Fusion-based quantum computation

Mihir Pant
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Sara Bartolucci, Patrick Birchall, Hector Bombin, Hugo Cable, Chris Dawson, Mercedes Gimeno-Segovia, Eric Johnston, Konrad Kieling, Naomi Nickerson, Mihir Pant, Fernando Pastawski, Terry Rudolph, Chris Sparrow
arXiv:2101.09310

Fusion-based quantum computation (FBQC):

A general framework for fault-tolerant quantum computation with only:

Resource States:

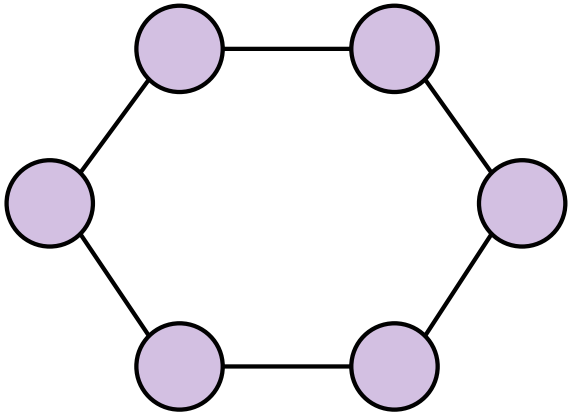
- Small constant sized entangled states

Fusions:

- Destructive entangling measurements

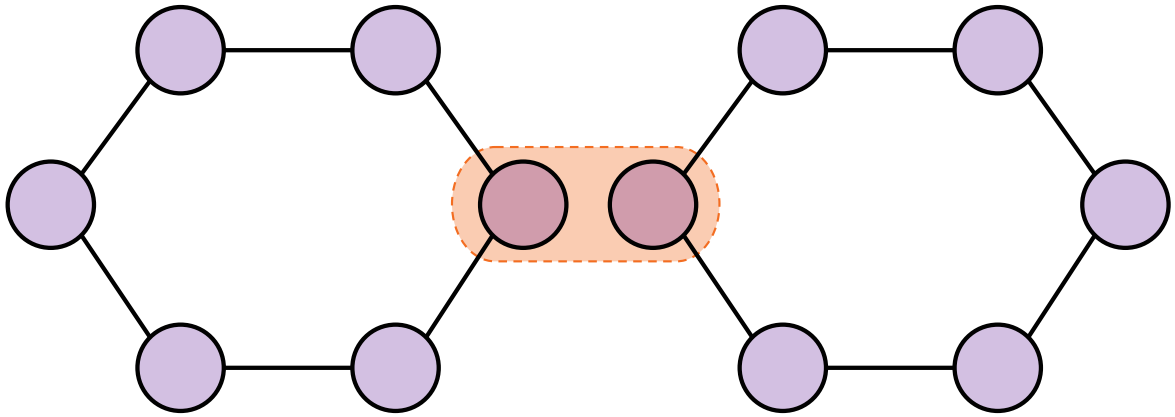
} Easy for photons

Overview of FBQC: Resource State



- Constant size stabilizer states
- Low errors

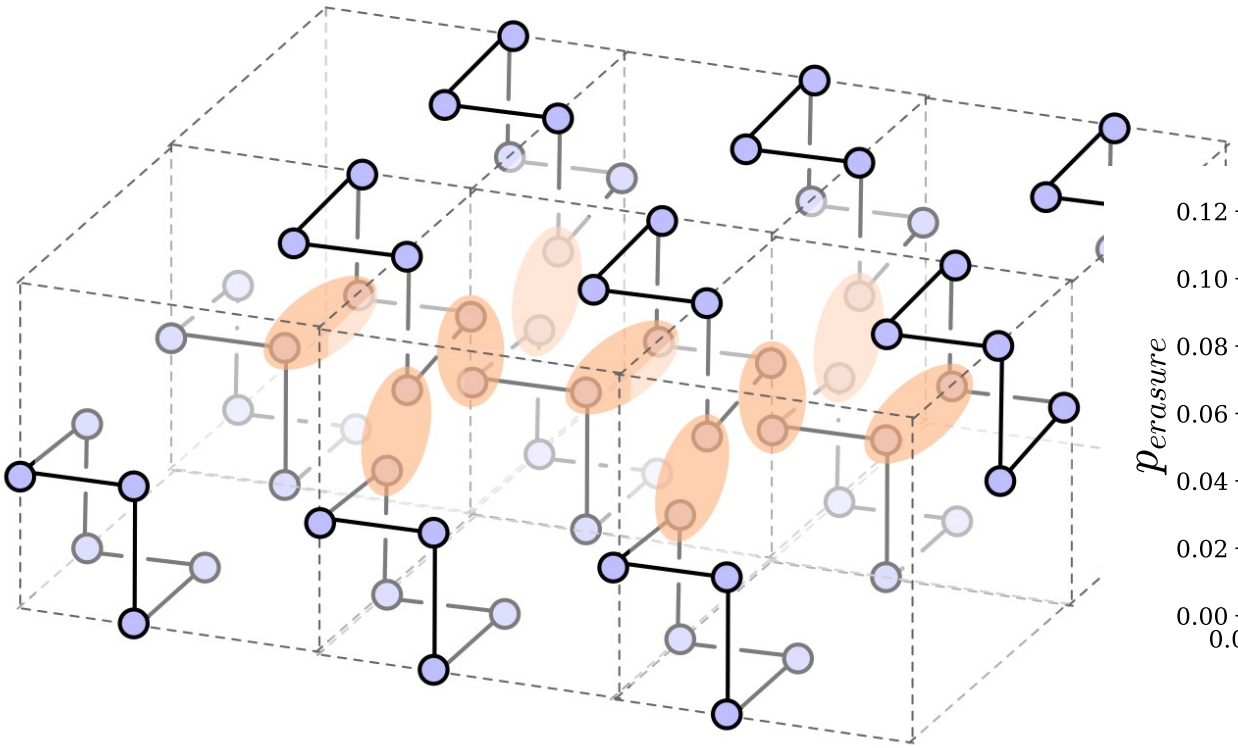
Overview of FBQC: Fusion

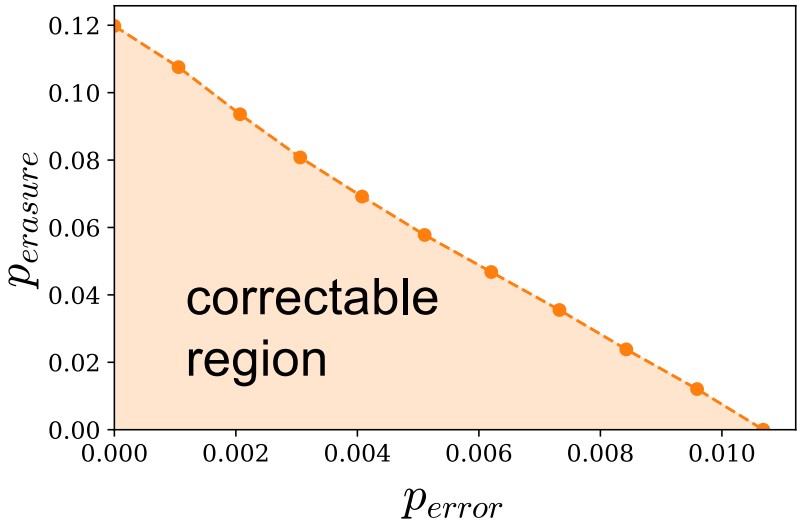


2 measurement bits:
XX, ZZ

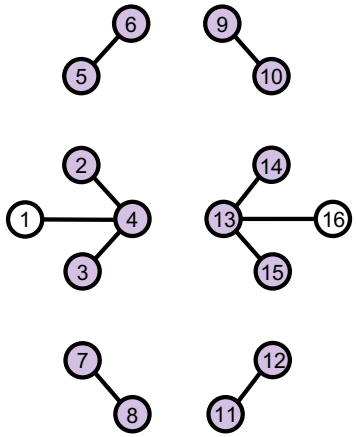
A measurement bit can be
- Erased ($p_{erasure}$)
- Flipped (p_{error})

Overview of FBQC: Fusion Network





Fault-tolerance in the fusion based framework: a toy example



Resource States, R

$$\left\langle \begin{pmatrix} X_1Z_4, \\ X_2Z_4, \\ X_3Z_4, \\ X_4Z_1Z_2Z_3, \end{pmatrix}, \begin{pmatrix} X_{14}Z_{13}, \\ X_{15}Z_{13}, \\ X_{16}Z_{13}, \\ X_{13}Z_{14}Z_{15}Z_{16} \end{pmatrix}, \begin{pmatrix} X_5Z_6, \\ X_6Z_5 \end{pmatrix}, \begin{pmatrix} X_7Z_8, \\ X_8Z_7 \end{pmatrix}, \begin{pmatrix} X_9Z_{10}, \\ X_{10}Z_9 \end{pmatrix}, \begin{pmatrix} X_{11}Z_{12}, \\ X_{12}Z_{11} \end{pmatrix} \right\rangle$$

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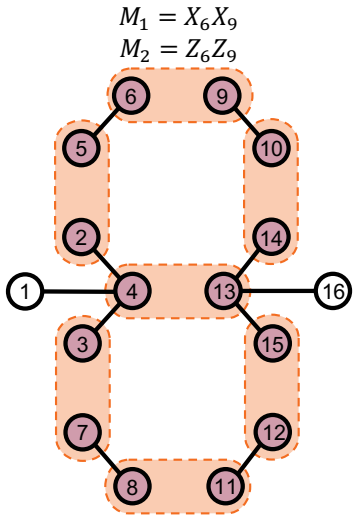

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Fusion, F

$$\left\langle \begin{pmatrix} X_2X_5, \\ Z_2Z_5 \end{pmatrix}, \begin{pmatrix} X_3X_7, \\ Z_3Z_7 \end{pmatrix}, \begin{pmatrix} X_6X_9, \\ Z_6Z_9 \end{pmatrix}, \begin{pmatrix} X_8X_{11}, \\ Z_8Z_{11} \end{pmatrix}, \begin{pmatrix} X_4X_{13}, \\ Z_4Z_{13} \end{pmatrix}, \begin{pmatrix} X_{10}X_{14}, \\ Z_{10}Z_{14}, \end{pmatrix}, \begin{pmatrix} X_{12}X_{15}, \\ Z_{12}Z_{15}, \end{pmatrix}, -\mathbf{1} \right\rangle$$

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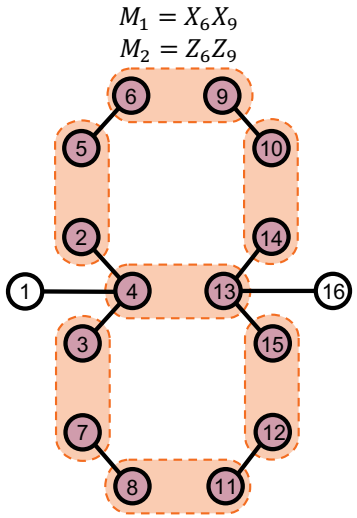

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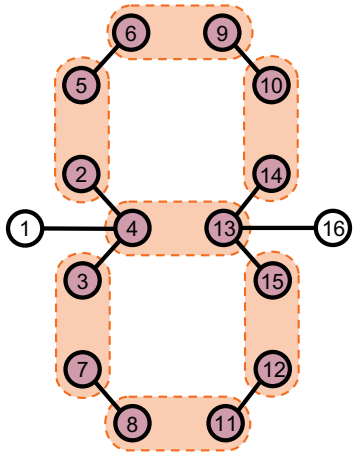
$$C = R \cap F$$

Fault-tolerance in the fusion based framework: a toy example



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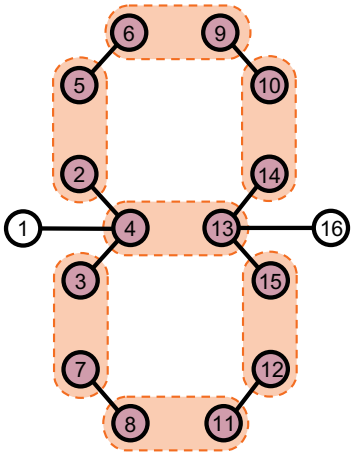
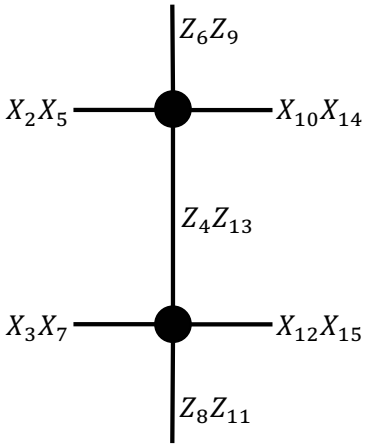
Checks, C	$\langle (X_2X_5)(Z_6Z_9)(X_{10}X_{14})(Z_4Z_{13}),\ \ (X_3X_7)(Z_8Z_{11})(X_{12}X_{15})(Z_{13}Z_4) \rangle$

Fault-tolerance in the fusion based framework: a toy example





Syndrome graph

Resource States, R	$\left\langle \begin{pmatrix} X_1Z_4, \\ X_2Z_4, \\ X_3Z_4, \\ X_4Z_1Z_2Z_3, \end{pmatrix}, \begin{pmatrix} X_{14}Z_{13}, \\ X_{15}Z_{13}, \\ X_{16}Z_{13}, \\ X_{13}Z_{14}Z_{15}Z_{16} \end{pmatrix}, \begin{pmatrix} X_5Z_6, \\ X_6Z_5 \end{pmatrix}, \begin{pmatrix} X_7Z_8, \\ X_8Z_7 \end{pmatrix}, \begin{pmatrix} X_9Z_{10}, \\ X_{10}Z_9 \end{pmatrix}, \begin{pmatrix} X_{11}Z_{12}, \\ X_{12}Z_{11} \end{pmatrix} \right\rangle$
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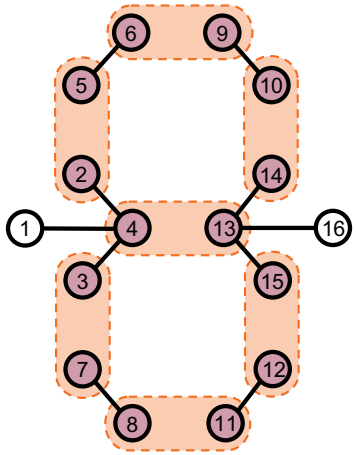
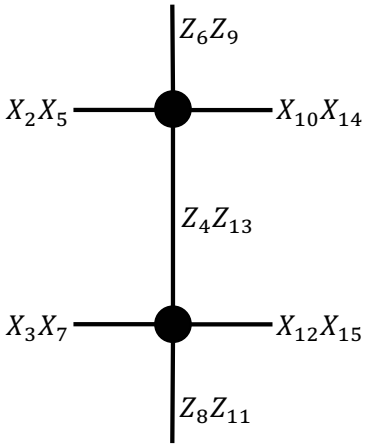
Fault-tolerance in the fusion based framework: a toy example





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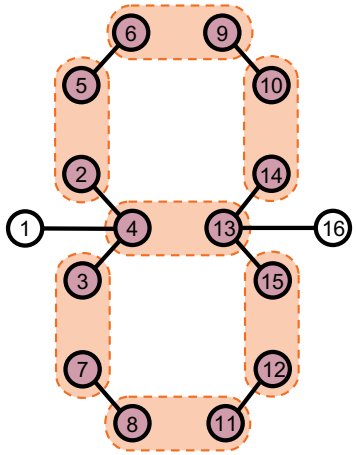
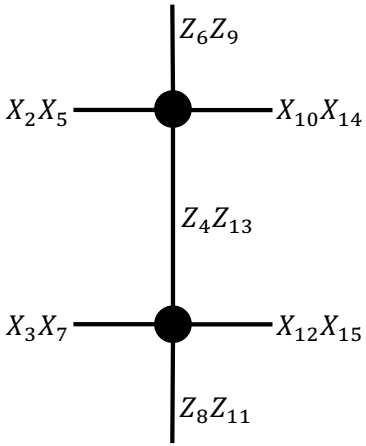
$$S = \mathcal{Z}_R(F)$$

(centralizer of F in R)

Fault-tolerance in the fusion based framework: a toy example





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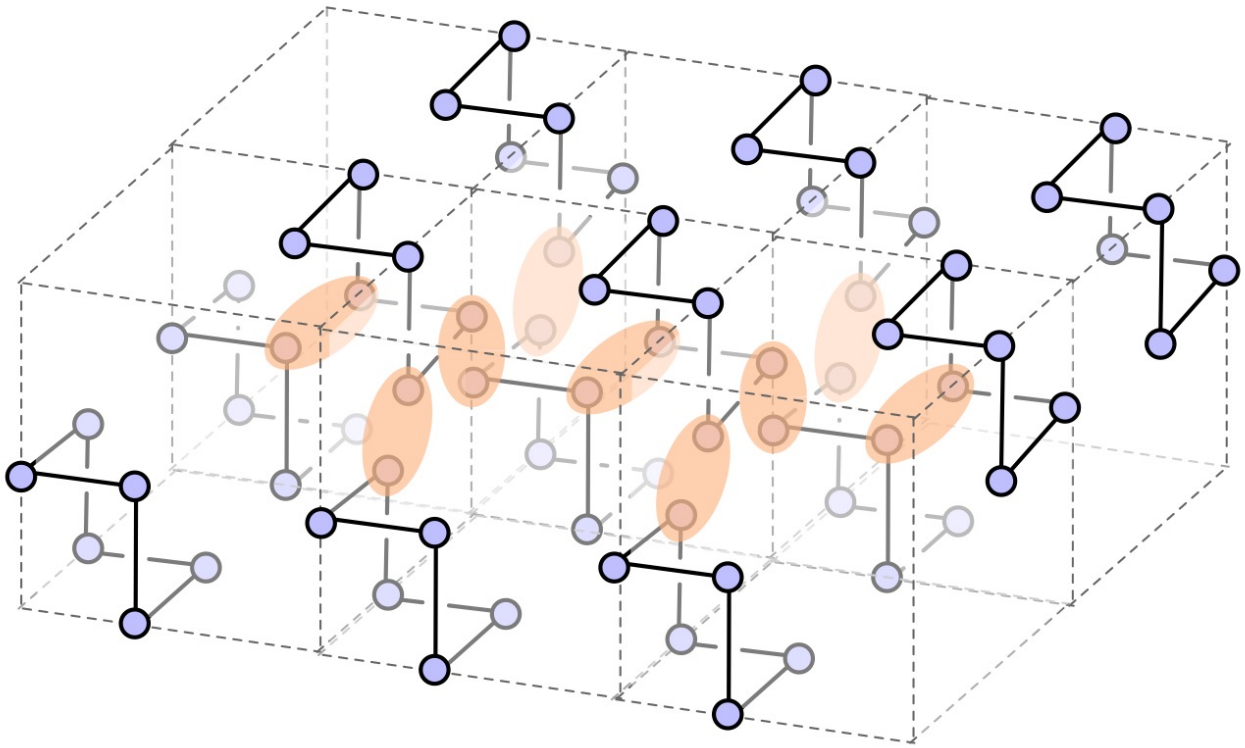
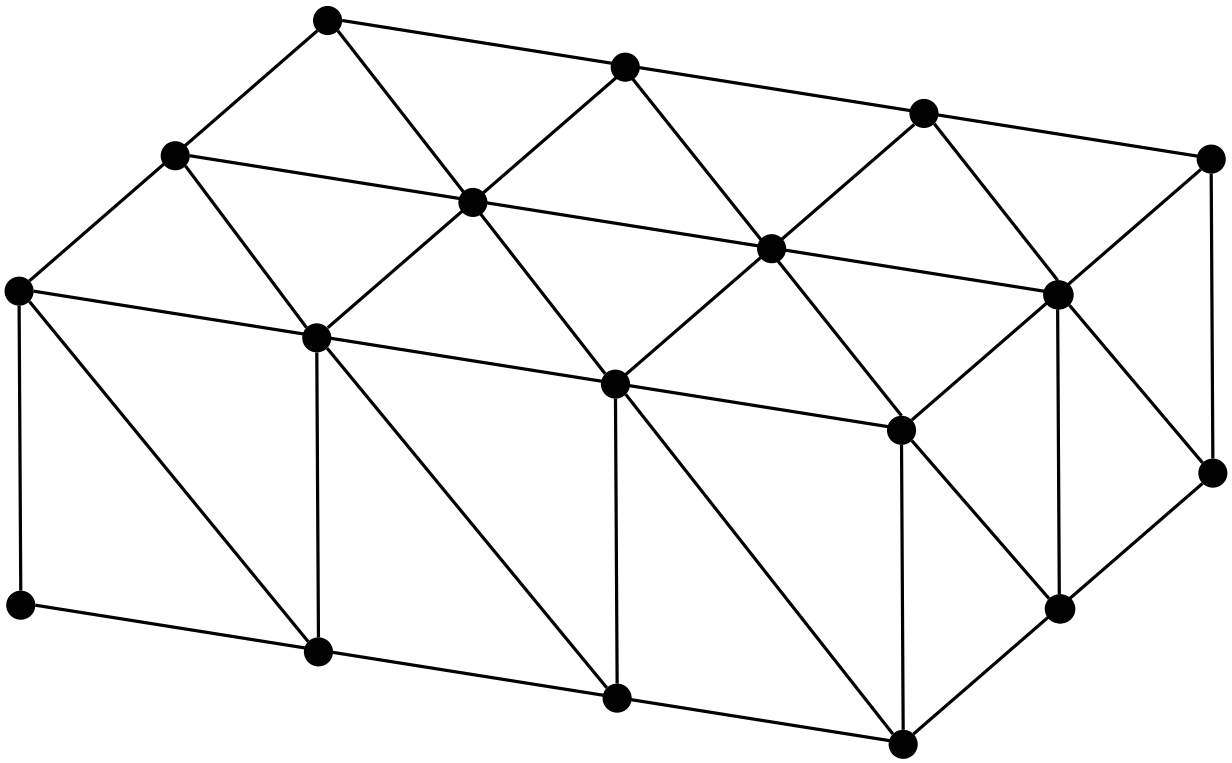
Surviving Stabilizer, S	$\langle \mathrm{C}, X_1(Z_4Z_{13})X_{16}, Z_1(Z_2Z_5)(X_6X_9)(Z_{10}Z_{14})(Z_{12}Z_{15})(X_8X_{11})(Z_3Z_7)(Z_4Z_{13})Z_{16} \rangle$

Fault-tolerant fusion network

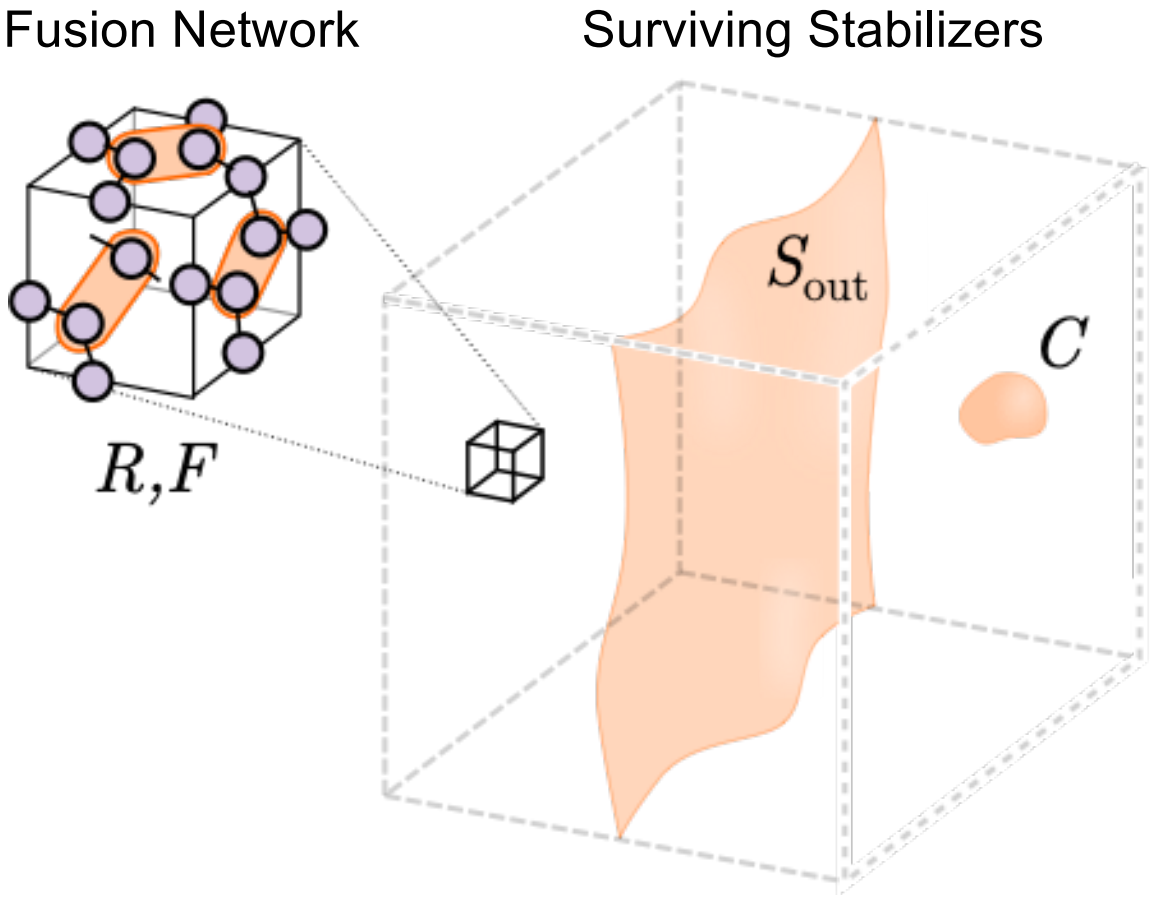


Fusion network: syndrome graph

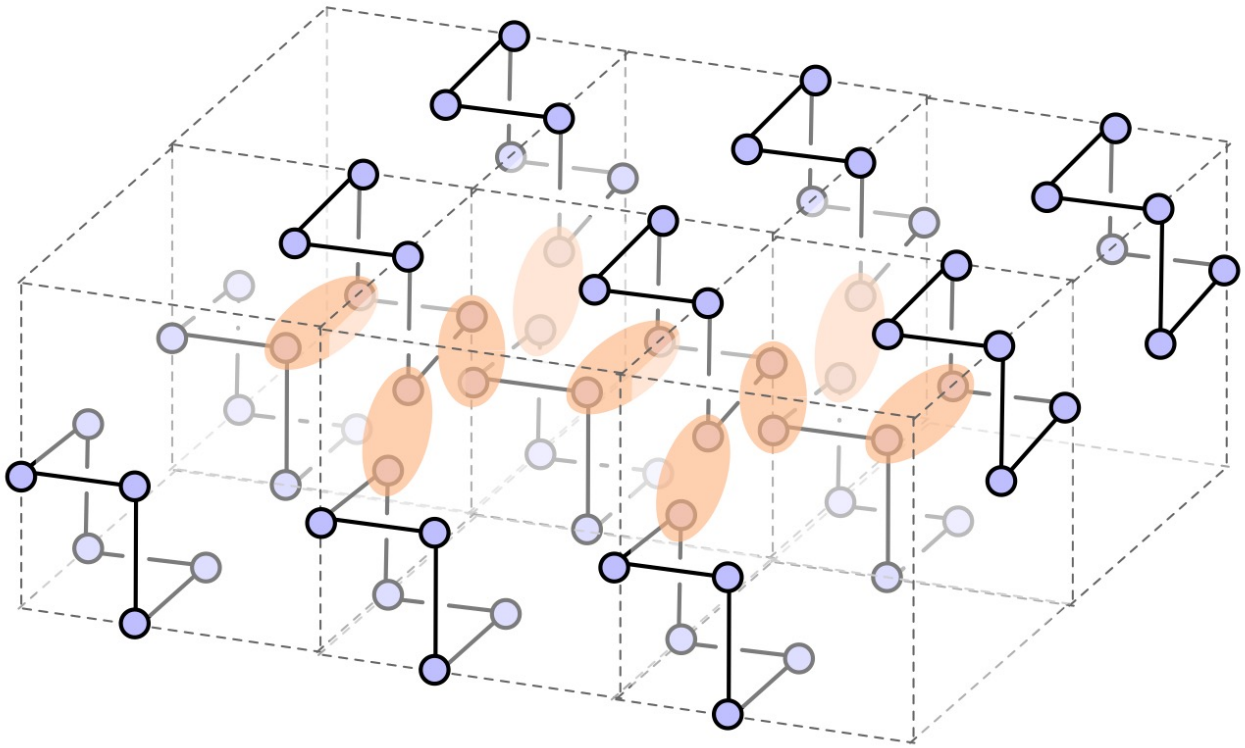


self-dual

Fusion network: surviving stabilizers

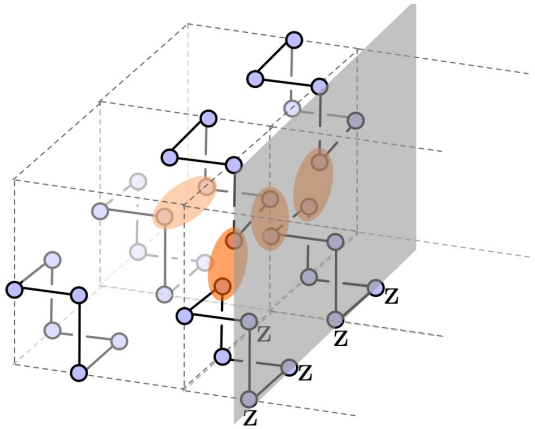


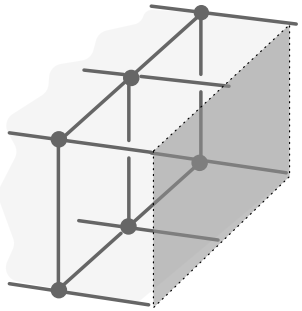
The Bulk



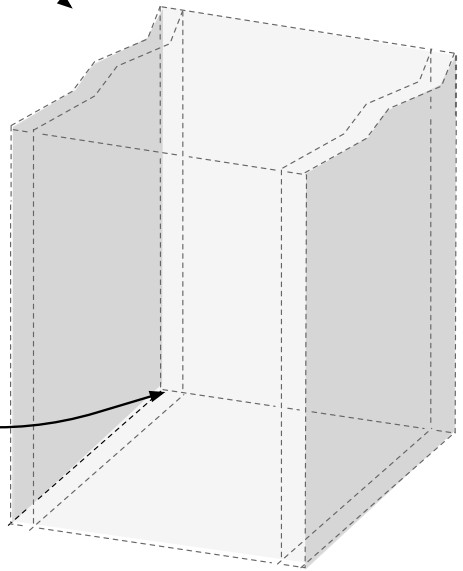
Logic

rough primal boundary

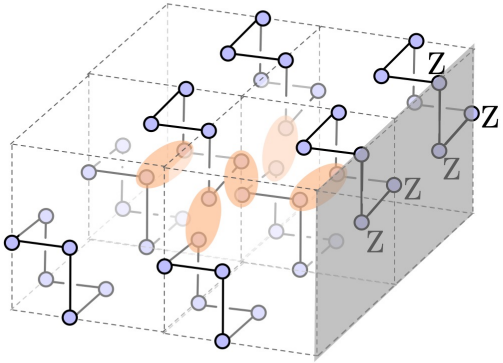


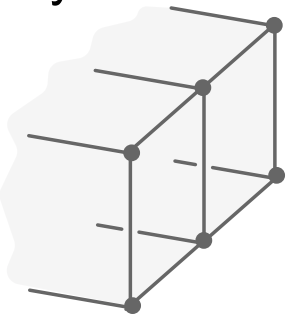


Identity gate



smooth primal boundary

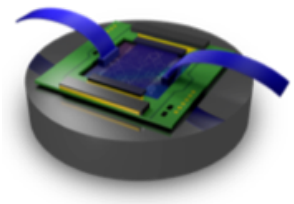




upcoming PsiQuantum publication

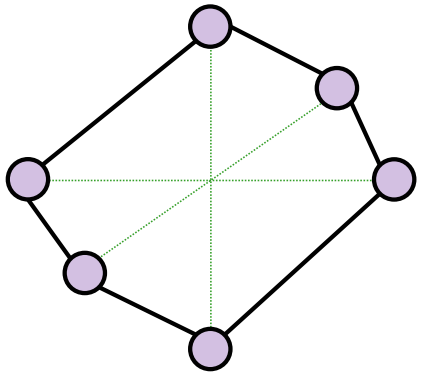
Fusion Networks in real space and time

The physical layout



Photonic resource state generator

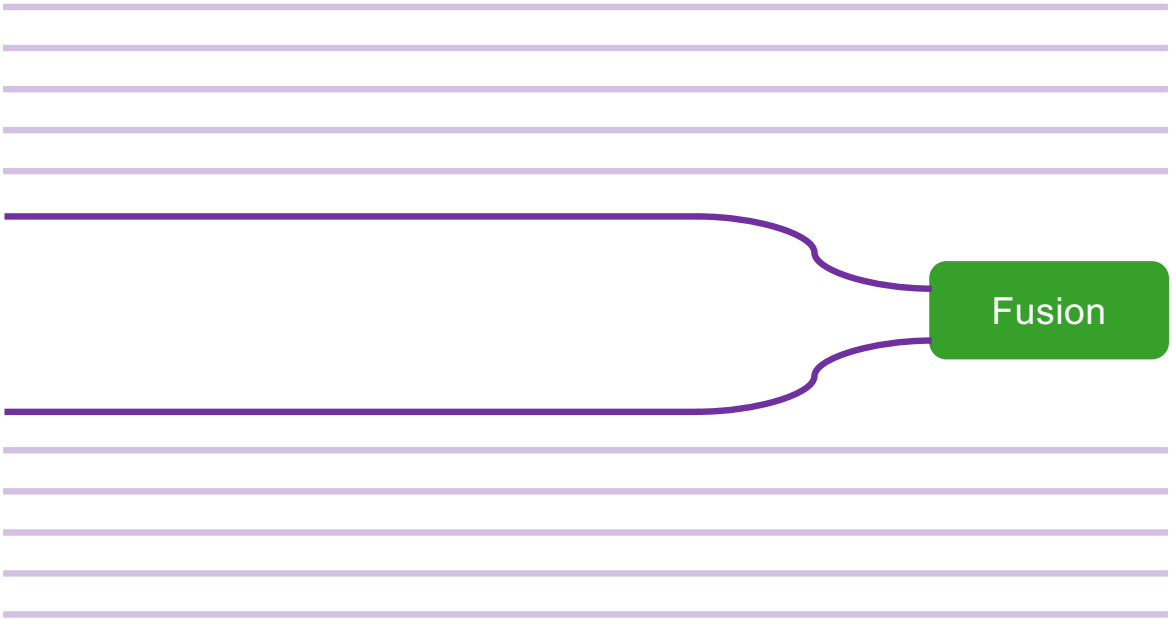
Every 1ns

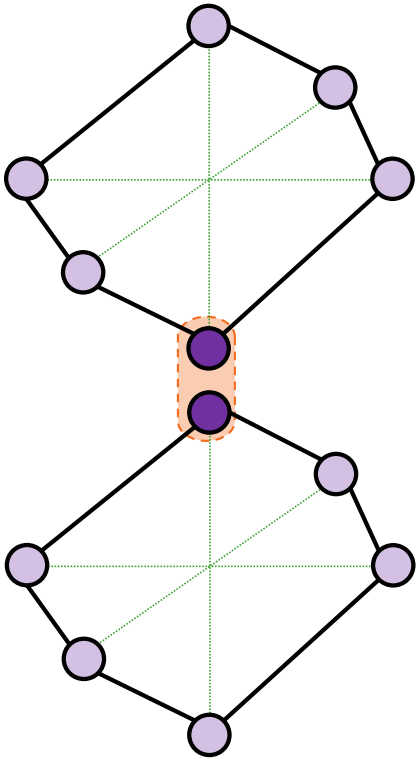


Each qubit is a dual rail qubit: one photon in two modes

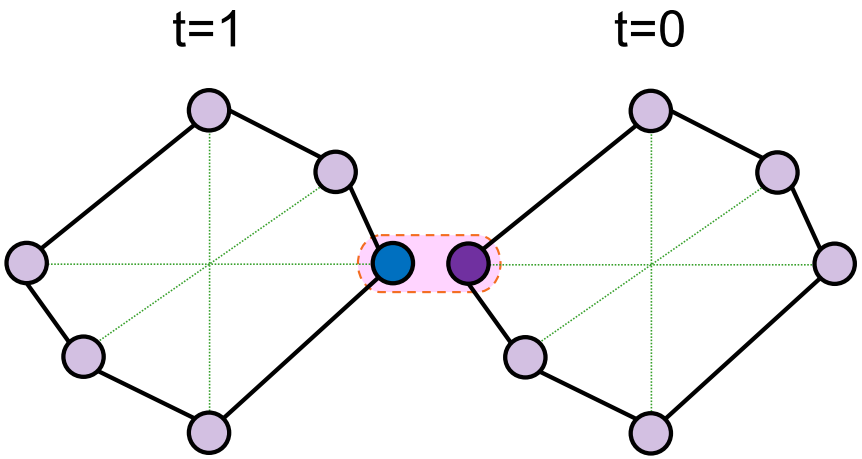
Linear optical cluster state

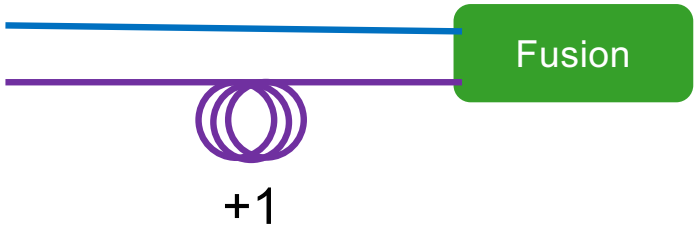
The physical layout: space-like fusions



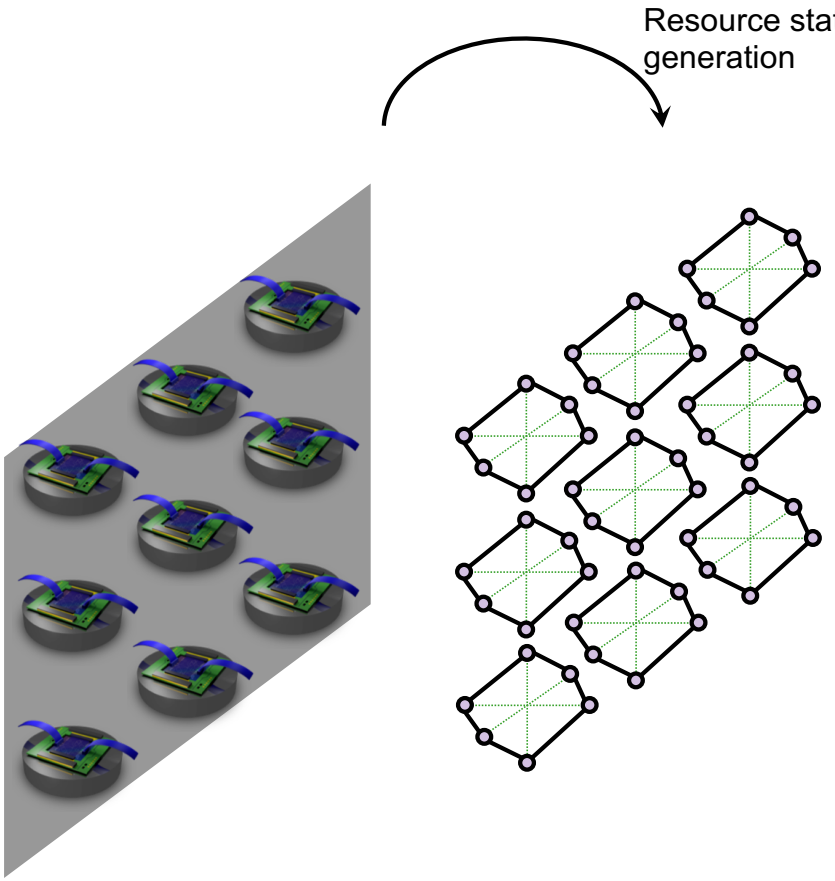


The physical layout: time-like fusions



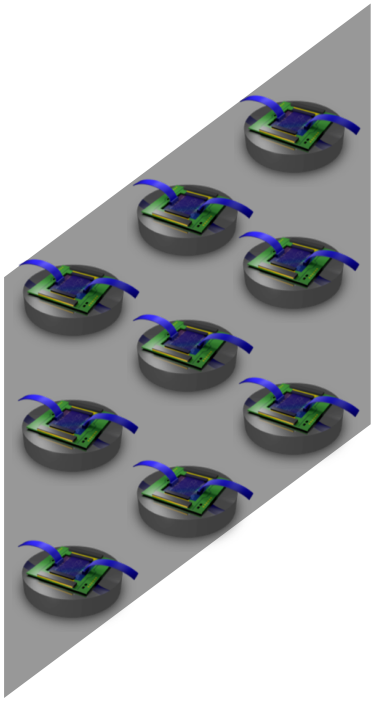


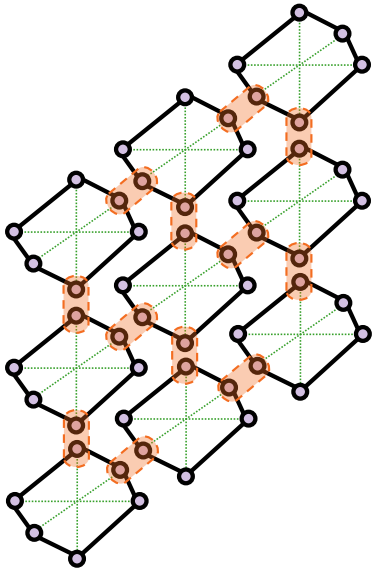
The physical layout



The physical layout

Space-like
fusions





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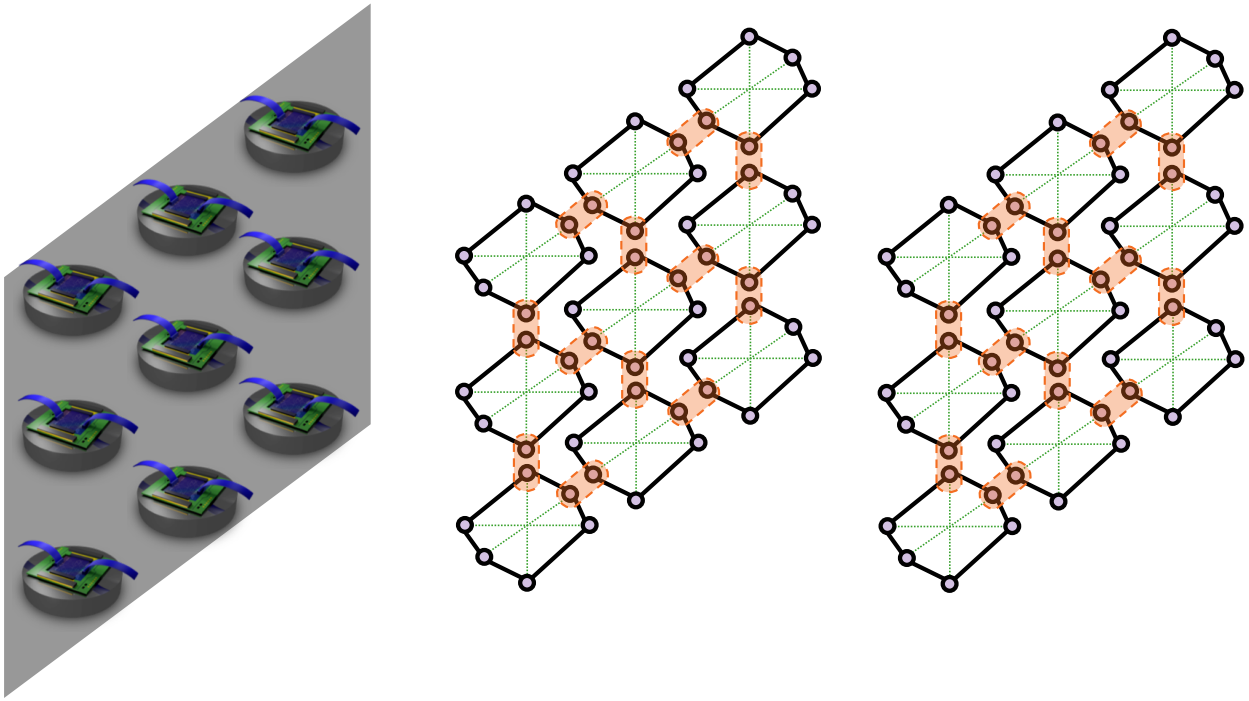

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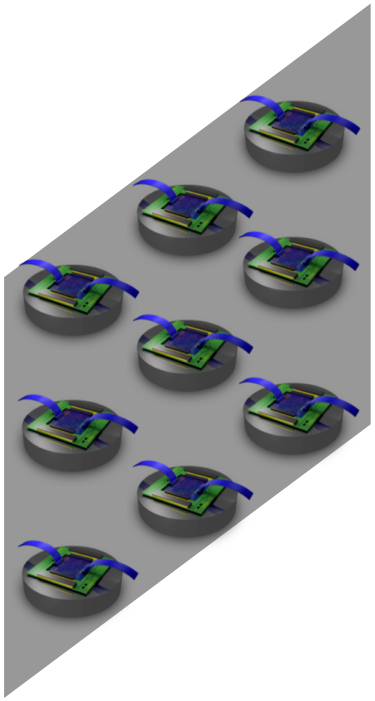
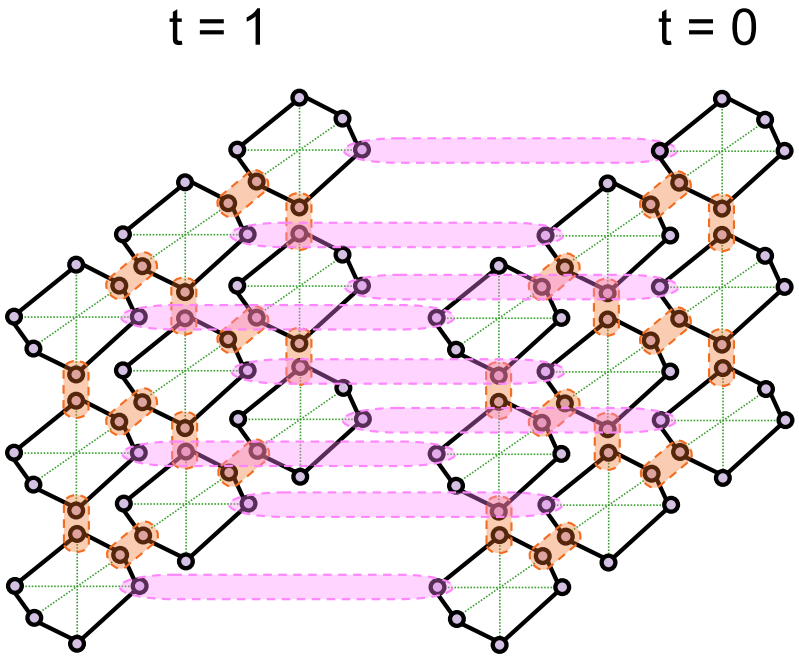
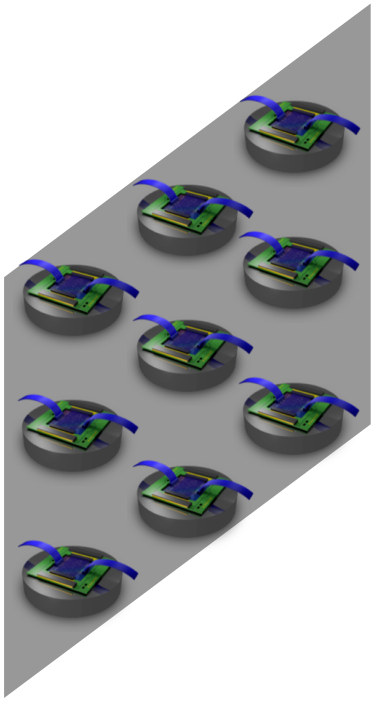
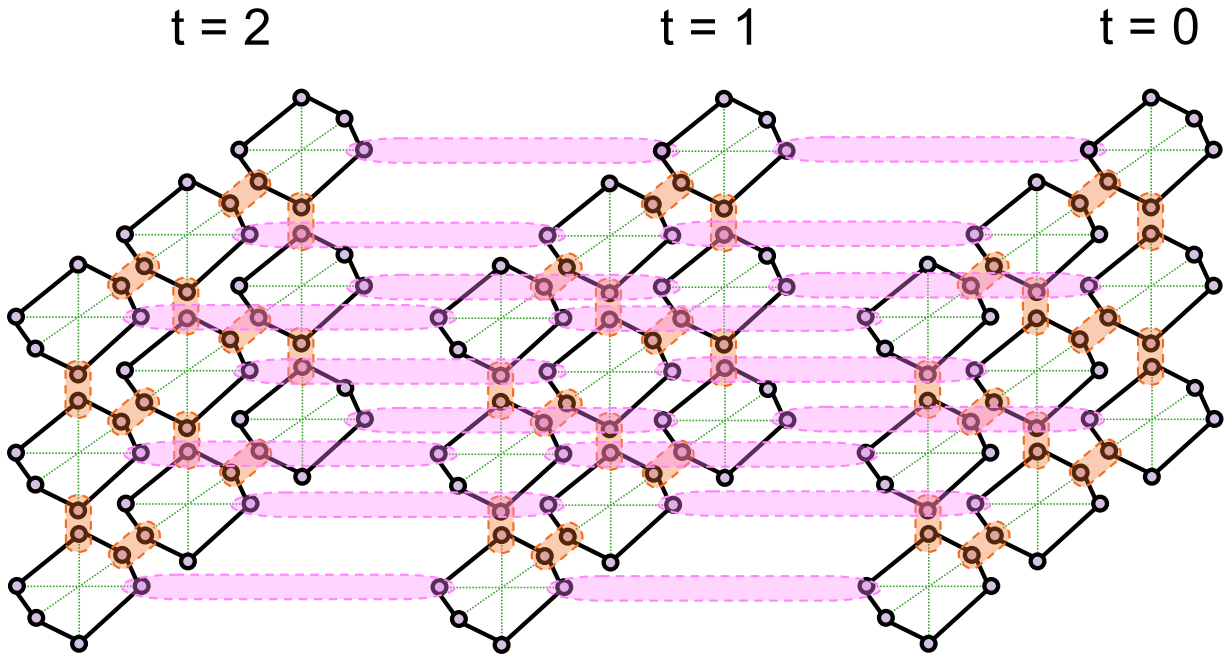


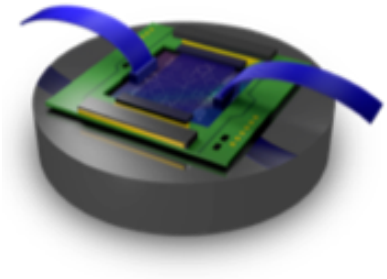


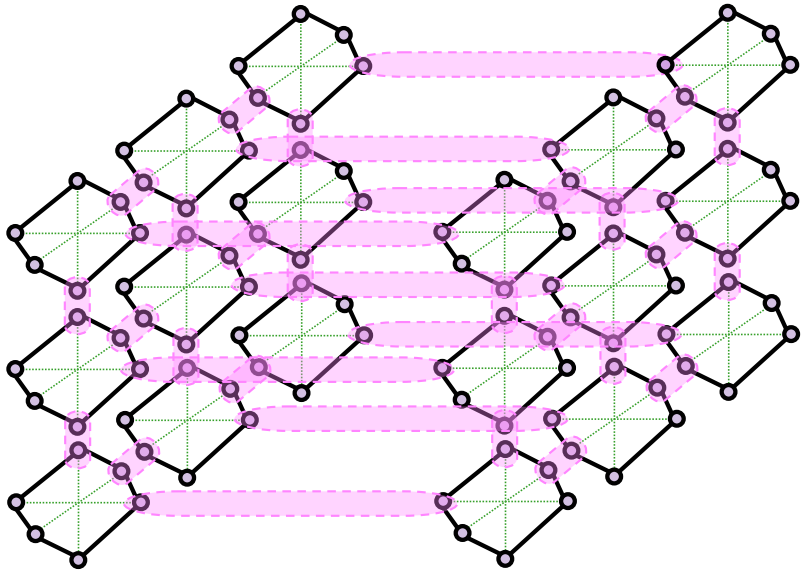
The physical layout





Reusing resources





upcoming PsiQuantum publication

Fusion Based Quantum Computing (FBQC)

- Fault-tolerance with natural hardware primitives

- Low depth modular structure
  - Constant lifetime of physical qubits

- Separation of logical and physical timescales
  - Operations in the bulk don’t depend on gate being performed

- Better handling of linear optic fusion failure
  - Loss tolerance for linear optical quantum computing

arXiv:2101.09310