Journal Club 2014/06/20 T.Yoshie

arXiv:1206.2042 [quant-ph]

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Protocol for Direct Counterfactual Quantum Communication

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It has long been assumed in physics that for information to travel between two parties in empty space, "Alice" and "Bob," physical particles have to travel between them. Here, using the "chained" quantum Zeno effect, we show how, in the ideal asymptotic limit, information can be transferred between Alice and Bob without any physical particles traveling between them.

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Quantum Communication:

quantum entanglement + measurement → Quantum Cryptography, Quantum Key Distribution

e.g. quantum teleportation ('93)

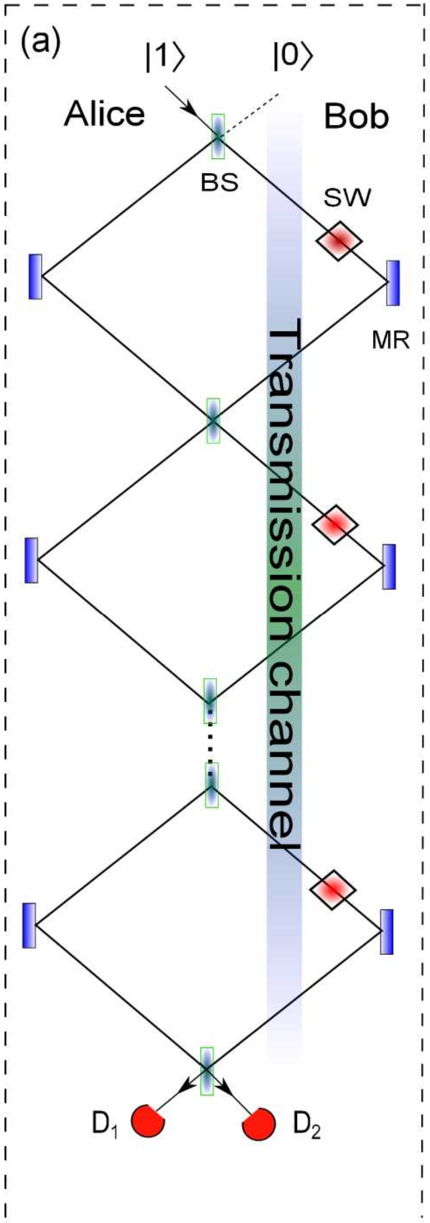
↓

Interaction free measurement (Quantum interrogation) → counterfactual communication ('09)

realized experimentally ('11, '12)

not perfect

Basic Idea (Mach-Zehnder interferometer)



- Bob tries to send a bit (0/1) to Alice
- Alice transmits a single photon to Bob

BS: Beam splitter

$$|10\rangle \rightarrow \cos\theta|10\rangle + \sin\theta|01\rangle$$
$$|01\rangle \rightarrow \cos\theta|01\rangle - \sin\theta|10\rangle$$

$$\theta = \pi / 2N$$

SW: Bob can open/close (bit 0/1)
open: photon passes

Final photon state
all open (bit 0) : D_2 clicks

$$|10\rangle \rightarrow \cos N\theta|10\rangle + \sin N\theta|01\rangle = |01\rangle$$

all close (bit 1) : D_1 clicks

$$|10\rangle \rightarrow \cos^{N-1}\theta\,(\cos\theta|10\rangle + \sin\theta|01\rangle) \approx |10\rangle$$

when D_2 clicks, photon reaches Bob

QZE

Chained M-Z (inner *N*-cycle, outer *M*-cycle)

photon initial state $|100\rangle$

all open (bit 0)

for m-th inner cycle

$$|010\rangle \rightarrow \cos N\theta_N |010\rangle + \sin N\theta_N |001\rangle = |001\rangle$$

photon does not go back to outer cycle

$$|100\rangle \rightarrow \cos^{M-1}\theta_M (\cos\theta_M |100\rangle + \sin\theta_M |010\rangle) \approx |100\rangle$$

D1 clicks: any of D3 does not click i.e. counterfactual

all close (bit 1)

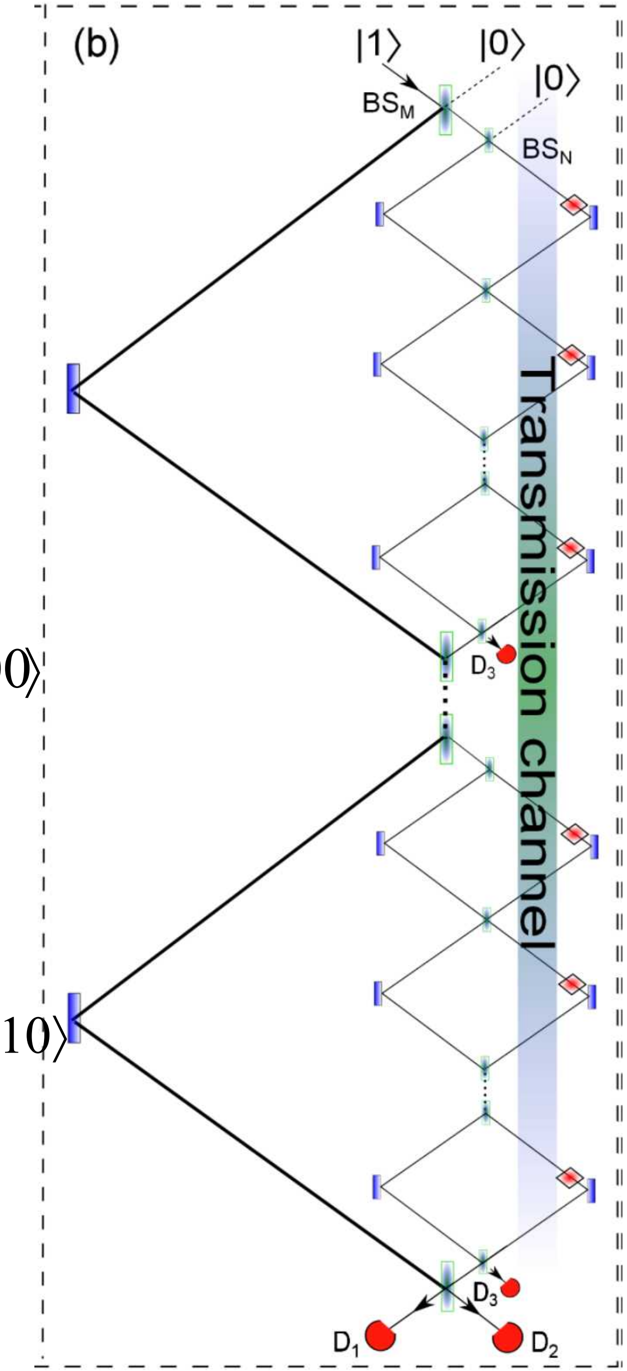
for m-th inner cycle

$$|010\rangle \rightarrow \cos^{N-1}\theta_N (\cos\theta_N |010\rangle + \sin\theta_N |001\rangle) \approx |010\rangle$$

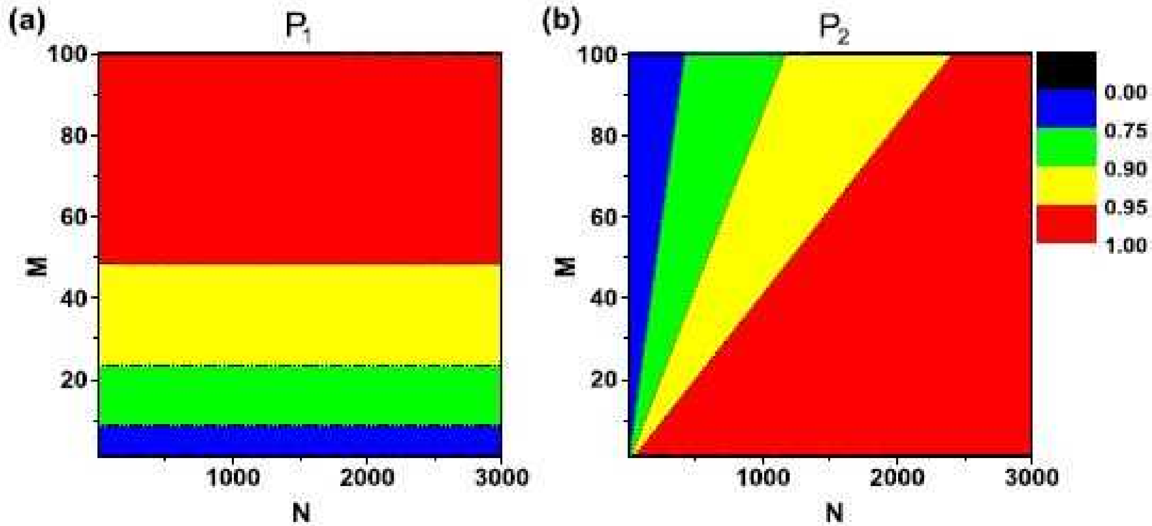
photon goes back to outer cycle

$$|100\rangle \rightarrow \cos M\theta_M |100\rangle + \sin M\theta_M |010\rangle = |010\rangle$$

D2 clicks: photon was not absorbed by SW's
i.e. counterfactual

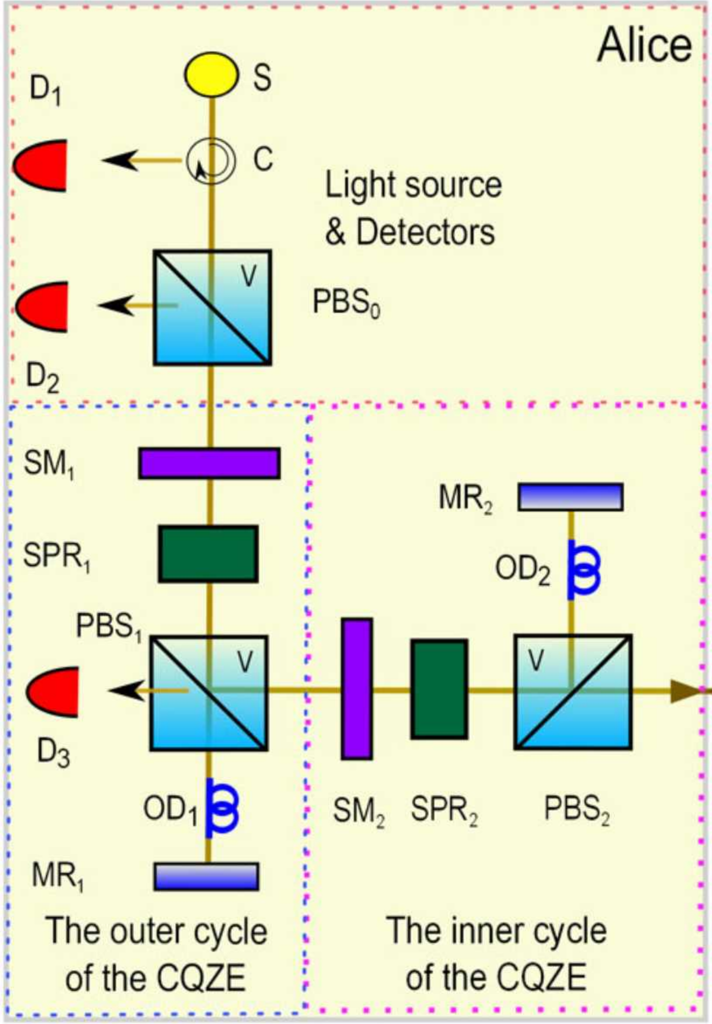


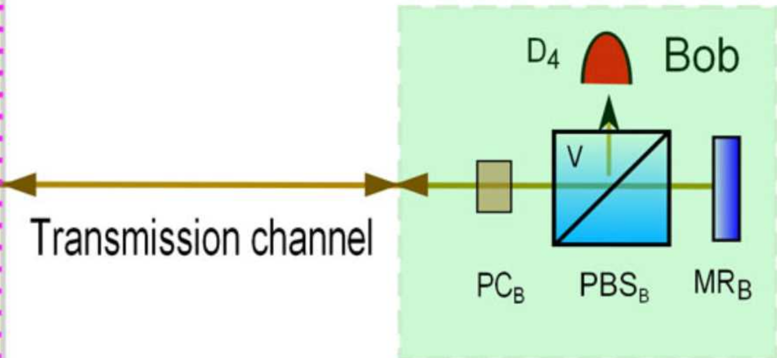
Efficiency : Probability of D_i clicks



$P_1 = 0{:}984$, $P_2 = 0{:}982$ for $M = 150$, $N = 10\,000$

Proposal for experimental setup: Two Mickelson-type interferometer





Use photon polarization

- H/V : horizontal/vertical
- source : stream of H pol. photon

PBS: reflects only V photon

SPR: switchable phase rotator

$|H\rangle \rightarrow \cos\beta|H\rangle + \sin\beta\ |V\rangle$

SM: switchable mirror to keep photons for M/N cycles

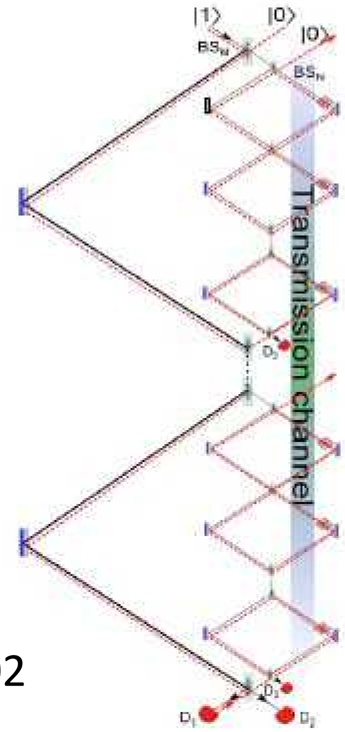
PB: Pockels cell

H pol. unchanged (bit 0)	D_1 clicks
change H pol. to V pol. (bit 1)	D_2 clicks

discussion of Counter factuality

L. Vaidman arXiv:1304.6689 [quant-ph]
Comment on "Protocol for Direct Counterfactual Quantum Communication"

In case of bit-1 (switch close, D_2 clicks), communication is counterfactual,
but for bit-0 (switch open), it is not counterfactual, because ....
Given a click at D_1, the probability for finding the photon
by a nondemolition measurement of the projection operator
on the transmission channel is one



H. Salih et.al. arXiv:1404.5392 [quant-ph]
(Phys. Rev. Lett. 112, 208902 (2014)
Reply to "Comment on Protocol for Direct
Counterfactual Quantum Communication"
Vaidman misunderstands principle of QM

L. Vaidman Phys. Rev. A 87, 052104
Past of a quantum particle

Z-H. Li, M. Al-Amri, and M. S Zubairy   Phys. Rev. A 88, 046102
Comment on "Past of a quantum particle"