Efficient Simulation of Multimode Bosonic Systems: A Tensor Network and Monte Carlo based method

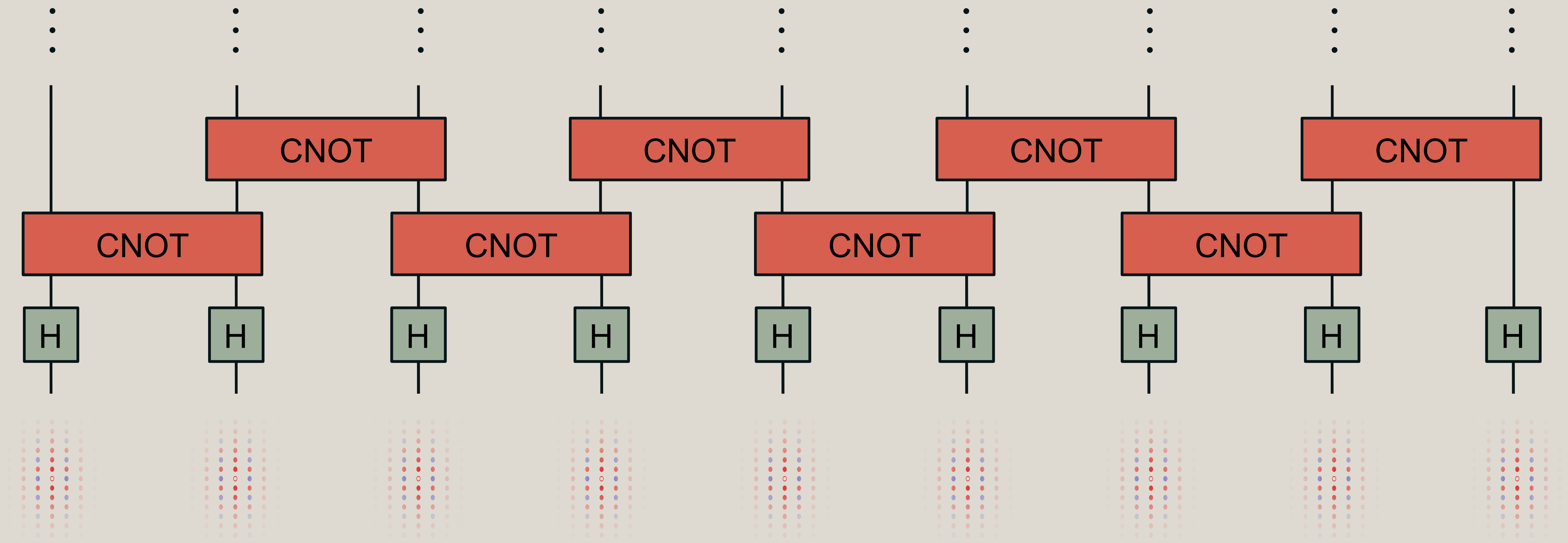
Jean-Baptiste Bertrand, Baptiste Royer

March 18th, 2024

Fonds de recherche Nature et technologies Québec
CRSNG NSERC
Nord Quantique
UdS Université de Sherbrooke

Goal:

Simulating *large* quantum circuits where the quibt are encoded in ***bosonic modes***



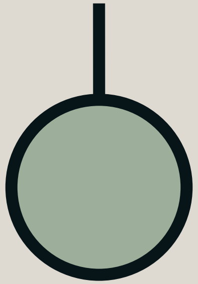
Goal:

Simulating ***large*** quantum circuits where the quibt are encoded in ***bosonic modes***

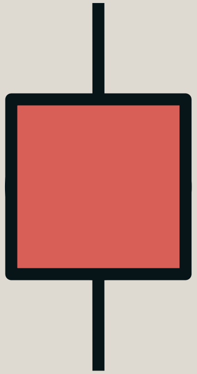
Systems with n bosonic modes become difficult to simulate quickly due to exponential Hilbert space growht, in order to cicumvent this, we need to be clever

Tensor Networks allow you to represents systems in more efficient ways

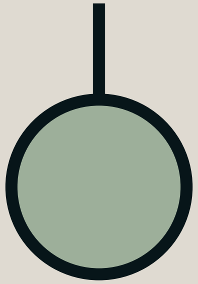
$$\psi_i \rightarrow$$

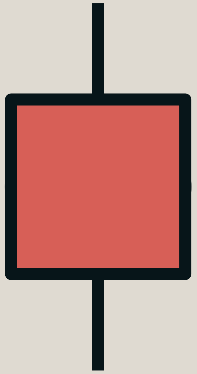


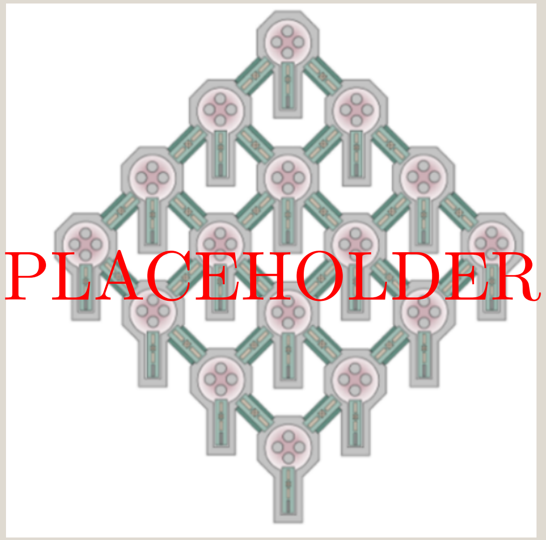
$$\hat{O}_i^j \rightarrow$$



Tensor Networks allow you to represents systems in more efficient ways

$\psi_i \rightarrow$ 

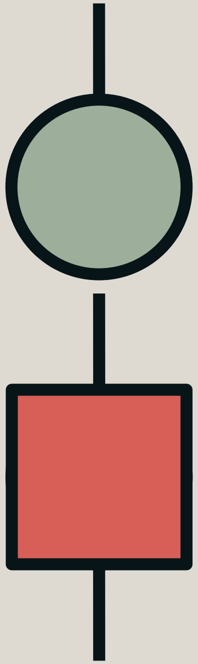
$\hat{O}_i^j \rightarrow$ 

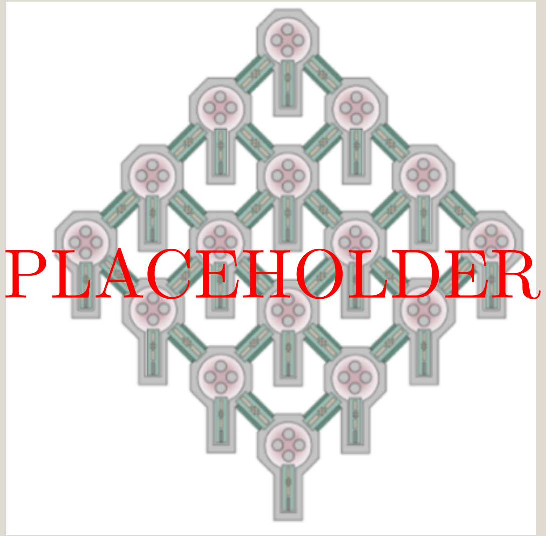


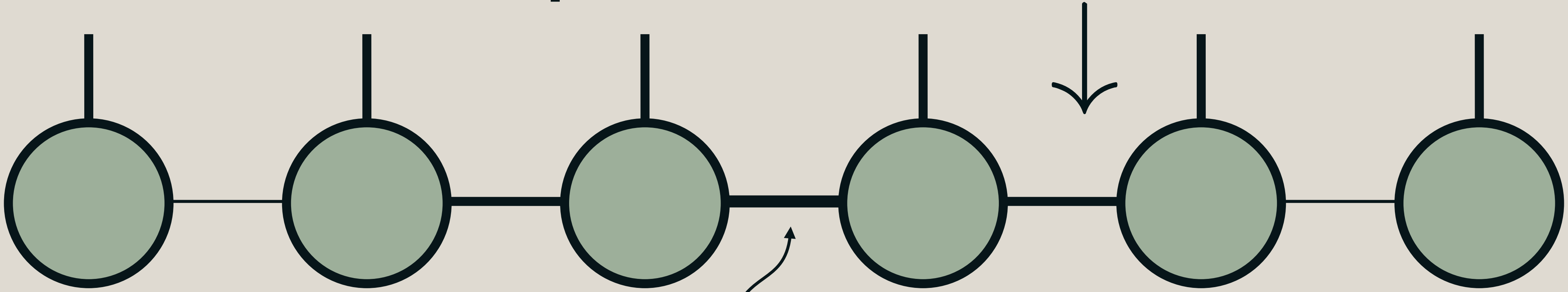
Tensor Networks allow you to represents systems in more efficient ways

$$\psi_i \rightarrow$$

$$\hat{O}_i^j \rightarrow$$

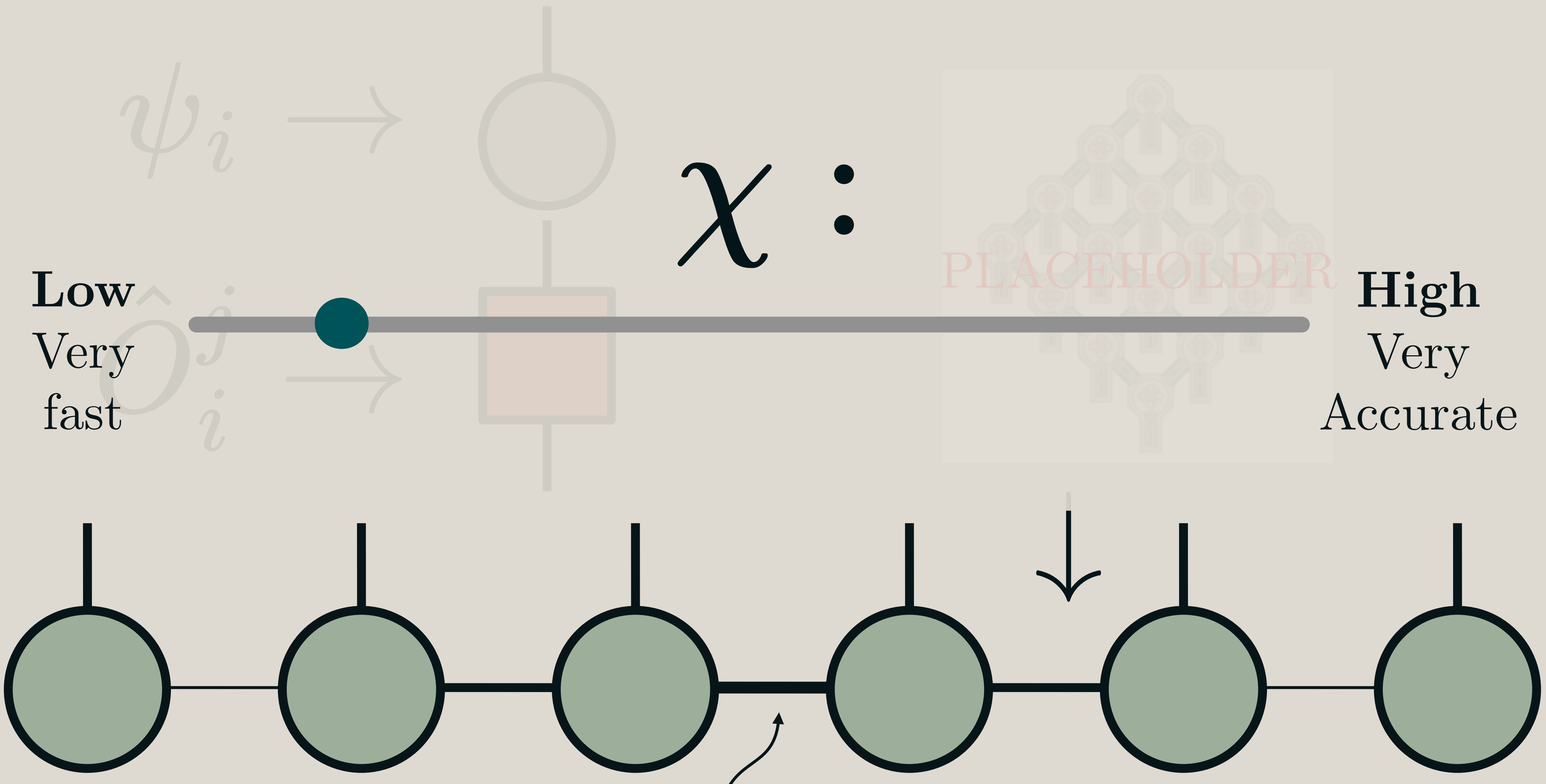






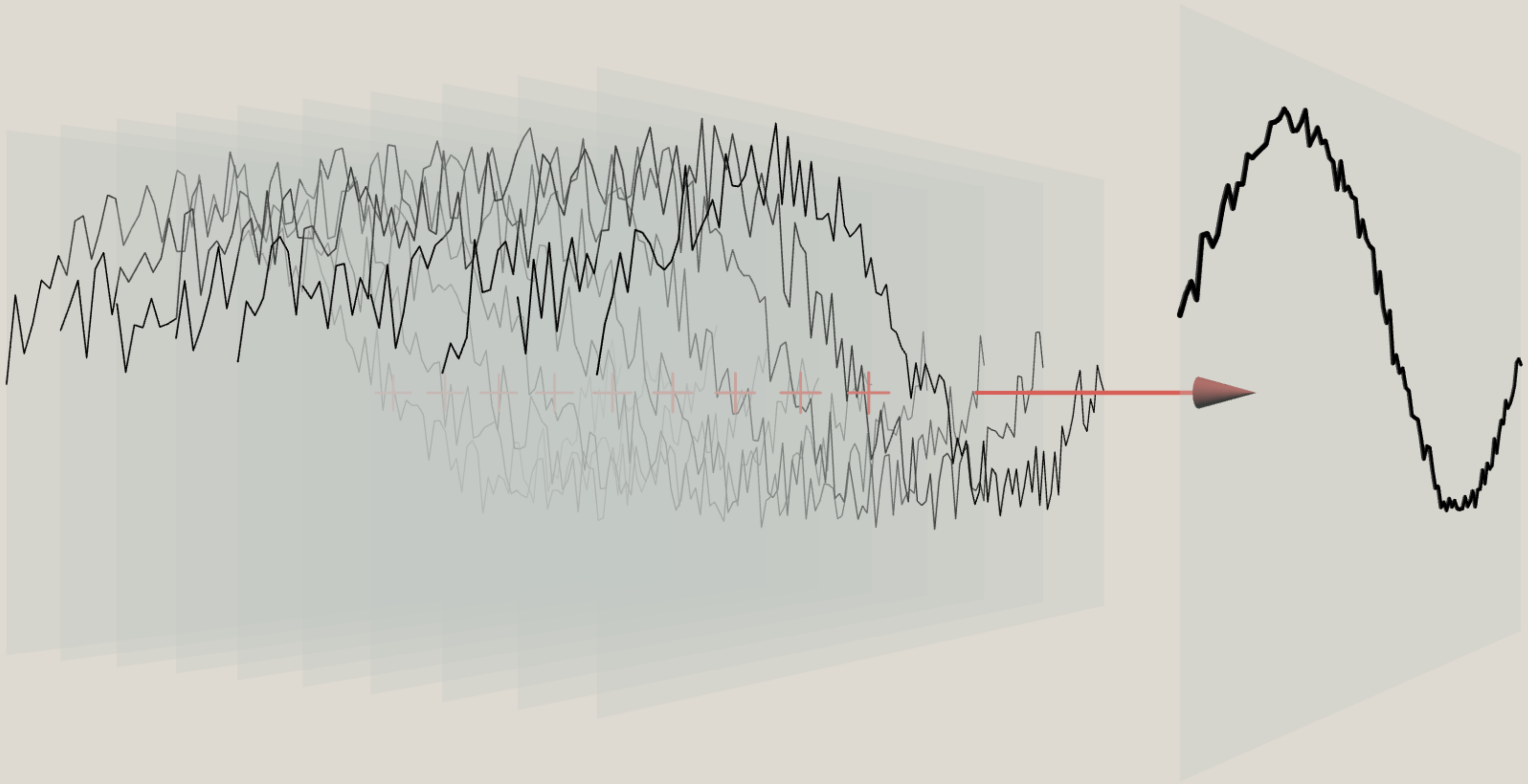
bond dimension (χ) = this dimension

Tensor Networks allow you to represents systems in more efficient ways



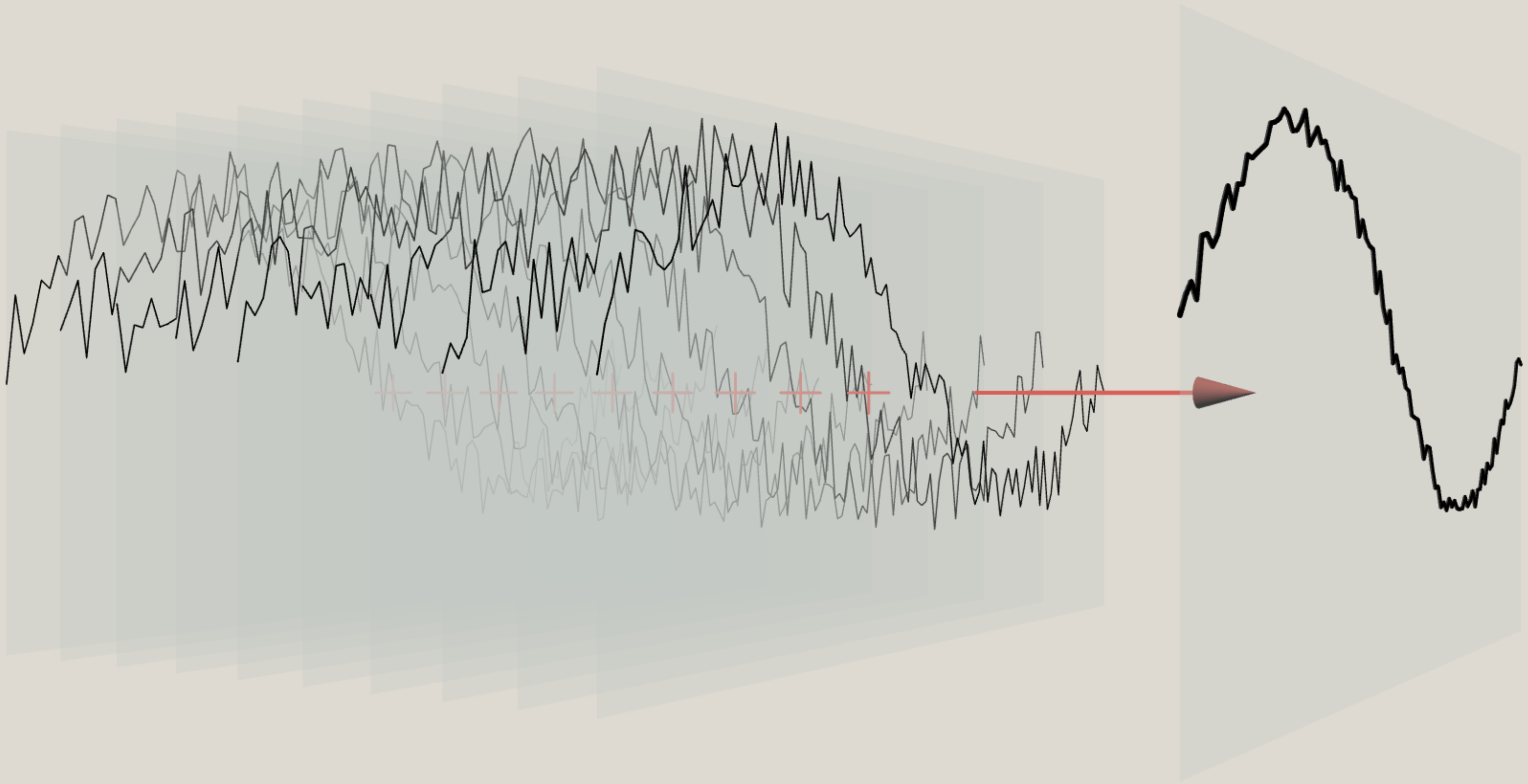
bond dimension (χ) = this dimension

Monte Carlo: using vectors instead of density matricies



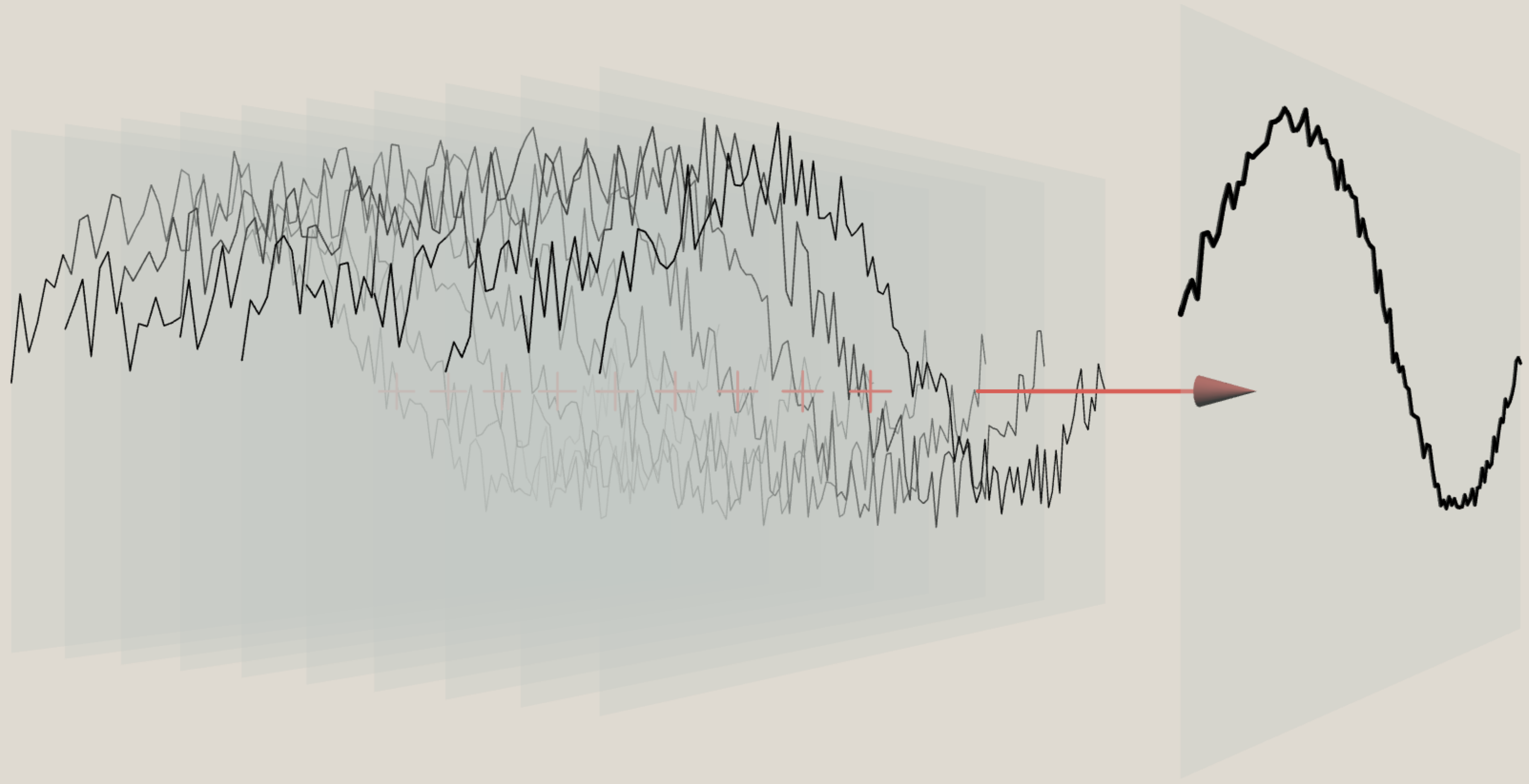
Monte Carlo: using vectors instead of density matricies

$$\rho \rightarrow \text{expensive in memory, use } |\psi\rangle \text{ instead}$$



Monte Carlo: using vectors instead of density matricies

$$\rho \to \text{expensive in memory, use } |\psi\rangle \text{ instead}$$



$$\text{avg}\big(K_0|\psi\rangle,\, K_0|\psi\rangle,\, K_1|\psi\rangle,\, K_0|\psi\rangle,\, K_2|\psi\rangle,\, K_0|\psi\rangle,\, \ldots\big) \approx C(\rho)$$

Using the right basis: Better intuition and better performances

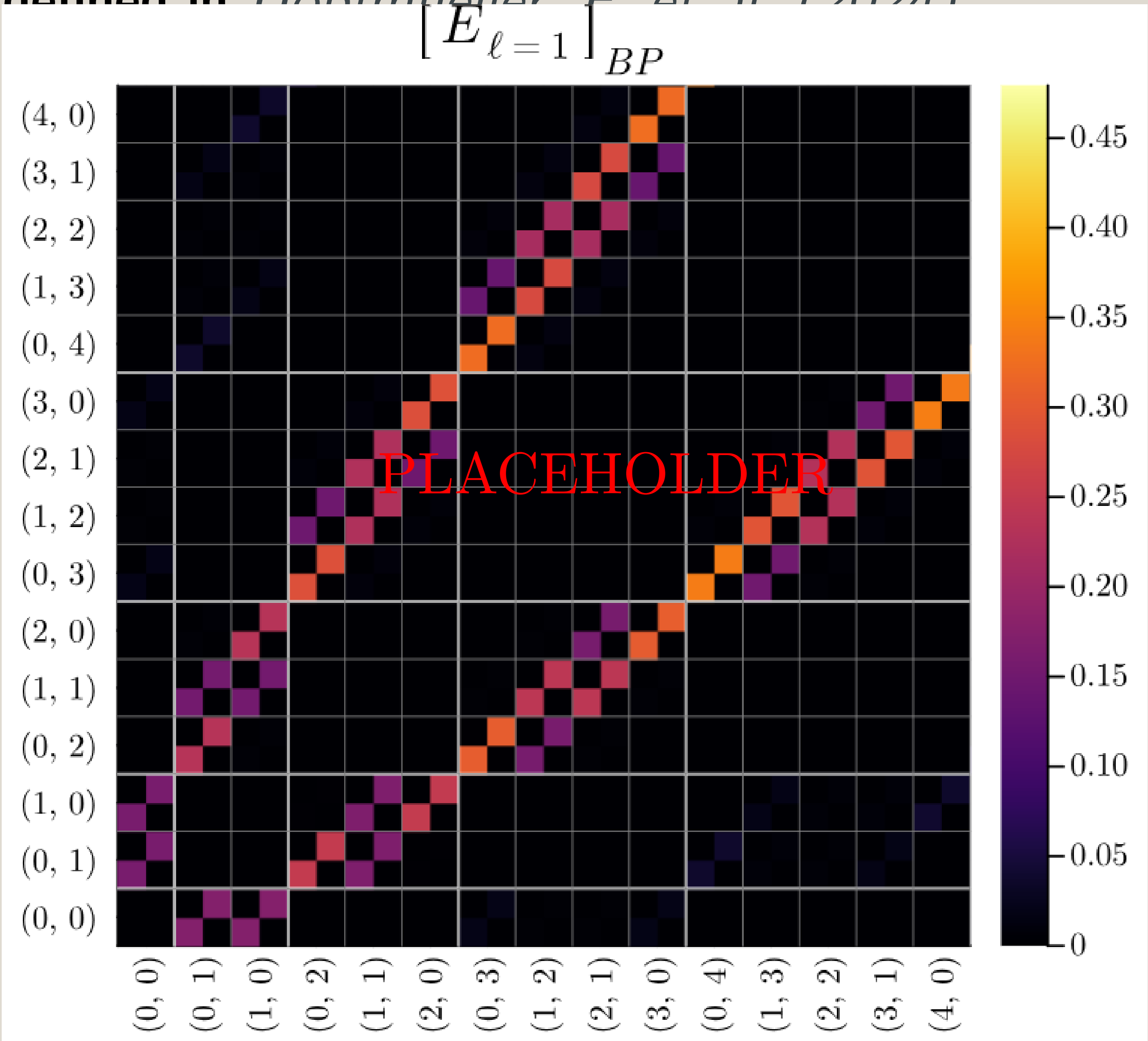
The *sBs basis*, defined in *Hopfmueller, F. et al. (2024)*

$$\mathcal{H}_B = \underbrace{\mathcal{H}_l}_{\text{GKP codespace}} \otimes \mathcal{H}_e$$

Defined from sBs

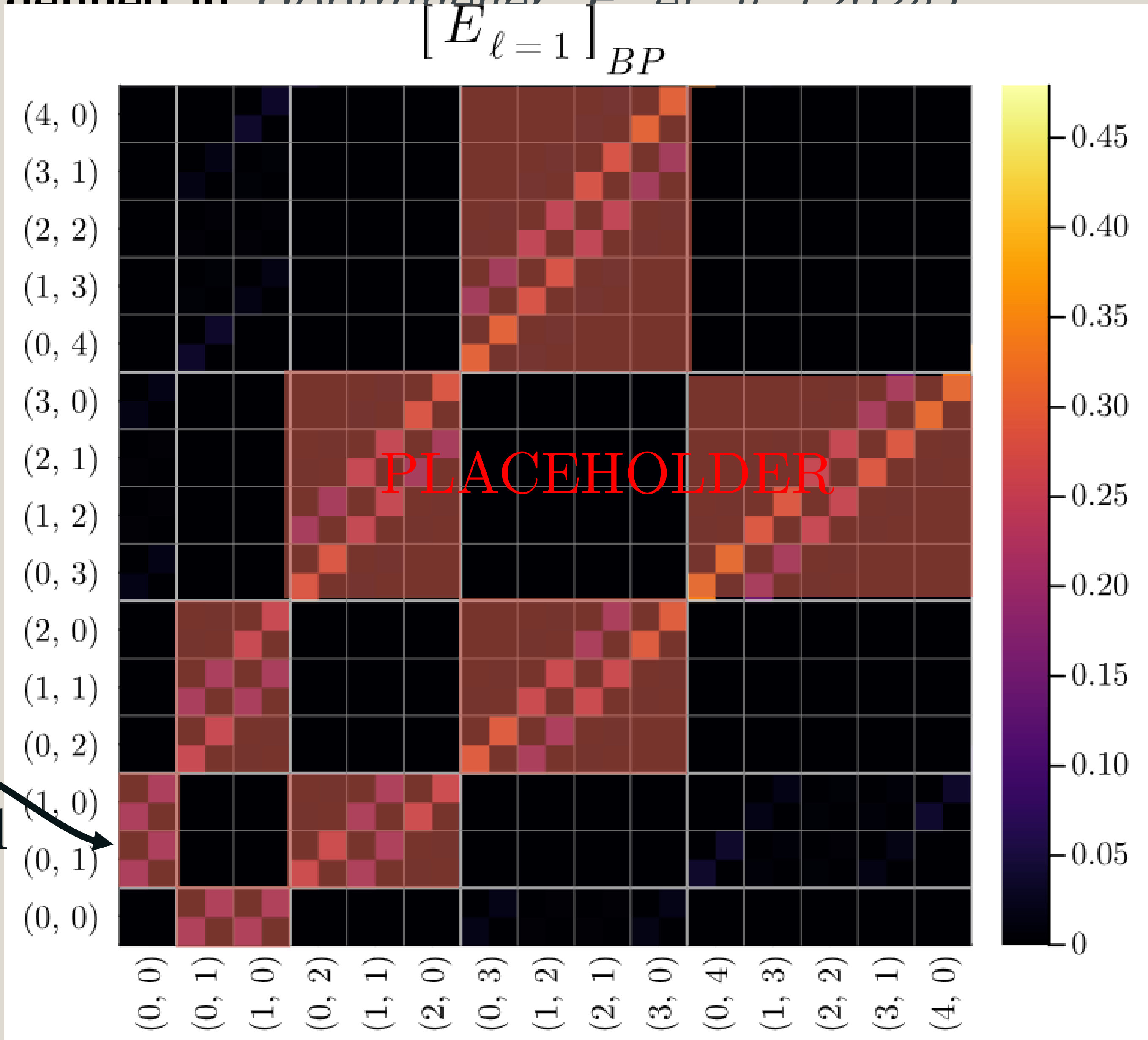
Using the right basis: Better intuition and better performances

The *sBs basis*, defined in Hopfmueller, F. et al. (2024)



Using the right basis: Better intuition and better performances

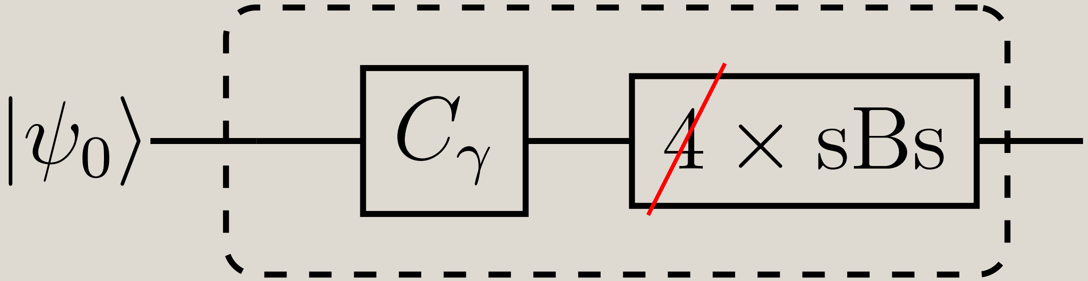
The *sBs basis*, defined in Hopfmueller, F. et al. (2024)

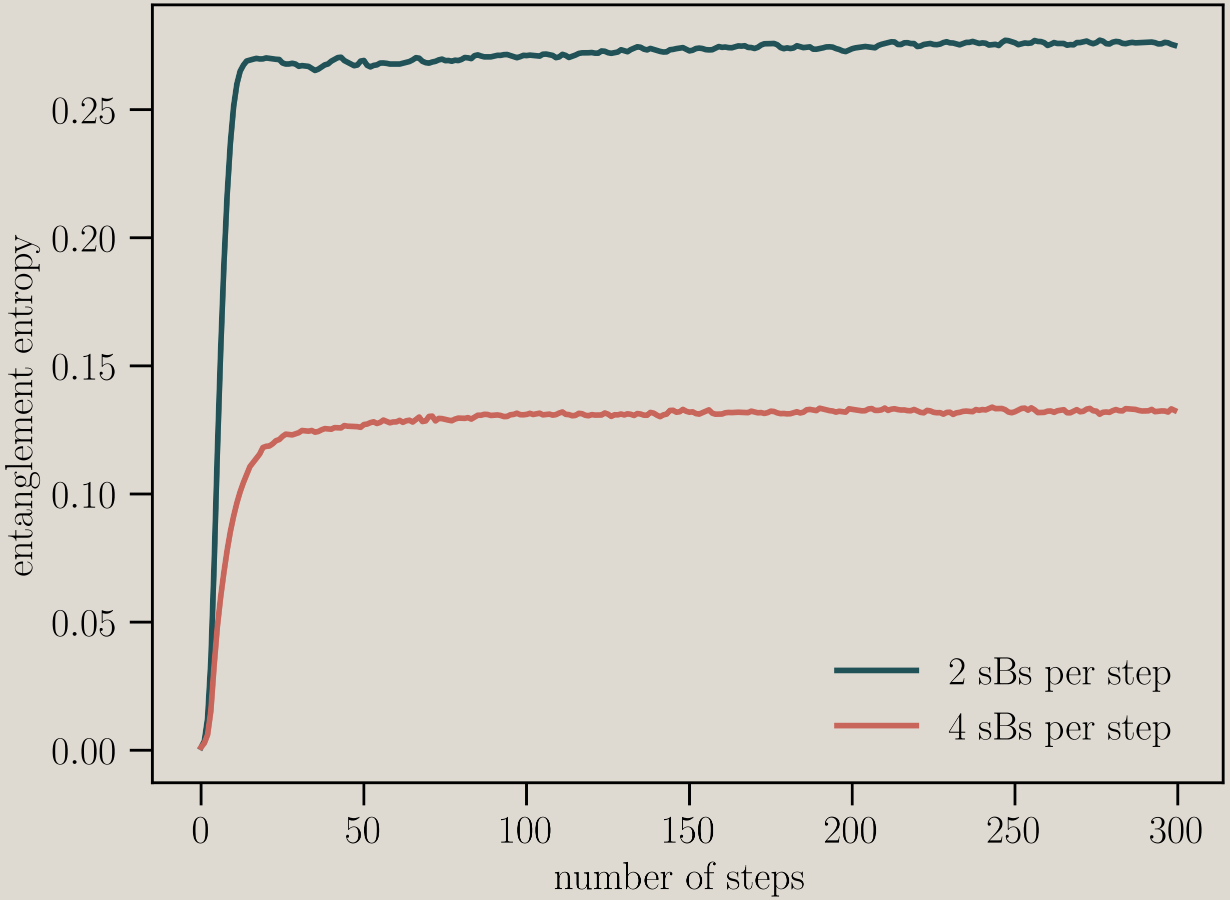


Shift in errorspace

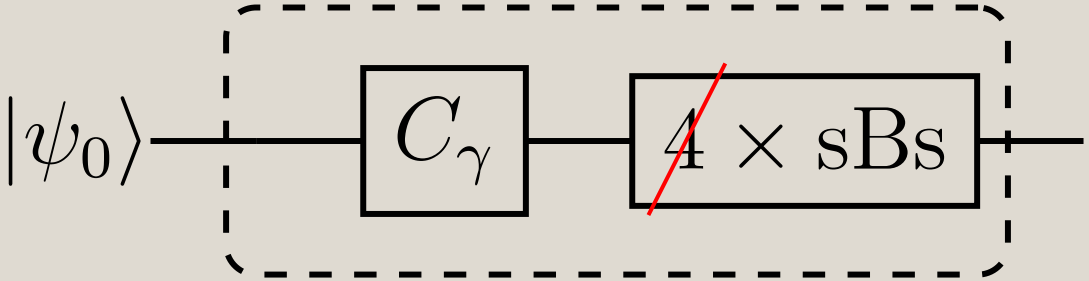
Identity on logical space

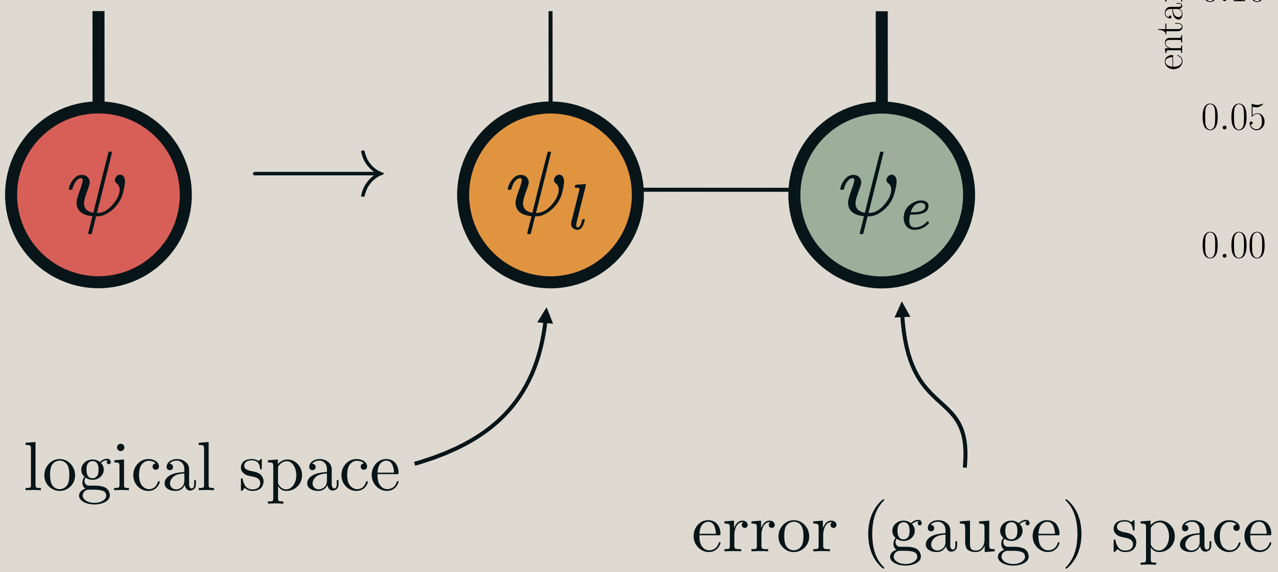
Results: a study of entenglement entropy between the logical and gauge space

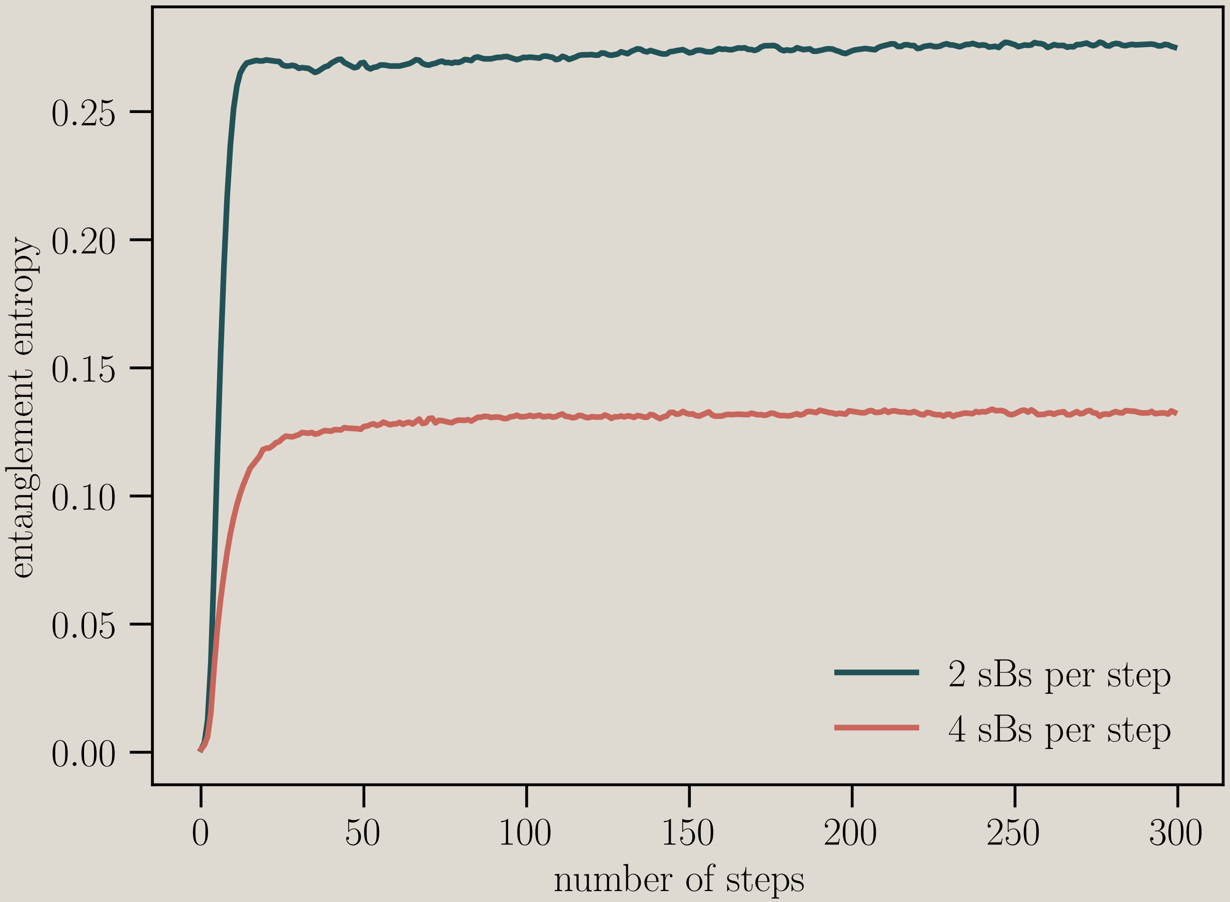




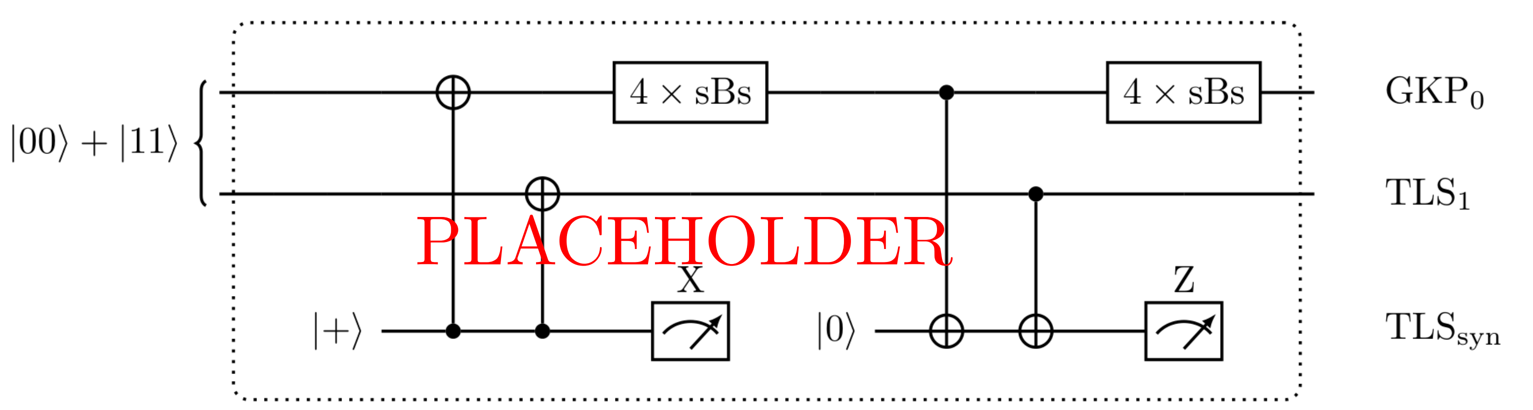
Results: a study of entenglement entropy between the logical and gauge space

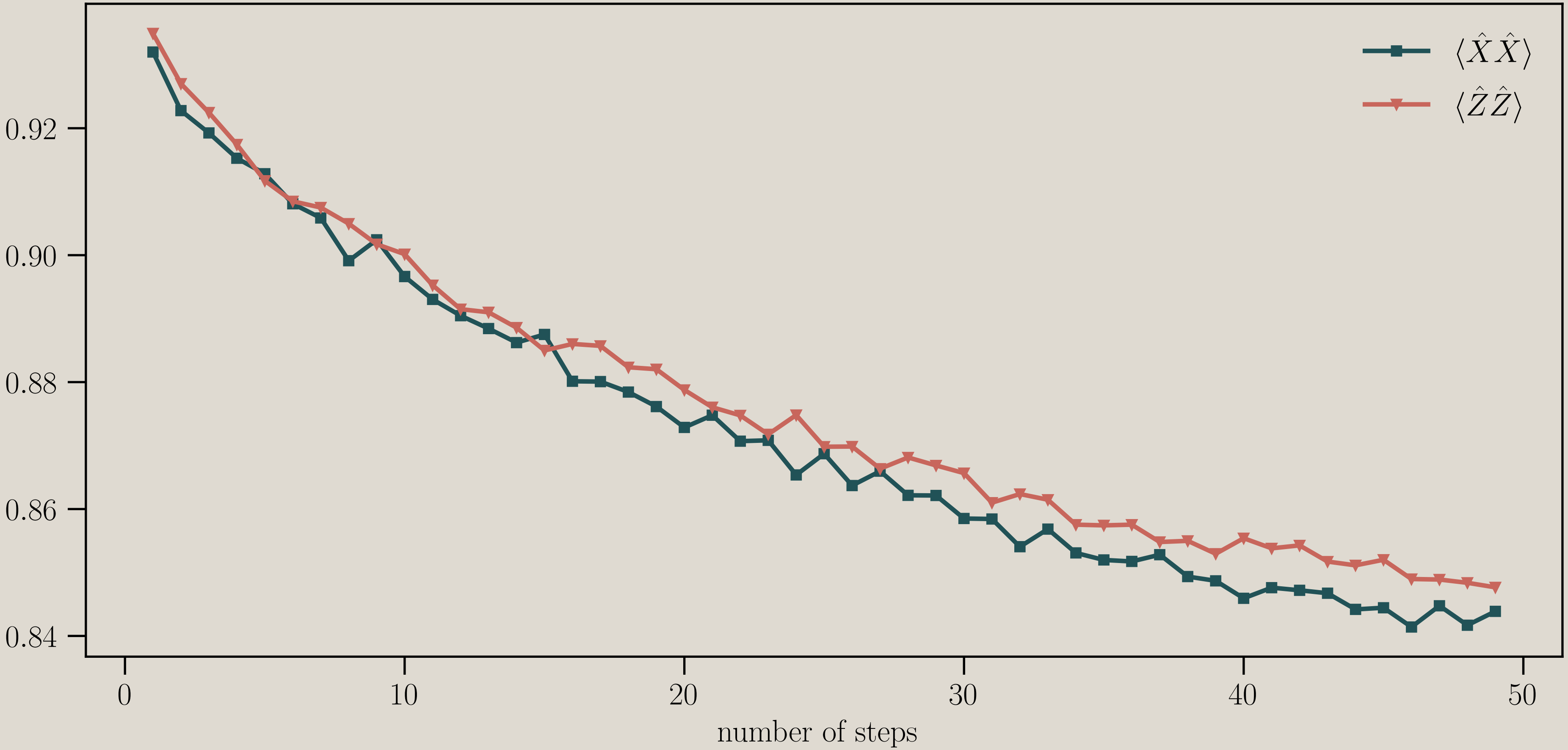






Results: Stabilising a Bell Pair





Building on these tools to study more complex questions

- Simulating larger circuits and studying the performaces of bosonic codes
  - Simulating code concatenation
- Studying the limits of the framework
  - Studying the required bond dimention
  - Studying the ability to represent noise acuratley
- Study the benefits of differents TN structures

Thank you for listening!

Color palette

Principal colors

#C8665C

#005358

« Black and white »

#071519

#DFDAD1

#919191

Secondary colors

#9DAF9A

#856C93

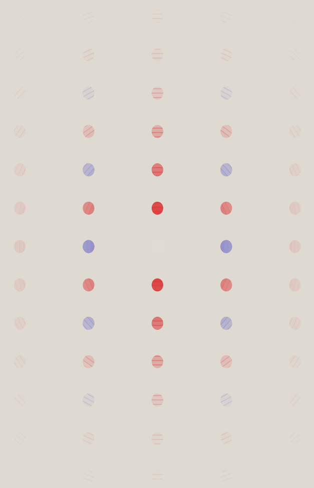
#E19449

#B6C3B4

#B2A3B2

#E2B78A

Colormap



$$|\psi_0\rangle\langle\psi_0| \qquad |\psi_1\rangle\langle\psi_1| \qquad |\psi_2\rangle\langle\psi_2| \qquad \cdots \qquad \approx \rho$$