

SFU



Beyond Qubit

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**CANADA
RESEARCH CHAIRS
CHAIRES DE
RECHERCHE DU
CANADA**

Qubit

$|1\rangle$ —●—

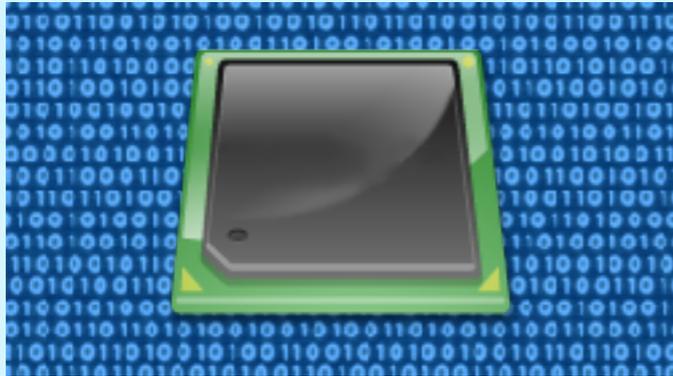
$|0\rangle$ —●—

$$|\psi\rangle = c_0|0\rangle + c_1|1\rangle$$

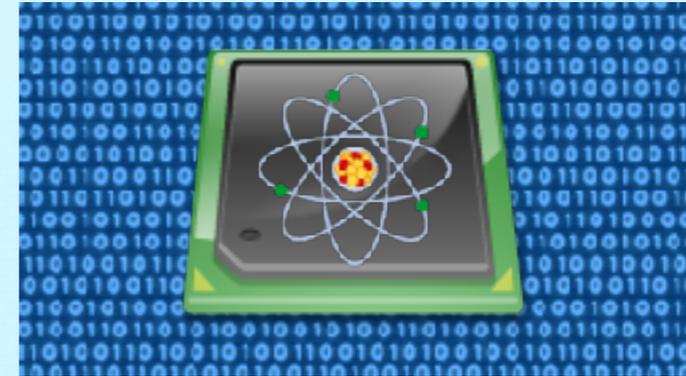
Well developed hardware, algorithms, programming tools, ...

Why qubit?

Why qubit?

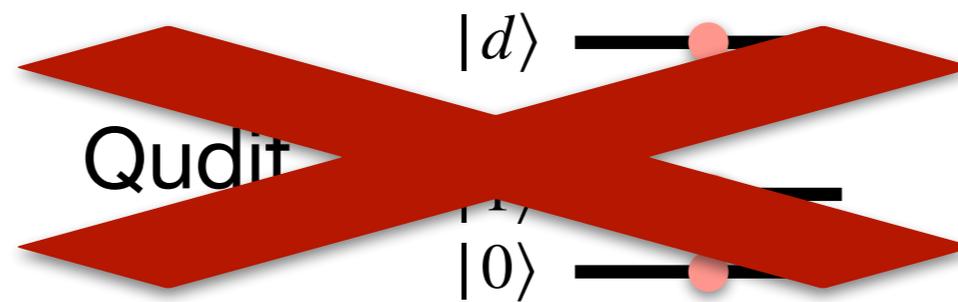


Classical (bit)

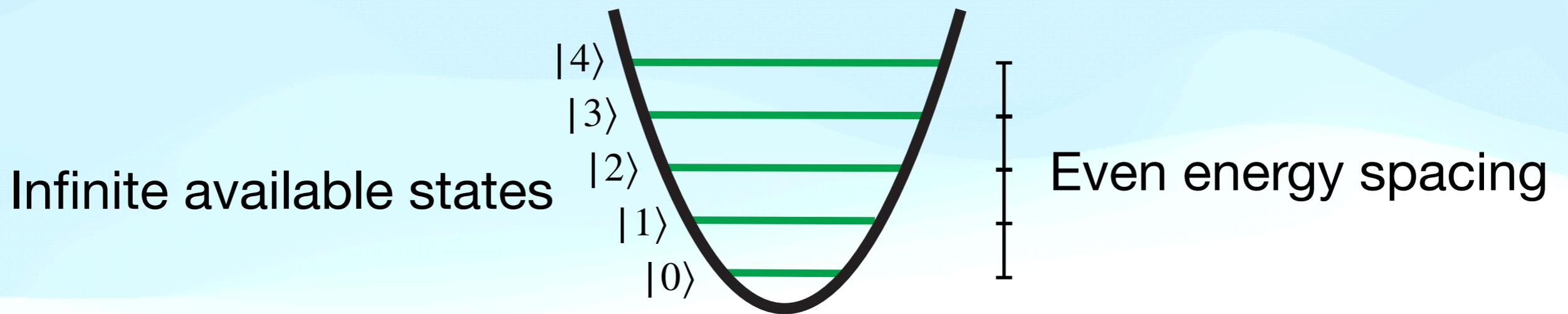


Quantum (qubit)

What else?



Bosonic system

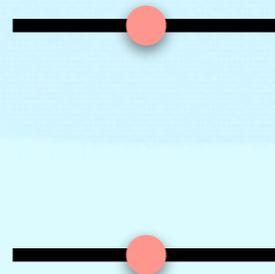


Bosonic systems = Harmonic oscillators

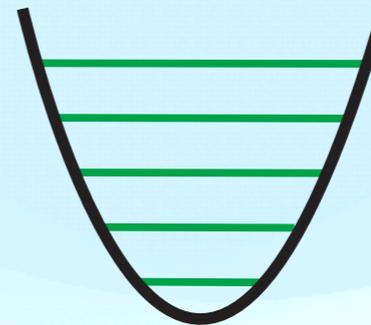
$$[\hat{Q}, \hat{P}] = i\hbar$$

Physical Platforms

Qubit

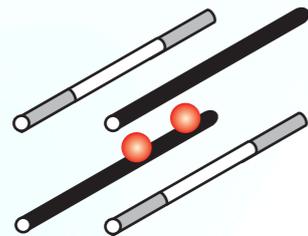
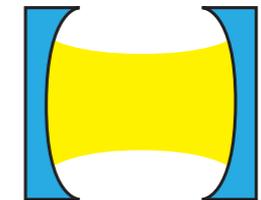


Bosonic



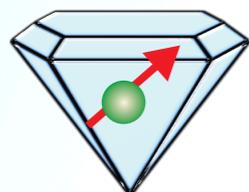
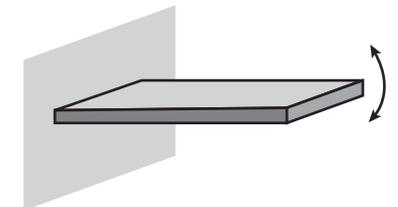
Superconductor

Microwave resonator



Trapped ion

Mechanical oscillator



Defect center

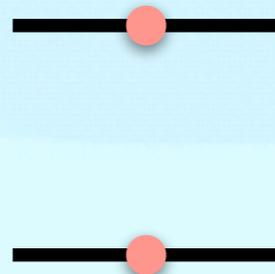
Photon



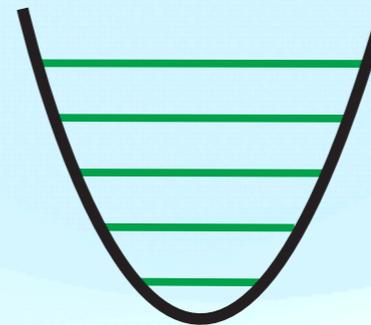
Engineering new platforms?

Physical Platforms

Qubit

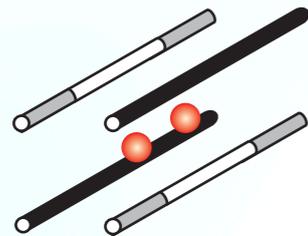
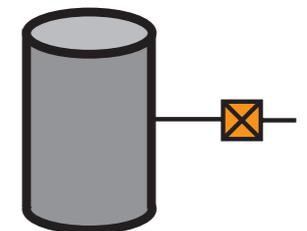


Bosonic



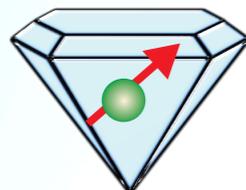
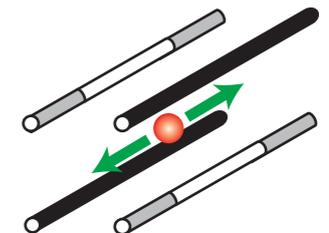
Superconductor

Microwave resonator



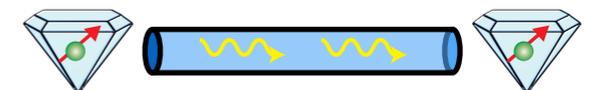
Trapped ion

Mechanical oscillator



Defect center

Photon

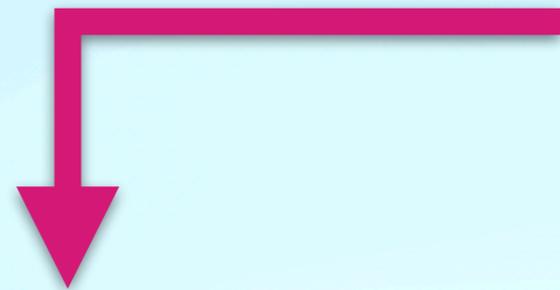


Bosonic system is already there!

Why boson?

More (degree of) freedom

Bosonic code



$$|\psi_L\rangle = c_0 |0_L\rangle + c_1 |1_L\rangle$$

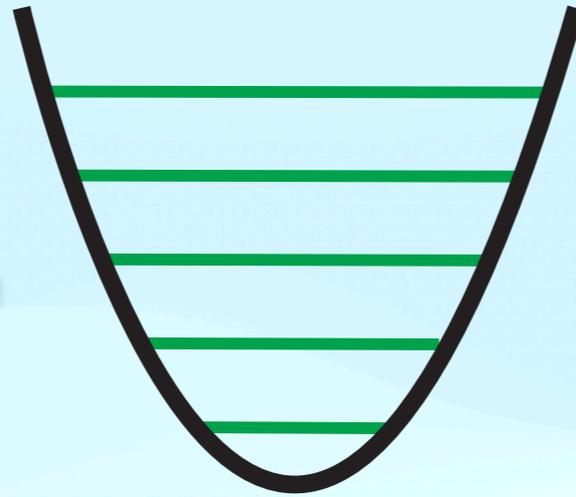
$$|\Psi_0\rangle \equiv |0_L\rangle$$

$$|\Psi_1\rangle \equiv |1_L\rangle$$

$$|\Psi_2\rangle$$

$$|\Psi_3\rangle$$

$$|\Psi_4\rangle$$

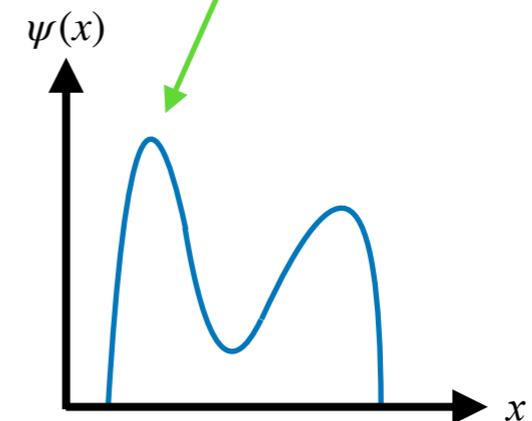


Continuous-Variable
Quantum information



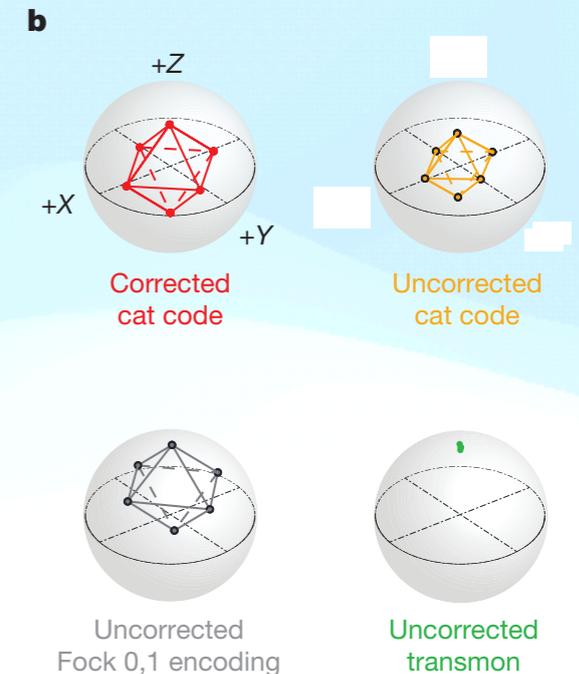
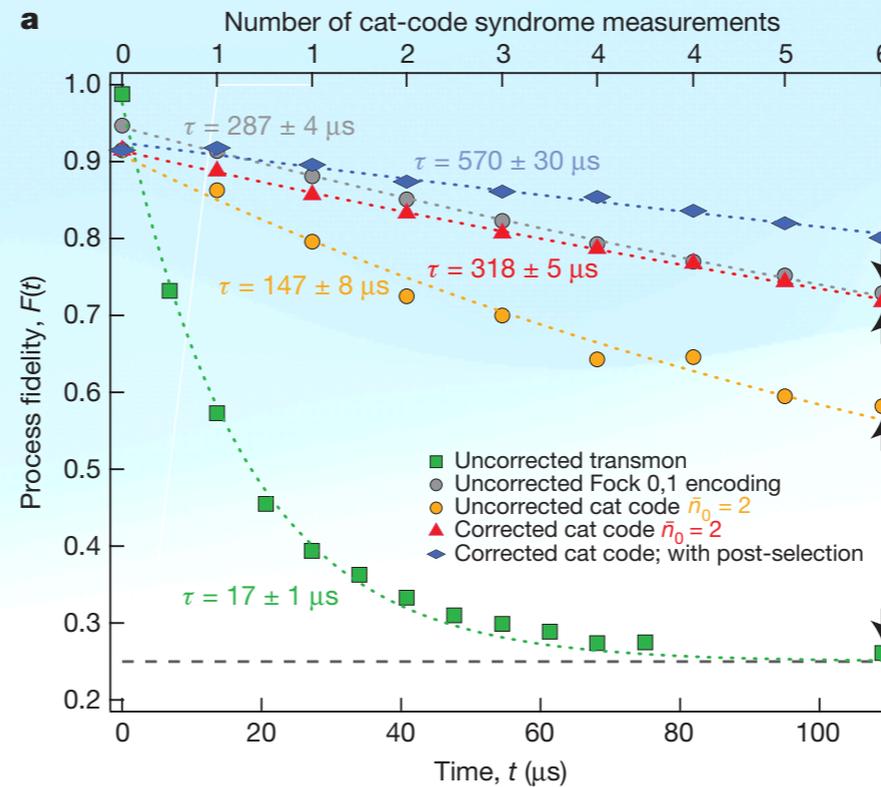
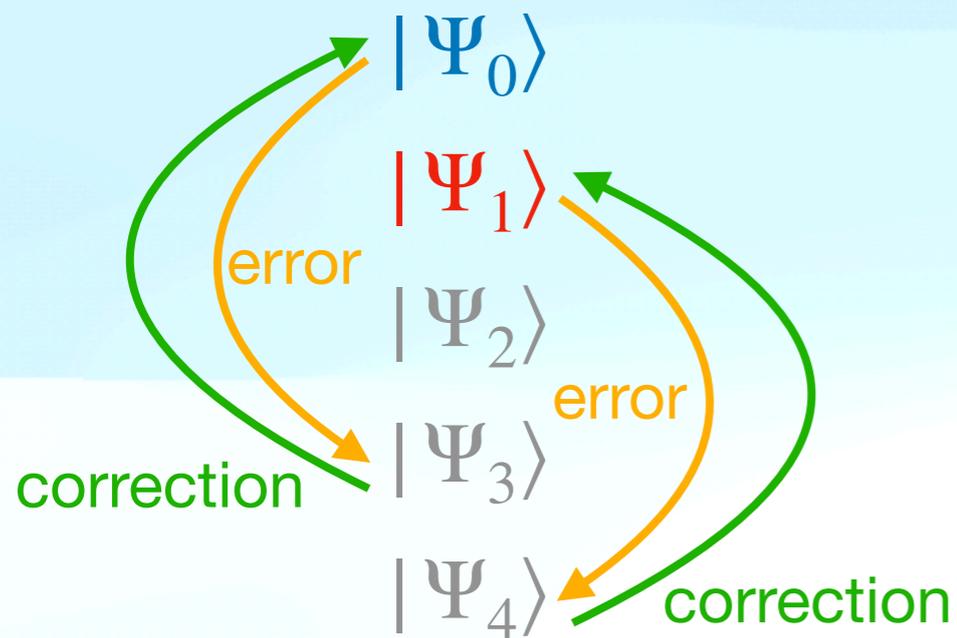
$$|\psi\rangle = \int \psi(x) |x\rangle dx$$

Continuous
wavefunction



Bosonic code

Break-even point for Error Correction



LETTER

Nature 536, 441 (2016)

doi:10.1038/nature18949

Extending the lifetime of a quantum bit with error correction in superconducting circuits

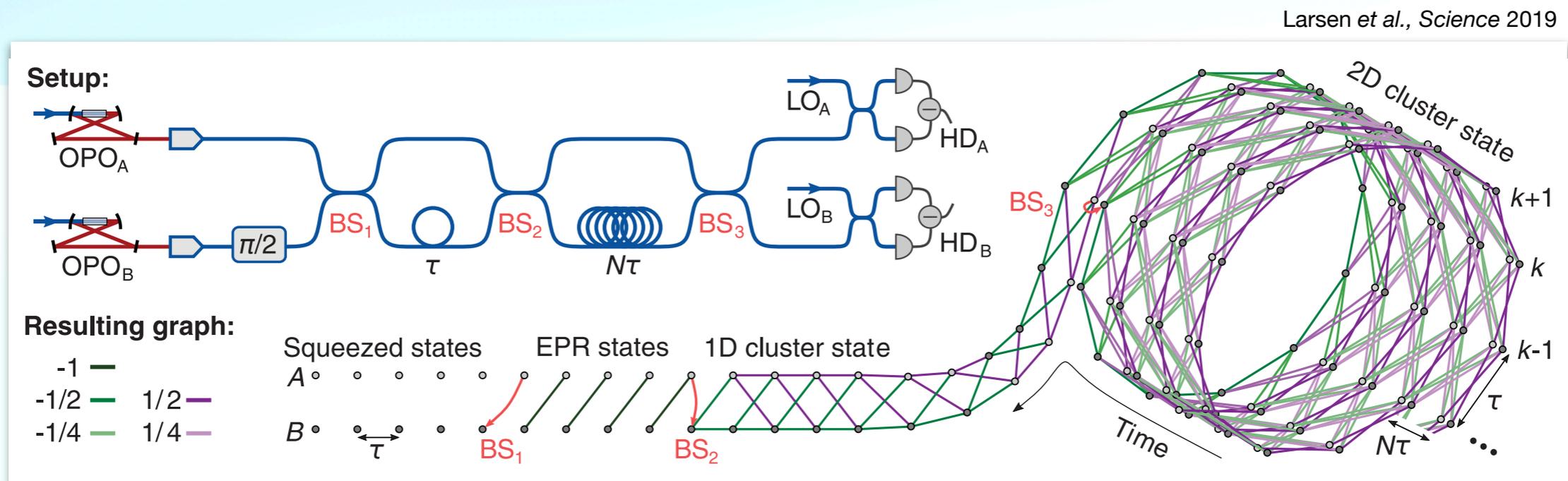
Nissim Ofek^{1*}, Andrei Petrenko^{1*}, Reinier Heeres¹, Philip Reinhold¹, Zaki Leghtas^{1†}, Brian Vlastakis¹, Yehan Liu¹, Luigi Frunzio¹, S. M. Girvin¹, L. Jiang¹, Mazyar Mirrahimi^{1,2}, M. H. Devoret¹ & R. J. Schoelkopf¹

Continuous Variable

$$|0\rangle|0\rangle + |1\rangle|1\rangle \quad \longrightarrow \quad \int |x\rangle|x\rangle dx$$

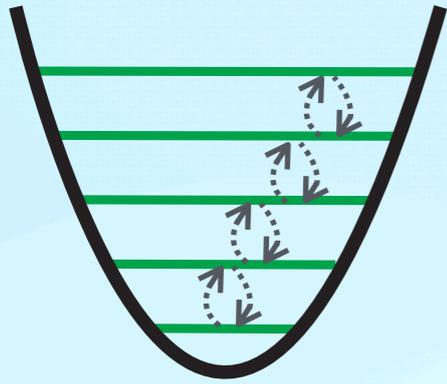
Bell state
1 e-bit

EPR state
 $\approx (\log \bar{n} + 1)$ e-bit

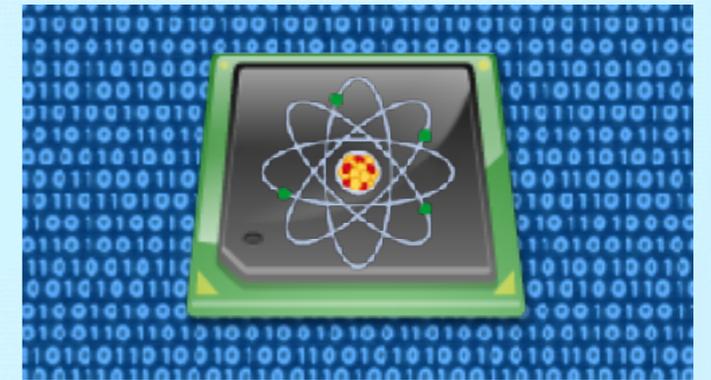


CV entanglement between 1 million mode

Challenges (yet)



Optimal control and implementation?



Programming CV or qubit-bosonic systems?



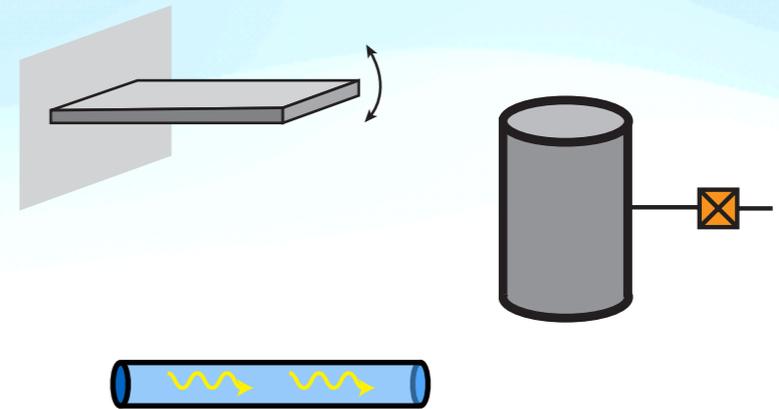
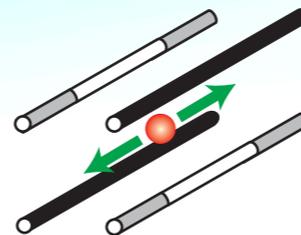
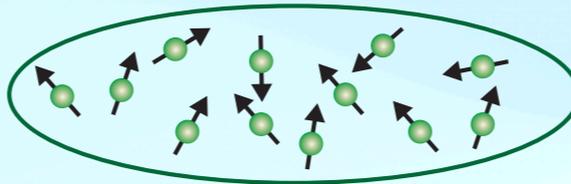
Translating algorithms from qubit to CV?



Beyond Qubit

Bosonic systems:

- Everywhere
- More freedom
- More entanglement
- Platform advantages



Should we give them more attention?