TIME INDEPENDENT QUANTUM CIRCUITS

or

MODULAR QUANTUM CIRCUITS

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Turin, May 2017

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A FEW REMARKS

No real experiment

No proposal for experiment

Just theory or even speculation

Everything which is not
forbidden by the laws of physics,
is experimentally feasible

Turin, May 2017

ABSOLUTELY NO DETAILS

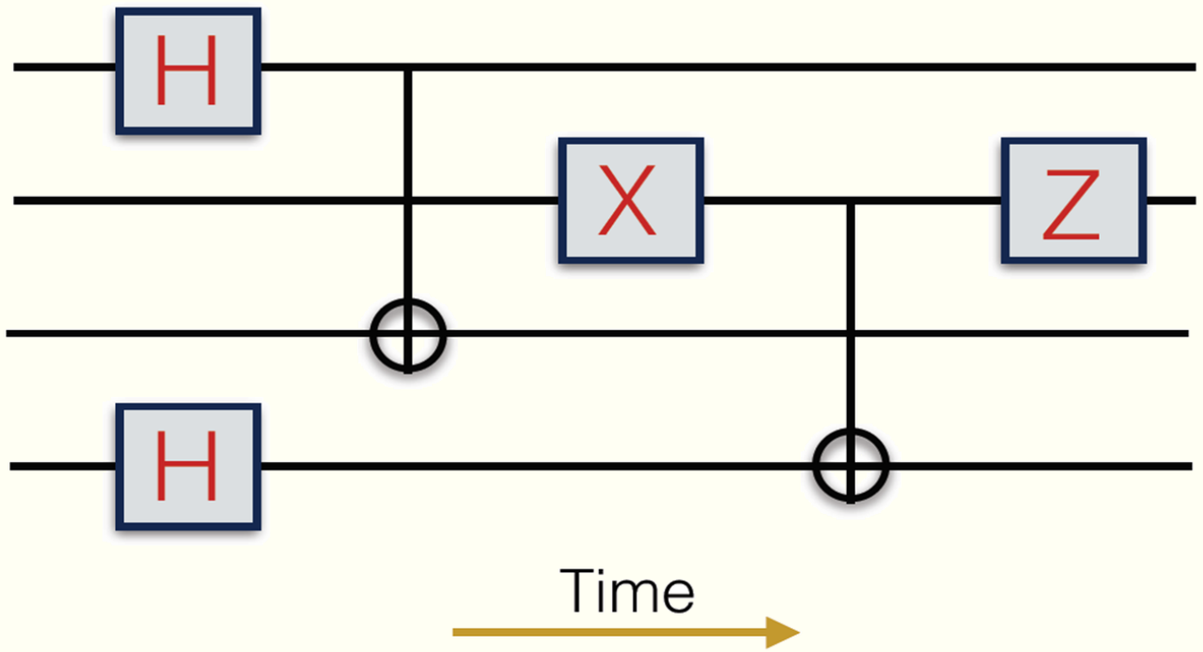
Time independent quantum circuits with local interactions

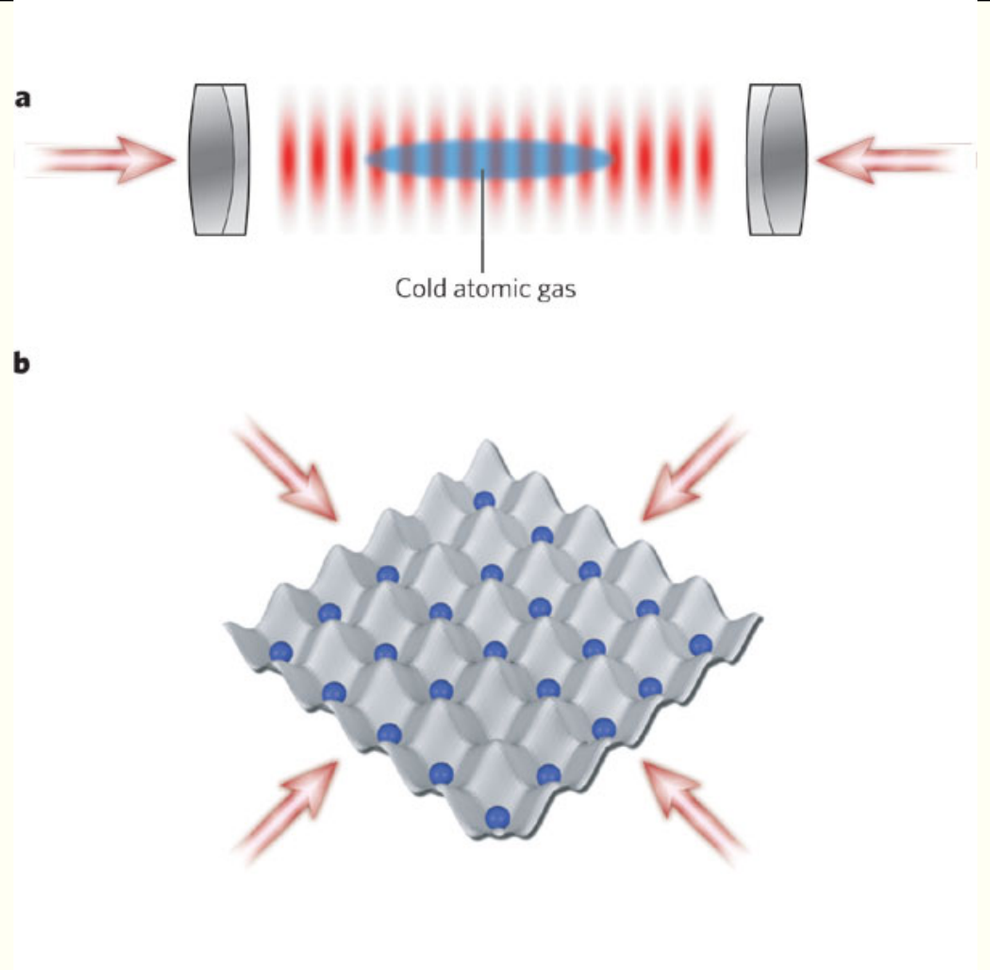
Sahand Seifnashri, Farzad Keyanvash, Jahangir Nobakht, Vahid Karimipour

Phys. Rev. A 93, 062342 (2016)

Turin, May 2017

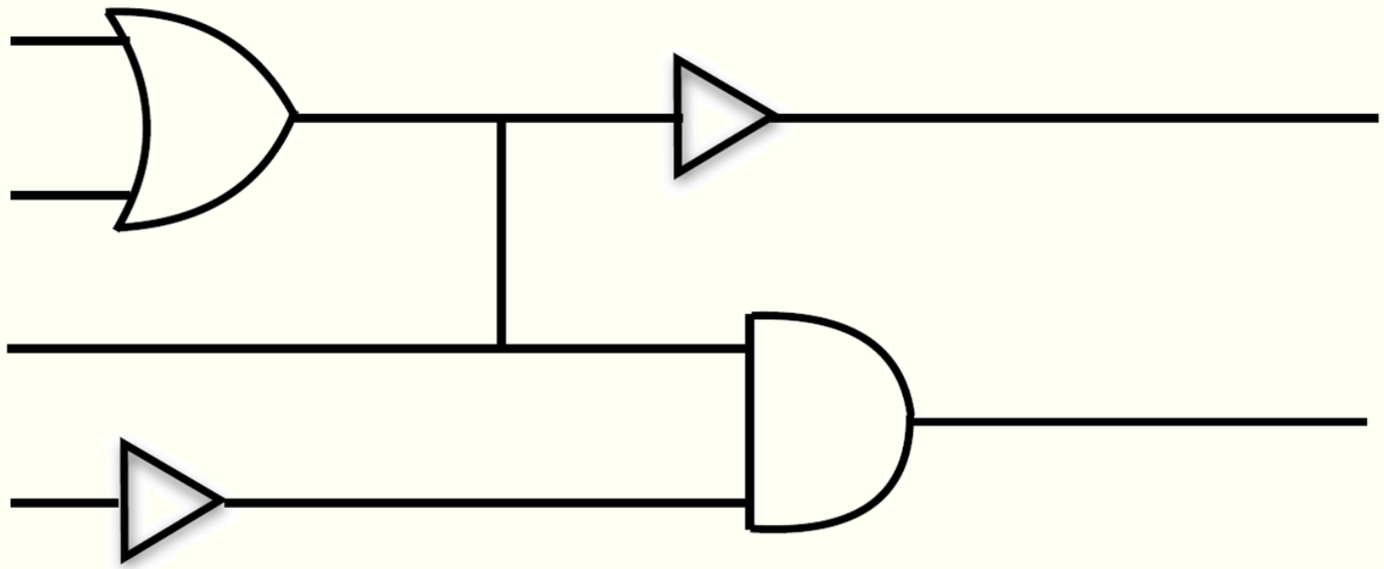
Quantum Circuit





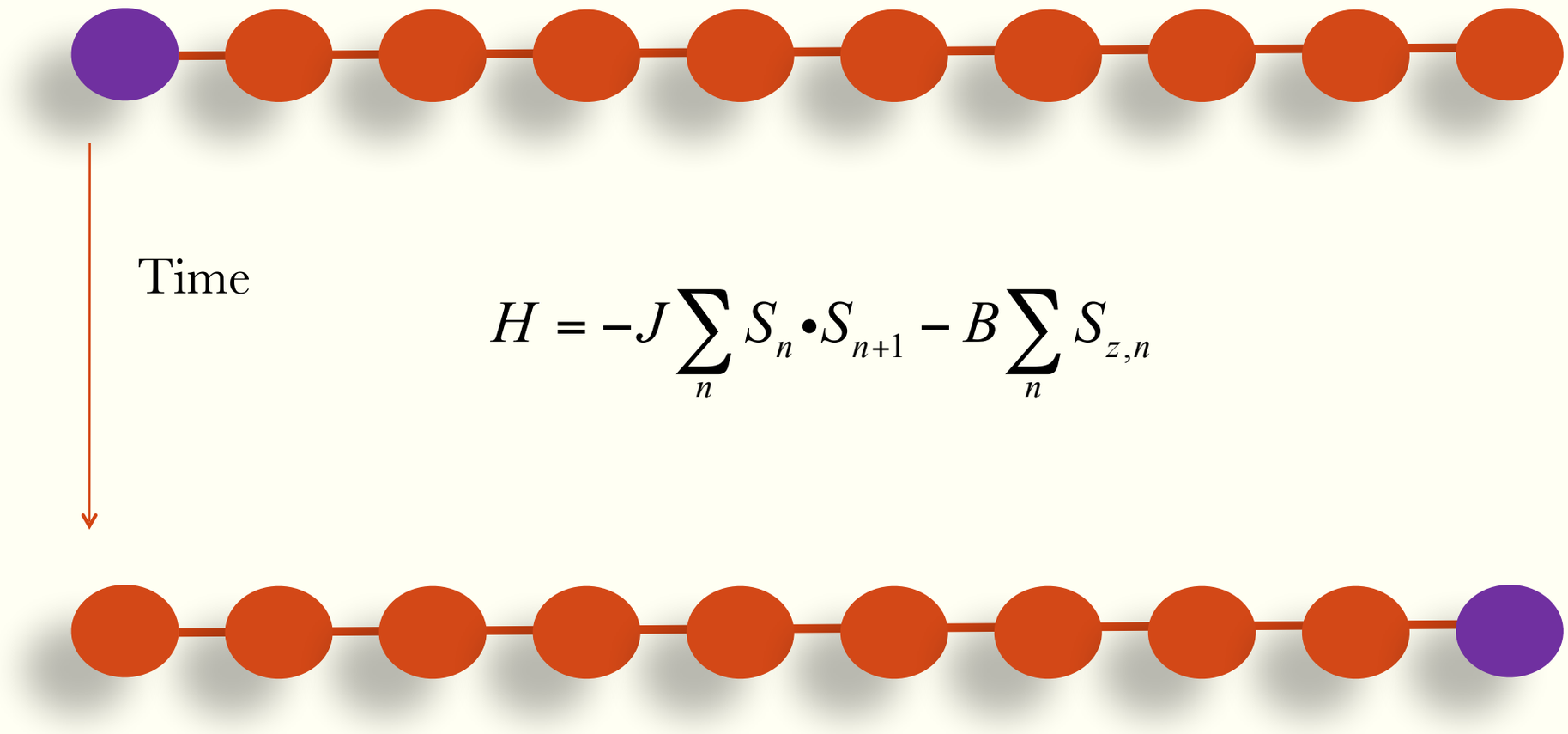
- Horizontal lines represent flow of time
- Gates are localized in time
- A great deal of external control is needed

Classical Circuit



Space

Quantum Wires



$$H = -J\sum_n S_n \bullet S_{n+1} - B\sum_n S_{z,n}$$

S. Bose, Quantum Communication Through an Unmodulated Spin Chain,

Phys. Rev. Lett. **91**, 207901 (2003).

What we like to happen

$$|\varphi\rangle|g.s\rangle = \left(a|\bullet\rangle + b|\color{#0a7a3a}{\bullet}\rangle\right)|\bullet\bullet\bullet\bullet\bullet\bullet\bullet\rangle$$

$$|\Psi(0)\rangle = a|\bullet\bullet\bullet\bullet\bullet\bullet\bullet\bullet\rangle + b|\color{#0a7a3a}{\bullet}\bullet\bullet\bullet\bullet\bullet\bullet\bullet\rangle$$

Time

$$|\Psi(t_0)\rangle = a|\bullet\bullet\bullet\bullet\bullet\bullet\bullet\bullet\rangle + b|\bullet\bullet\bullet\bullet\bullet\bullet\bullet\color{#0a7a3a}{\bullet}\rangle$$

$$|g.s\rangle|\varphi\rangle = |\bullet\bullet\bullet\bullet\bullet\bullet\bullet\rangle\left(a|\bullet\rangle + b|\color{#0a7a3a}{\bullet}\rangle\right)$$

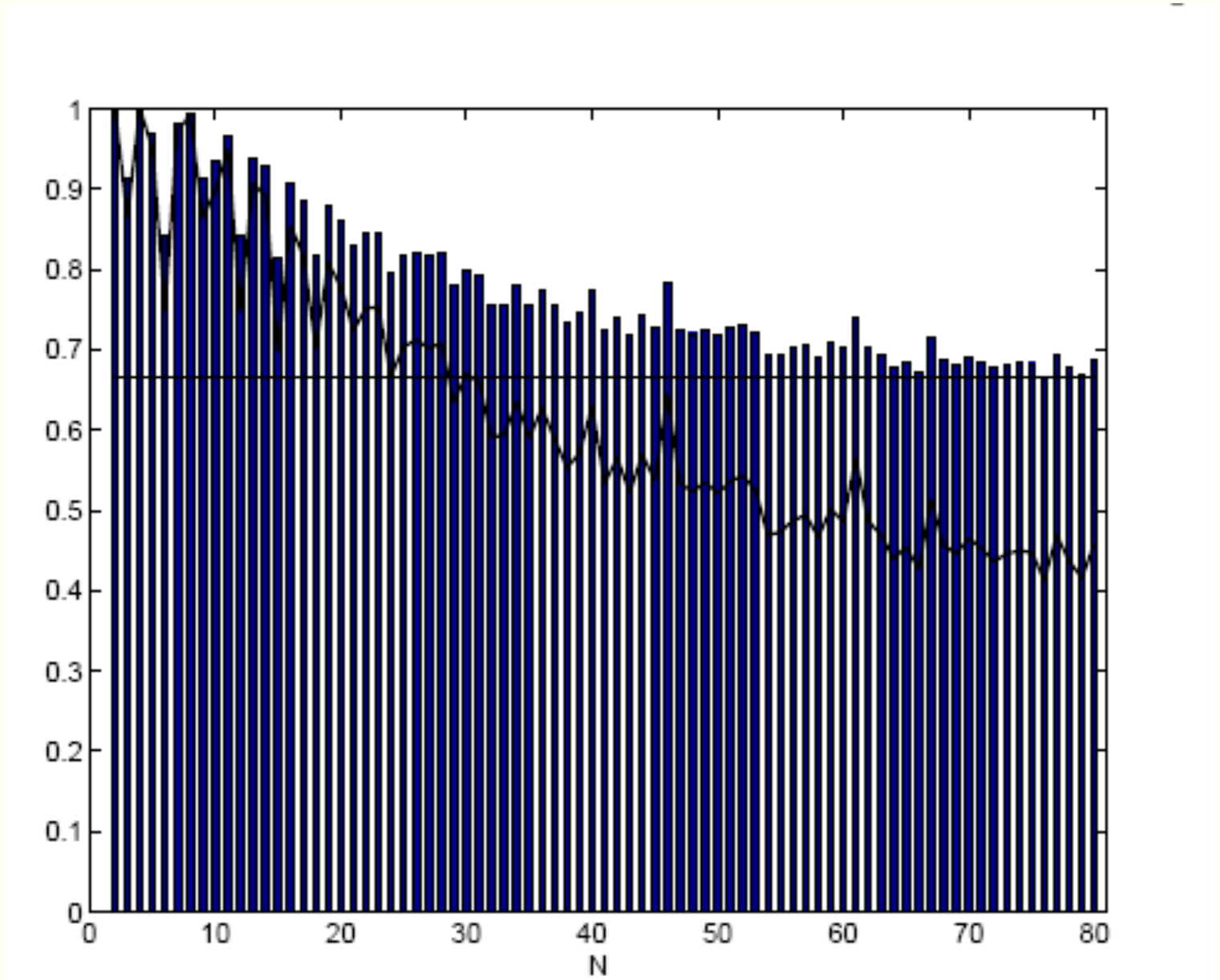
What actually happens

$$\left|\Psi(0)\right\rangle = a\left|\bullet\bullet\bullet\bullet\bullet\bullet\bullet\bullet\right\rangle + b\left|\bullet\bullet\bullet\bullet\bullet\bullet\bullet\bullet\right\rangle$$

Time

$$\left|\Psi(t_0)\right\rangle = a\left|\bullet\bullet\bullet\bullet\bullet\bullet\bullet\bullet\right\rangle + b\left|\quad\right\rangle$$

$$\overline{F(\varphi,\rho_N)} = \frac{2}{3}$$



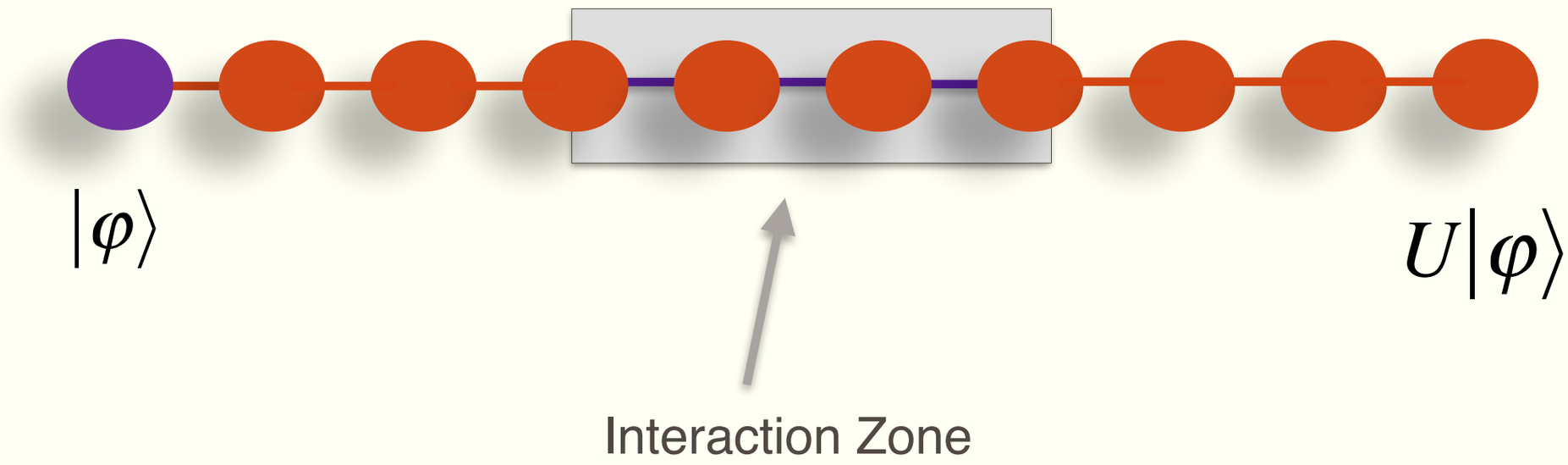
Quantum Gates

Time Independent Universal Computing with Spin Chains: Quantum Plinko Machine

Kevin Thompson, Can Gokler, Seth Lloyd and Peter Shor.

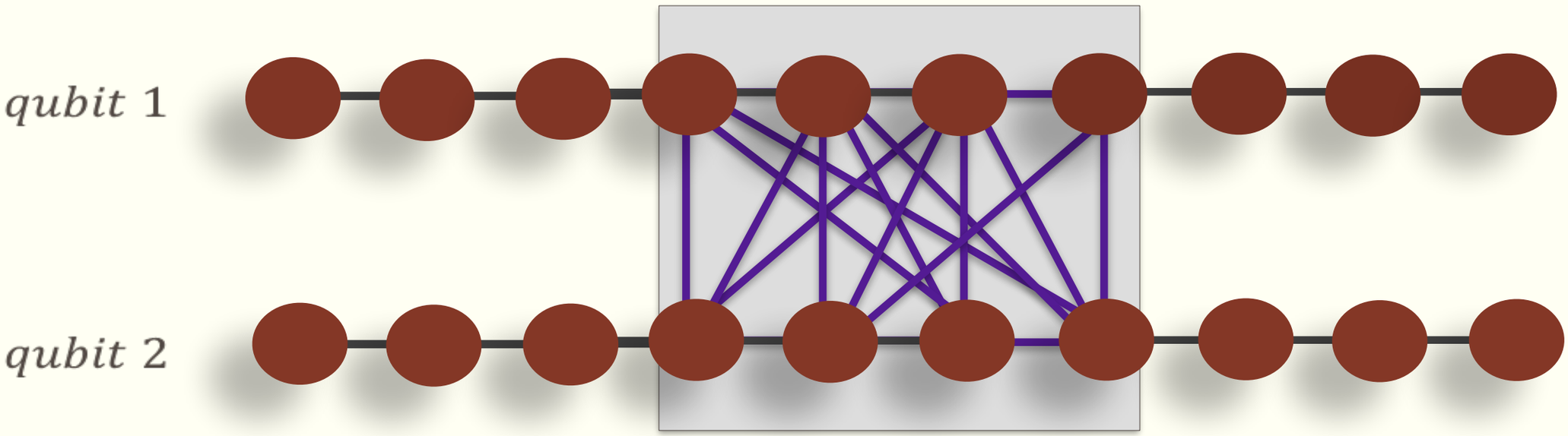
New Journal of Physics (2016)

$$e^{i\theta X} \qquad e^{i\phi Z}$$



$$H = \sum_{i,j} \frac{1-\sigma_{z,i}}{2} \otimes \frac{1-\sigma_{z,j}}{2}$$

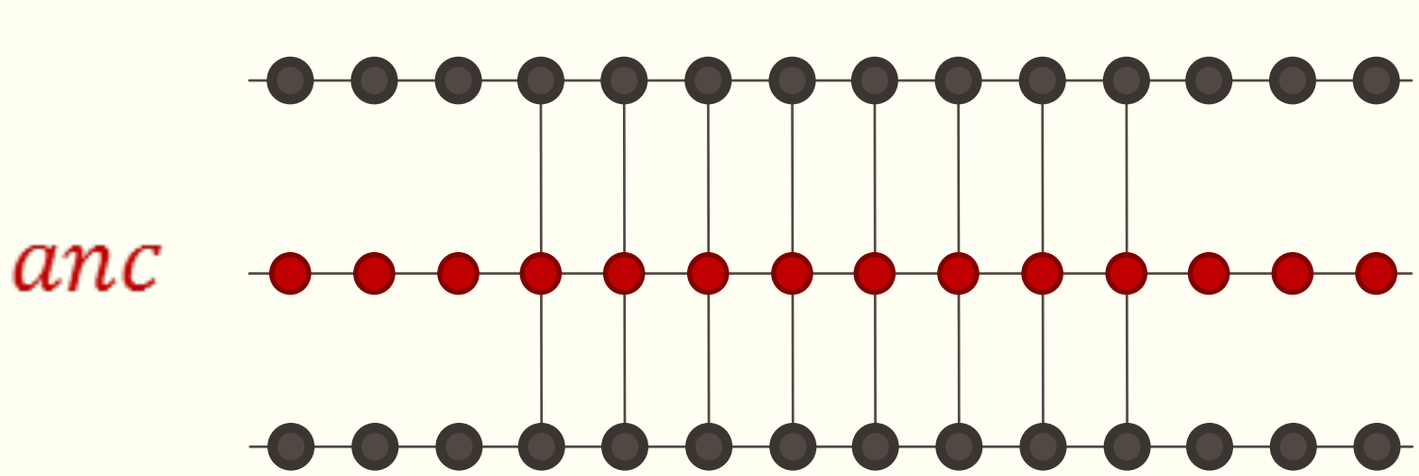
CZ Gate

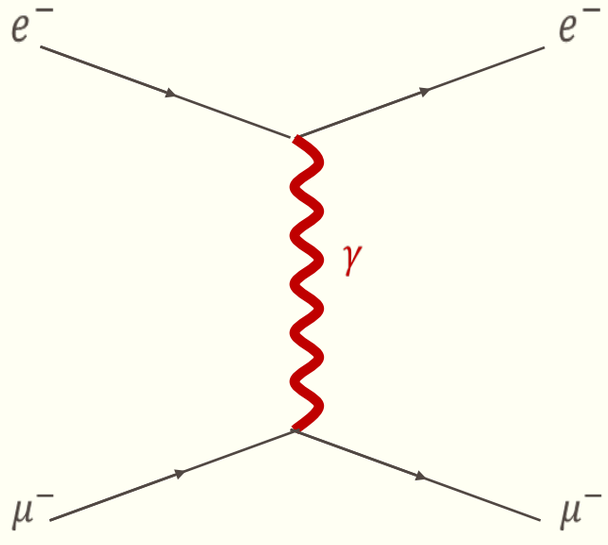


The drawback is long-range interactions

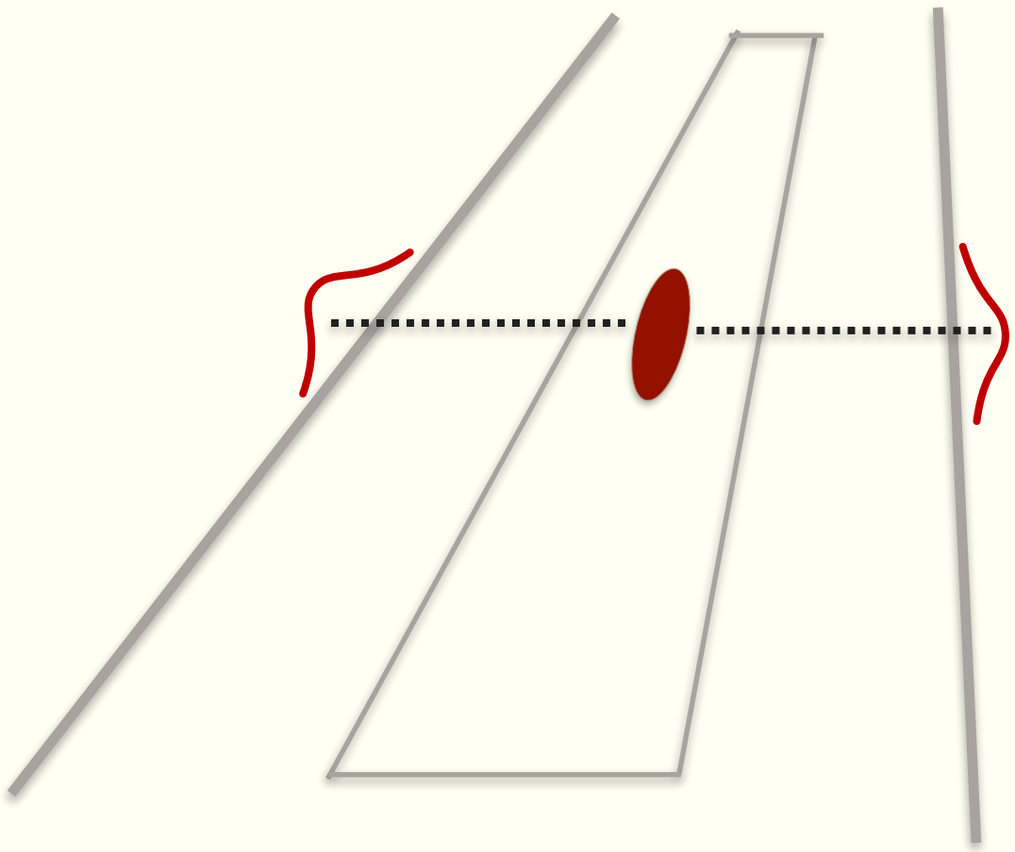
A lesson from gauge theory

Using gauge particles to mediate long-range interactions





The effective interaction



$$CZ = \begin{pmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & -1 \end{pmatrix}$$

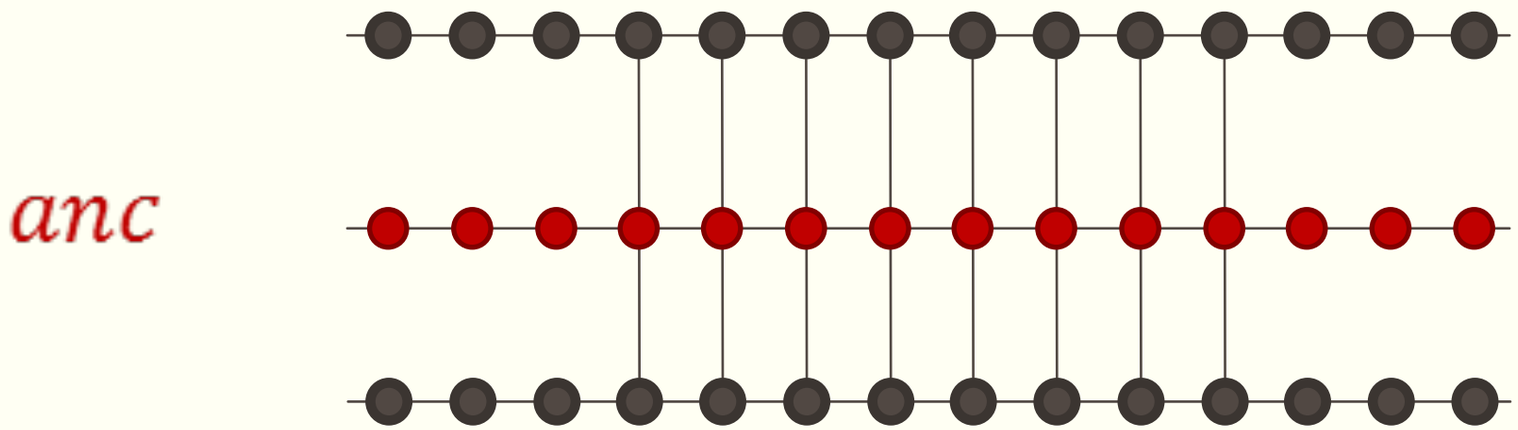
So we need an ancillary chain with

1- Doubly degenerate ground state

2- Large gap

3- an inter-chain Hamiltonian whose effective interaction generates CZ

Photon=Ancillary Rail



$$H^{anc} = \frac{1}{4m}\sum_{i=0}^{N-1}\left(\mathbb{I} - Z_i - \frac{X_iX_{i+1} + Y_iY_{i+1}}{2}\right)$$

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The ancillary rail has two degenerate ground states $|\Omega\rangle$ $|\psi\rangle$

$$|\Omega\rangle = |0000.....0\rangle \qquad |\psi\rangle = \frac{1}{\sqrt{N}} \sum_x |000.....1.....000\rangle$$

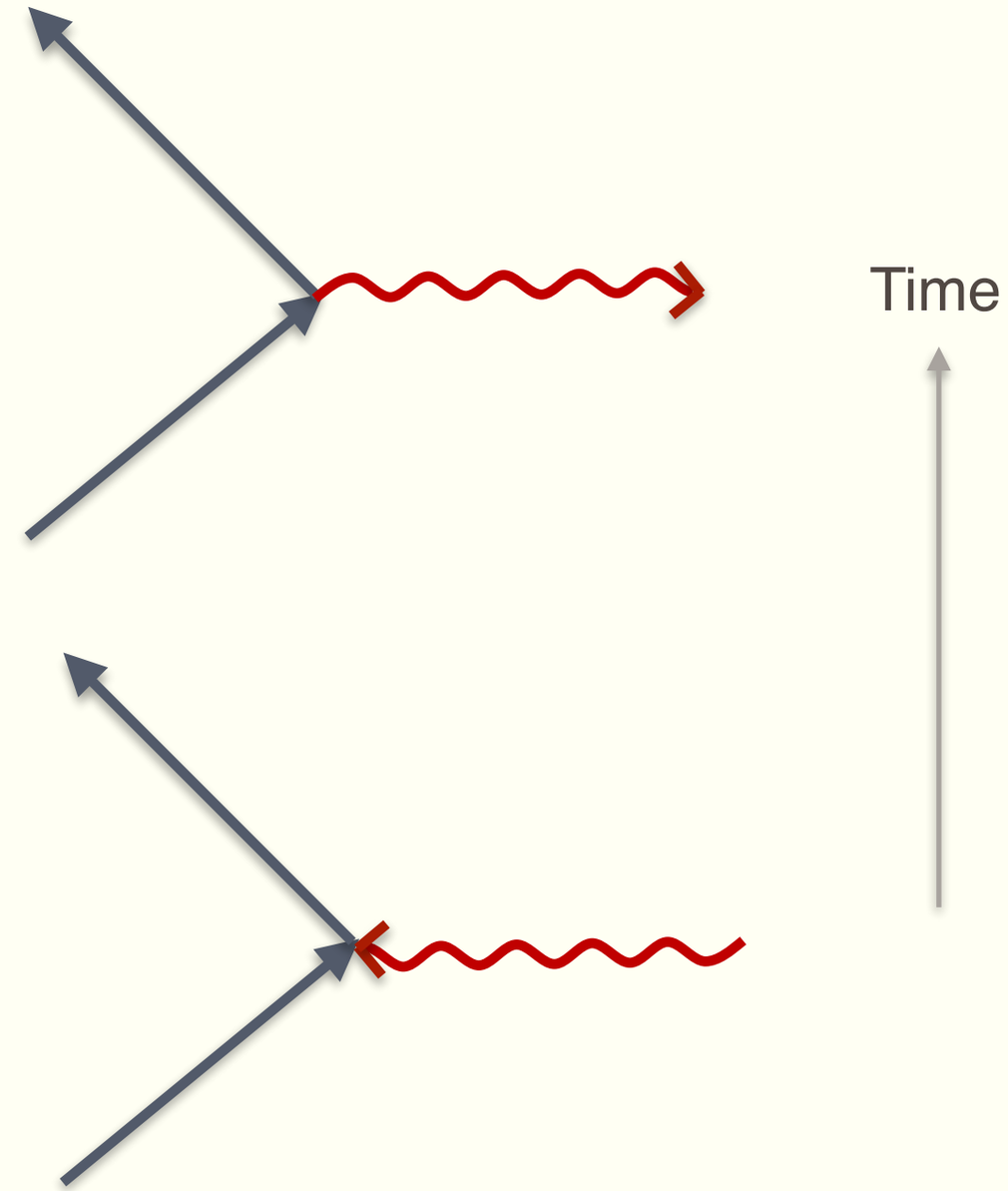
The large gap, allows us to always stay in the ground space

The local interactions

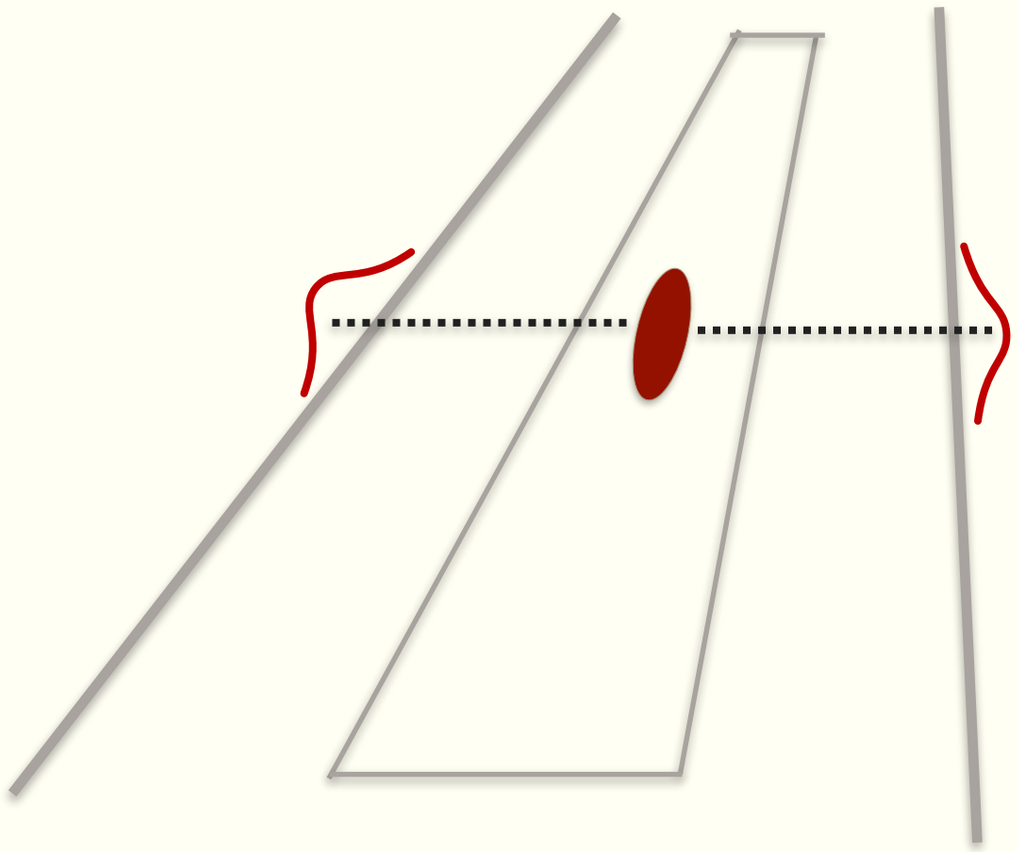
$$V_{eff} = \hat{N} \otimes X$$

$$V_{eff}|1\rangle \otimes |0\rangle = |1\rangle \otimes |1\rangle$$

$$V_{eff}|1\rangle \otimes |1\rangle = |1\rangle \otimes |0\rangle$$



The effective interaction



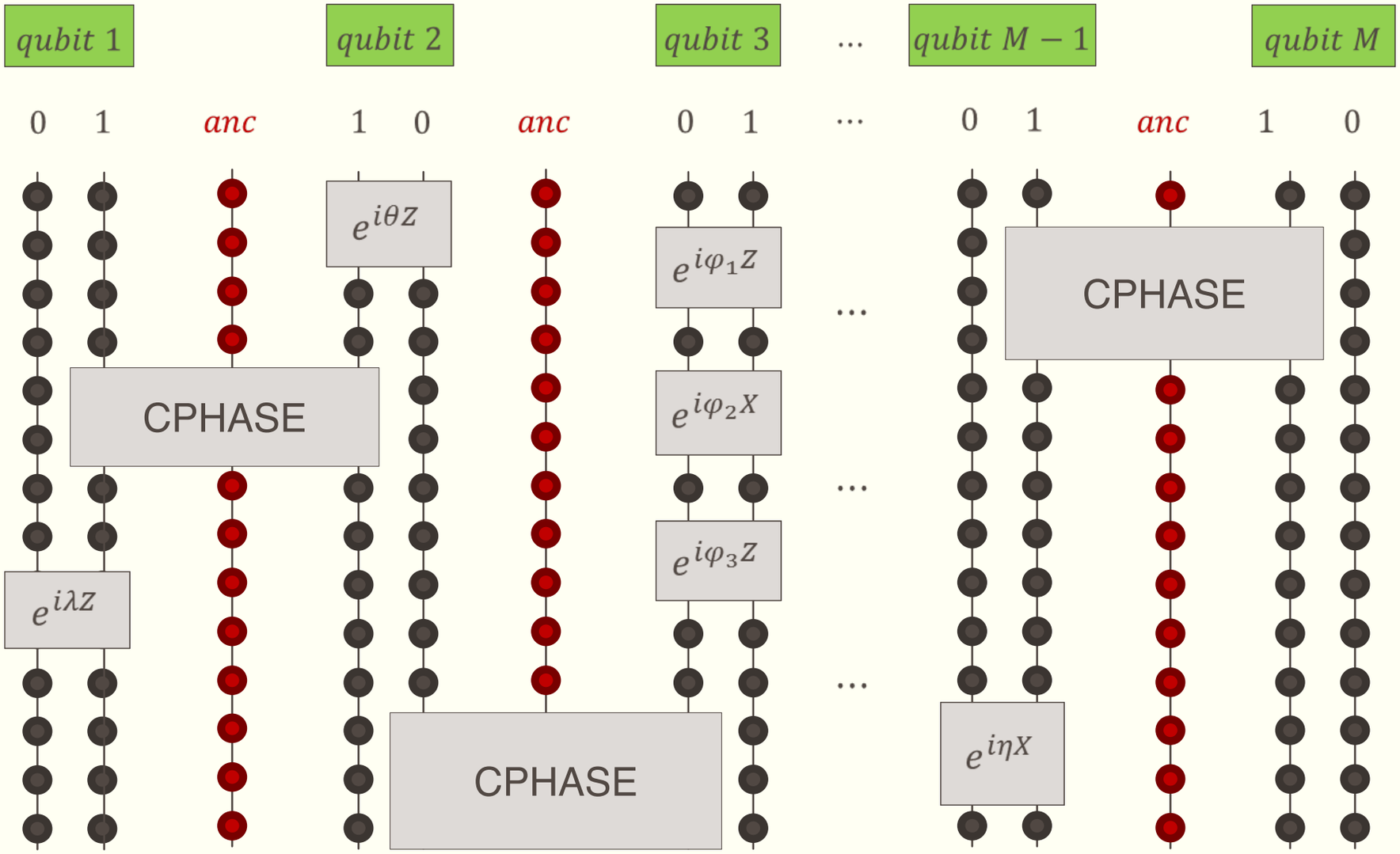
$$V = \sum_j n_j \otimes \sigma_{x,j}$$

$$P = |\Omega\rangle\langle\Omega| + |\psi\rangle\langle\psi|$$

$$V_{eff} = PVP$$

$$V_{eff} = \hat{N} \otimes X$$

Summary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qubit 2
qubit 3
...
qubit M − 1
qubit M
0 1
anc
1 0
anc
0 1
...
0 1
anc
1 0
$e^{i\theta Z}$
$e^{i\varphi_1 Z}$
$e^{i\varphi_2 X}$
$e^{i\varphi_3 Z}$
CPHASE
CPHASE
$e^{i\lambda Z}$
$e^{i\eta X}$

Thank you for your attention