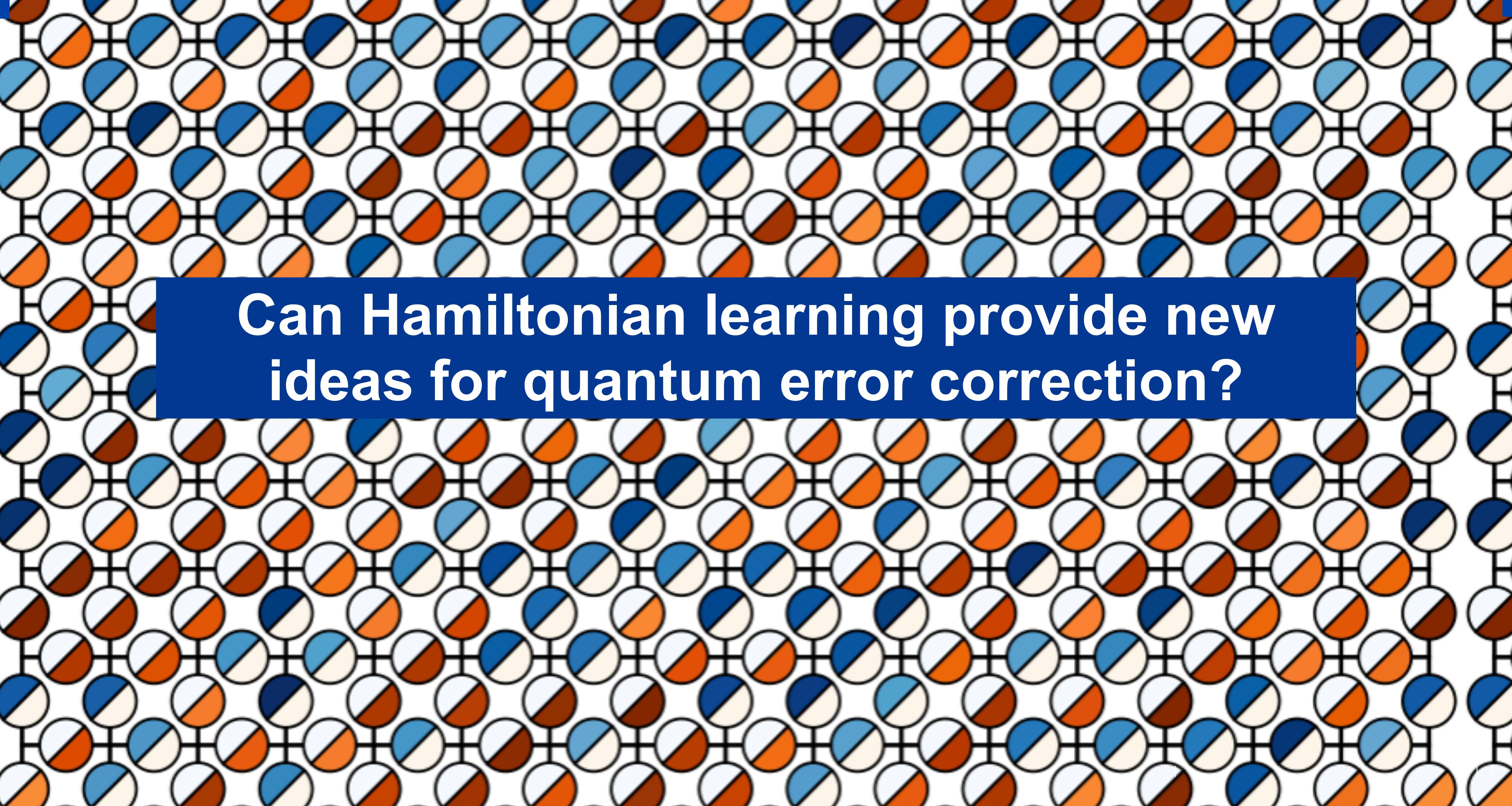


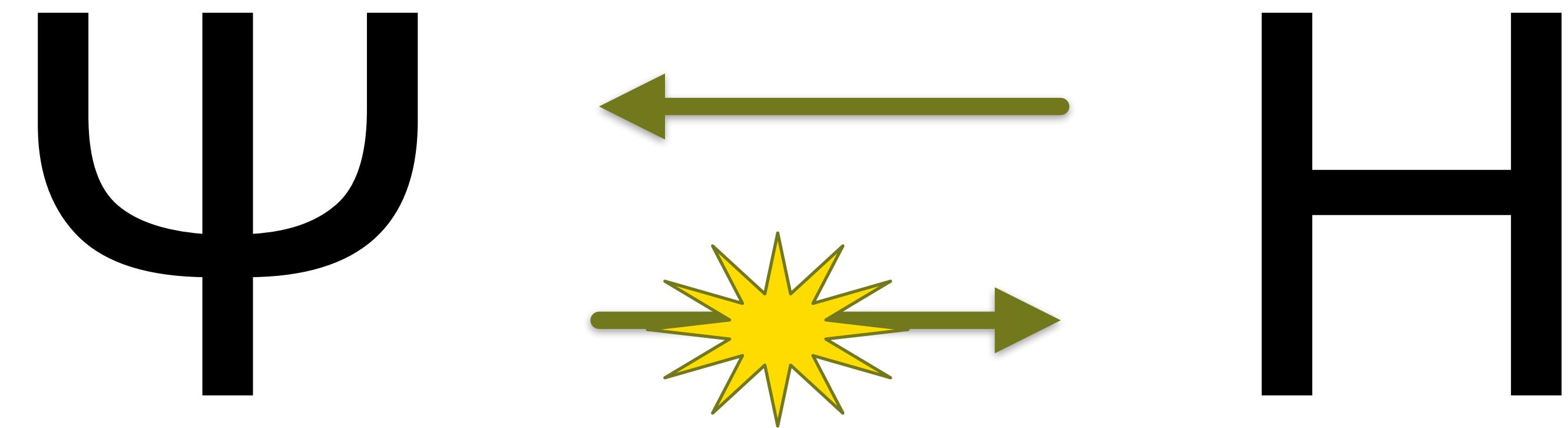
Hamiltonian Learning for Quantum Error Correction

Eliška Greplová, ETH Zürich



Can Hamiltonian learning provide new
ideas for quantum error correction?

Wave-function vs. Hamiltonian

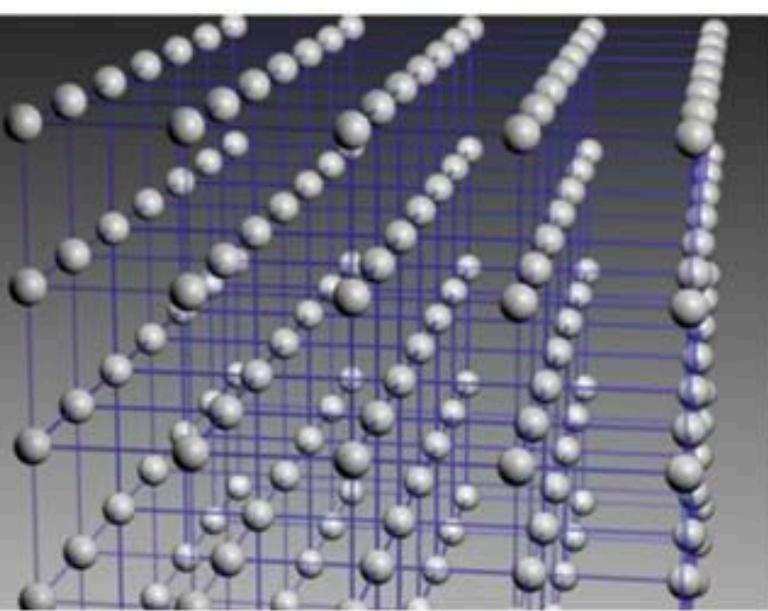
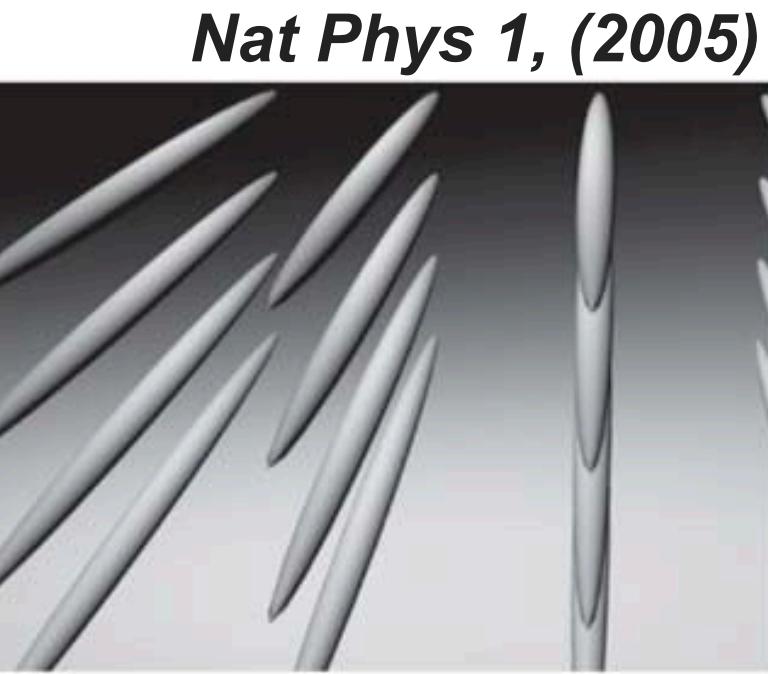
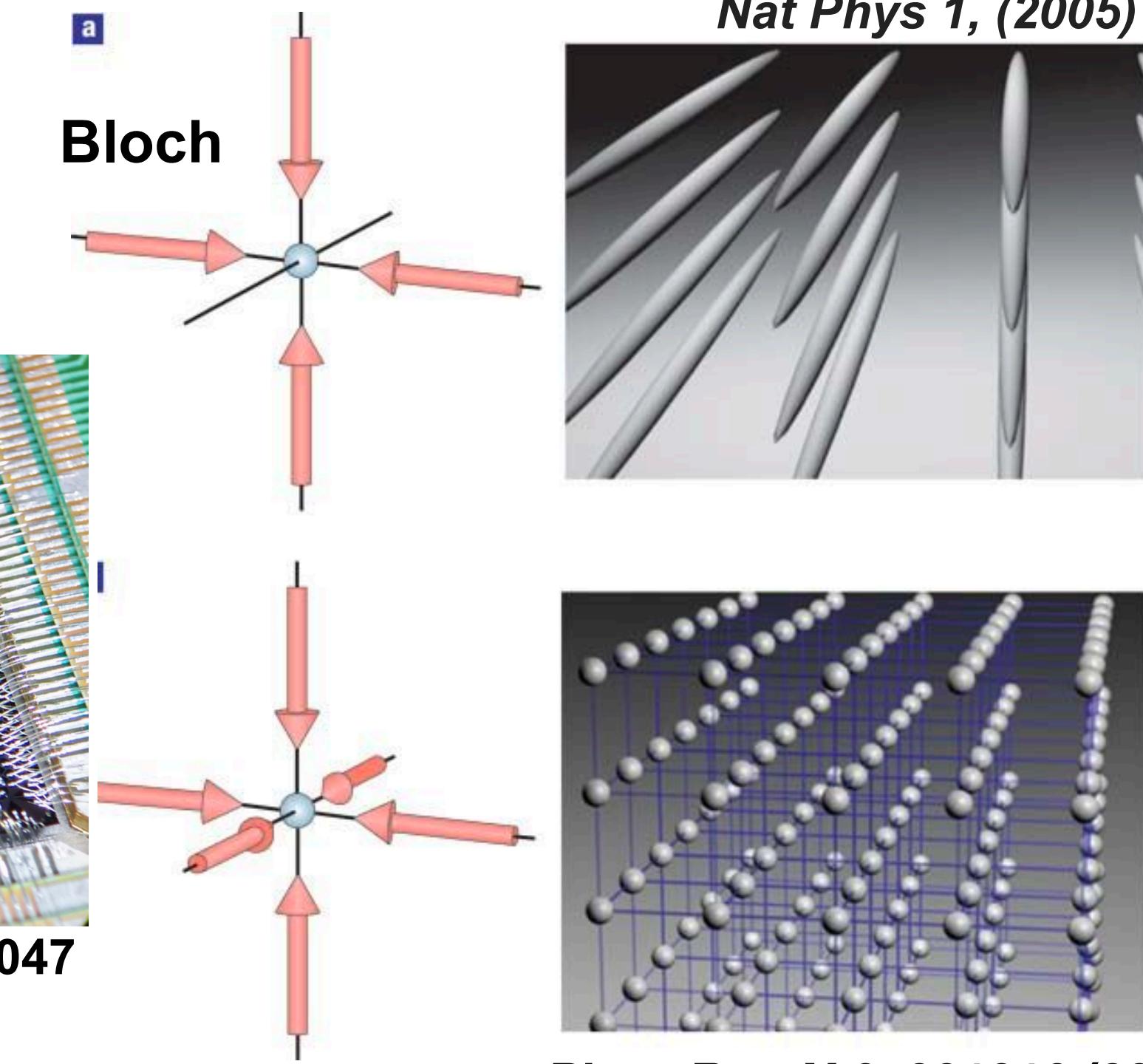
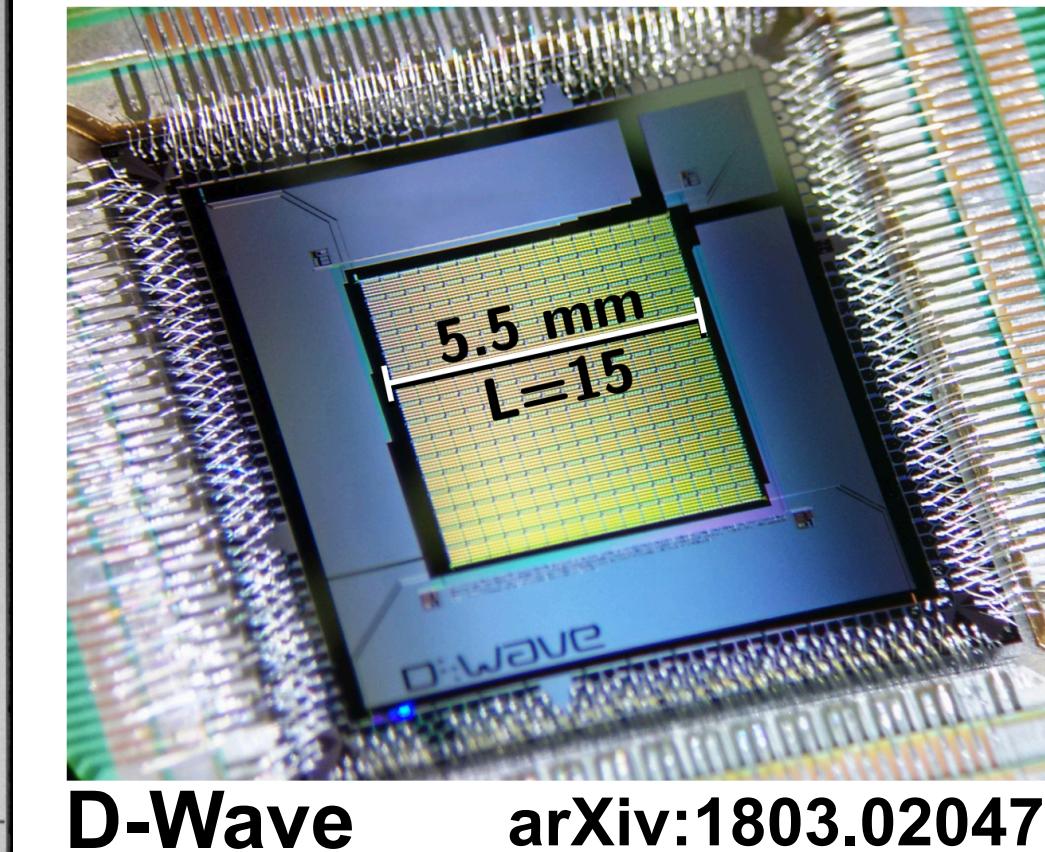
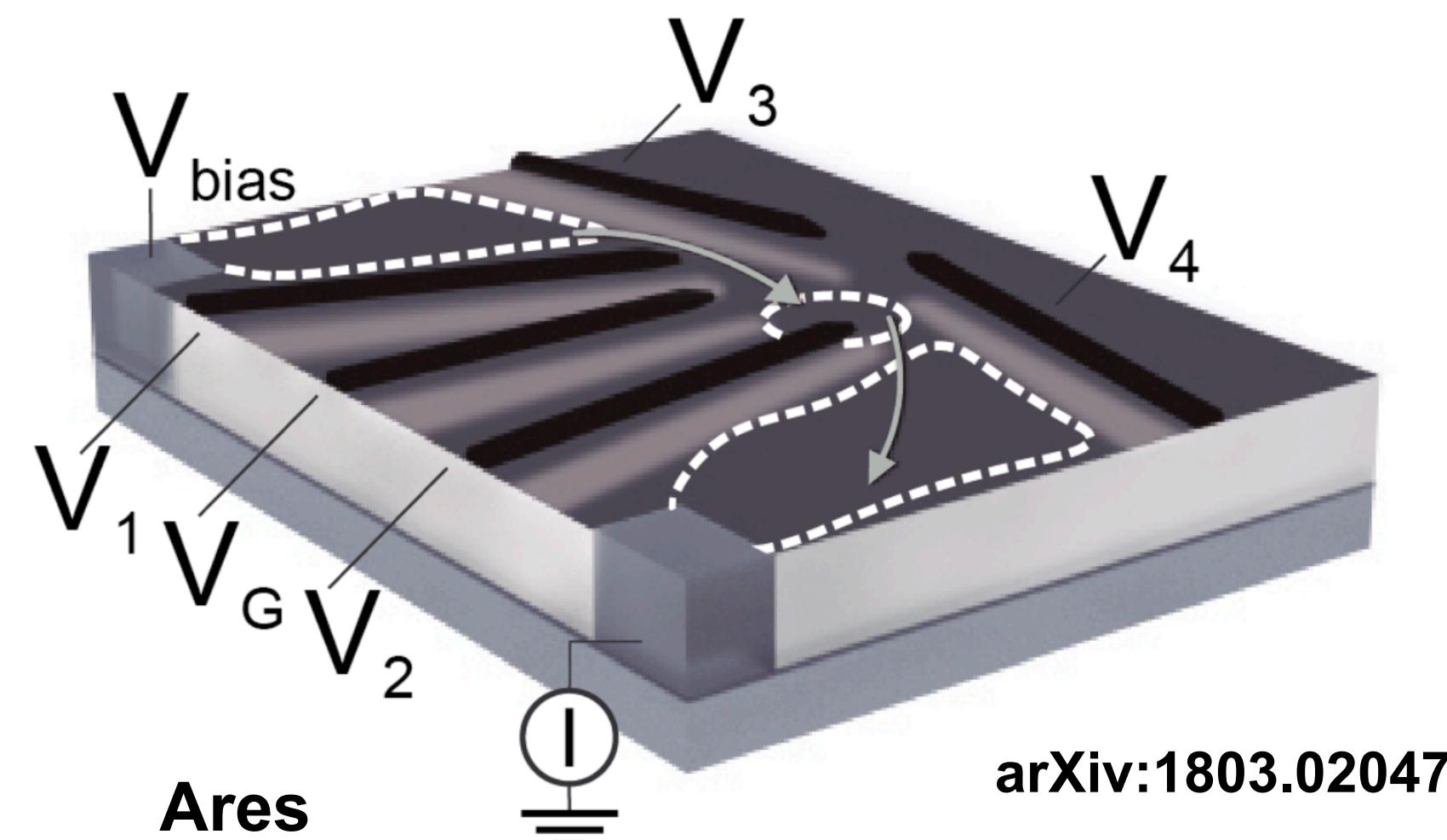
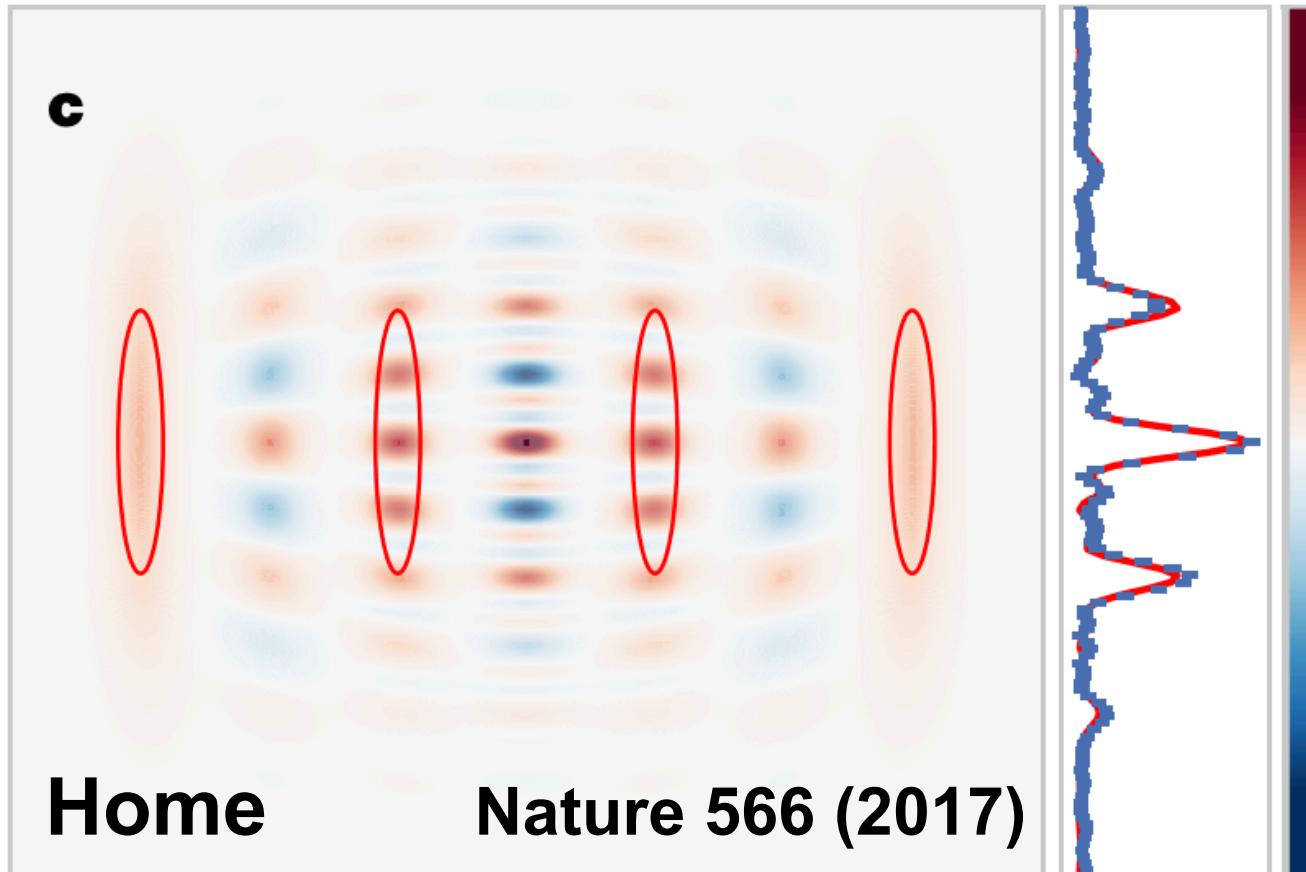
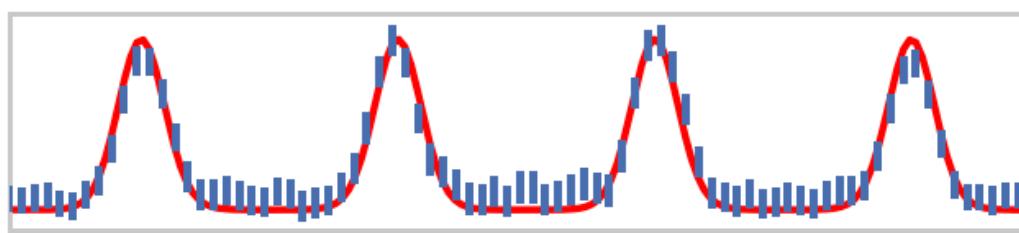
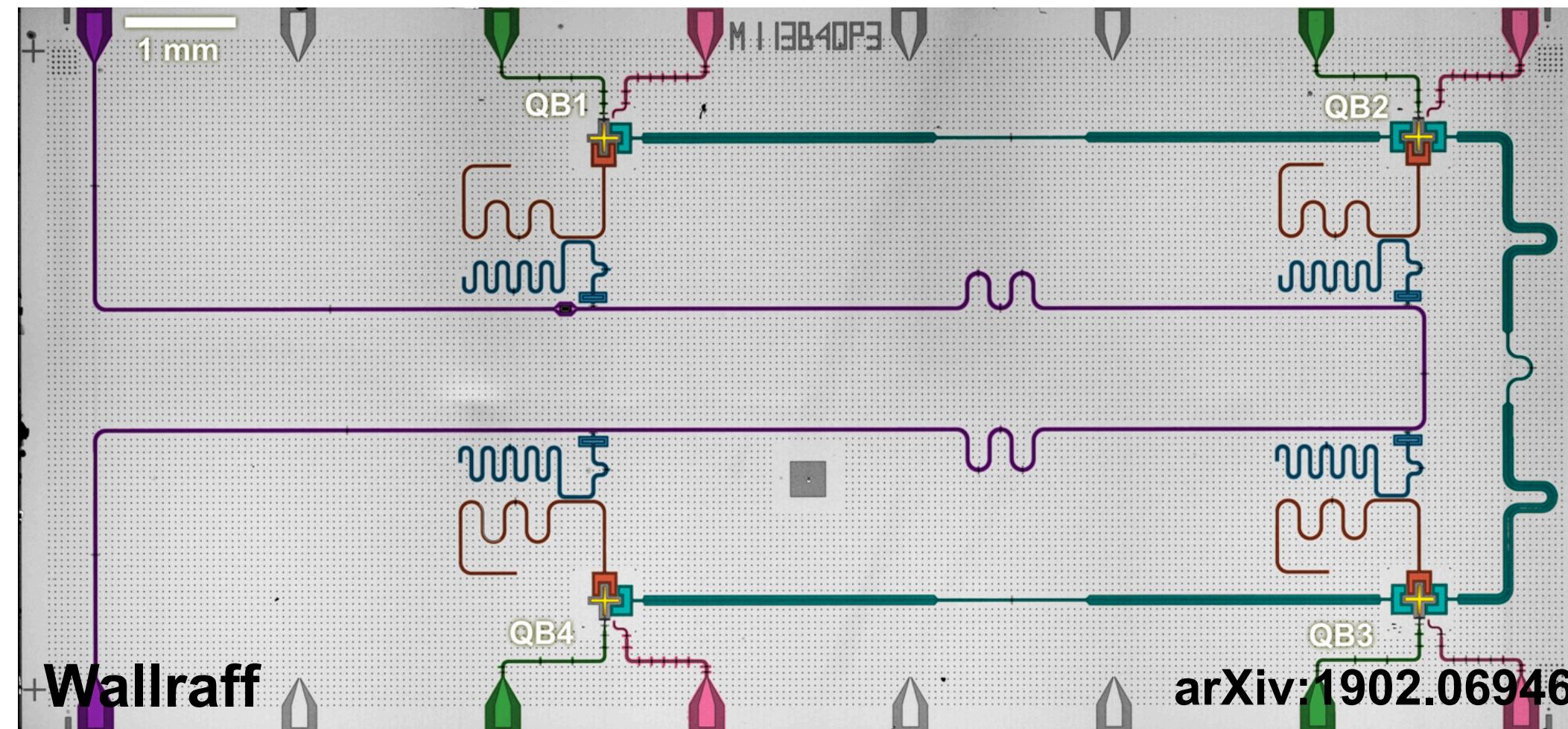


Phys. Rev. Lett. 112, 190501 (2014)

Phys. Rev. Lett. 122, 020504 (2019)

UPHYS

QIP devices - Hamiltonian Engineering

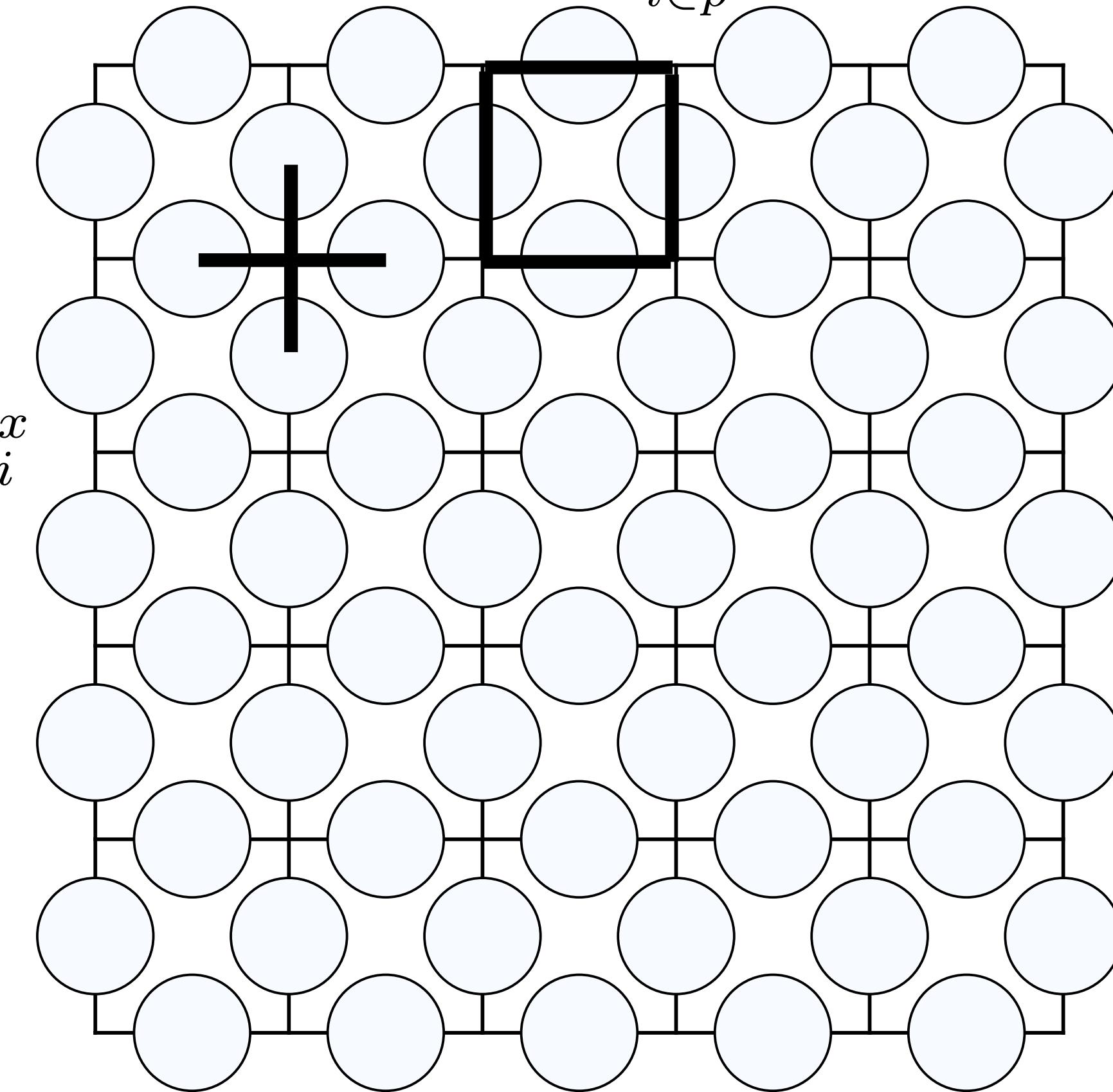


Relevant Problem: Quantum Error Correction: Toric Code

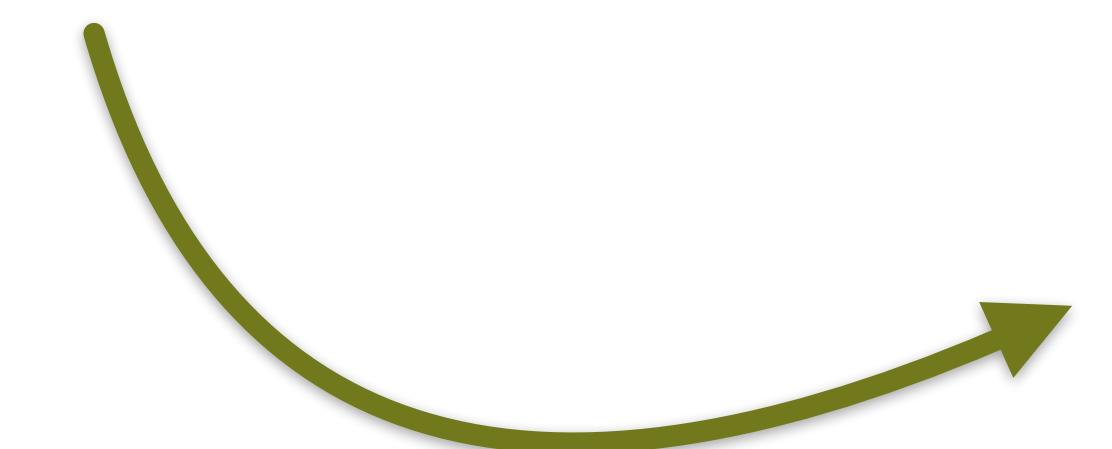
$$H = - \sum_s A_s - \sum_p B_p$$

$$A_s = \prod_{i \in s} \sigma_i^x$$

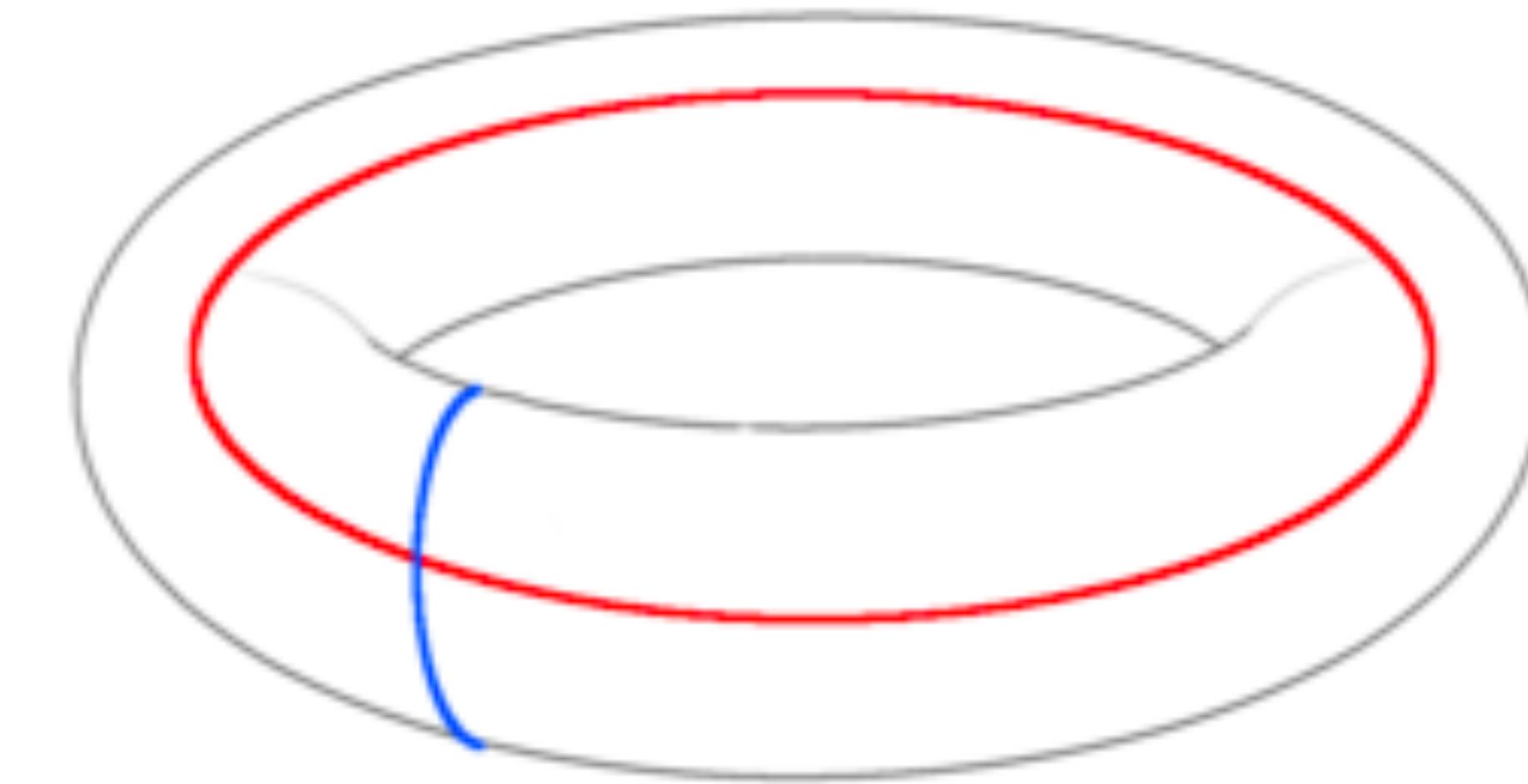
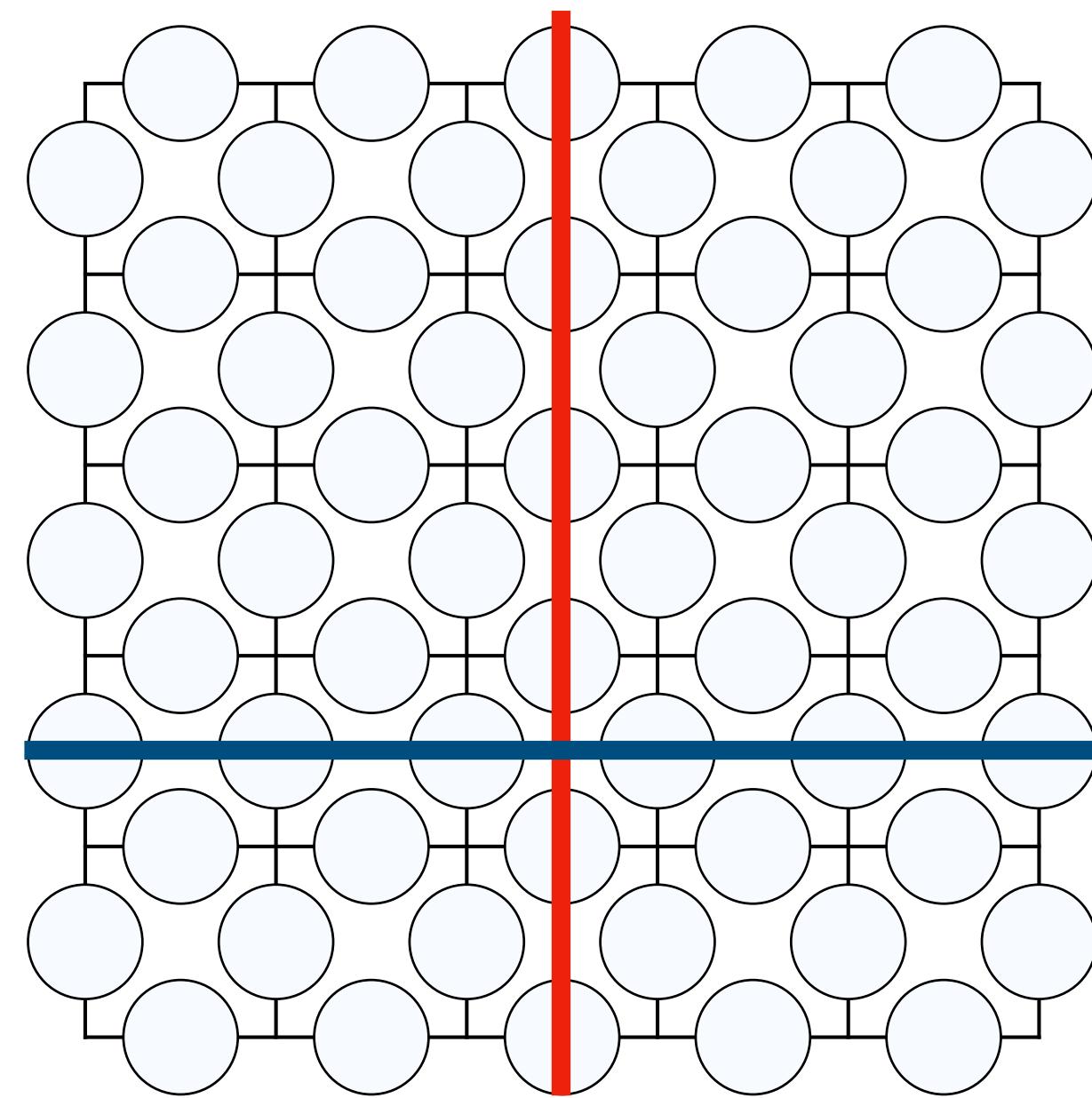
$$B_p = \prod_{i \in p} \sigma_i^z$$



ground state encodes 2 qubits

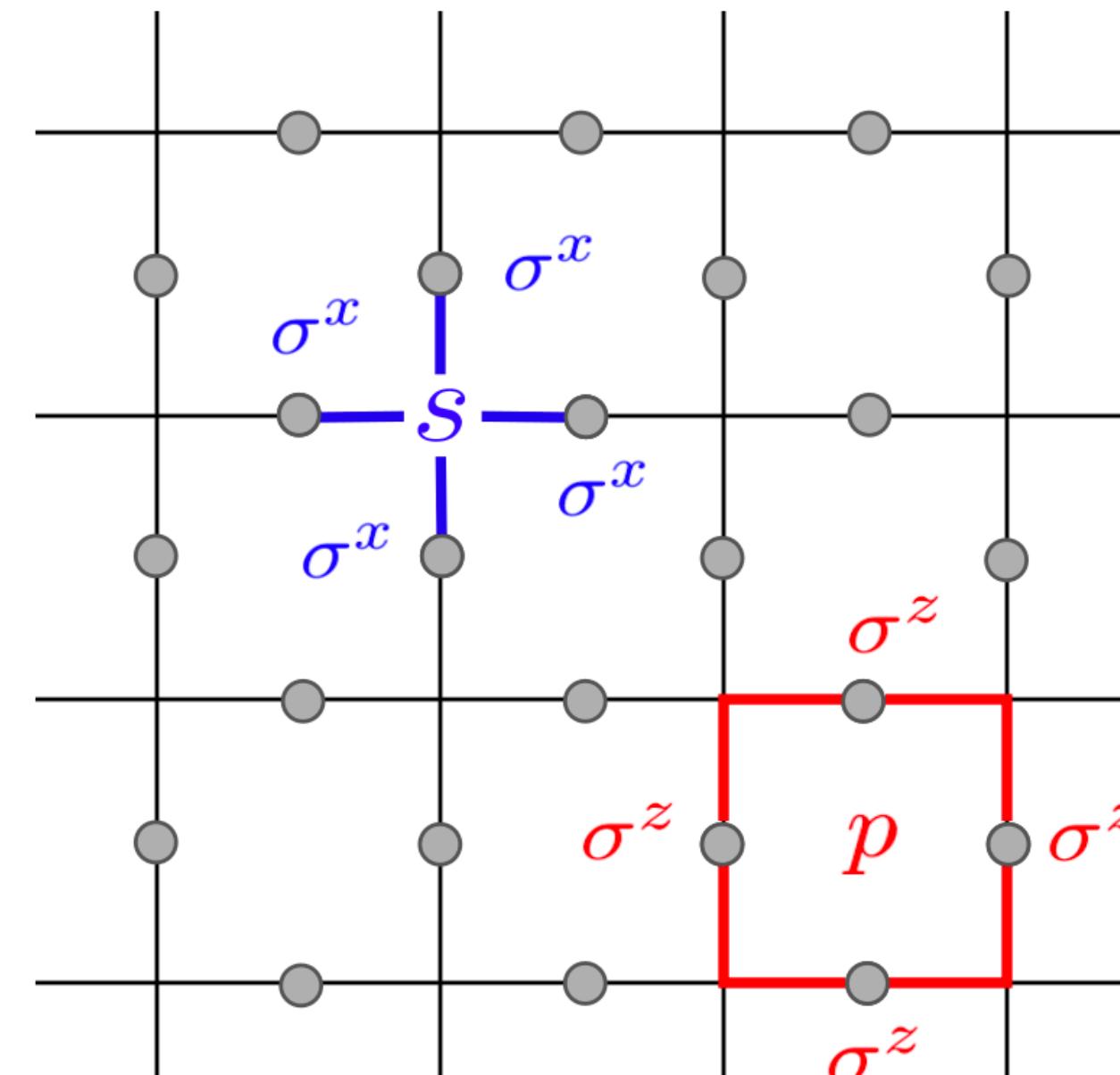


Topological ground state



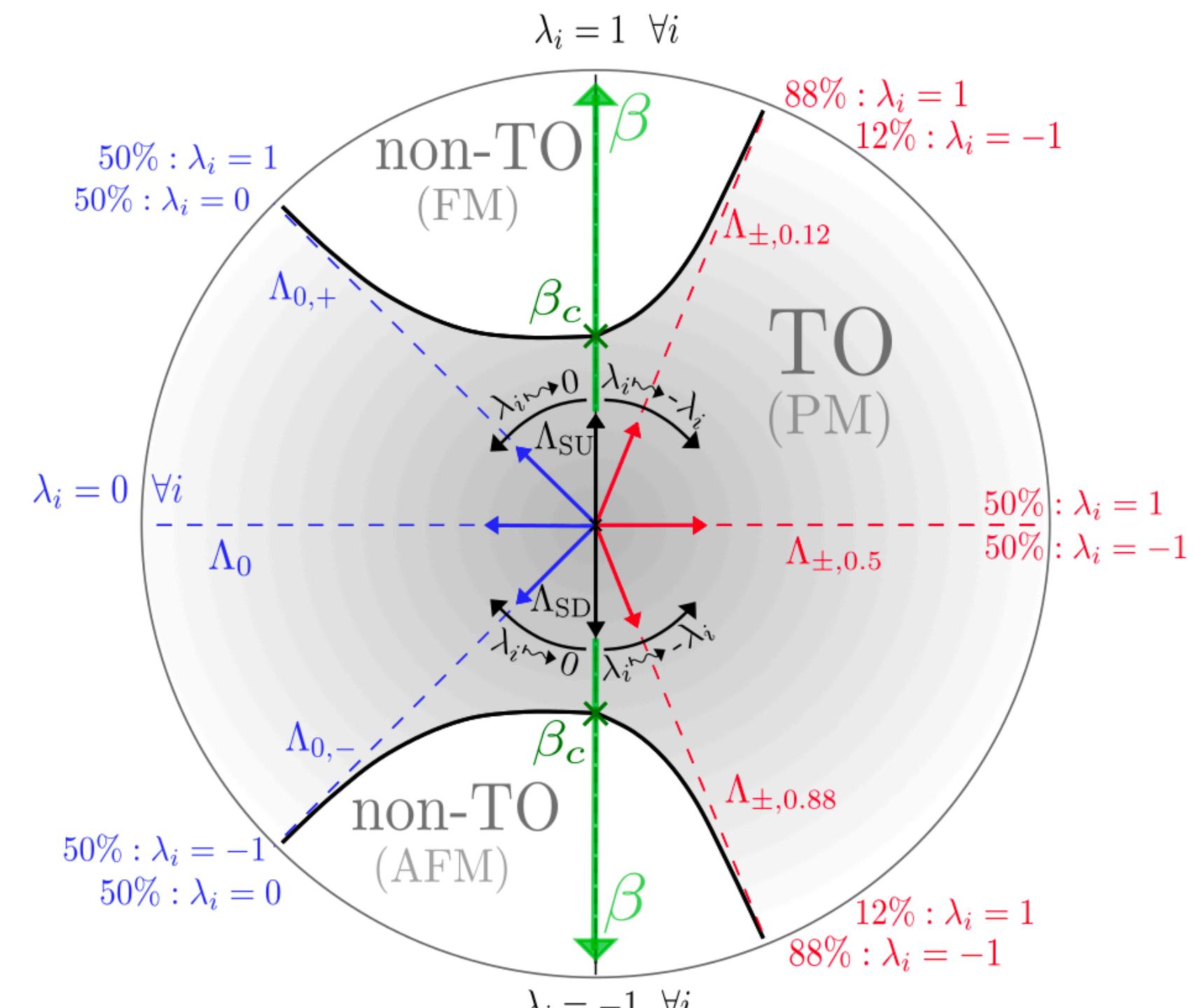
One has to flip the whole row of spins to change the state.
On the torus this can be done in two directions - two qubits.

Quantum Info vs CondMat



Decoder

Reliable quantum memory



Families of solvable models

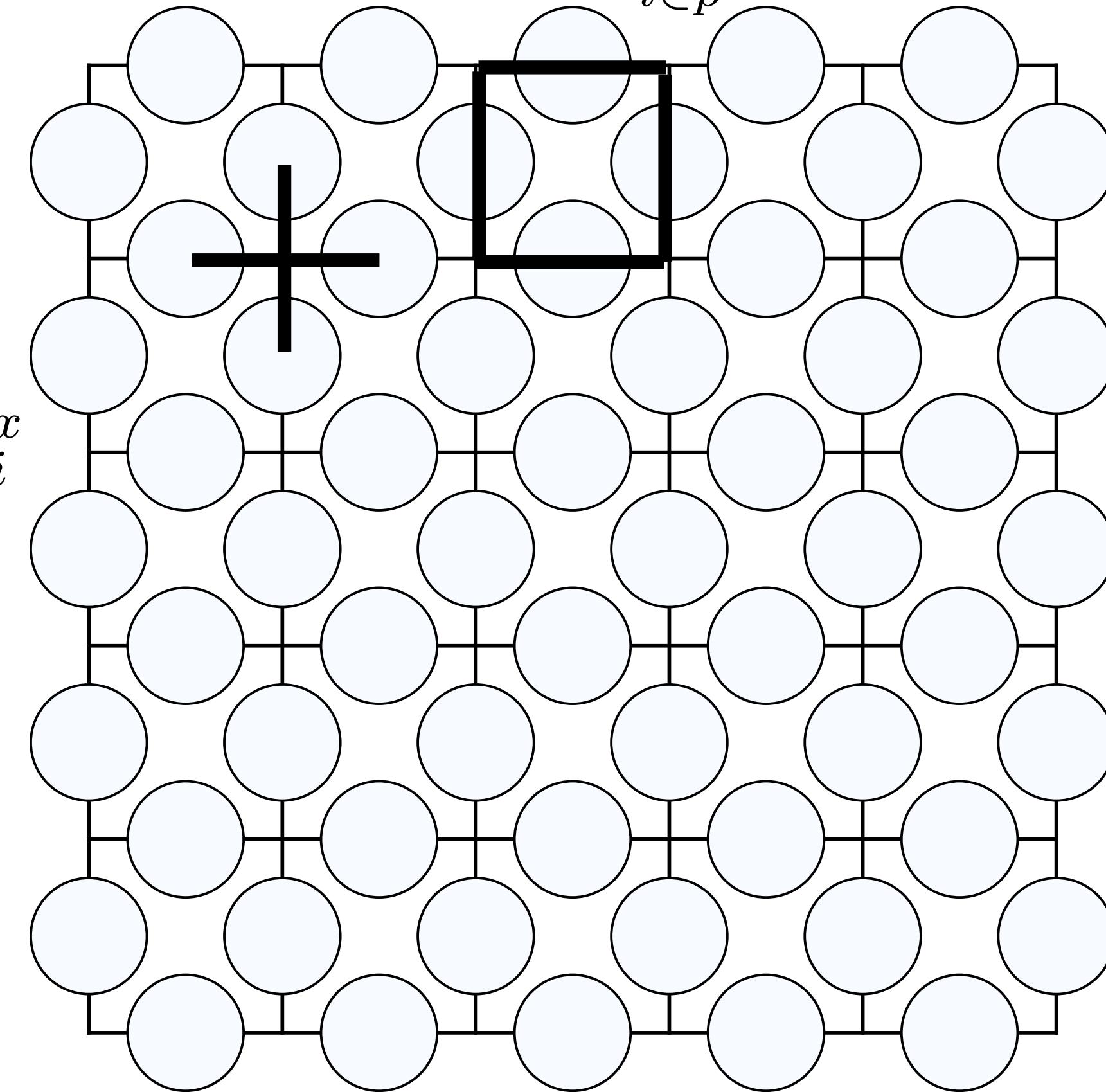
Behaviour and statistics of excitations

Relevant Problem: Quantum Error Correction: Toric Code

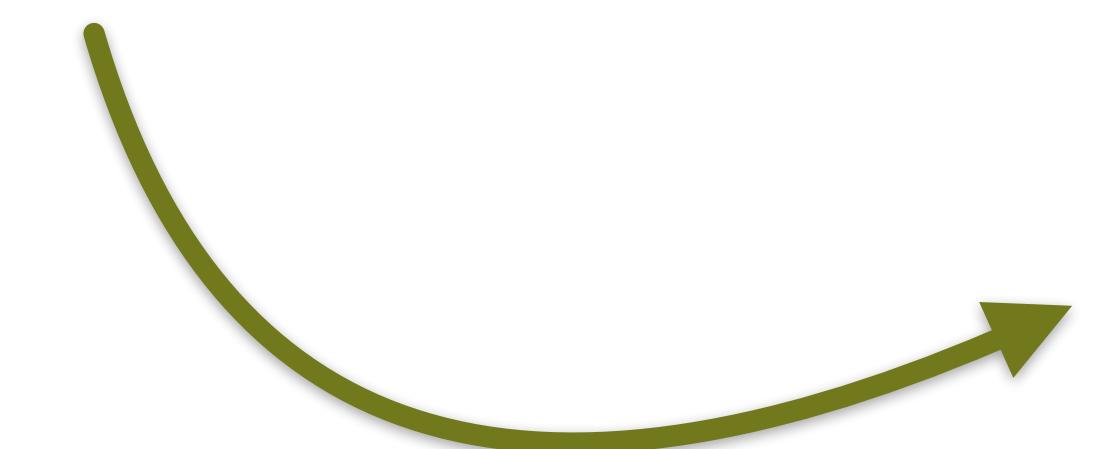
$$H = - \sum_s A_s - \sum_p B_p$$

$$A_s = \prod_{i \in s} \sigma_i^x$$

$$B_p = \prod_{i \in p} \sigma_i^z$$



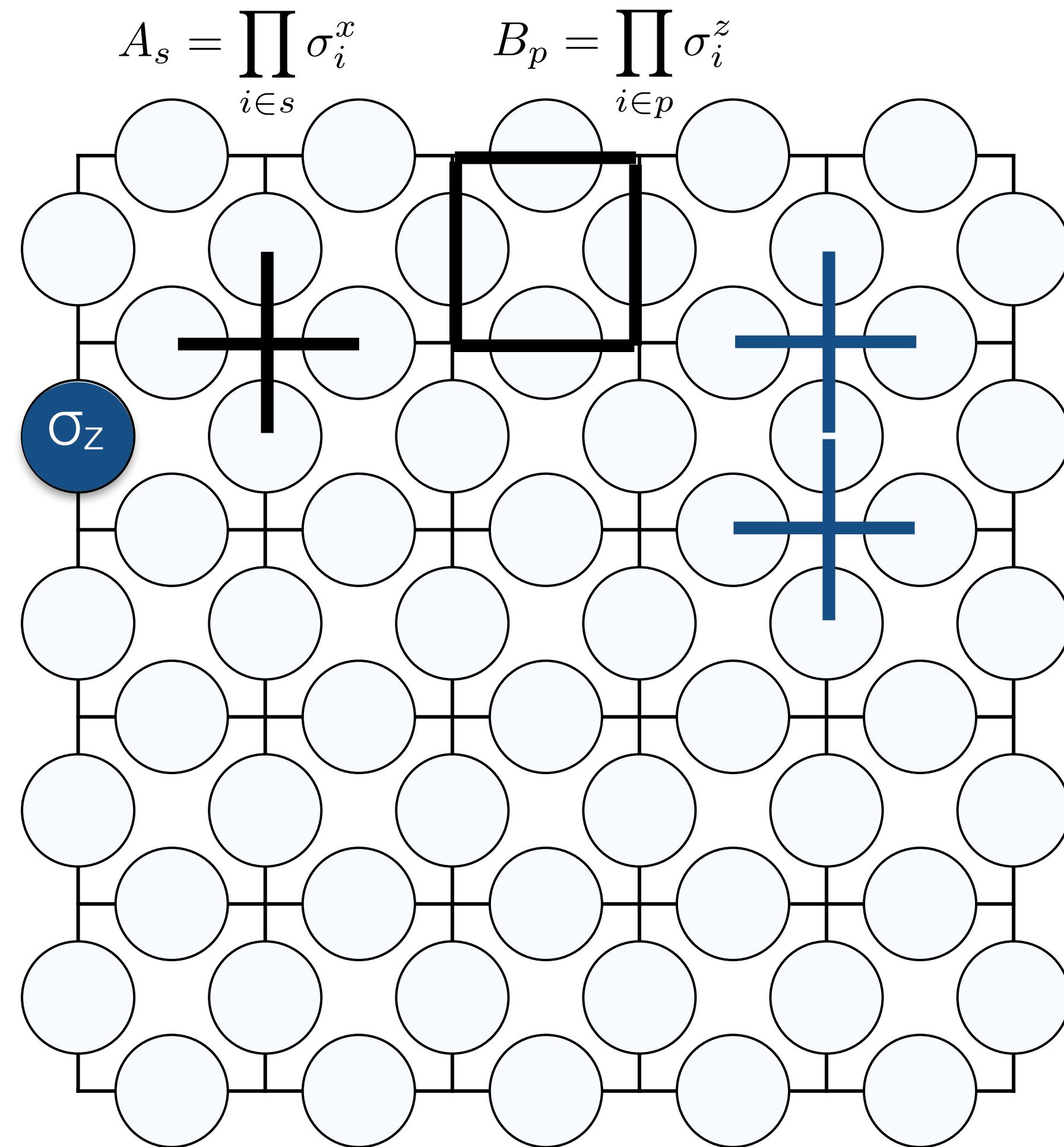
ground state encodes 2 qubits



Relevant Problem: Quantum Error Correction: Toric Code

$$H = \sum_s \left(-A_s + e^{-\sum_{i \in s} \beta_{z,i} \sigma_i^z} \right) - \sum_p B_p$$

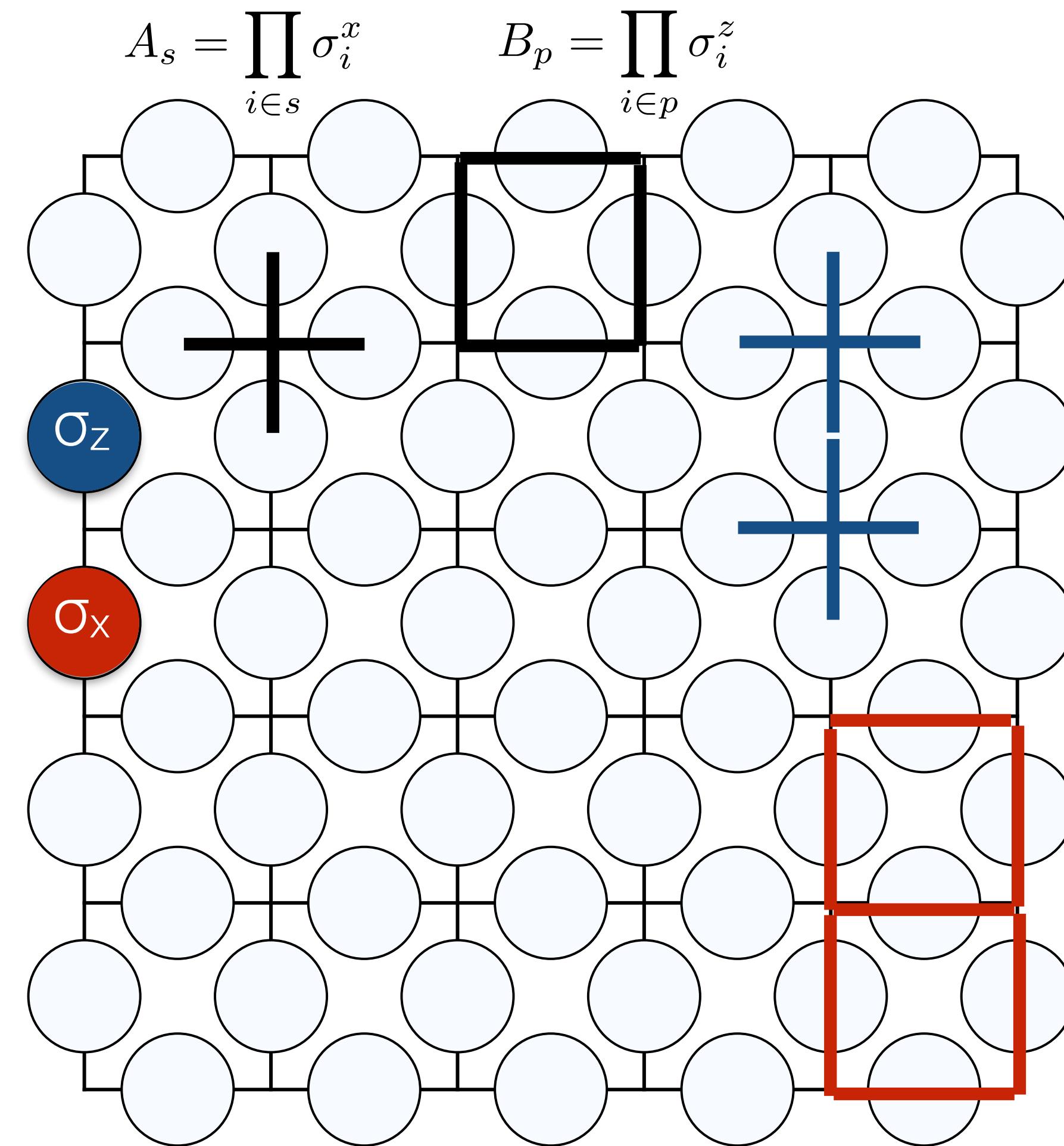
Remains solvable!
Degenerate ground state!



Relevant Problem: Quantum Error Correction: Toric Code

$$H = - \sum_s A_s + \sum_p \left(-B_p + e^{-\sum_{i \in p} \beta_{x,i} \sigma_i^x} \right)$$

Remains solvable!
Degenerate ground state!



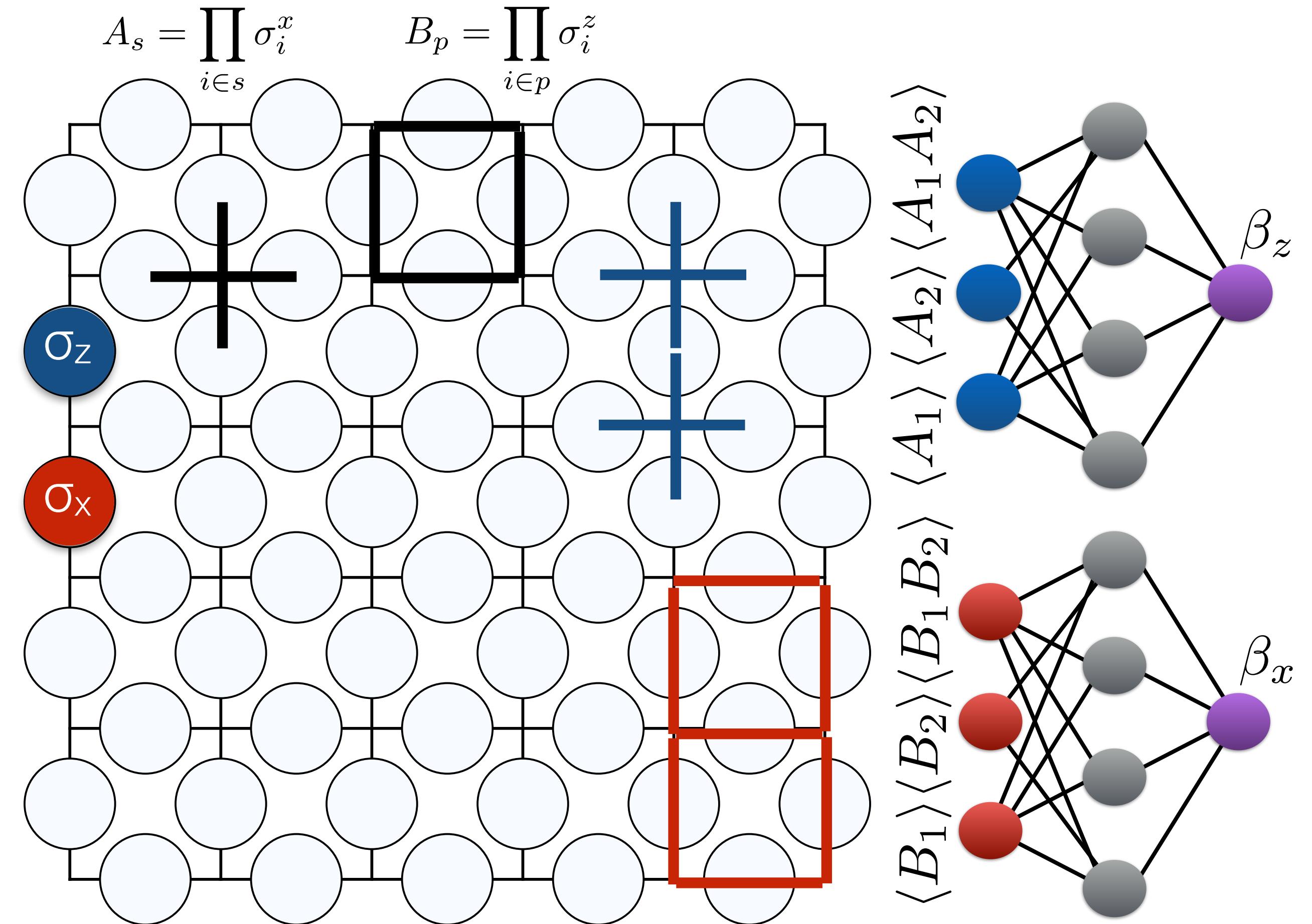
Relevant Problem: Quantum Error Correction: Toric Code

$$H = \sum_s \left(-A_s + e^{-\sum_{i \in s} \beta_{z,i} \sigma_i^z} \right)$$

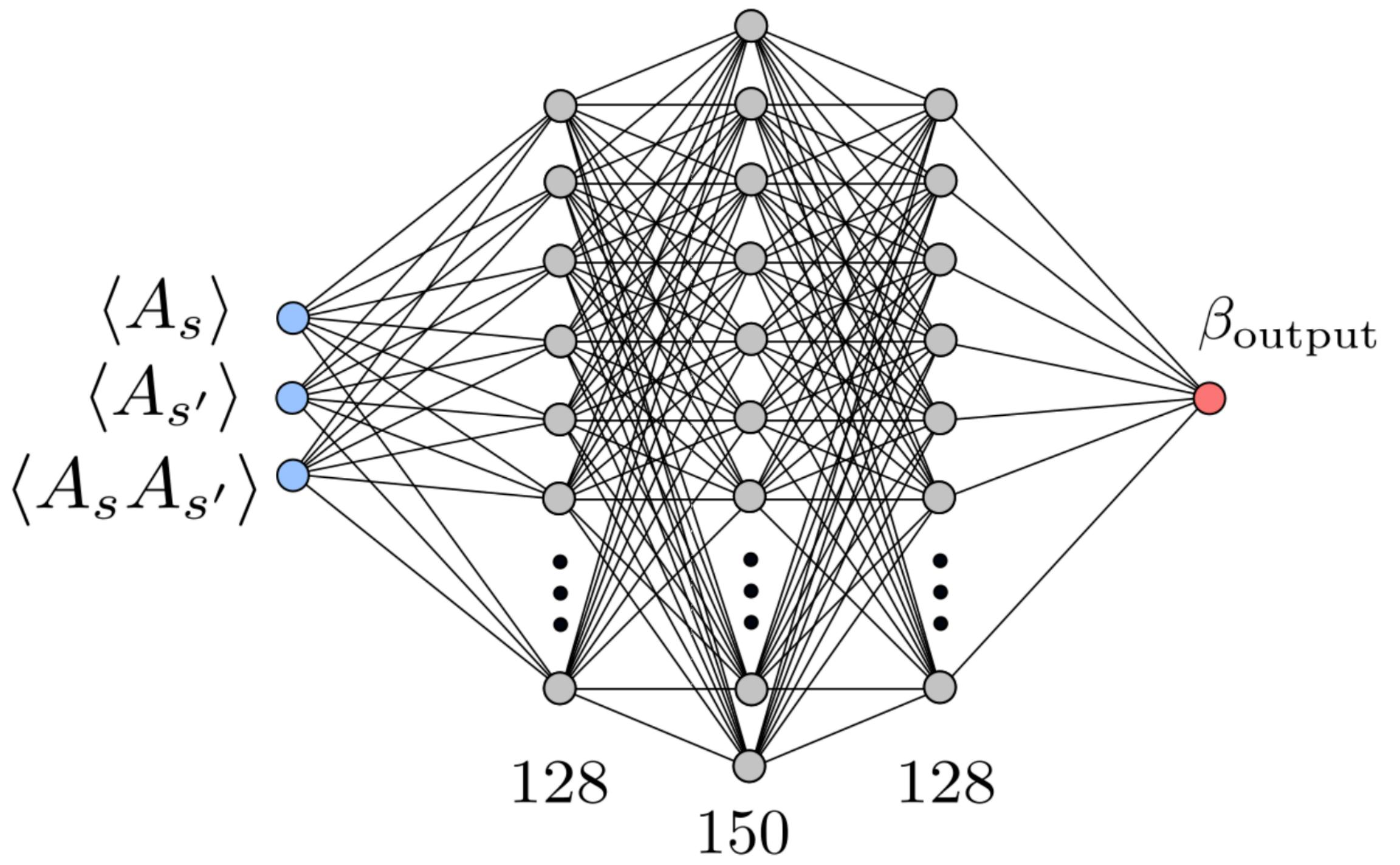
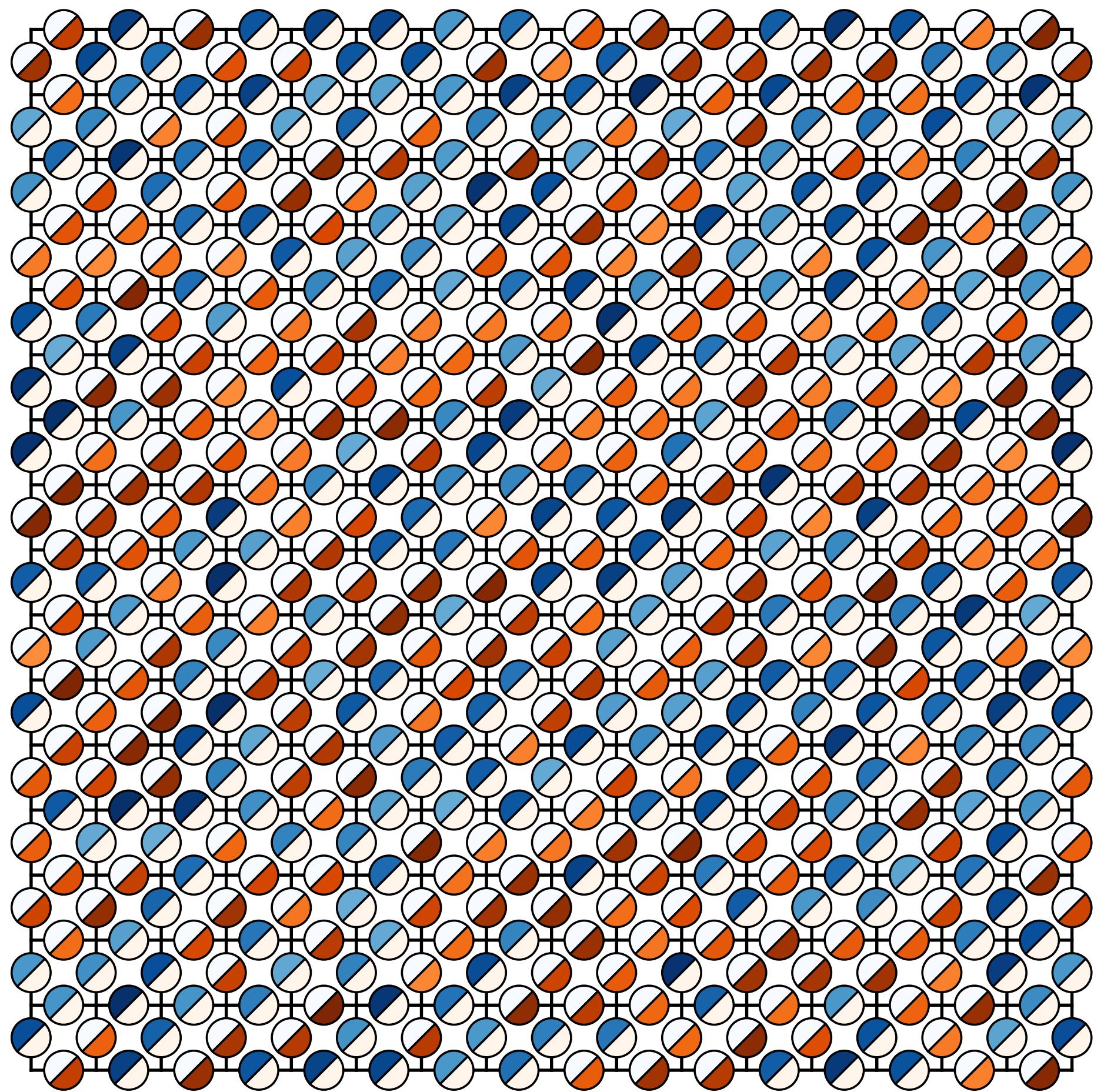
$$- \sum_p B_p$$

$$H = - \sum_s A_s$$

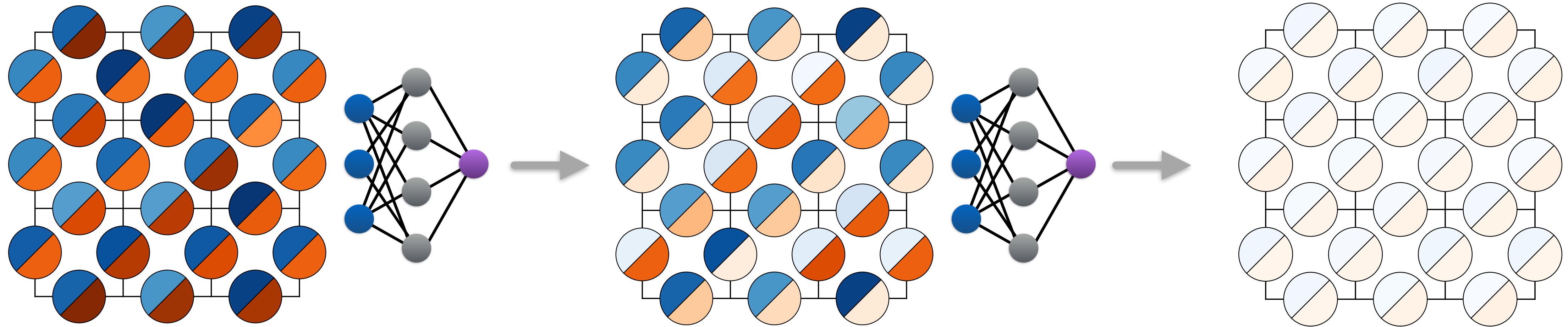
$$+ \sum_p \left(-B_p + e^{-\sum_{i \in p} \beta_{x,i} \sigma_i^x} \right)$$



We train on scalable analytical states



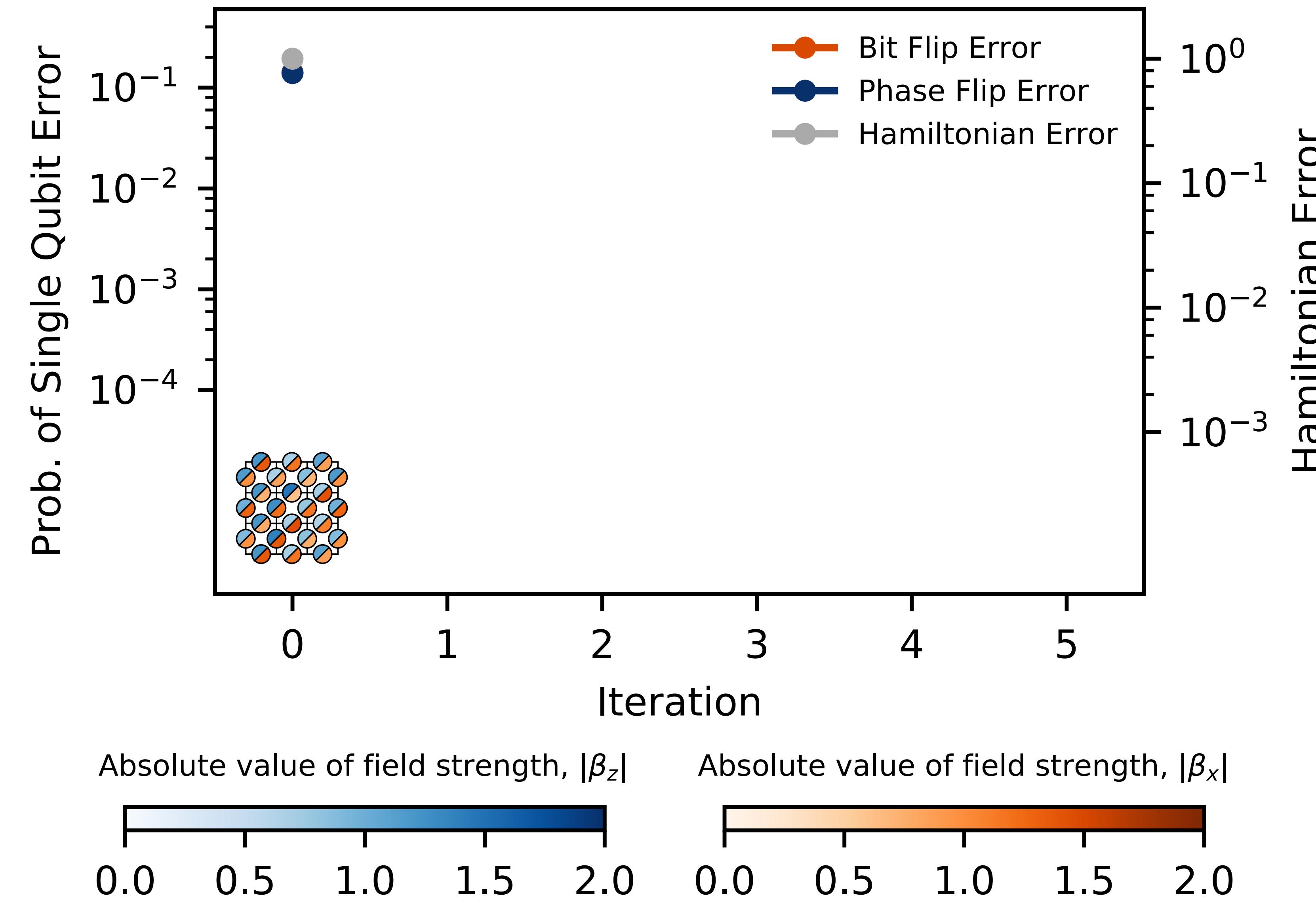
Iterative application of the trained model

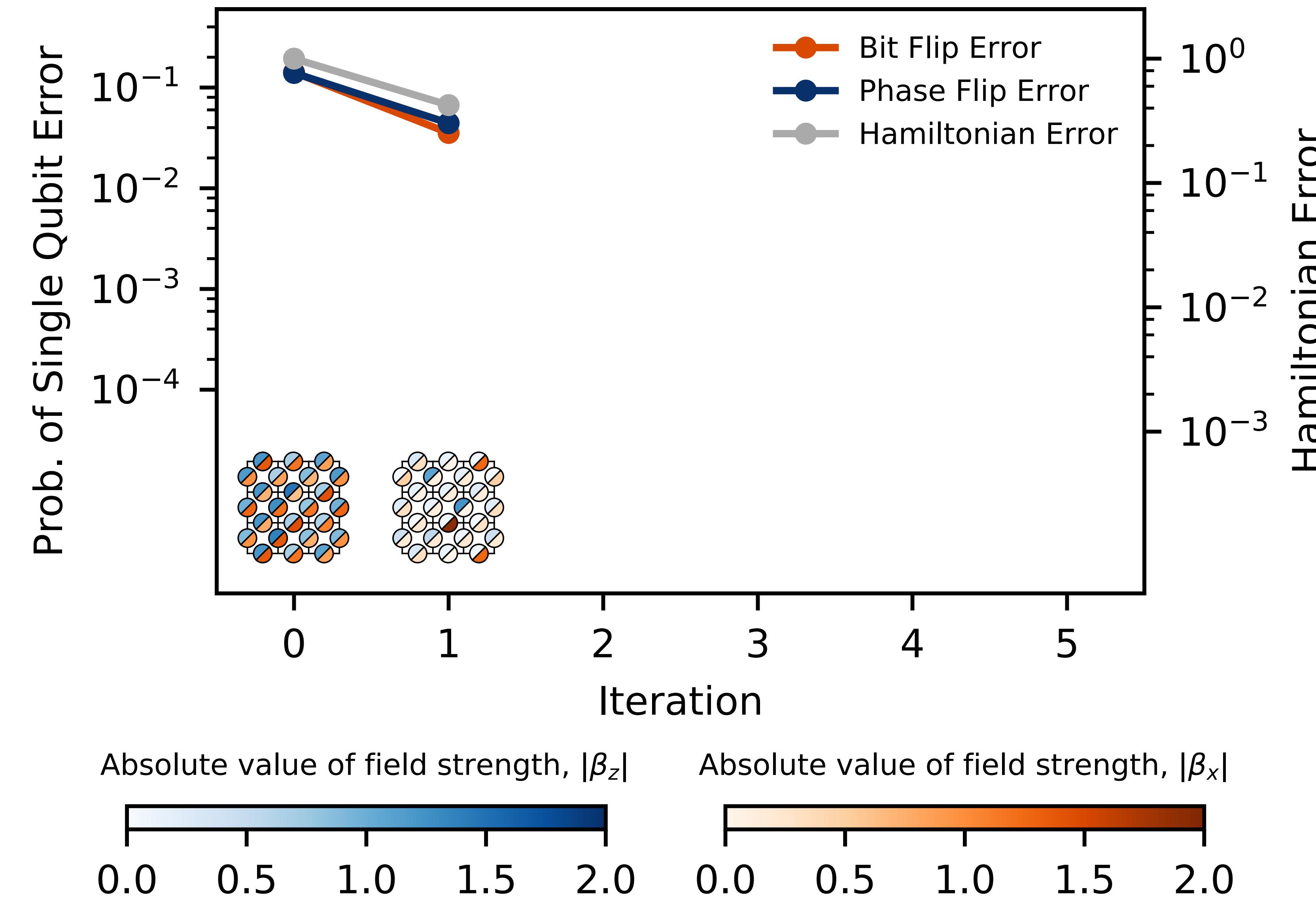


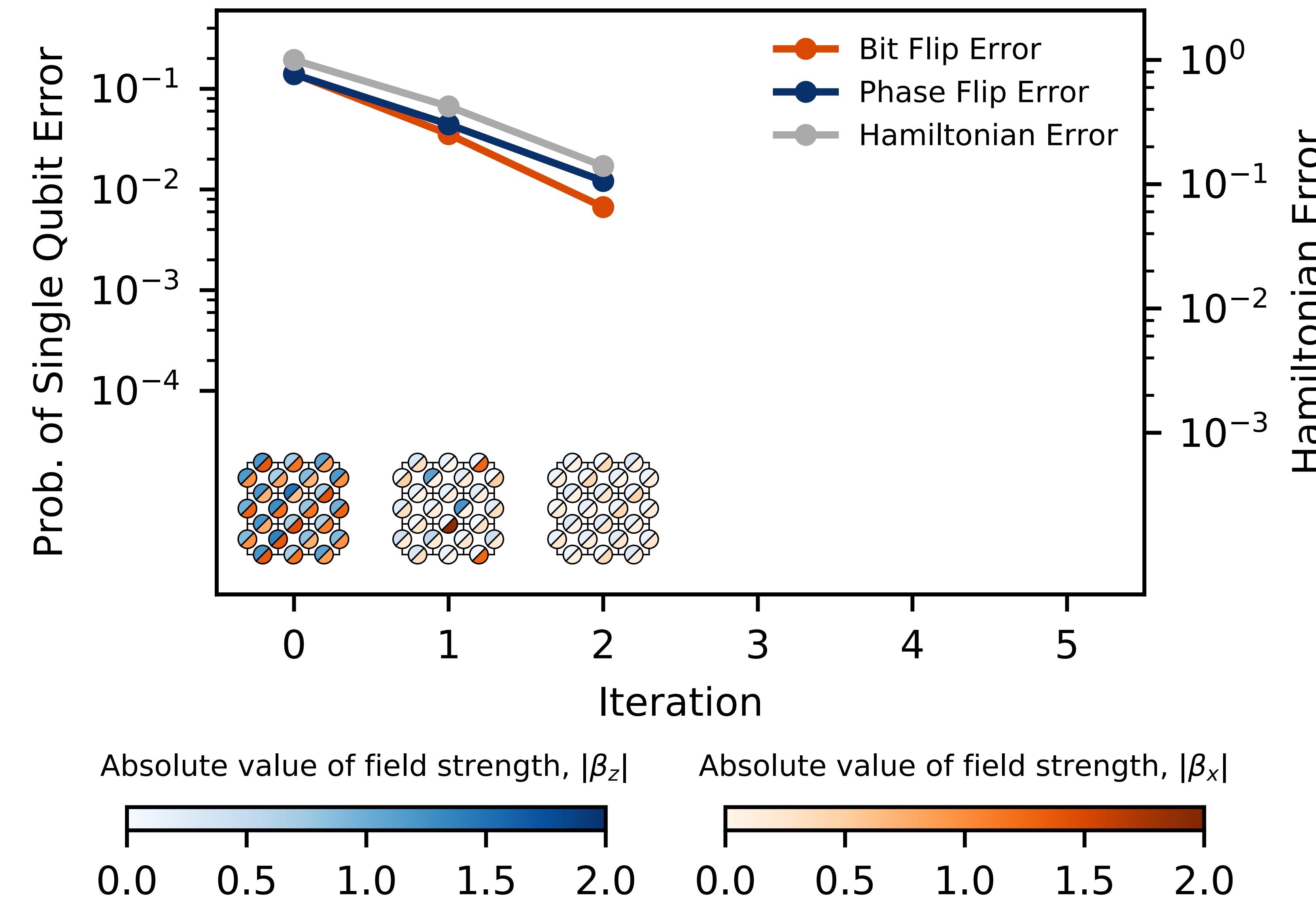
Measurements of success

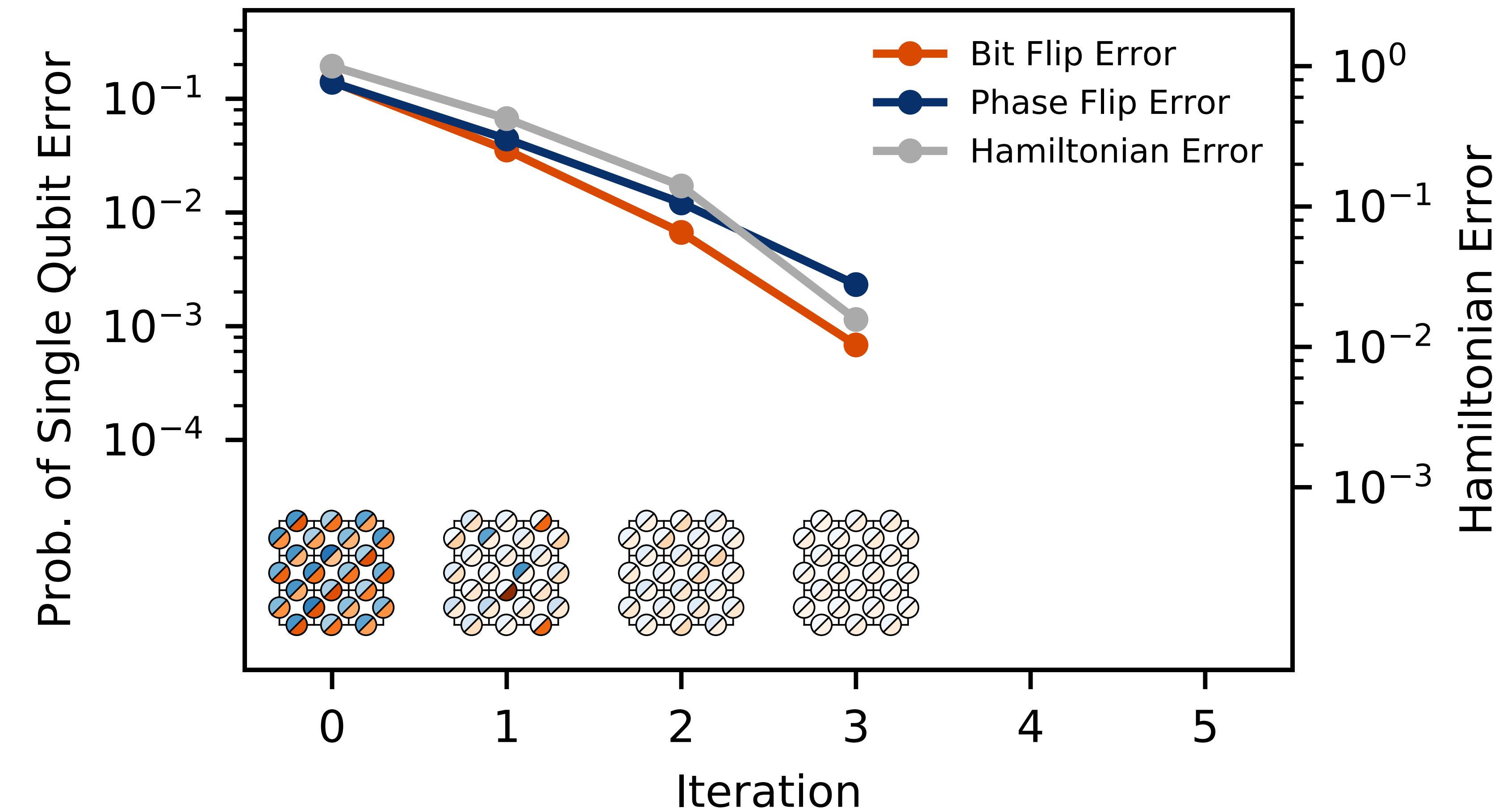
(1) STATE: "What is the probability that single qubit will flip spin or phase? Can we guarantee established thresholds?"

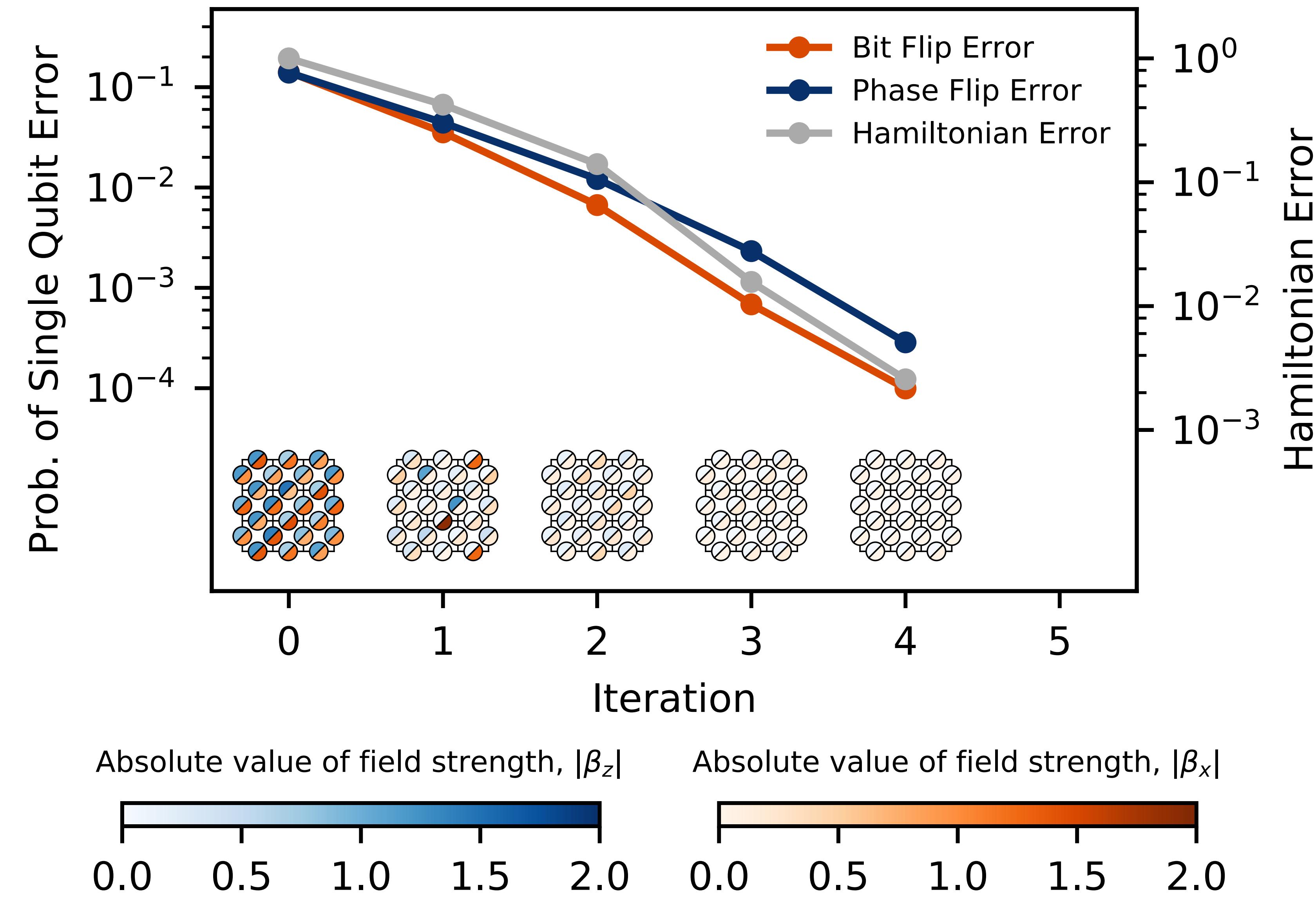
(2) HAMILTONIAN: "How 'far' are we from the ideal toric code Hamiltonian?"

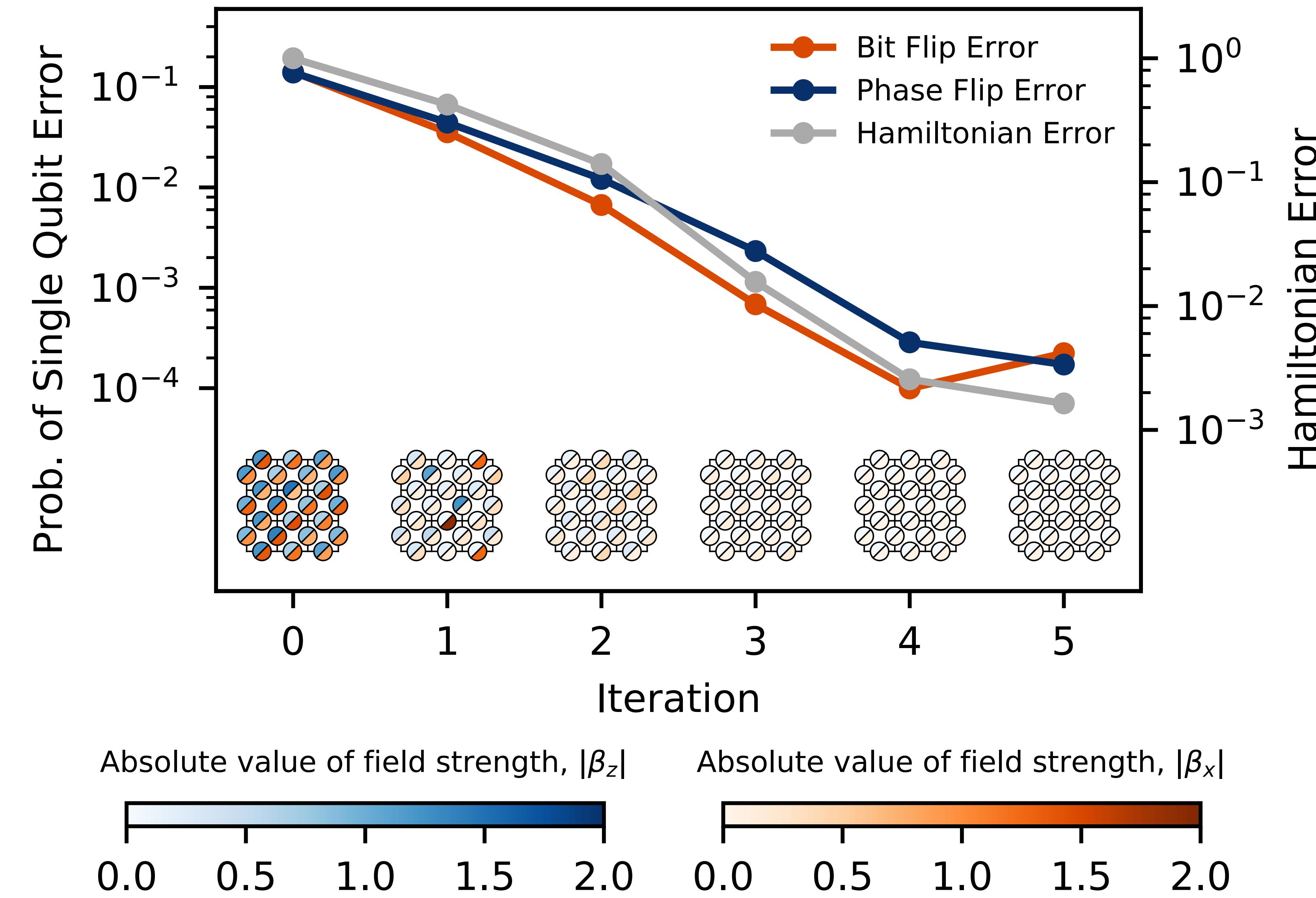






Absolute value of field strength, $|\beta_z|$ Absolute value of field strength, $|\beta_x|$ 





“We learn noisy topological code
Hamiltonian by measuring LINEAR number
of expectation values.”

“We learn systematic errors in the
Hamiltonian engineering.”

“Error correction on the Hamiltonian level.”



Agnes Valenti



Evert van Nieuwenburg



Sebastian Huber

Thank you for your attention!