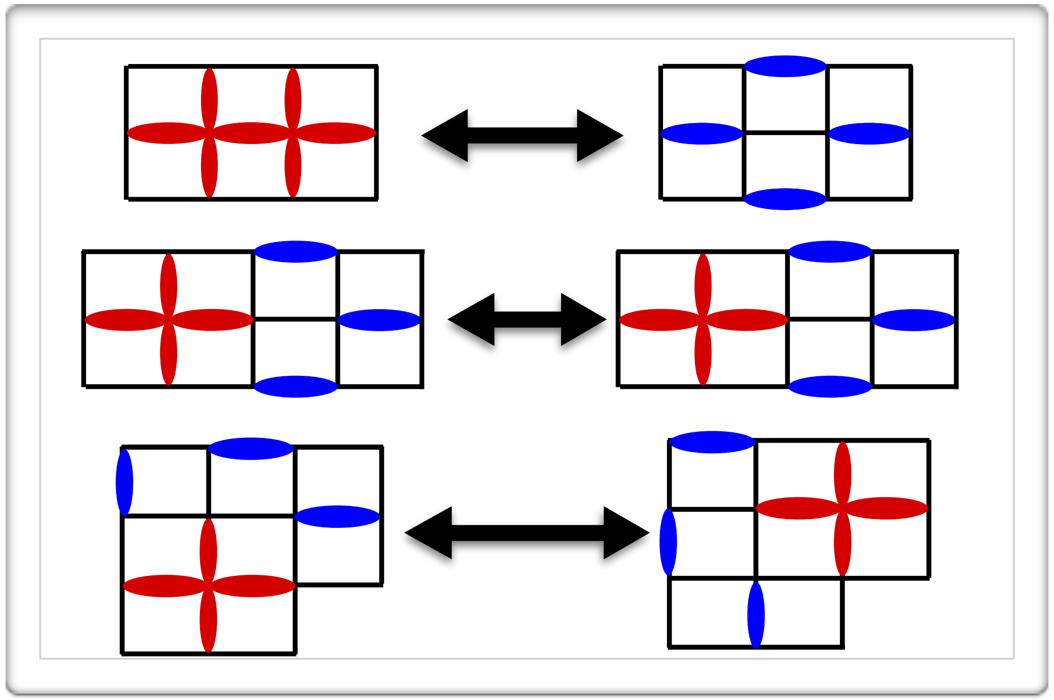
$$H_{QDPM} = H_{QDM}$$

$+$ pentamer terms

Pentamer Dynamics and Hamiltonian

$$H = \overbrace{-t_0 \sum \mathrm{KE}_0 + \sum \mathrm{PE}_0}^{H_{QDM}}$$

$$\left.\begin{aligned} &- t_1 \sum \mathrm{KE}_1 + v_1 \sum \mathrm{PE}_1 \\ &\quad\vdots \\ &- t_n \sum \mathrm{KE}_n + v_n \sum \mathrm{PE}_n \end{aligned}\right\} H_{pentamer}$$



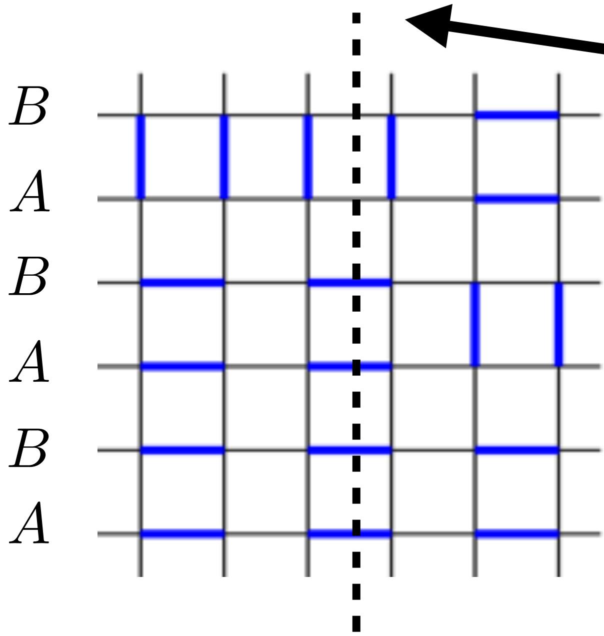
$$|\Psi_{\mathrm{RK}}\rangle = \frac{1}{\sqrt{\mathcal{N}}} \sum_C |C\rangle$$

RK point

$$t_l / v_l = 1$$

$$l = 0, 1, \ldots, n$$

For the QDM

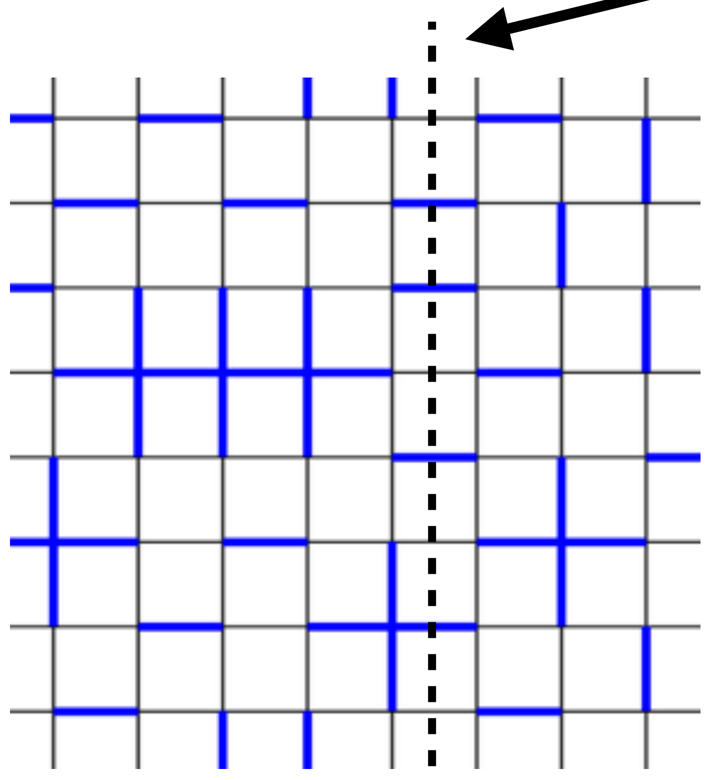


$$W^y_{QDM} = N_A - N_B = \begin{cases} -L/2 \\ \vdots \\ -1 \\ 0 \\ 1 \\ \vdots \\ L/2 \end{cases}$$

$$[H_{QDM}, W^y_{QDM}] = 0$$

In the QDPM a new winding number is conserved

$$W^y_{QDPM} = (N_A - N_B)\mathrm{mod}3 = \begin{cases} 1 \\ 0 \\ 2 \end{cases}$$

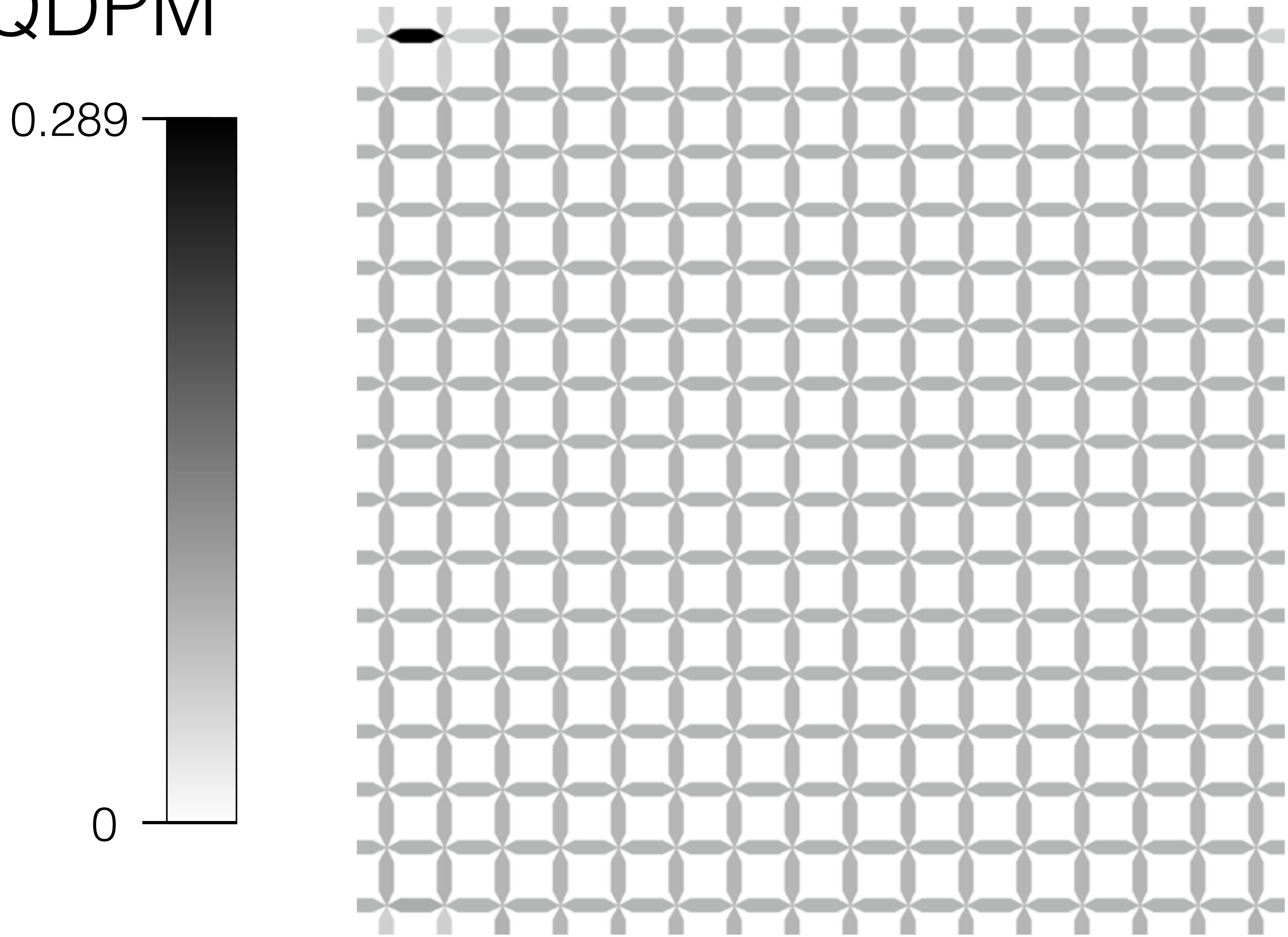


$$[H_{QDPM}, W^y_{QDM}] \neq 0$$

$$[H_{QDPM}, W^y_{QDPM}] = 0$$

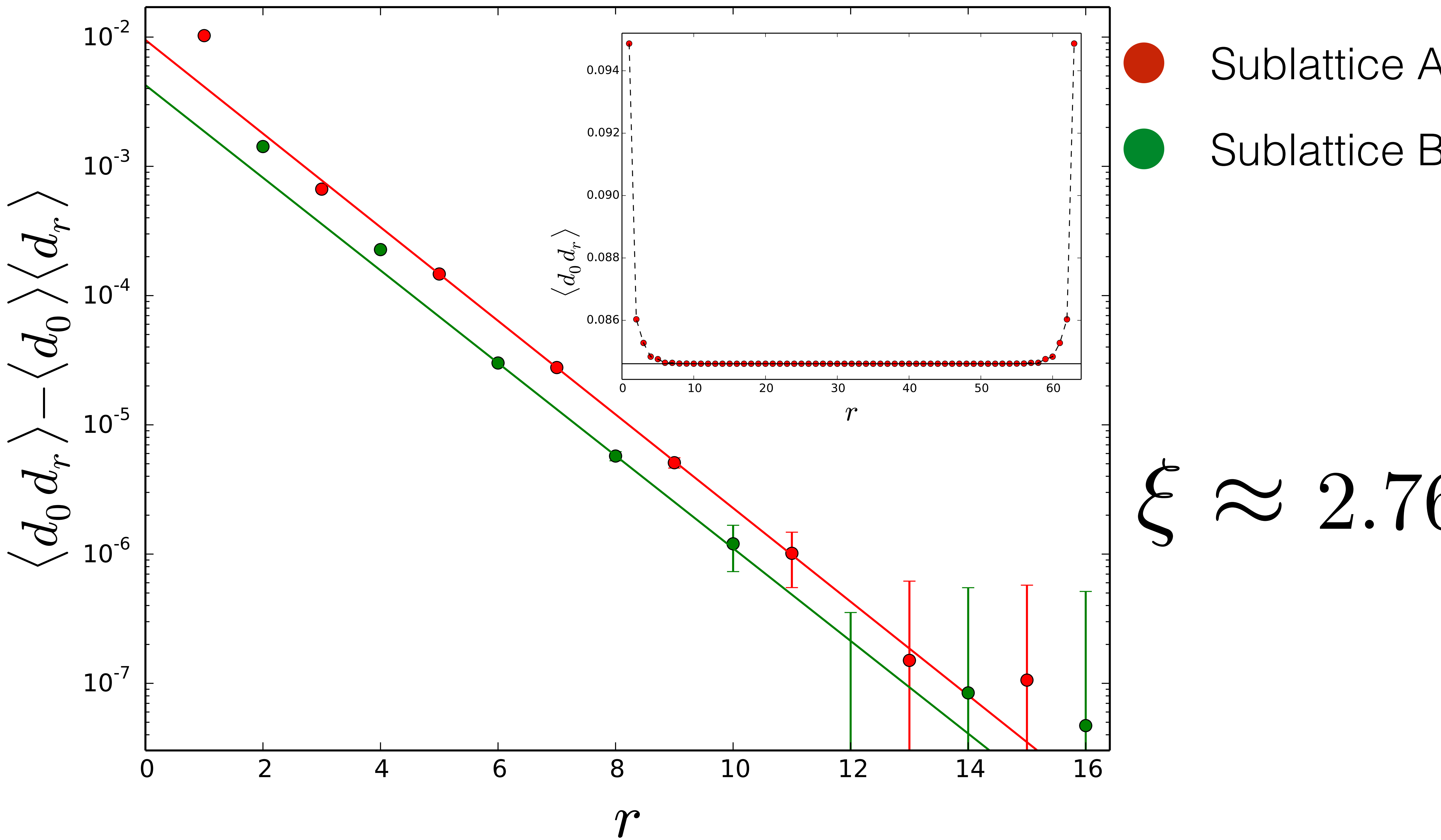
Monte Carlo Results of the QDPM at the RK Point

Grey scale of dimer correlations in the QDPM



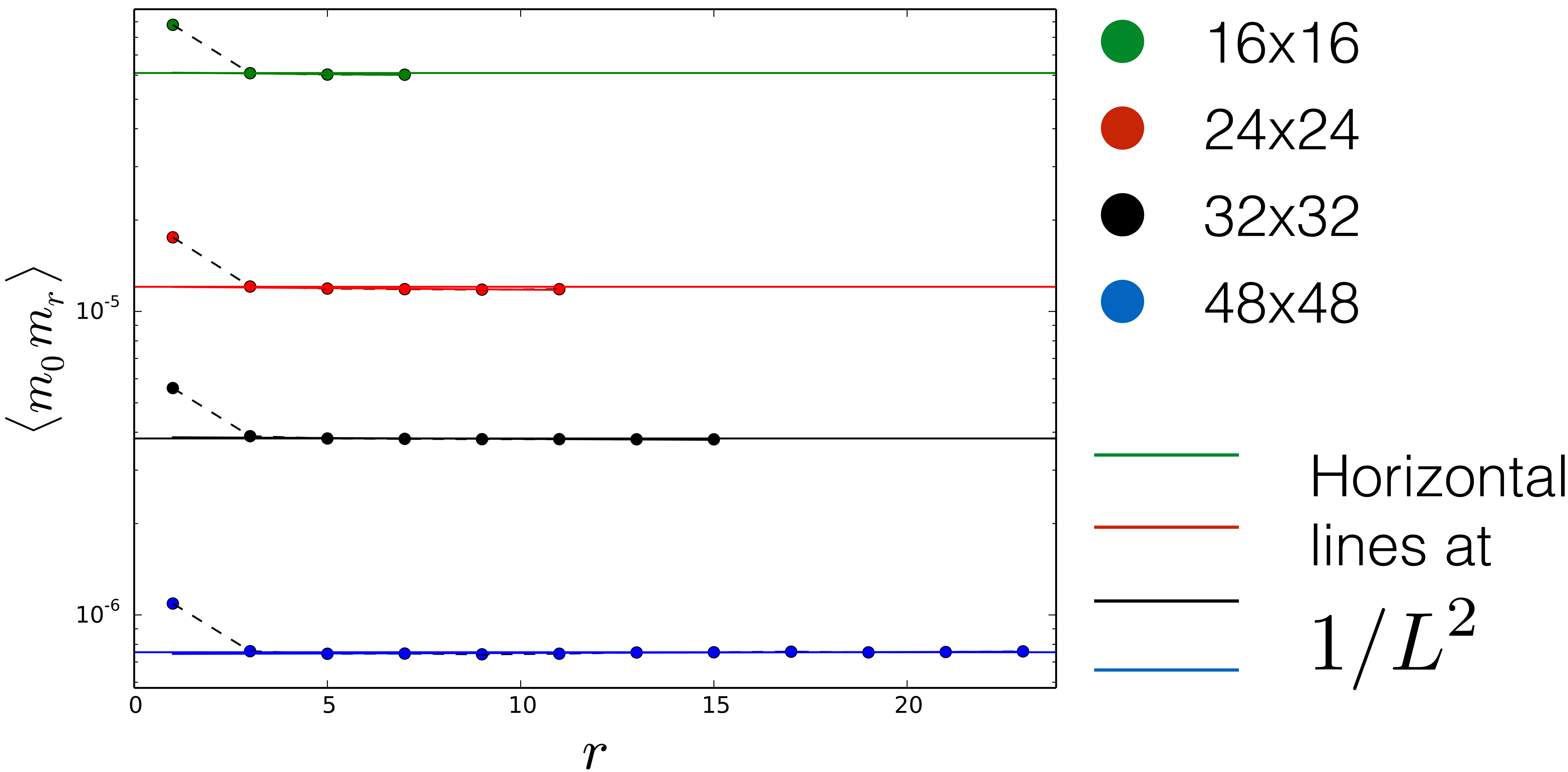
Exponentially Decaying Dimer Correlations

64x64 Lattice



$$\xi \approx 2.76$$

Monomer Correlations



Conclusions

- We propose a quantum dimer-pentamer model which may exhibit Z_3 topological order.
- Using a Monte Carlo method we sample the ground state wave function at the RK point to calculate the dimer and monomer correlations.
- We show evidence of a dimer liquid state at the RK point.
- We show evidence of deconfined monomers at the RK point.

Future Work

- Calculate the imaginary time correlations to estimate the energy gap.
- Investigate signatures of topological order in the entanglement entropy.
- Determine the phase diagram away from the RK point.