

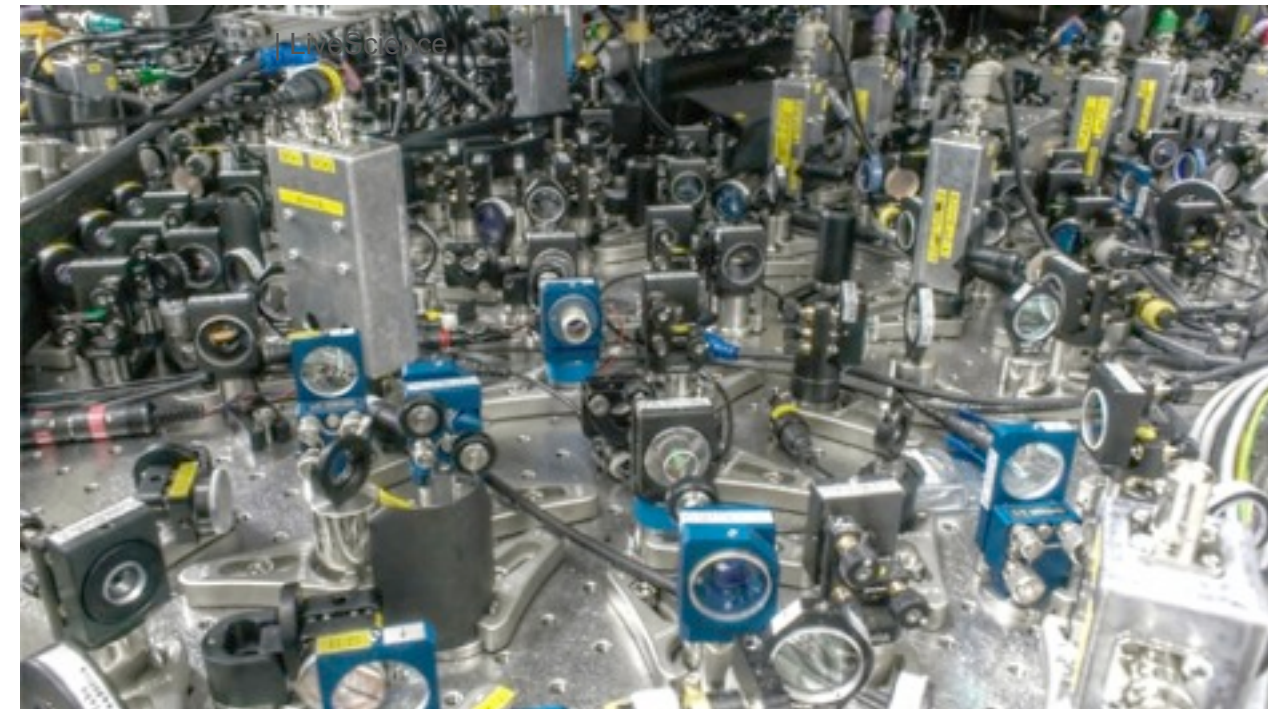
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SCIENCE

Quantum Leap: Scientists Teleport Bits of Light

By [Clara Moskowitz](#)
Published April 14, 2011



連続量の手法を用いた量子ビットテレポーテーションの研究
—ハイブリッド量子情報処理に向けて—

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“Computational basis”

Quantum states for quantum information processing

“Qubits”

$$|\psi_2\rangle = c_0|0\rangle + c_1|1\rangle = \sum_{n=0}^1 c_n |n\rangle$$

$$c_n = \langle n | \psi_2 \rangle \quad (n = 0, 1)$$

“Continuous variables” (CV)

$$|\psi\rangle = \int_{-\infty}^{\infty} dx \, \psi(x) |x\rangle \quad |\psi\rangle = \sum_{n=0}^{\infty} c_n |n\rangle$$

$$\psi(x) = \langle x | \psi \rangle$$

$$c_n = \langle n | \psi \rangle$$

Schrödinger picture

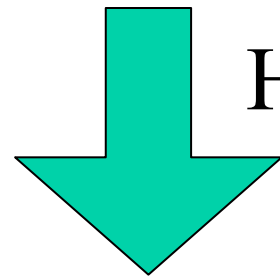
Qubits

Continuous variables

computational basis

$\{|0\rangle, |1\rangle\}$ bit flip σ_x

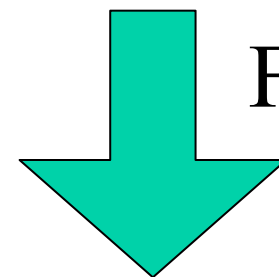
$\{|x\rangle\}$ $\hat{X}(s) = e^{-2is\hat{p}}$ x -displacement



Hadamard

conjugate basis

$\{|+\rangle, |-\rangle\}$ phase flip σ_z
 $|\pm\rangle = \frac{|0\rangle \pm |1\rangle}{\sqrt{2}}$



Fourier

$\{|p\rangle\}$ $\hat{Z}(s) = e^{2is\hat{x}}$ p -displacement

CNOT $|x\rangle|x'\rangle \rightarrow |x\rangle|x+x' \bmod 2\rangle$

QND $|x\rangle|x'\rangle \rightarrow |x\rangle|x+x'\rangle$

$\pi/8$ gate

$$T = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{4}} \end{pmatrix}$$

Cubic phase gate

$$e^{ik\hat{x}^3} |\psi\rangle$$

Heisenberg picture

$$e^{-ik\hat{x}^3} \hat{x} e^{ik\hat{x}^3} = \hat{x}$$

$$e^{-ik\hat{x}^3} \hat{p} e^{ik\hat{x}^3} = \hat{p} + \frac{3}{2}k\hat{x}^2$$

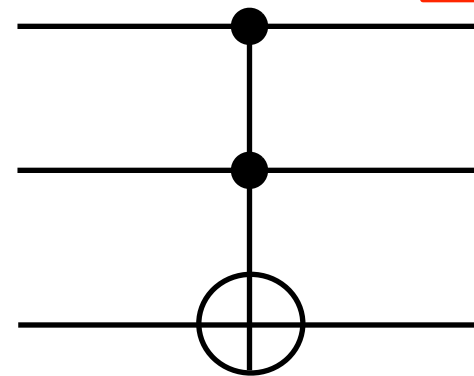
Schrödinger picture

Qubits

$$\text{CNOT } |x\rangle|x'\rangle \rightarrow |x\rangle|x+x' \bmod 2\rangle$$

$$\pi/8 \text{ gate} \quad T = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{4}} \end{pmatrix}$$

Toffoli gate



$$|x\rangle|x'\rangle|x''\rangle \rightarrow |x\rangle|x'\rangle|xx' + x'' \bmod 2\rangle$$

$$|x\rangle|x'\rangle|0\rangle \rightarrow |x\rangle|x'\rangle|xx' \bmod 2\rangle$$

Continuous variables

$$\text{QND } |x\rangle|x'\rangle \rightarrow |x\rangle|x+x'\rangle$$

$$\text{Cubic phase gate } e^{ik\hat{x}^3} |\psi\rangle$$

$$e^{-i\hat{x}\hat{x}'\hat{p}''}$$

CV Toffoli gate

$$|x\rangle|x'\rangle|x''\rangle \rightarrow |x\rangle|x'\rangle|xx' + x''\rangle$$

$$|x\rangle|x'\rangle|0\rangle \rightarrow |x\rangle|x'\rangle|xx'\rangle$$

Heisenberg picture

$$e^{i\hat{x}\hat{x}'\hat{p}''} \hat{x} e^{-i\hat{x}\hat{x}'\hat{p}''} = \hat{x}$$

$$e^{i\hat{x}\hat{x}'\hat{p}''} \hat{x}' e^{-i\hat{x}\hat{x}'\hat{p}''} = \hat{x}'$$

$$e^{i\hat{x}\hat{x}'\hat{p}''} \hat{x}'' e^{-i\hat{x}\hat{x}'\hat{p}''} = \hat{x}\hat{x}' + \hat{x}''$$

“Computational basis”

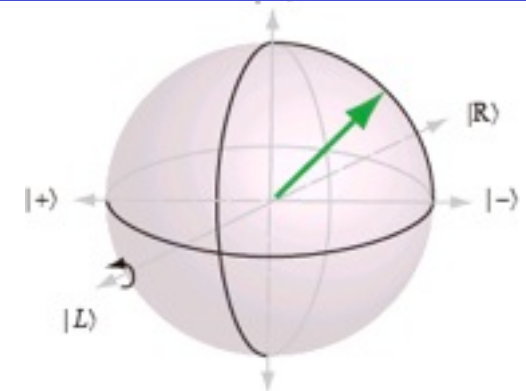
Quantum states for quantum information processing

“Qubits”

$$|\psi_2\rangle = c_0|0\rangle + c_1|1\rangle = \sum_{n=0}^1 c_n |n\rangle$$

$$c_n = \langle n | \psi_2 \rangle \quad (n = 0, 1)$$

Single photons



Photon counting

Single-photon source

“Continuous variables” (CV)

$$|\psi\rangle = \int_{-\infty}^{\infty} dx \psi(x) |x\rangle$$

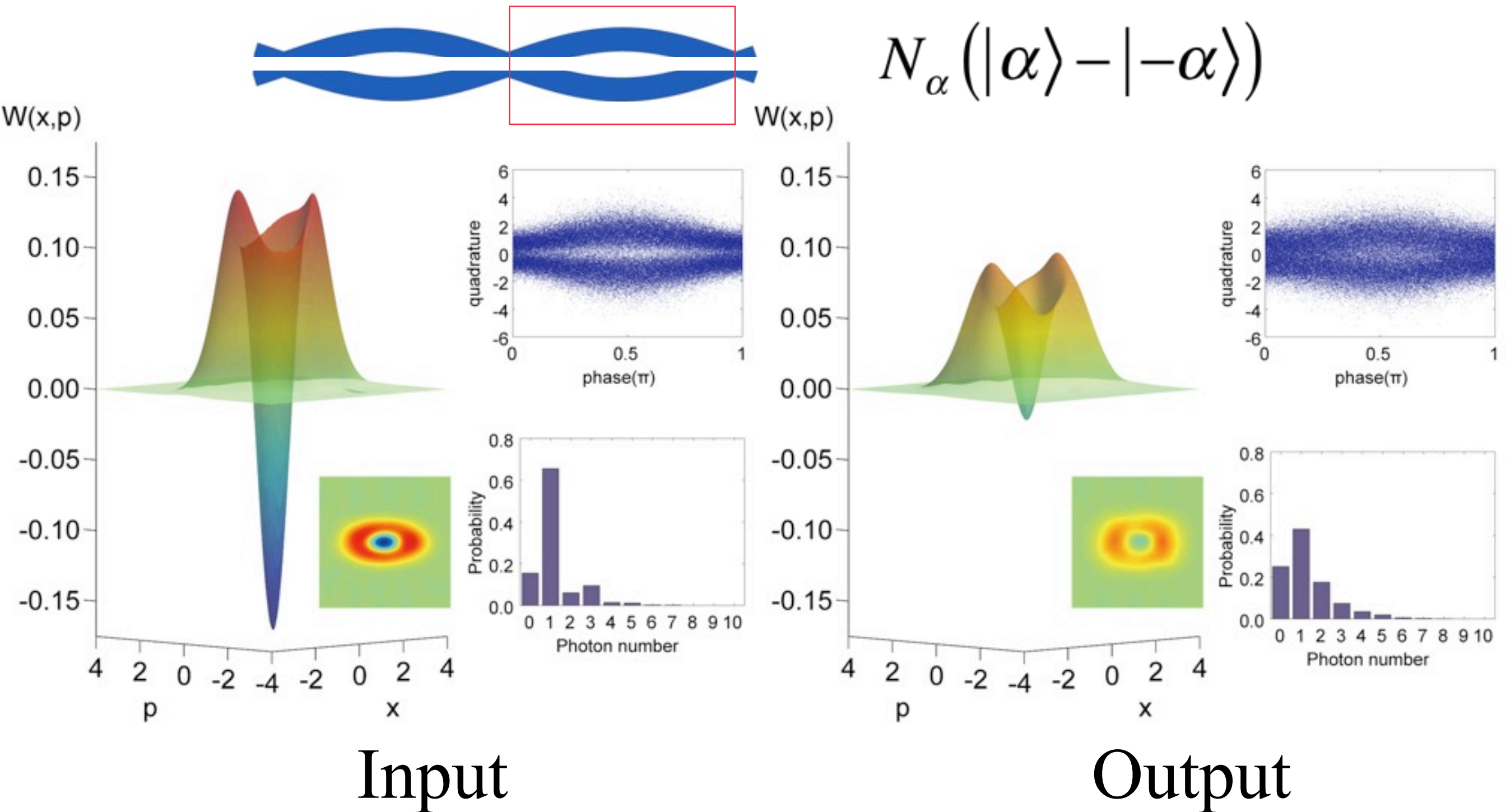
$$\psi(x) = \langle x | \psi \rangle$$

AM and FM signals
of optical beams



$c_n =$ Homodyne measurement
High level of squeezing

Teleportation of a Schrödinger cat state of light





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16.05.2011 20:50

Ученые из Японии телепортировали запутанный квант

Автор: Сергей Мингажев



ABC News

Scientists teleport Schrodinger's cat

By Carl Holm for ABC Science Online

Updated Fri Apr 15, 2011 12:13pm AEST

N. Lee, H. Benichi, Y. Takeno, S. Takeda, J. Webb, E. Huntington, & A. Furusawa, Science 332, 330 (2011)

Teleportation of Schrödinger cats

Creation of EPR beams

Hybrid technology

High level of squeezing

APD

PD

Bob

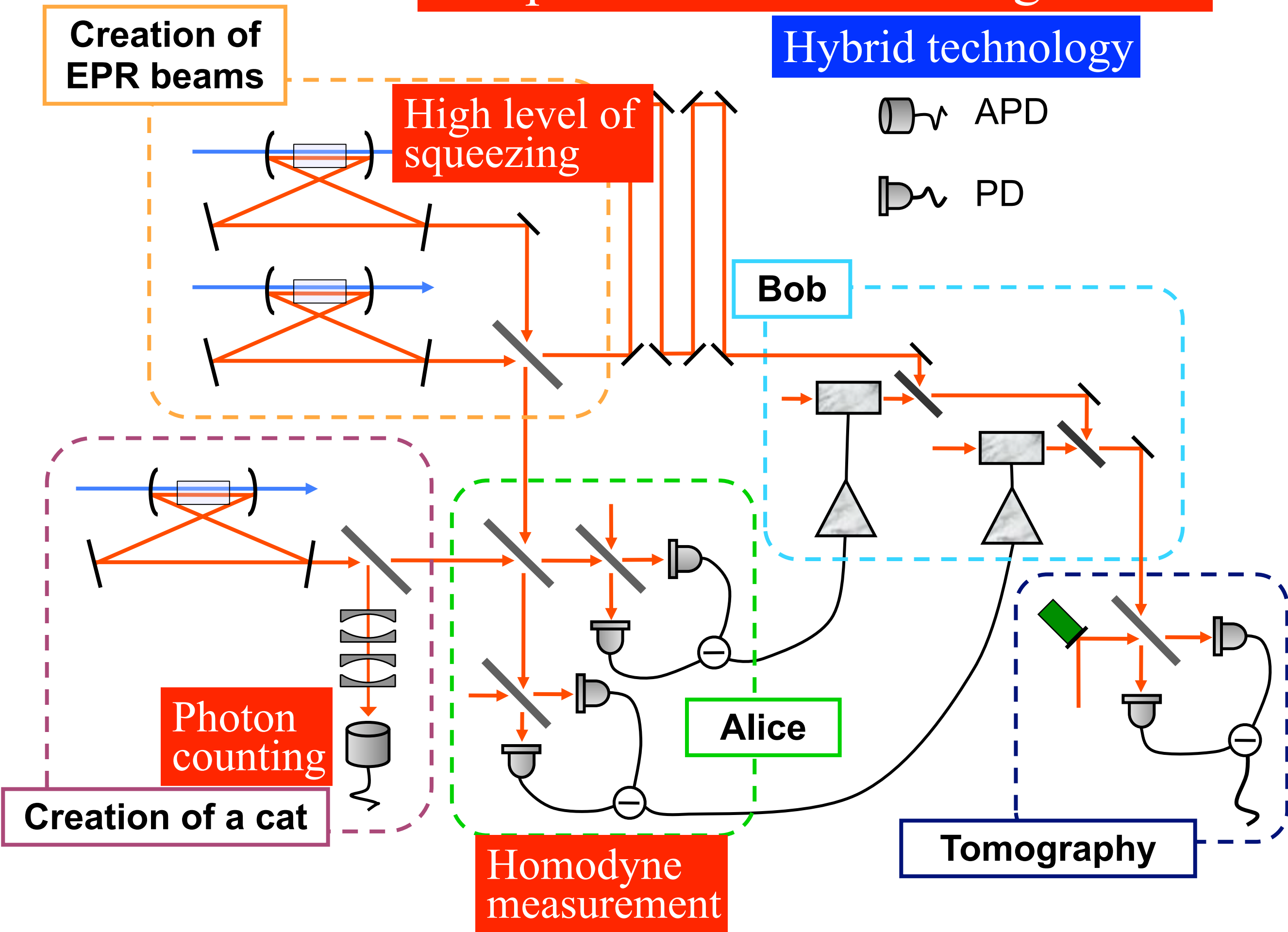
Photon counting

Creation of a cat

Alice

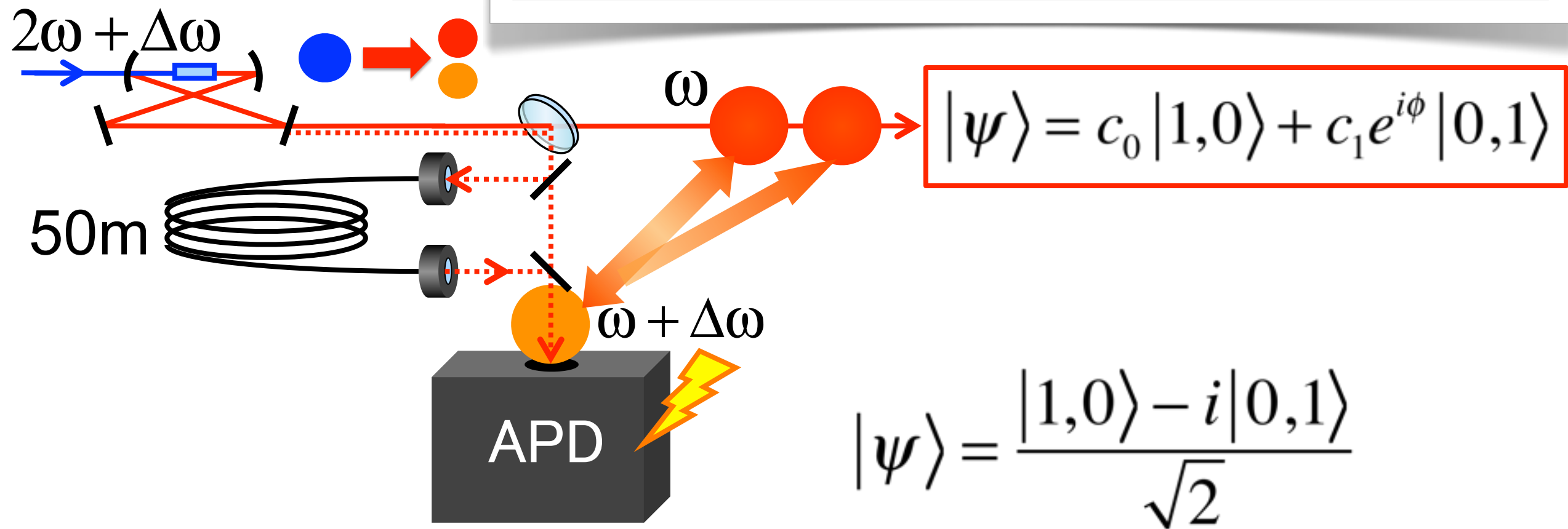
Homodyne measurement

Tomography

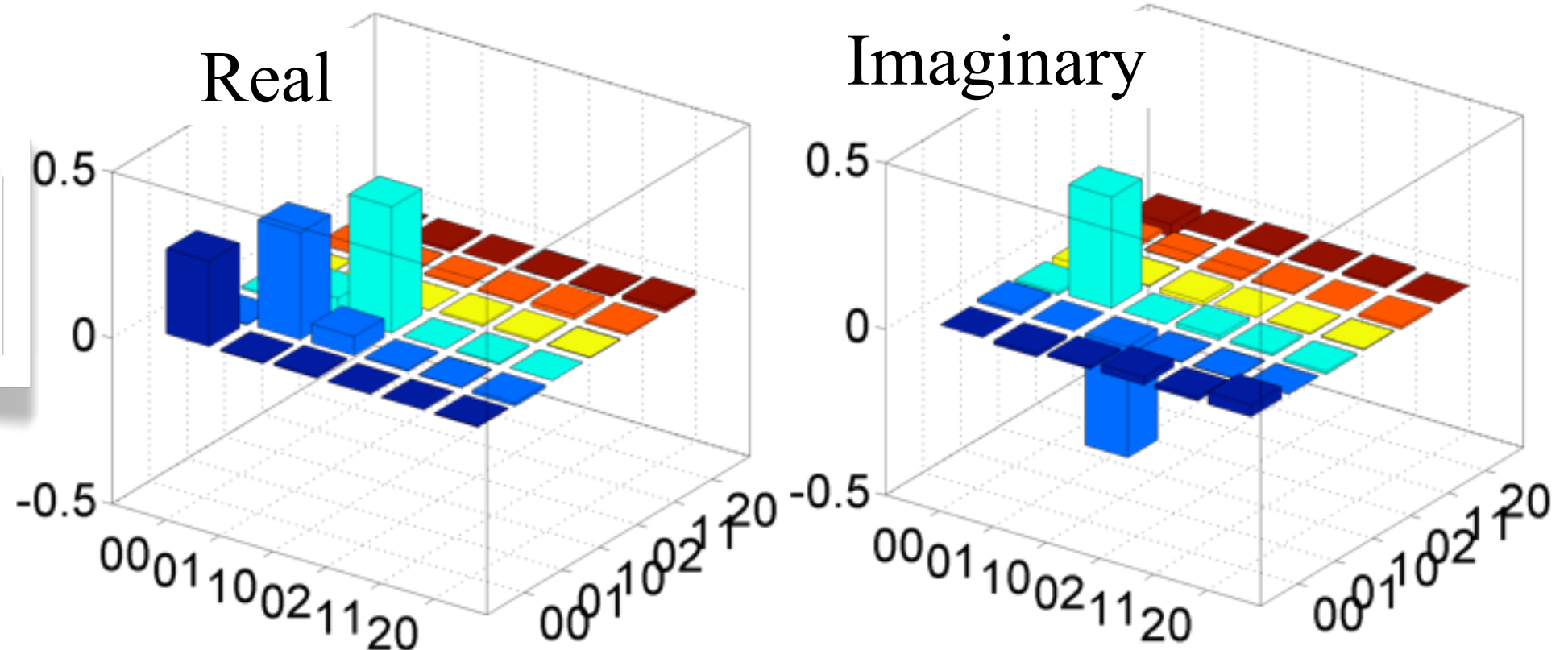


Now working on

Teleportation of time-bin qubits

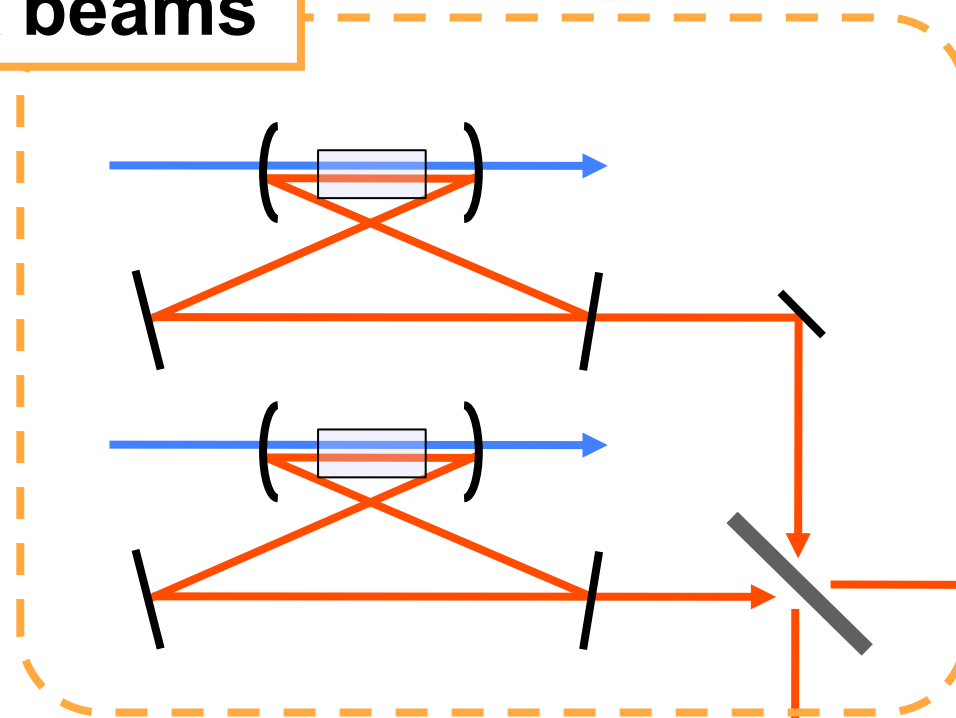


Dual-homodyne
Tomography



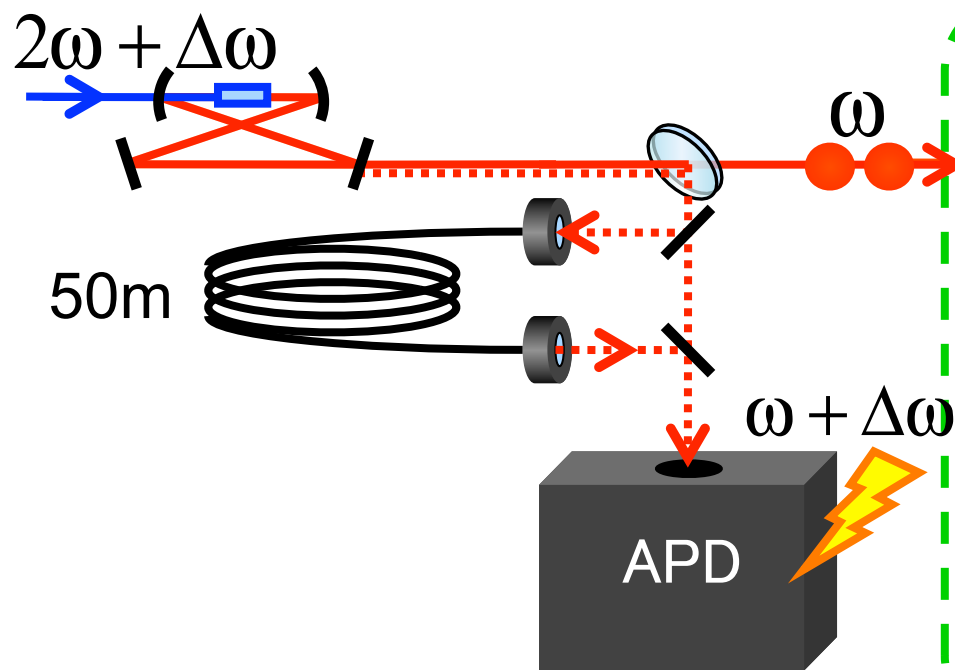
Teleportation of Schrödinger cats

Creation of
EPR beams



APD
PD

Bob



Time-bin qubit

Alice

Tomography

