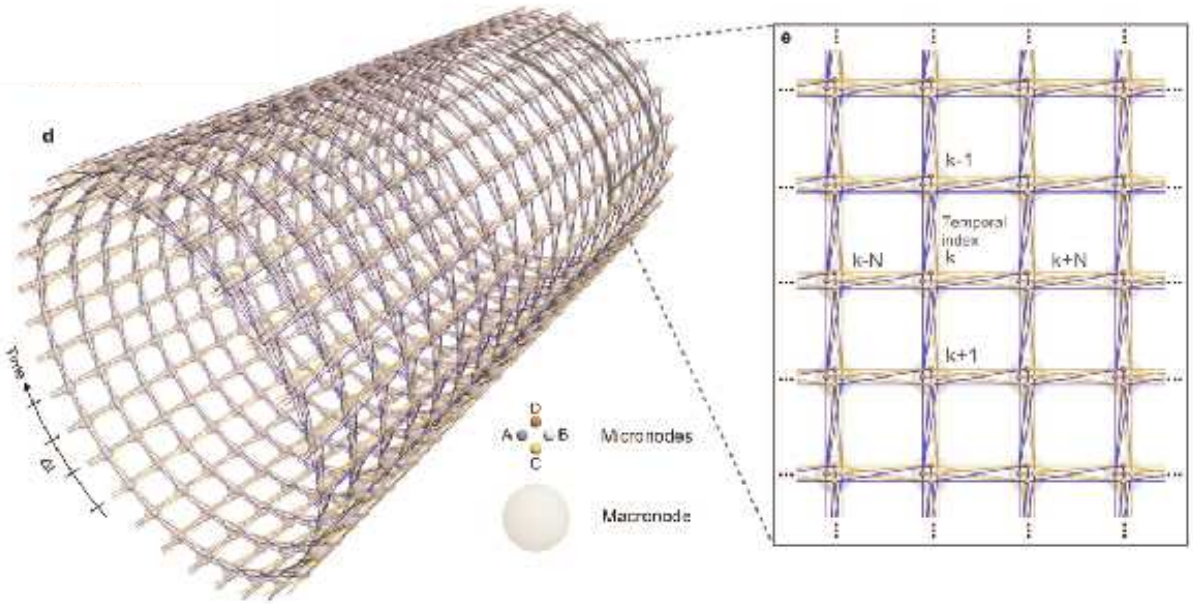


MOONSHOT
RESEARCH & DEVELOPMENT PROGRAM

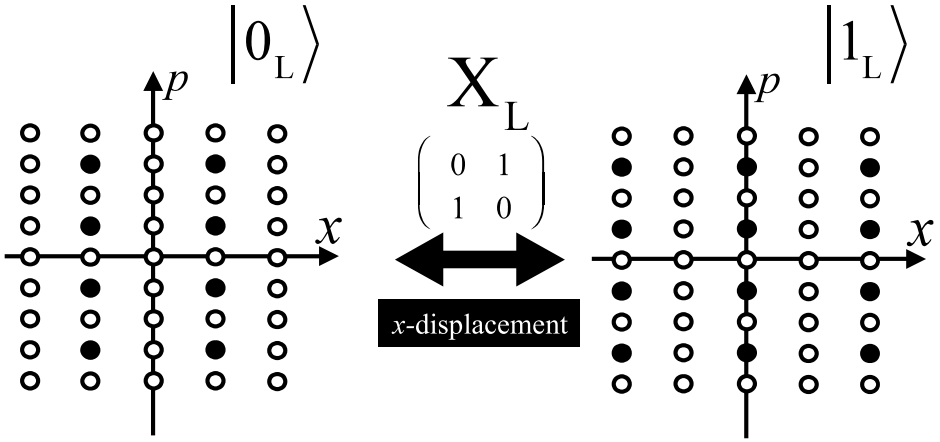
ムーンショット目標6
キックオフシンポジウム
2021年3月11日

誤り耐性型大規模汎用光量子コンピューターの研究開発

東京大学大学院工学系研究科物理工学専攻
古澤　明

GKP qubits & Logical operations

Logical qubits for Quantum error correction



Complex amplitude

$$\hat{a} = \hat{x} + i\hat{p}$$

$$\left[\hat{x}, \hat{p}\right] = \frac{i}{2}$$

$$\hbar = \frac{1}{2}$$

FM $\hat{p}$

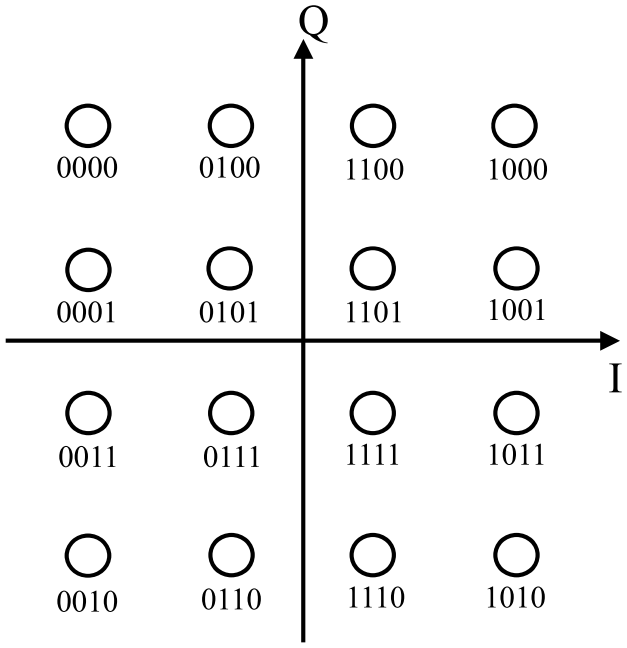
Quadrature Amplitude Modulation QAM

Coherent communication

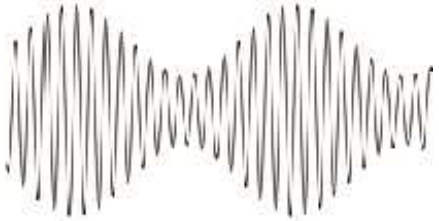
Radio

AM

FM



AM $\hat{x}$



GKP qubits & Logical operations

○ $+\infty$

● $-\infty$

Complex amplitude

$\hat{a} = \hat{x} + i\hat{p}$

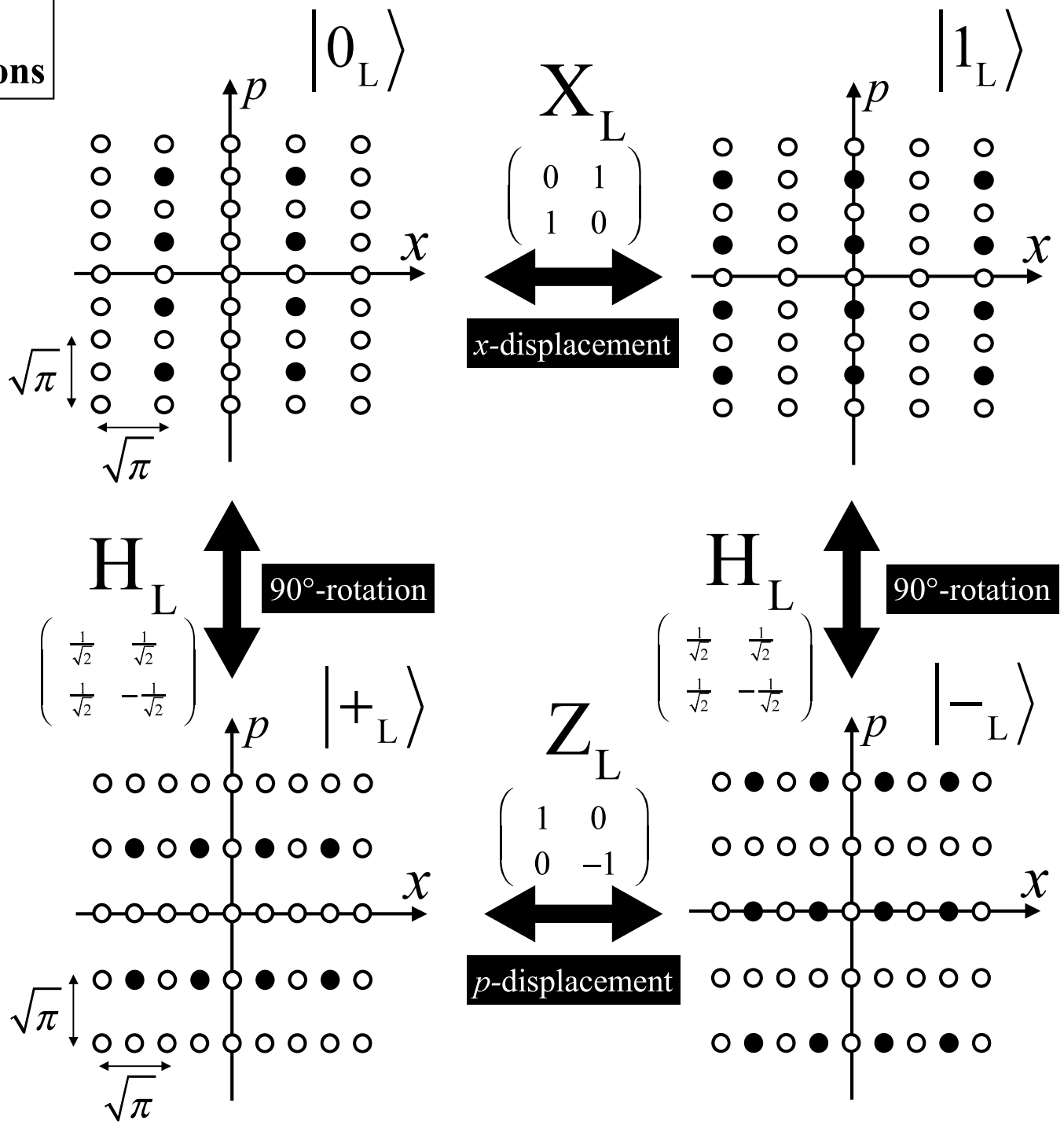
$\left[\hat{x}, \hat{p}\right] = \frac{i}{2}$

$\hbar = \frac{1}{2}$

Logical qubits for quantum error correction

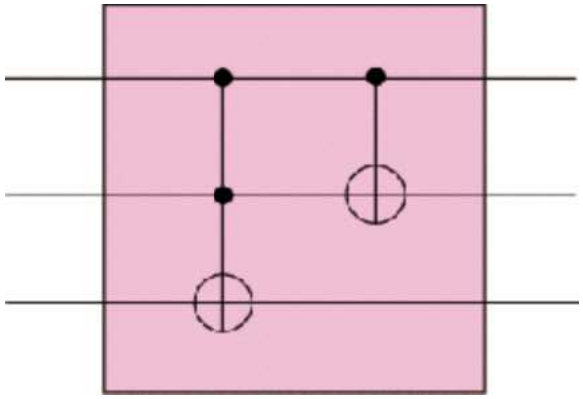
Clifford

Gaussian



Quantum computing

Quantum circuit model



Qubit
R. P. Feynman (1980)

Continuous variable
S. Lloyd and S. L. Braunstein (1999)

Measurement-based model (one-way quantum computing)

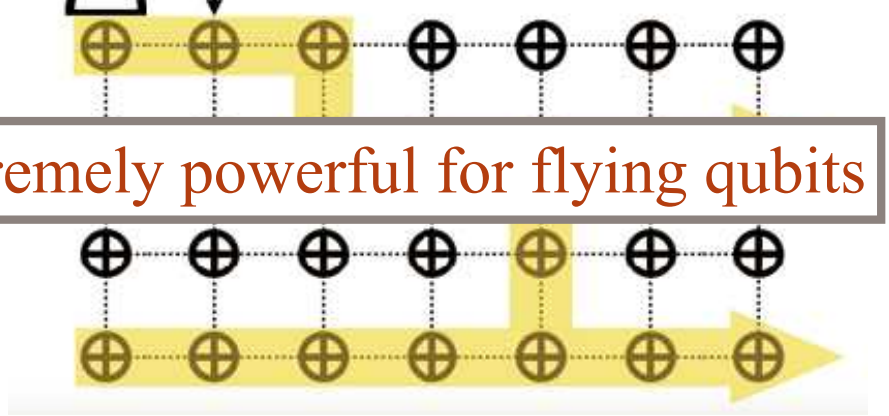
Measurement and Feedforward

Quantum look-up table

Large-scale entangled state (Cluster state)
Measurement and Feedforward

Extremely powerful for flying qubits

Sequential teleportation



Changing measurement bases = changing operation

Qubit
R. Raussendorf and H. J. Briegel (2001)

$$\oplus = \left(|0\rangle + |1\rangle\right)/\sqrt{2}$$

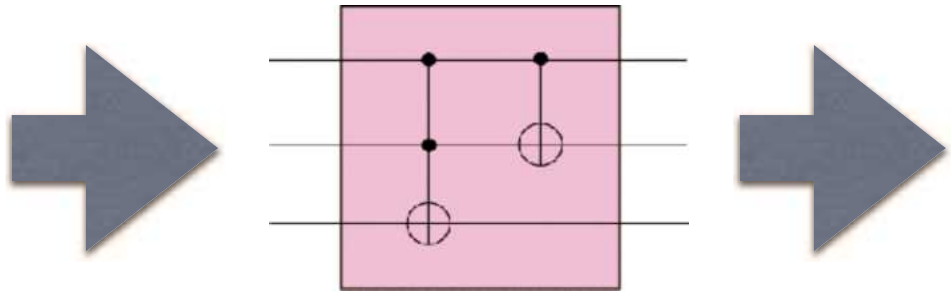
Continuous variable
N. C. Menicucci and P. van Loock et al. (2006)

$$\oplus = \int_{-\infty}^{+\infty} dx\,|x\rangle$$

Quantum computing with flying qubits (photons)

Quantum circuit model

flying qubits
photons

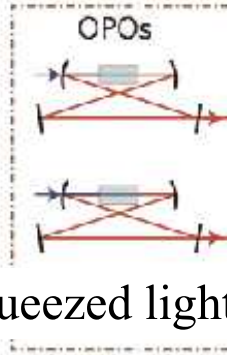


setup
g)

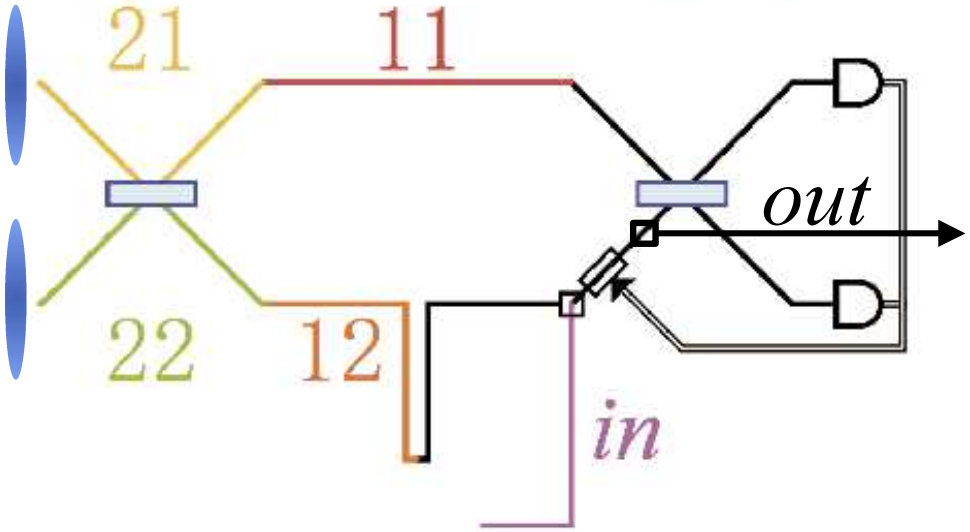
Measu
One-w

r state!!

g



Squeezed ligh



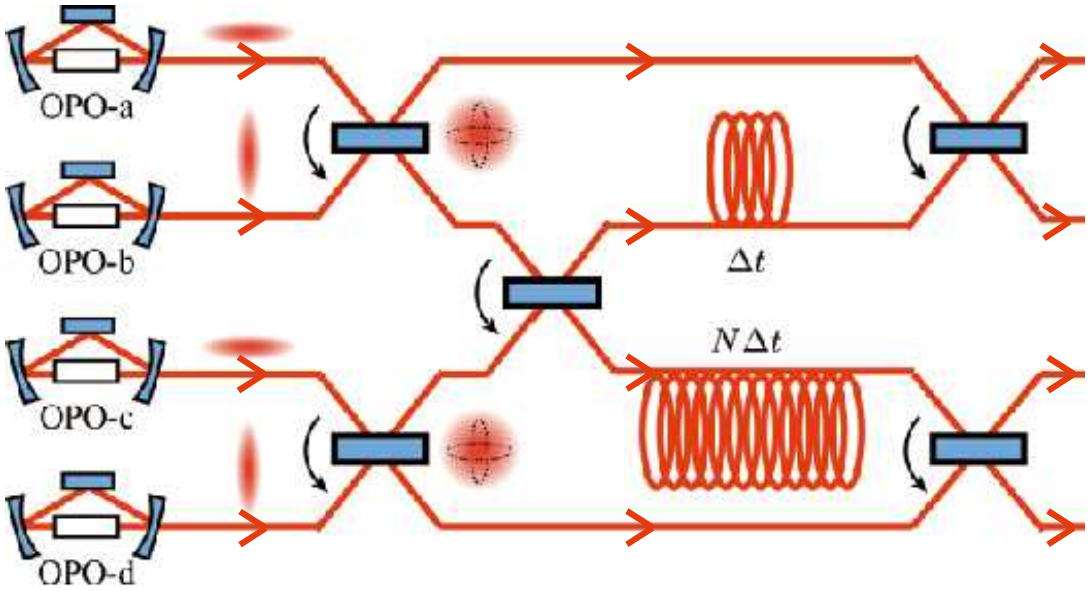
100

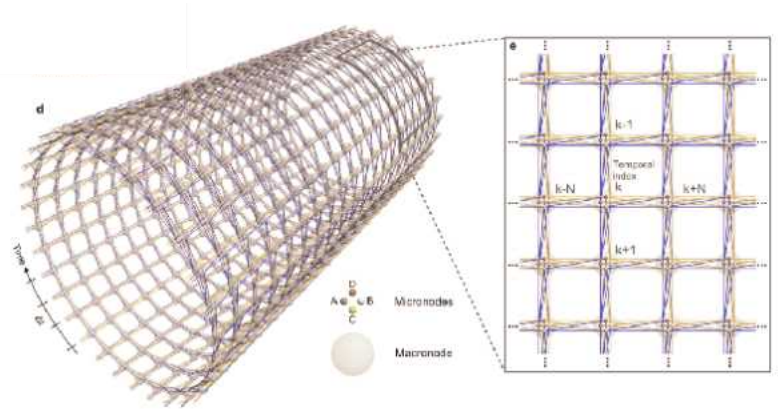
) (2016)

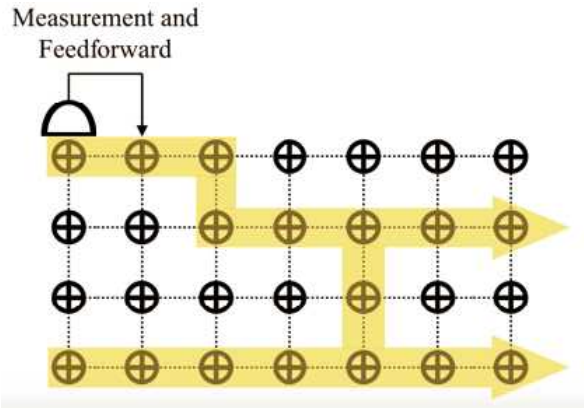
Large-scale quantum computing = fixed-size of the setup
Programmable

Time-domain multiplexed 2D cluster state

Quantum look-up table





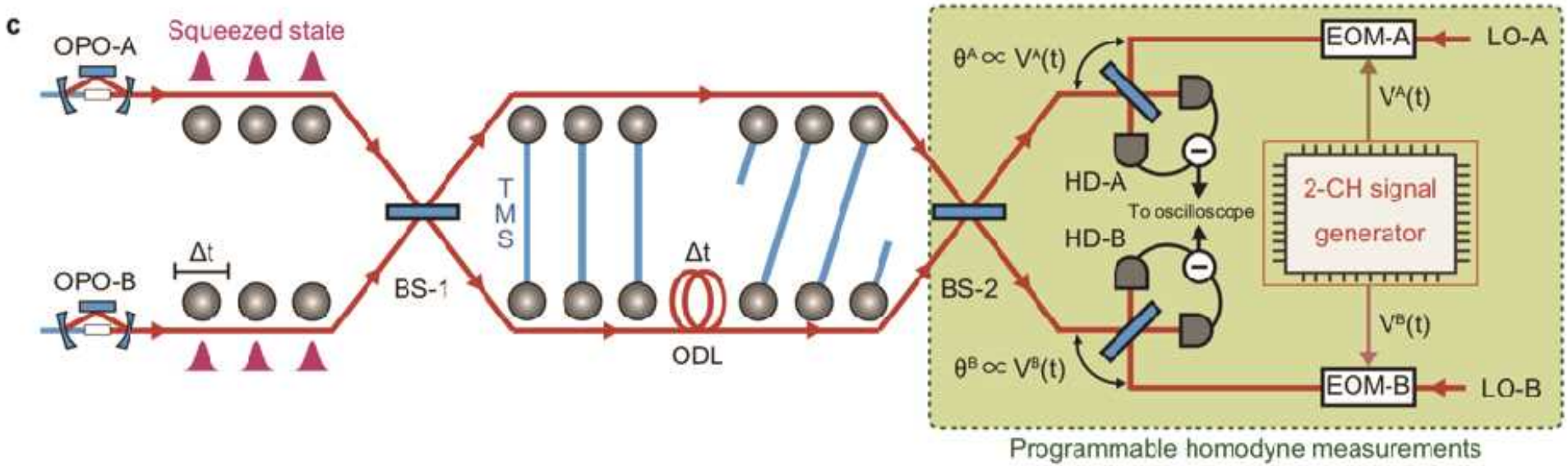


QUANTUM COMPUTING

Generation of time-domain-multiplexed two-dimensional cluster state

Science 366, 373 (2019)

Warit Asavanant[1], Yu Shiozawa[1], Shota Yokoyama[2], Baramee Charoensombutamon[1], Hiroki Emura[1], Rafael N. Alexander[3], Shuntaro Takeda[1,4], Jun-ichi Yoshikawa[1], Nicolas C. Menicucci[5], Hidehiro Yonezawa[2], Akira Furusawa[1]*



Phase rotation

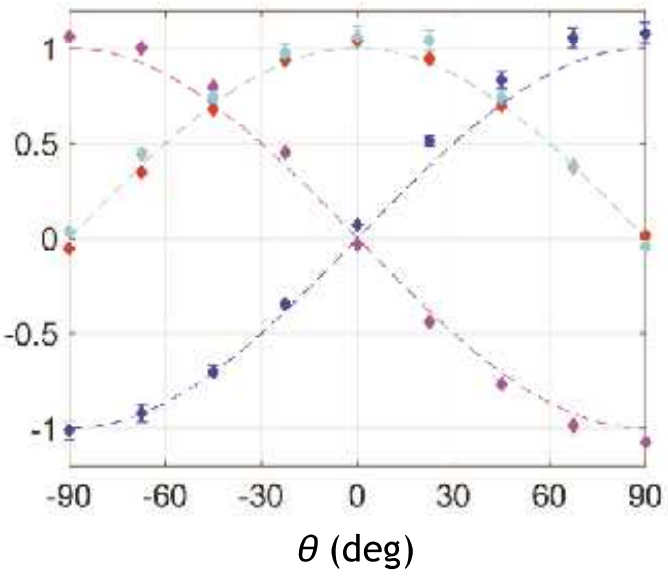
$$\begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

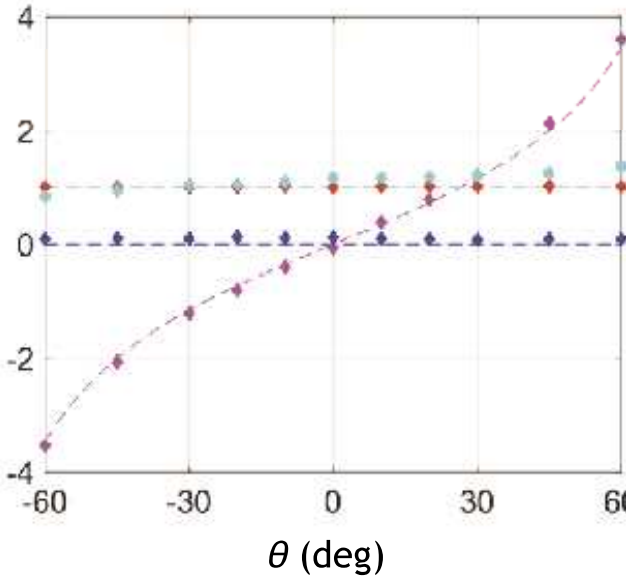
Shear

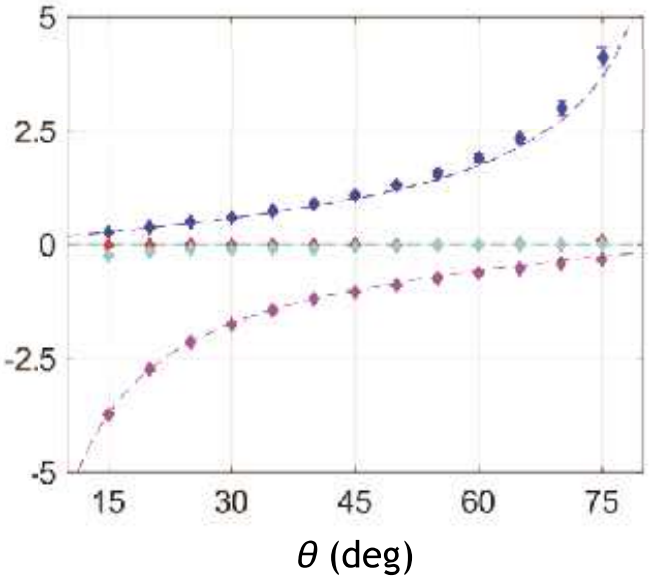
$$\begin{pmatrix} 1 & 0 \\ 2\tan\theta & 1 \end{pmatrix}$$

Squeezing

$$\begin{pmatrix} 0 & \tan\theta \\ -1/\tan\theta & 0 \end{pmatrix}$$



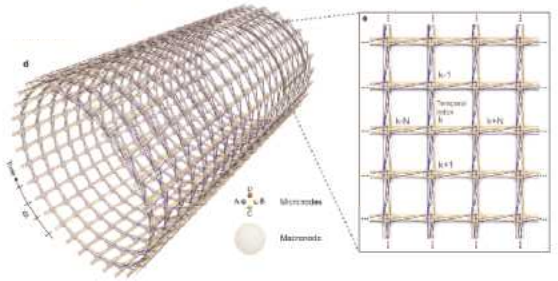


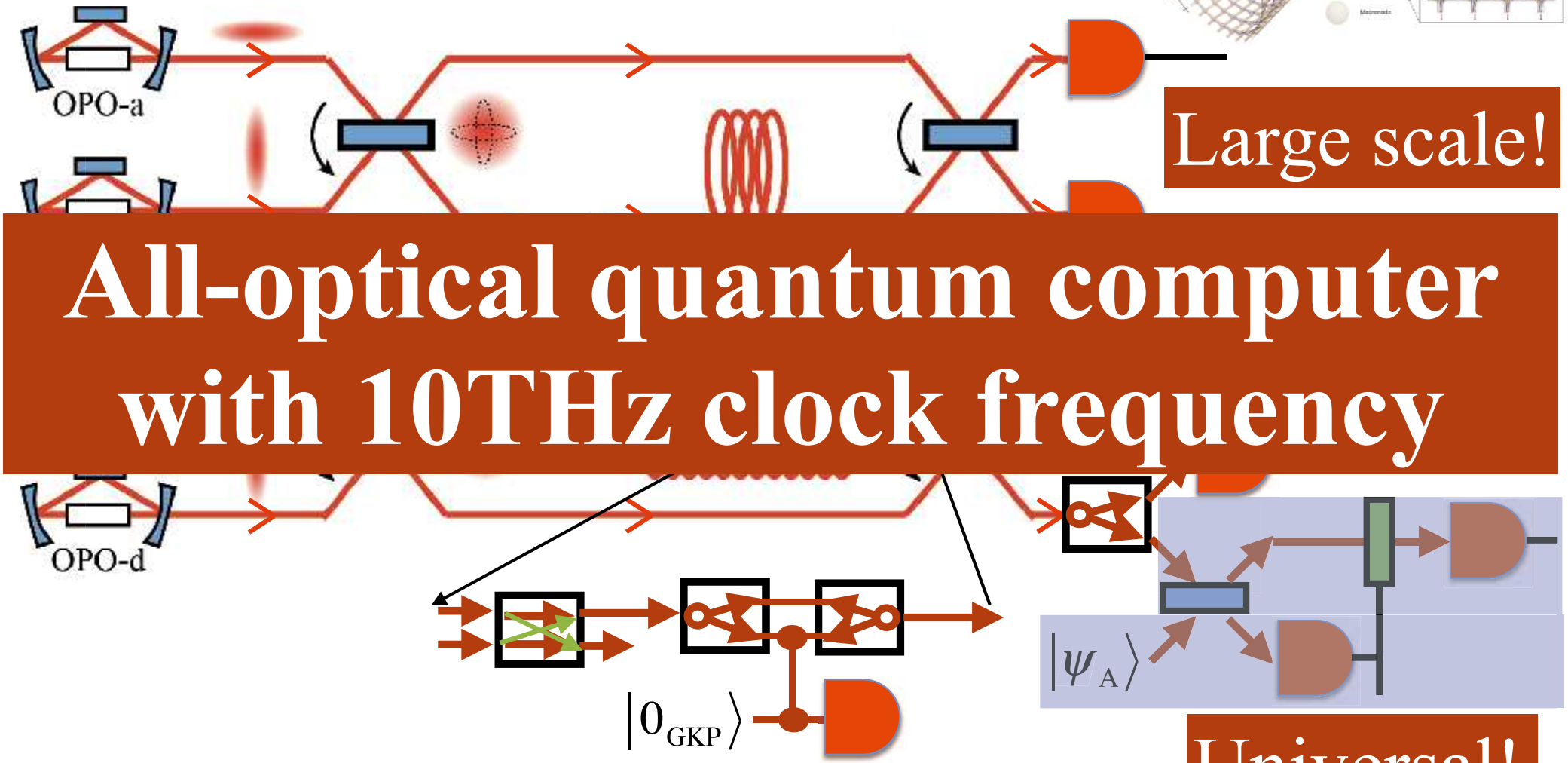


W. Asavanant et al., arXiv:2006.537 [quant-ph].

Summary

Optical parametric amplifier





Large scale!

All-optical quantum computer with 10THz clock frequency

Universal!

Fault tolerant!