

Title: Measurement-induced phase transitions in the toric code

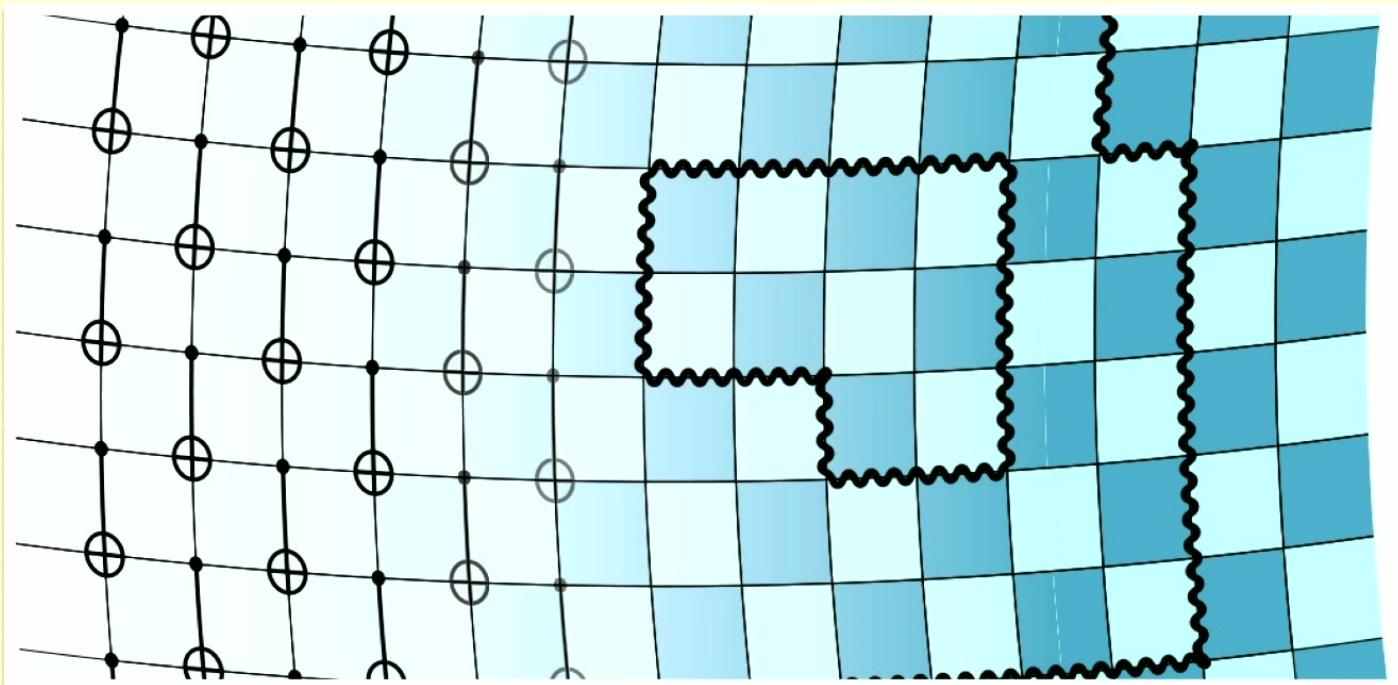
Speakers: Amirreza Negari

Date: May 15, 2023 - 2:00 PM

URL: <https://pirsa.org/23050143>

Abstract: We explore how measurements and unitary feedback can generate distinct phases of matter from a given resource state, with a specific focus on the toric code in two dimensions. First, we map random Pauli measurements on the toric code to a classical loop model with crossings, and we show how measurement-induced entanglement exactly maps to watermelon correlators of the loop model. Then, we consider measuring all but a 1d boundary of qubits, and we map this setup to hybrid circuits in 1+1 dimensions. In particular, we find that varying the probabilities of different Pauli measurements can drive phase transitions in the unmeasured boundary between phases with different orders and entanglement scaling, corresponding to short and long loop phases in the classical model. Finally, by utilizing single-site boundary unitaries conditioned on the bulk measurement outcomes, we generate mixed state ordered phases and transitions that can be experimentally diagnosed with linear observables. Our findings showcase the potential of measurement-based quantum computing setups in producing and manipulating phases of matter.

Zoom Link: <https://pitp.zoom.us/j/99159680593?pwd=V29wRit6T3NlSjZGTDEvTnRFcTlrUT09>



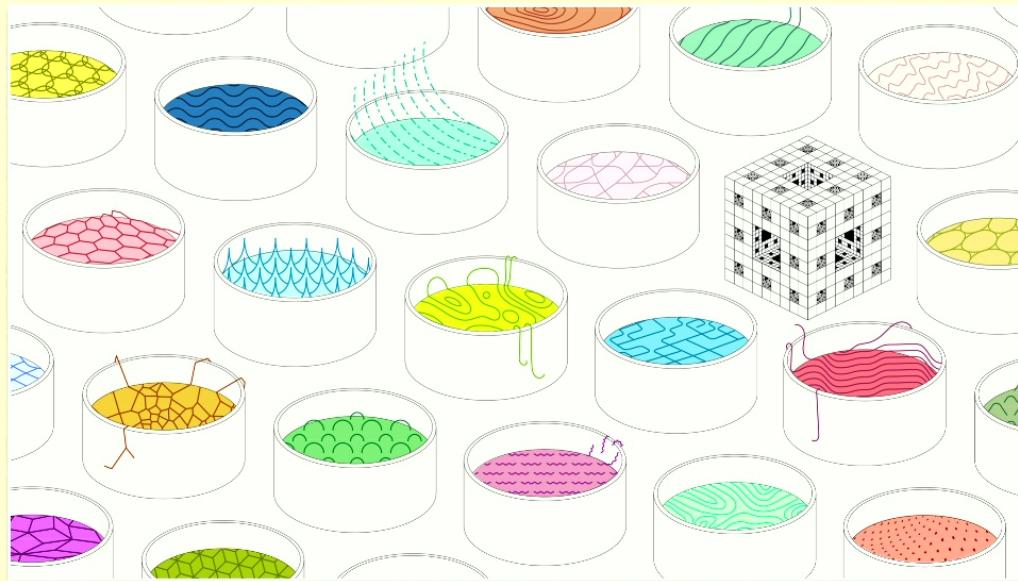
Measurement Induced phase transition in the Toric code

Amirreza Negari

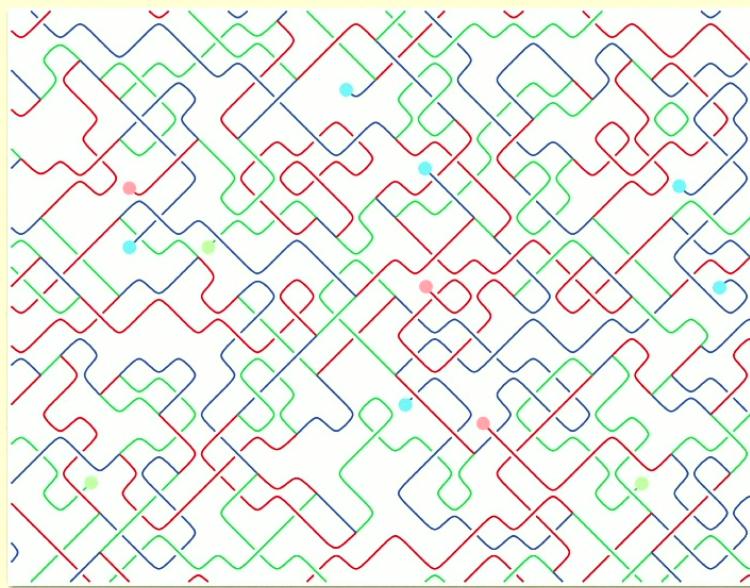
Joint work with Subhayan Sahu and Tim Hsieh

Background and Motivation

Quantum Matter

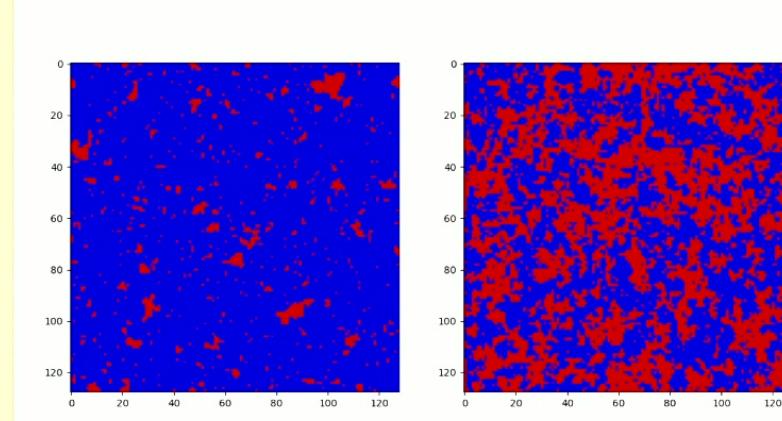


Toric code has topological order



Ising model

$$H = - \sum_{i,j} J_{ij} \sigma_i \sigma_j + h \sum_i \sigma_i$$

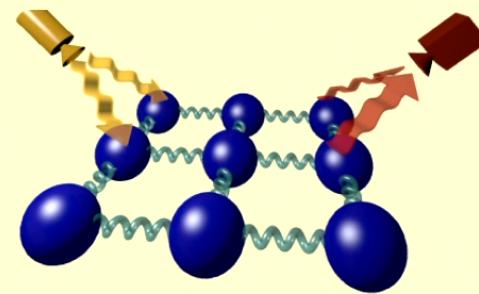


What else do we have beside Hamiltonians?

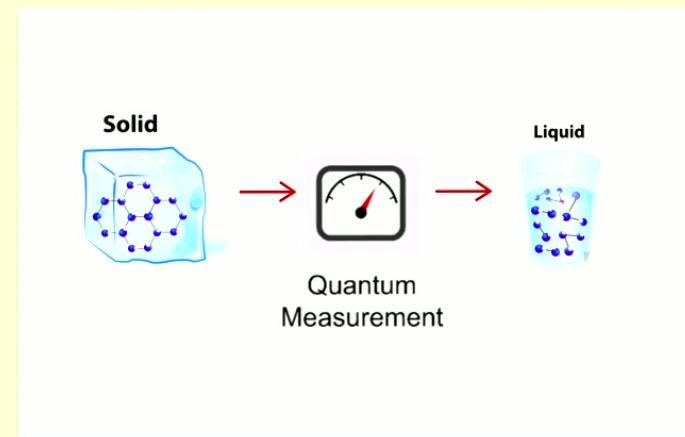
$$\frac{1}{\sqrt{2}}|\text{alive}\rangle + \frac{1}{\sqrt{2}}|\text{dead}\rangle \rightarrow \text{meter} \rightarrow |\text{dead}\rangle$$

Quantum
Measurement

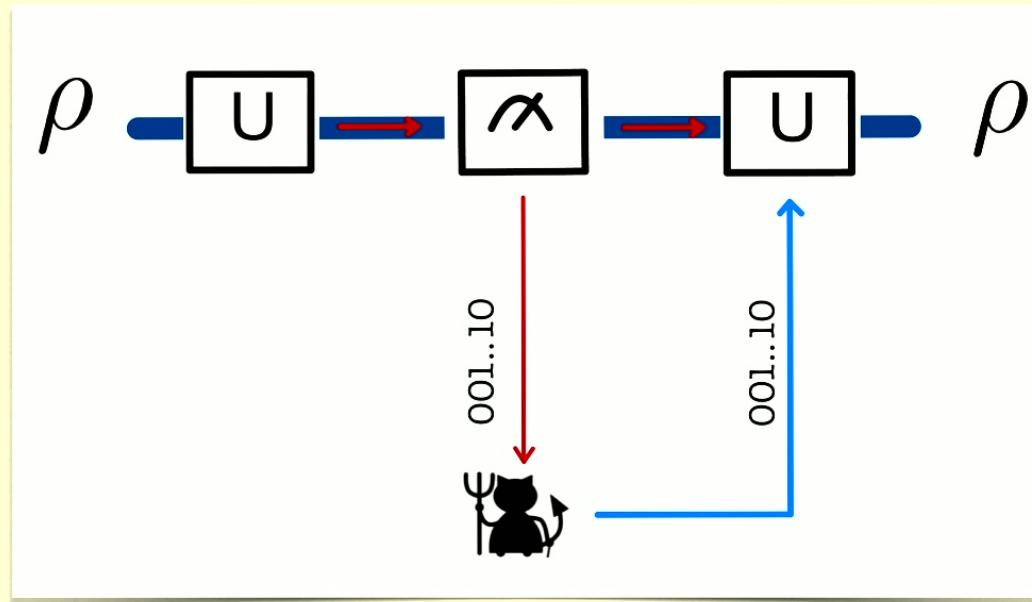
Learning the properties of Matter by direct measurements



Generating phases of matter by measurements?



“Native operations in quantum simulators”

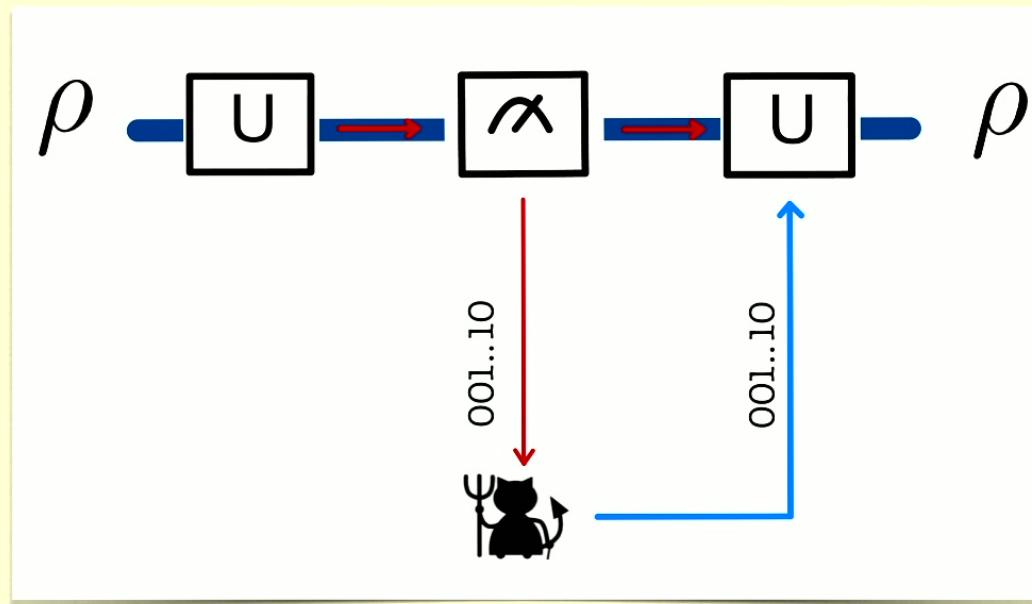


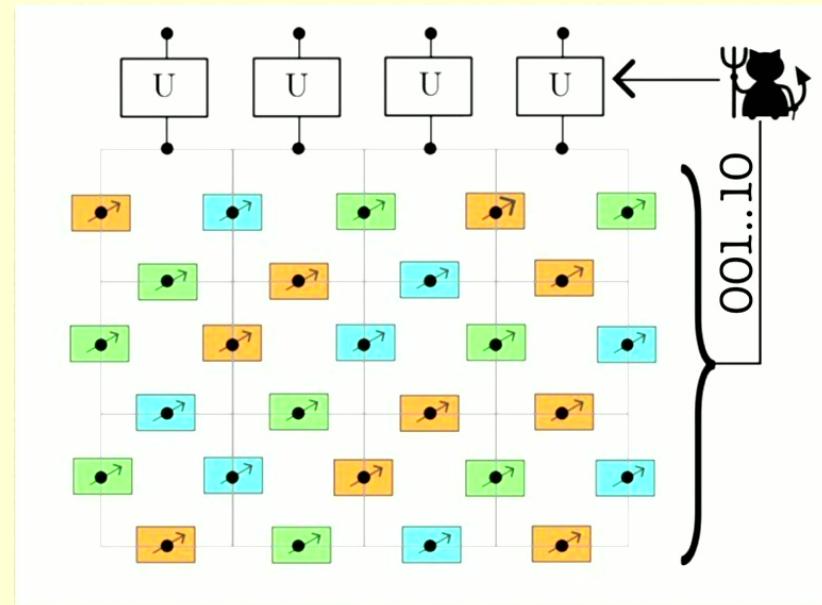
Our general goal:
Manipulating and generating phases of matter by
measurement and feedback.

Our setup:

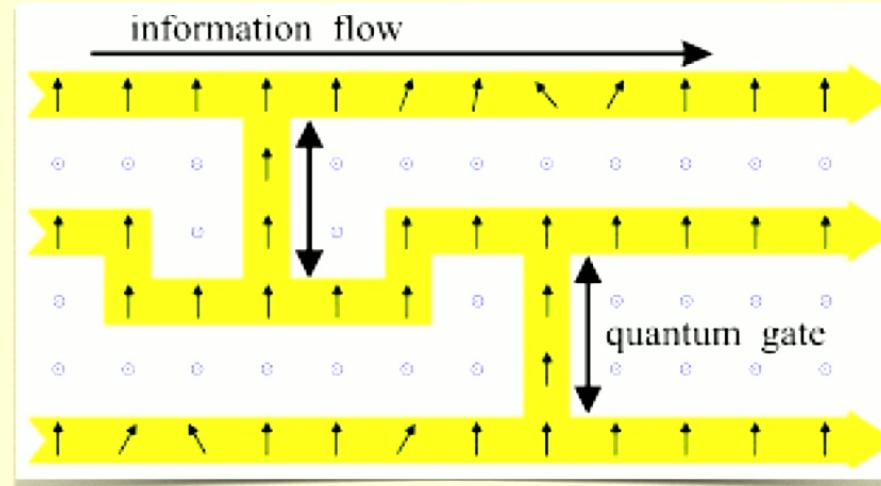
1. On-site measurements
2. On-site Unitaries
3. Feedback
4. Resource state (**Toric code**)

“Native operations in quantum simulators”

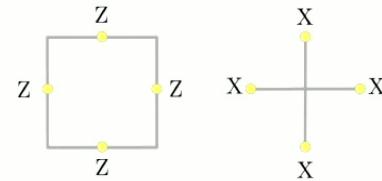
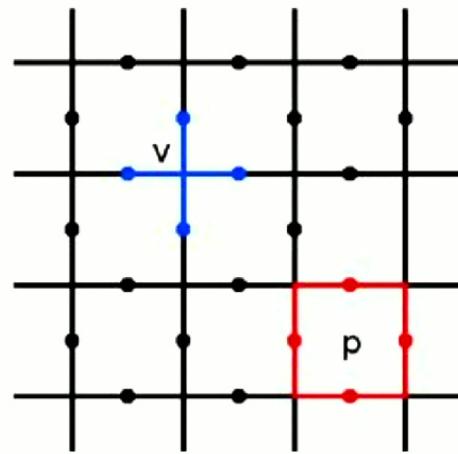




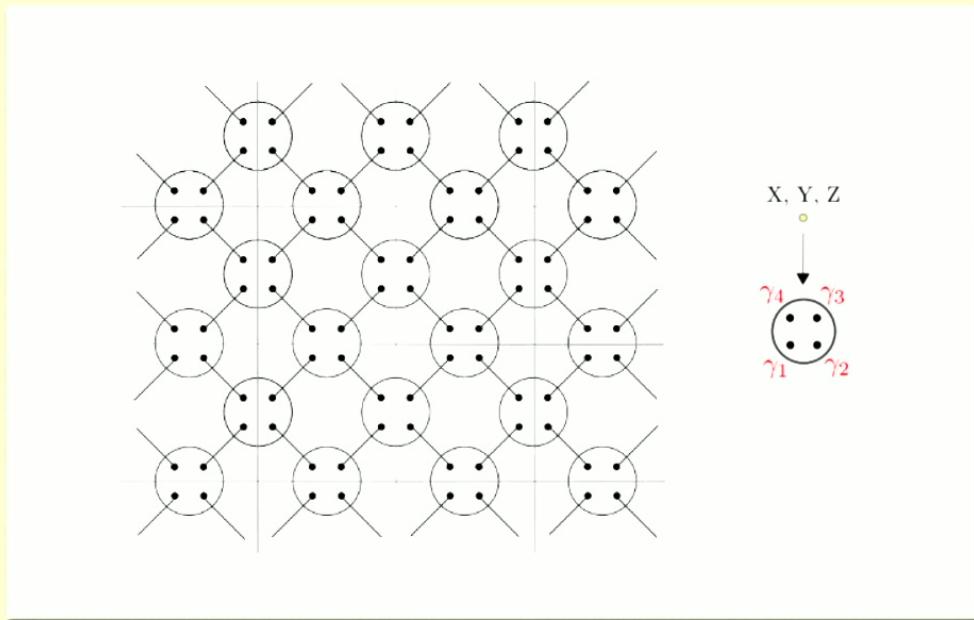
Inspired by Measurement based quantum computation (MBQC)

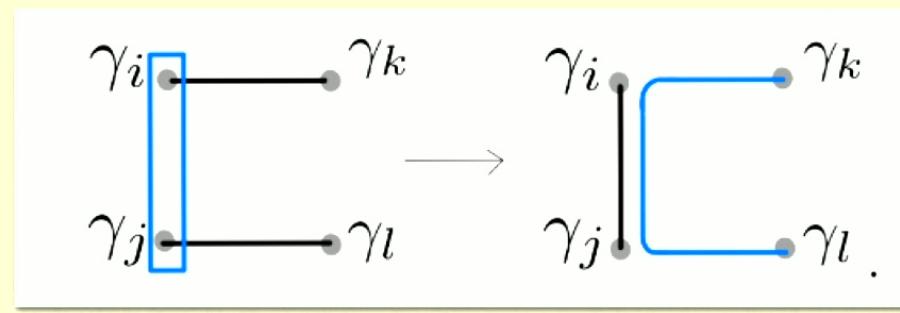


In this talk:
The emergence of phases of matter in the **Toric code**
with **MBQC** setup.



Another way of looking at Toric code by
Parton construction

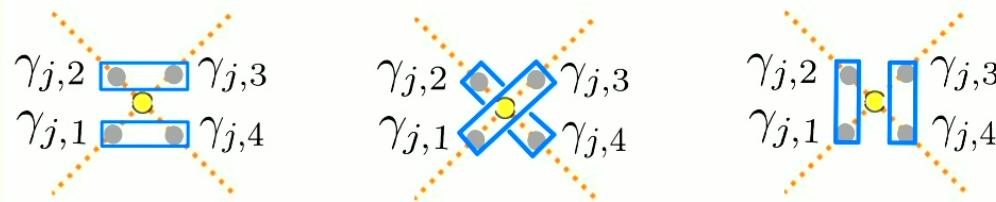


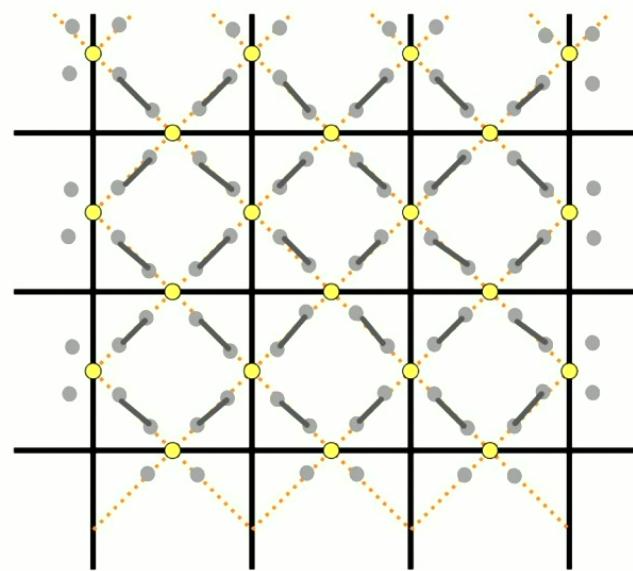


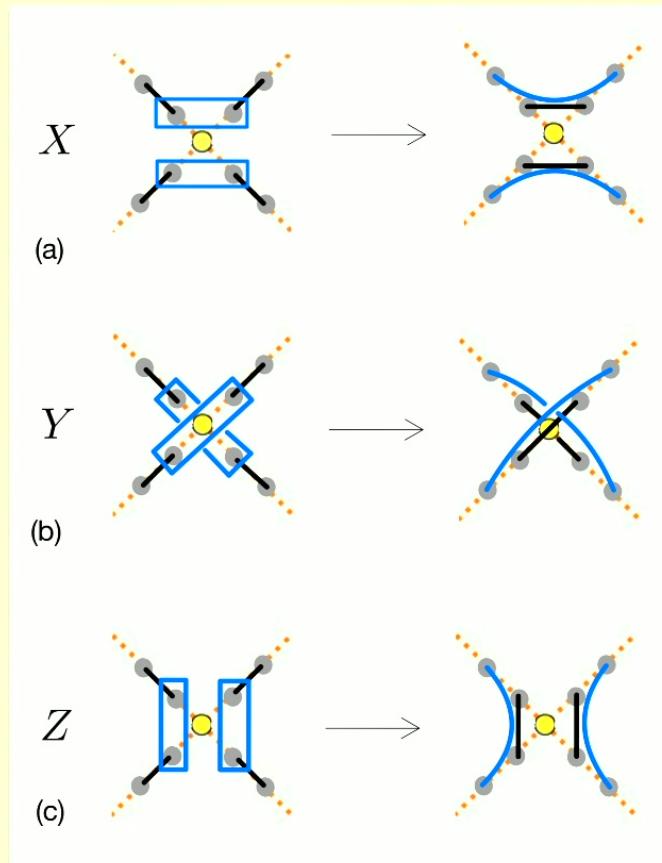
$$X_j = i\gamma_{j,1}\gamma_{j,2} = -i\gamma_{j,3}\gamma_{j,4}$$

$$Y_j = i\gamma_{j,1}\gamma_{j,3} = i\gamma_{j,2}\gamma_{j,4}$$

$$Z_j = i\gamma_{j,1}\gamma_{j,4} = -i\gamma_{j,2}\gamma_{j,3}$$



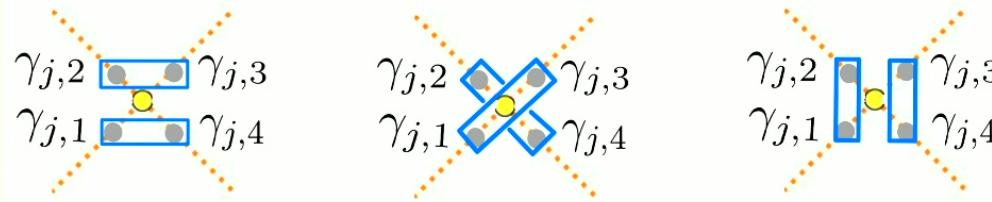


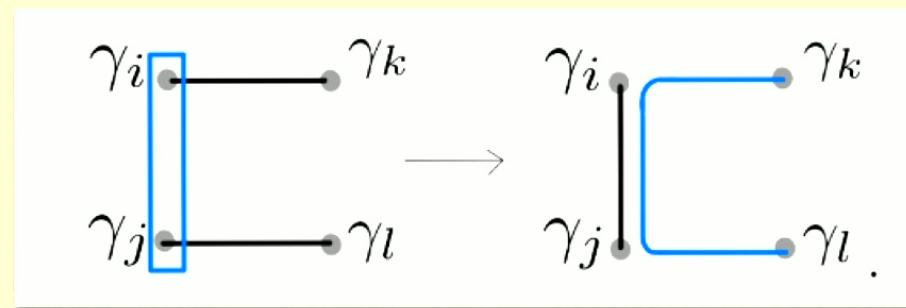


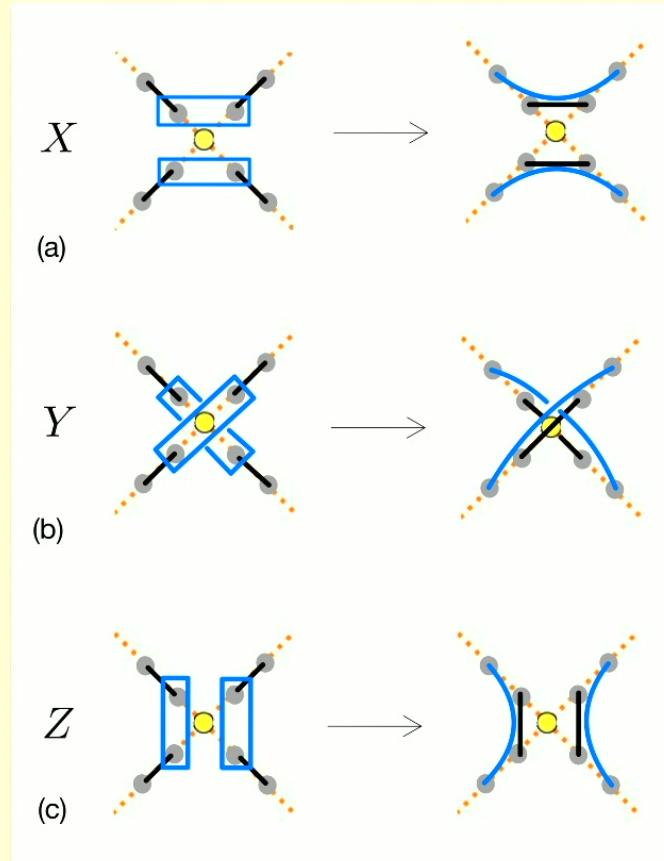
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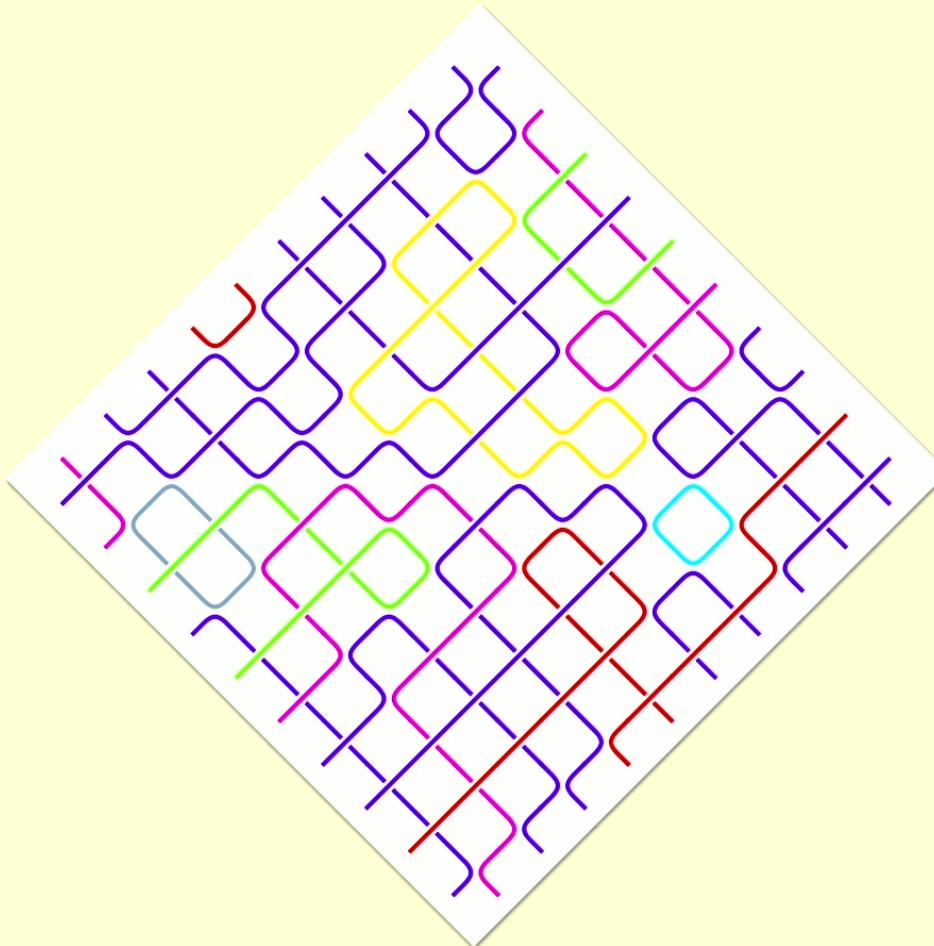
First Protocol:

A random measurement protocol (p, q) :

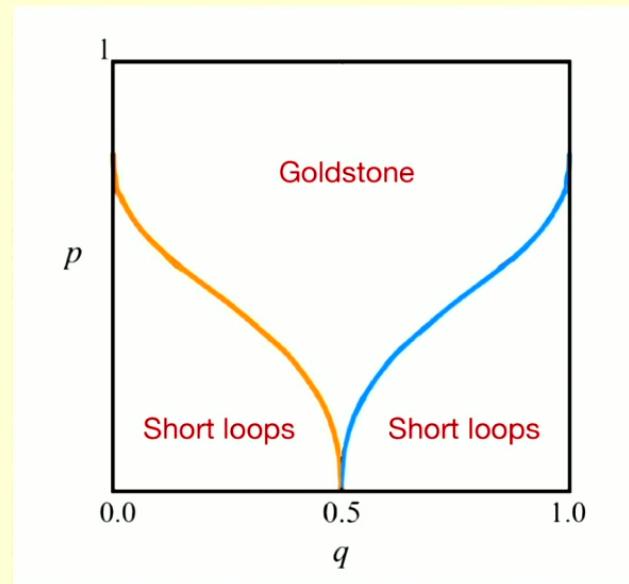
$$X \longrightarrow q(1 - p)$$

$$Y \longrightarrow p$$

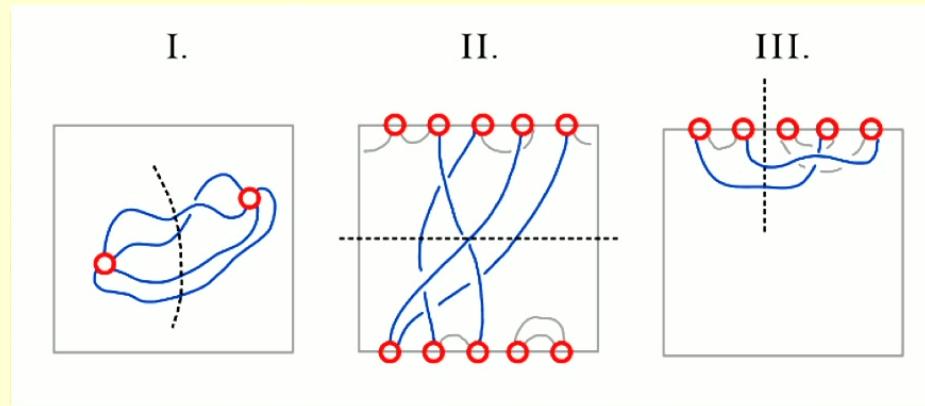
$$Z \longrightarrow (1 - q)(1 - p)$$

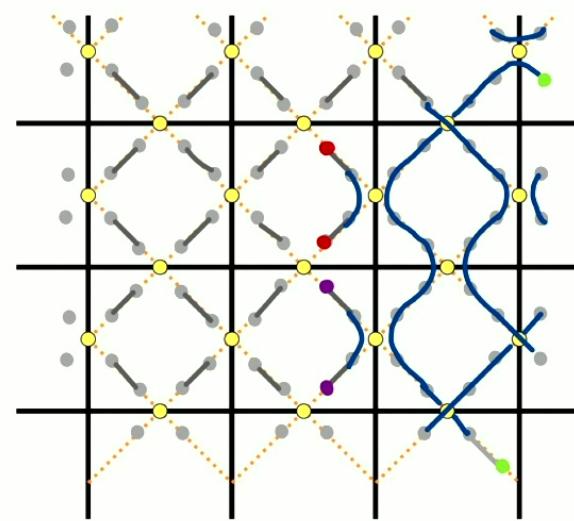


Classical phase diagram:



Order parameters of classical loop model:

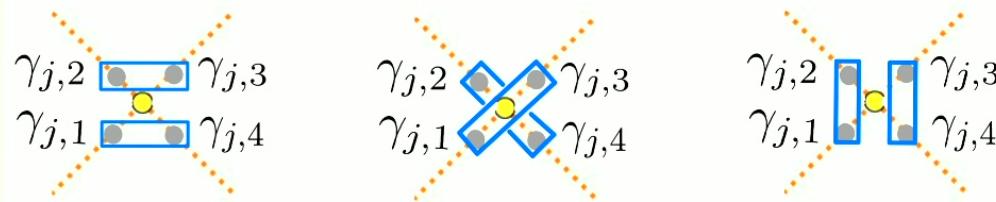


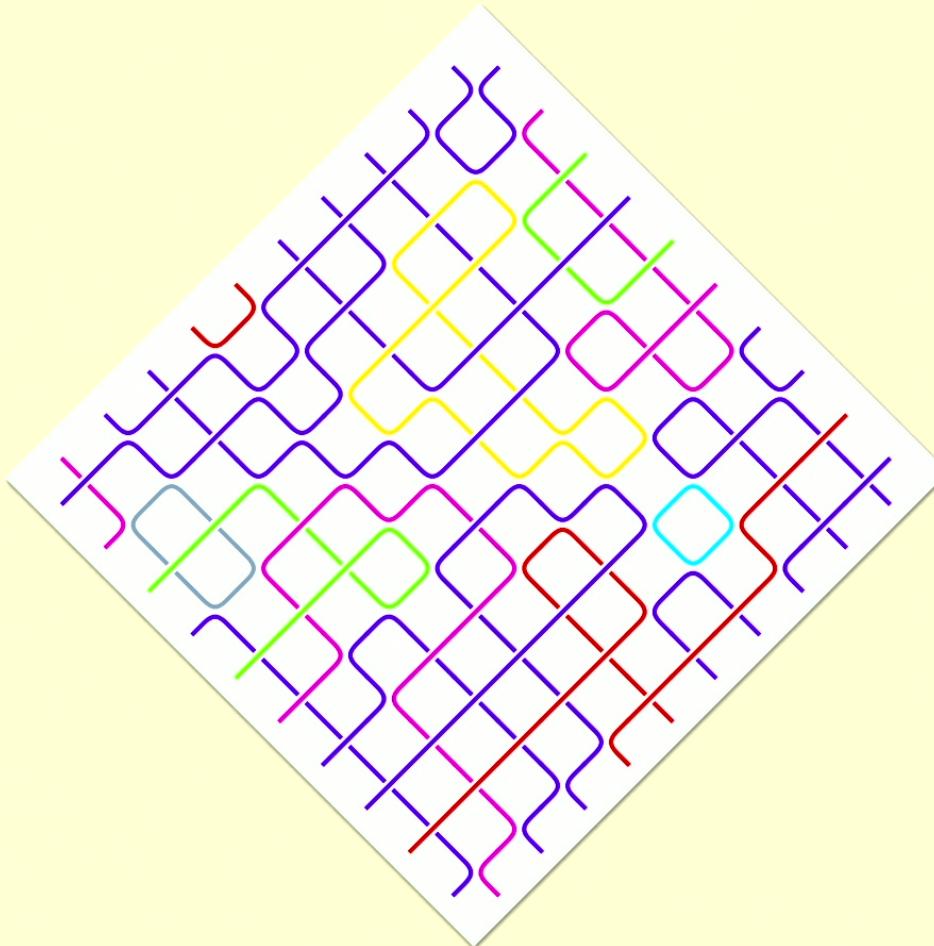


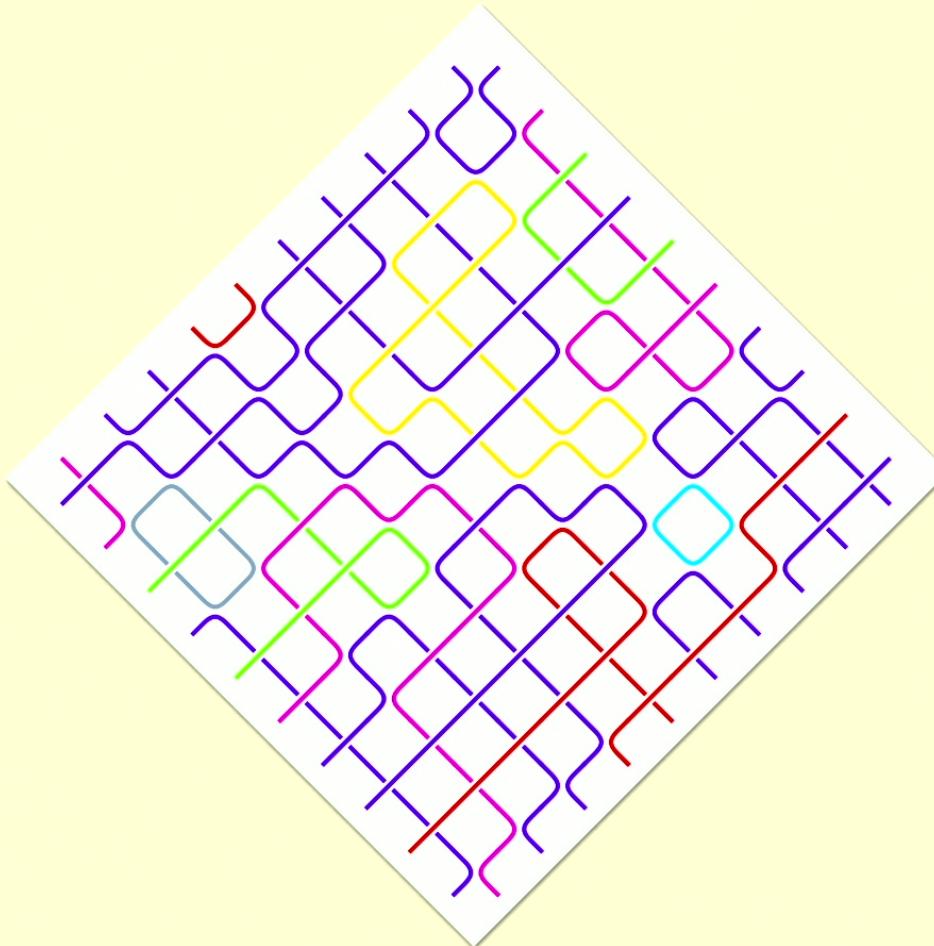
$$X_j = i\gamma_{j,1}\gamma_{j,2} = -i\gamma_{j,3}\gamma_{j,4}$$

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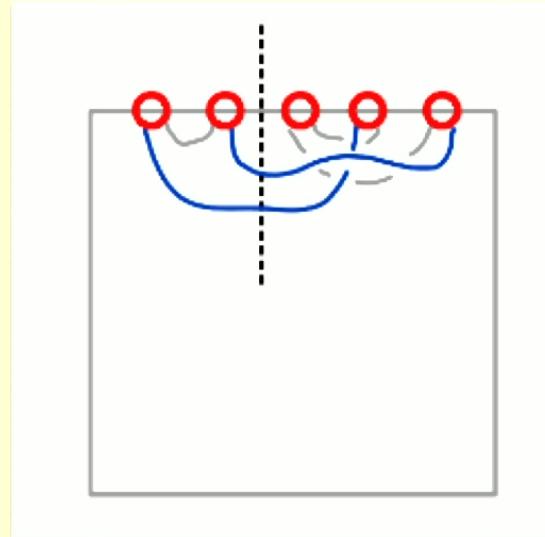
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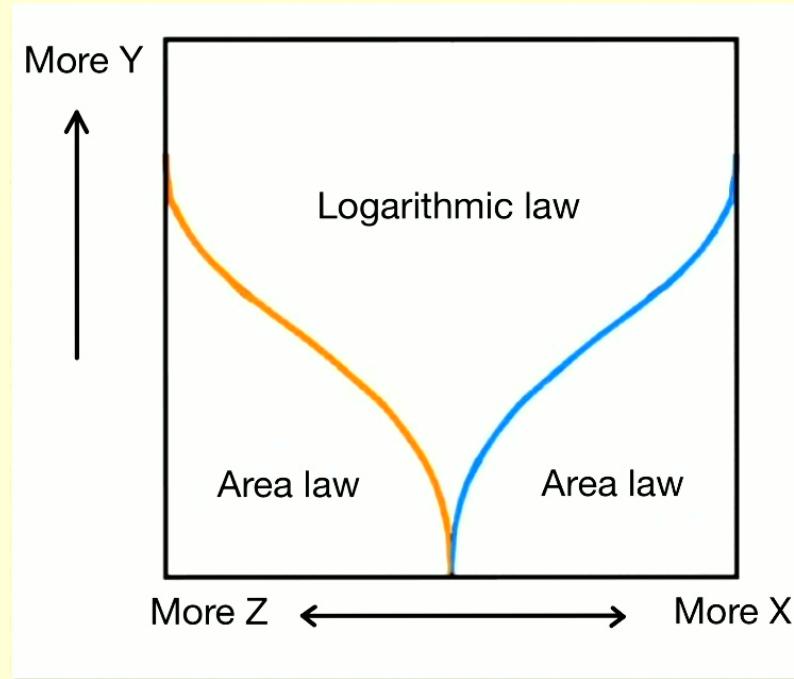


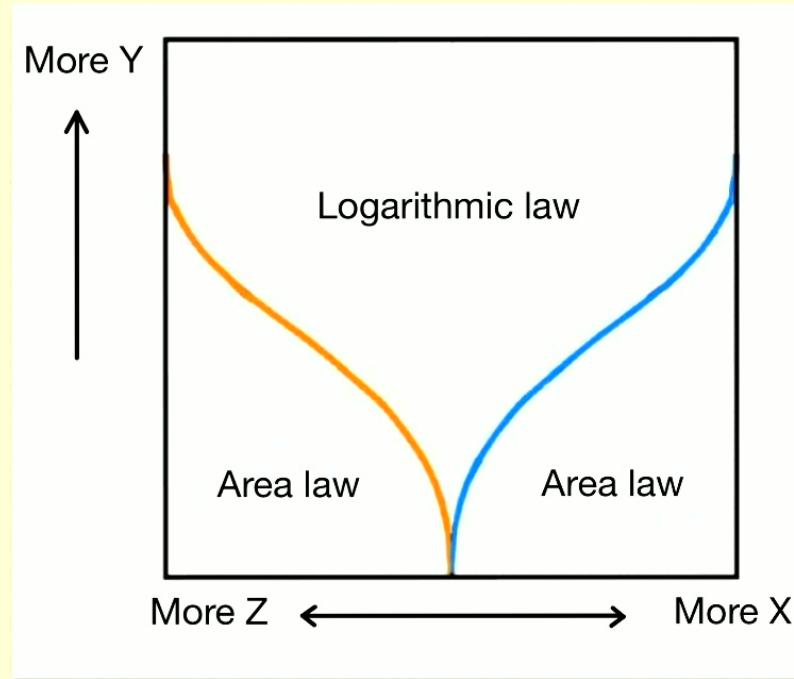


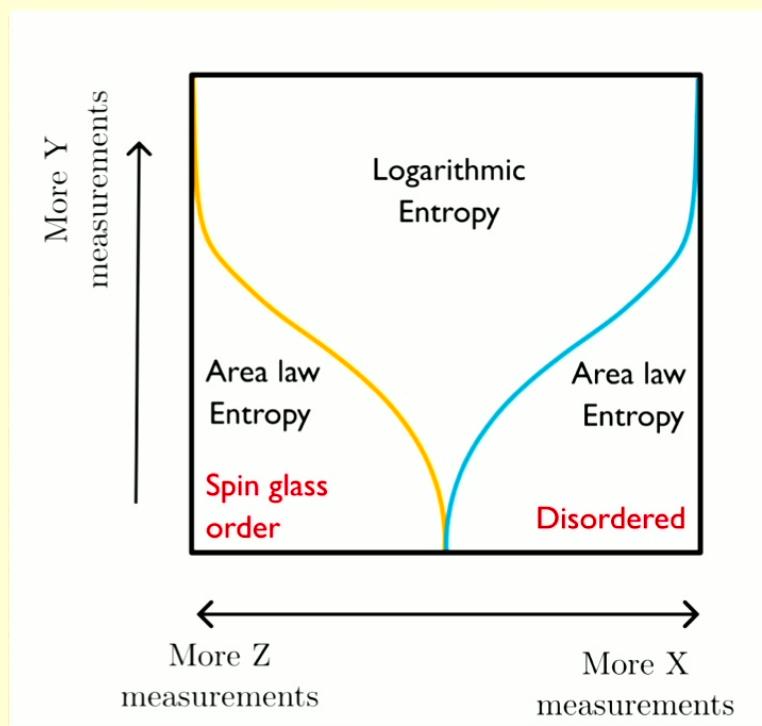


Measuring everything generates trivial product states





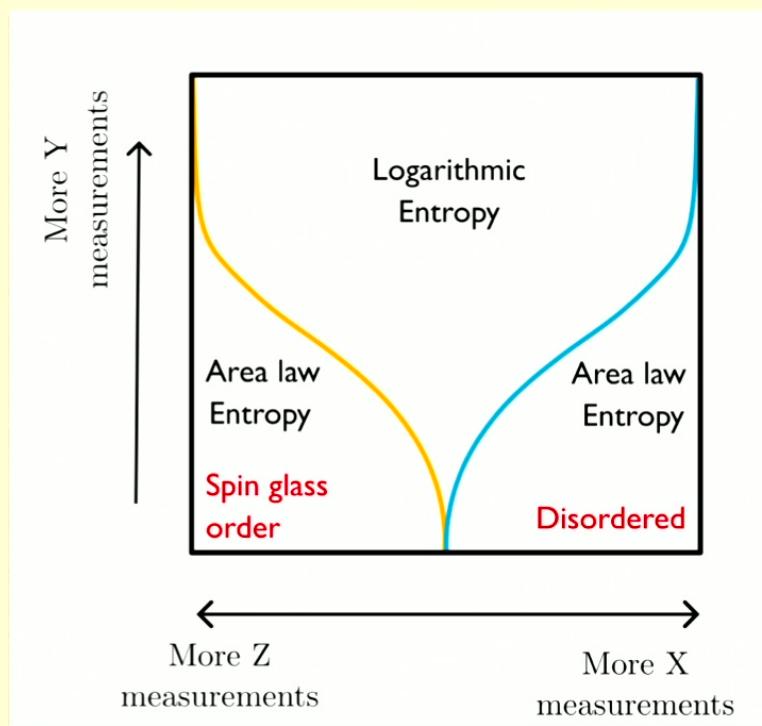




We don't like non-linear order parameters:

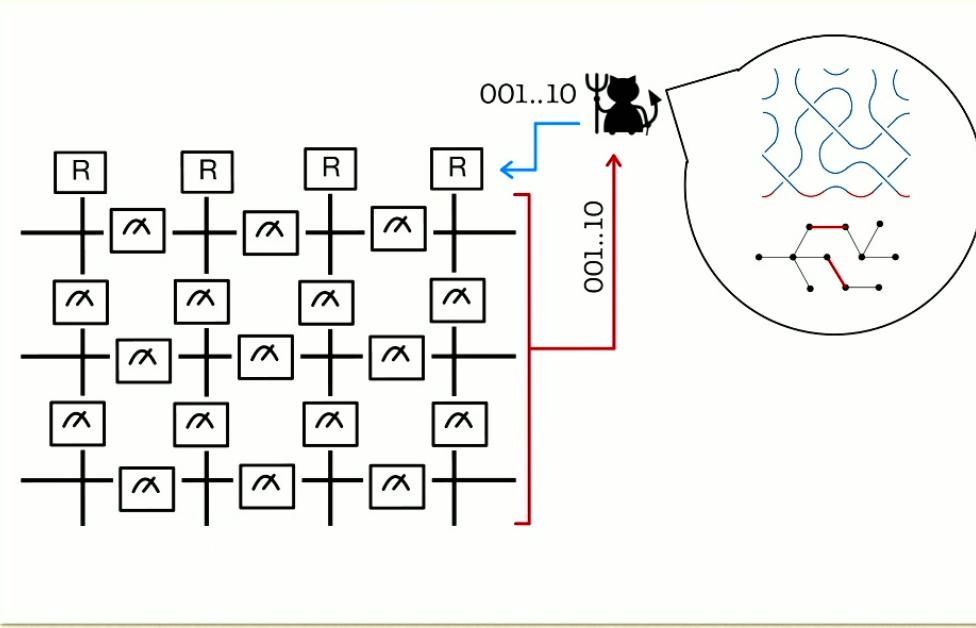
$$O = \frac{1}{L} \sum_{i,j}^L \langle \psi | Z_i Z_j | \psi \rangle^2$$

How about utilizing feedback and unitary operations?



We don't like non-linear order parameters:

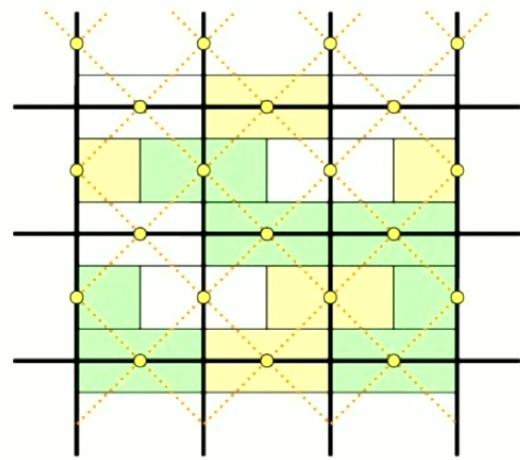
$$O = \frac{1}{L} \sum_{i,j}^L \langle \psi | Z_i Z_j | \psi \rangle^2$$



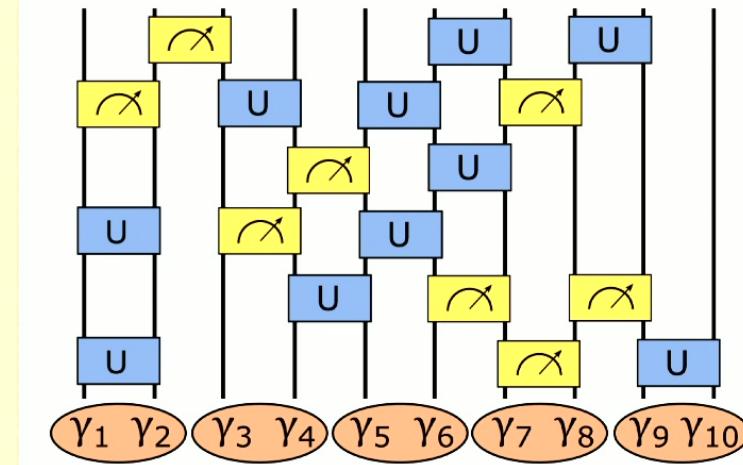
$$O = \frac{1}{L} \sum_{i,j}^L Tr(\rho Z_i Z_j)$$

Non-Pauli measurements protocols?

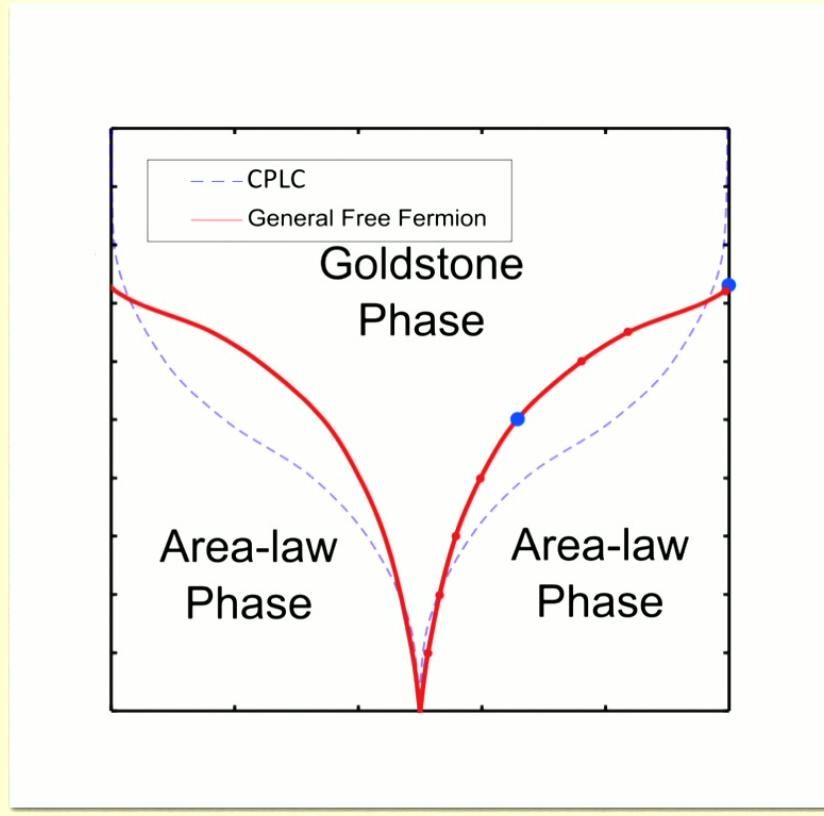
2+0



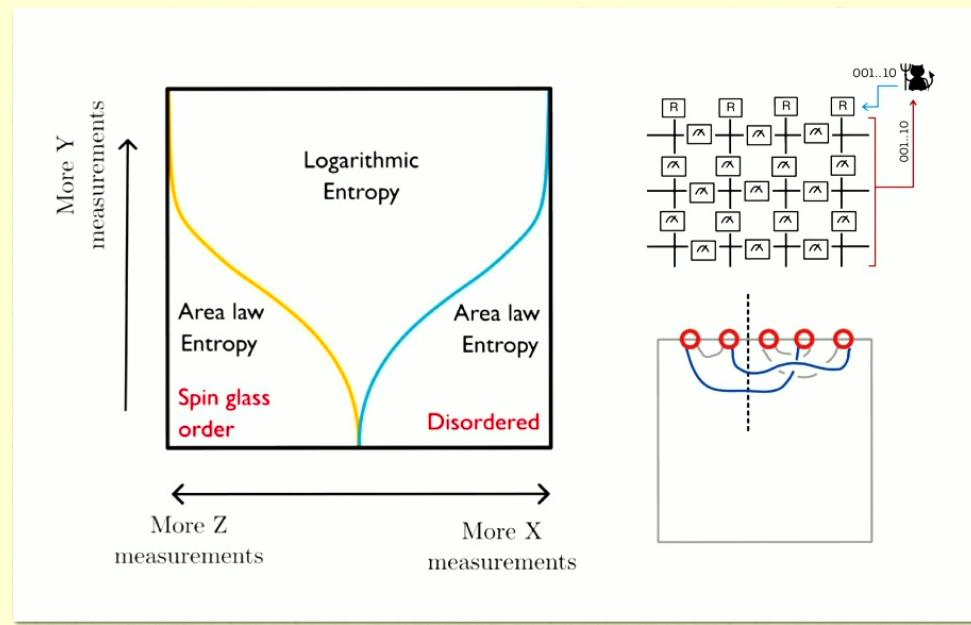
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Importing the results from Gaussian circuits.

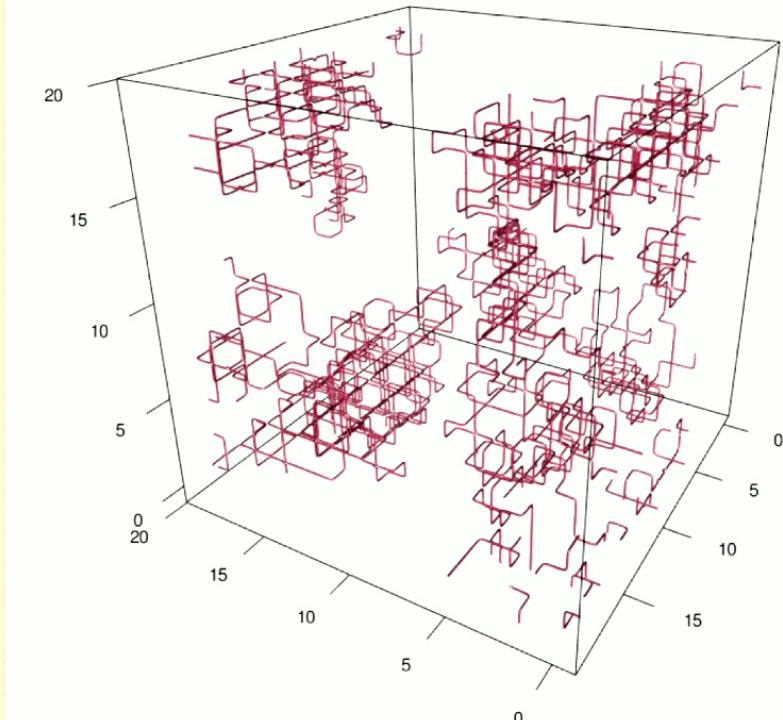


Showcase the potential of MBQC setups in producing and manipulating phases of matter.



Doing supervised measurement.

Example: Engineering ID cluster state, ... in boundary



Is random MIE related to intrinsic sign structure of the resource state?

Thank you