Title: Counterfactual communication protocols

Date: Aug 03, 2018 11:30 AM

URL: http://pirsa.org/18070056

Abstract: Possibility to communicate between spatially separated regions, without even a single photon passing between the two parties, is an amazing quantum phenomenon. The possibility of transmitting one value of a bit in such a way, the interaction-free measurement, was known for quarter of a century. The protocols of full communication, including transmitting unknown quantum states were proposed only few years ago, but it was shown that in all these protocols the particle was leaving a weak trace in the transmission channel, the trace larger than the trace left by a single particle passing through the channel. However, a simple modification of these recent protocols eliminates the trace in the transmission channel and makes all these protocols truly counterfactual.

FOUNDATIONS OF QUANTUM MECHANICS

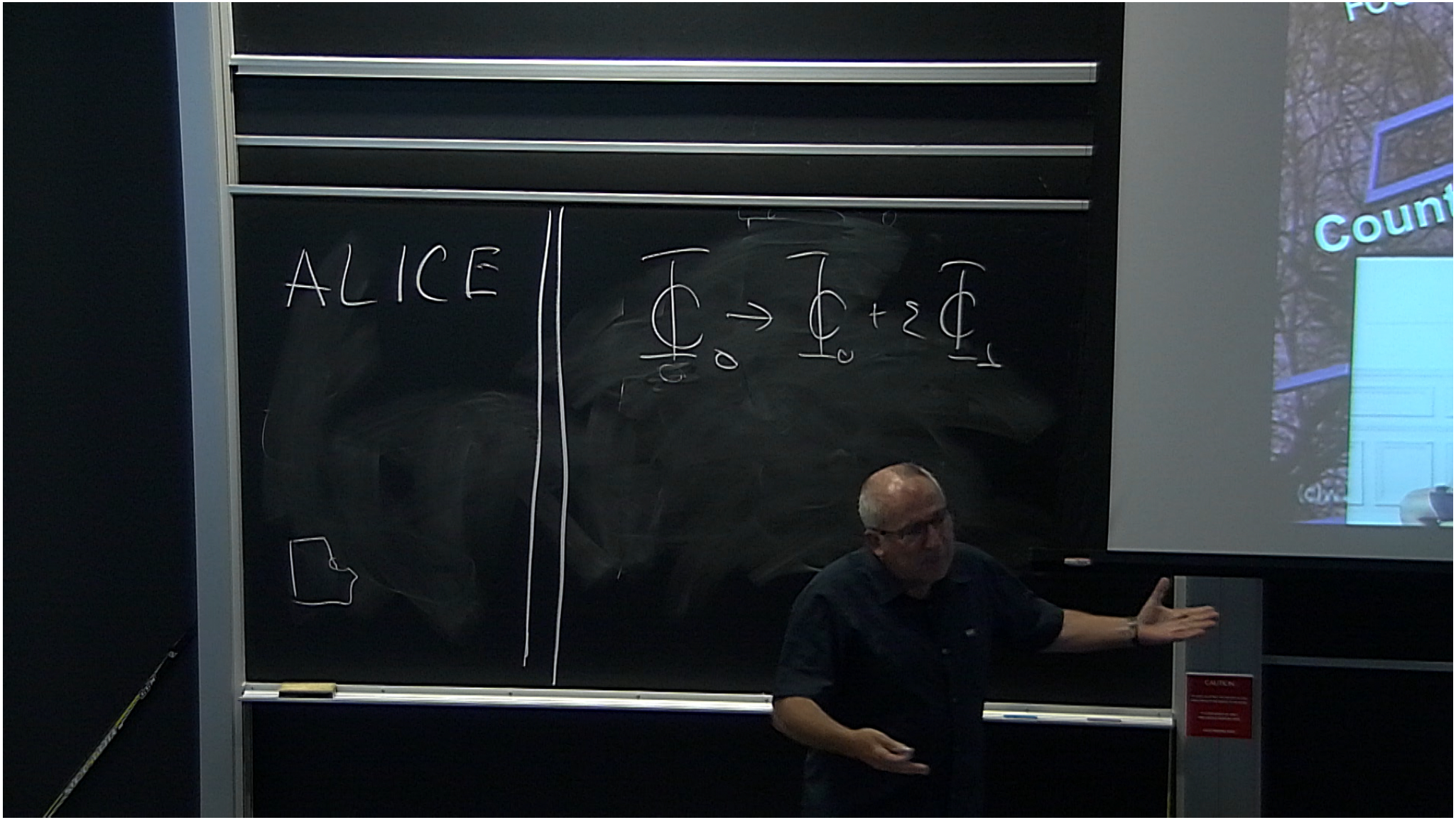
Counterfactual communication protocols

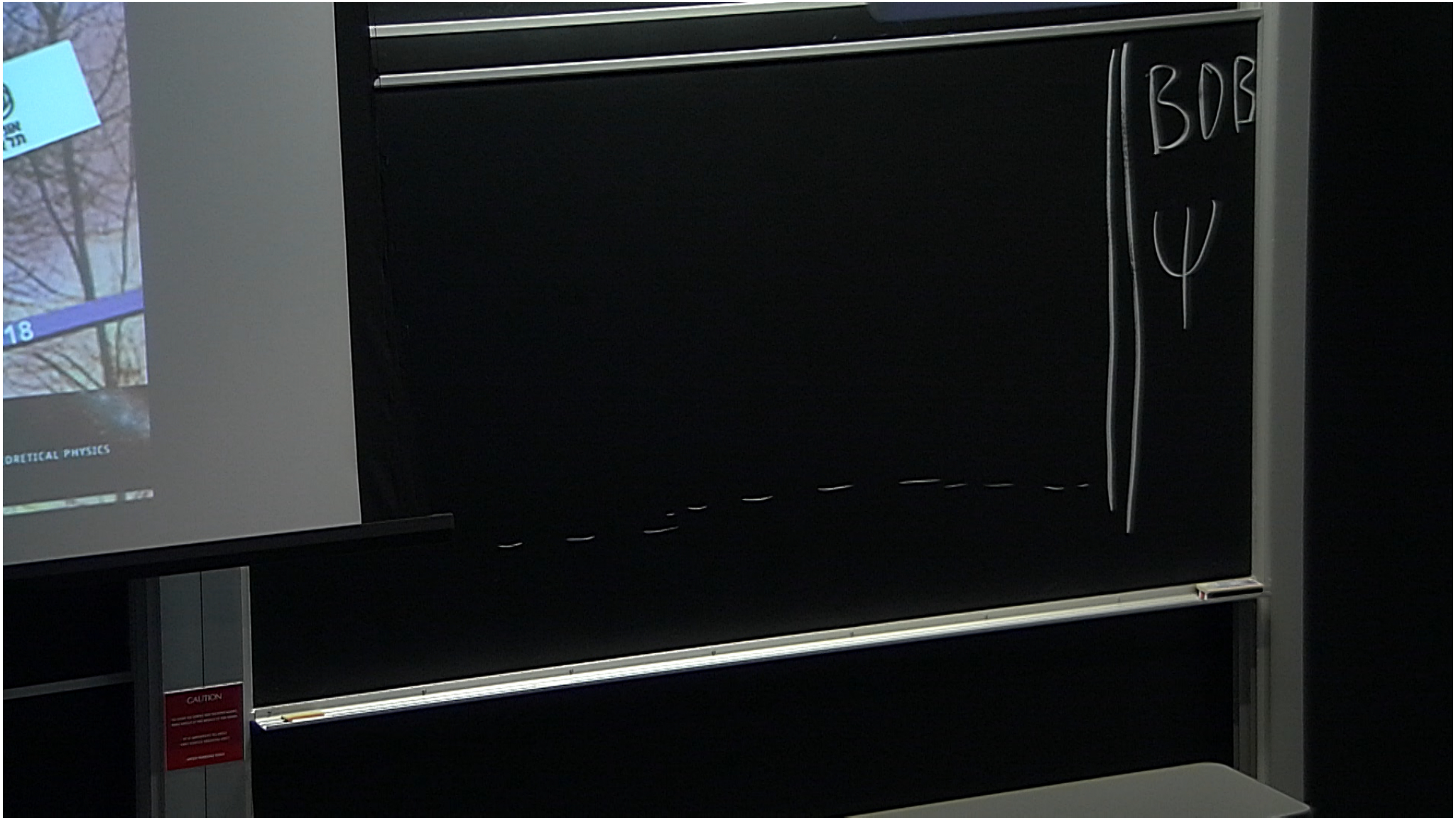
Lev Vaidman

TEL AVIV UNIVERSITY אוניברסיטת תל אביב

August 1, 2018

PERIMETER PI INSTITUTE FOR THEORETICAL PHYSICS


ALICE
Count


BOB
Ψ
CAUTION

Quantum counterfactual protocols

Counterfactual transmission of a quantum state: a new teleportation?

Interaction-free measurement of a presence of an object

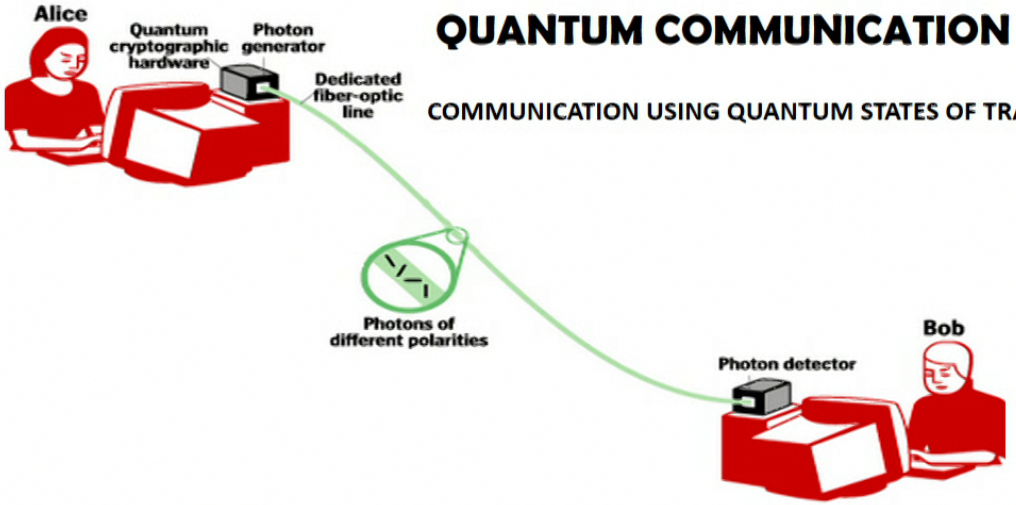
Interaction-free measurement of an absence of an object

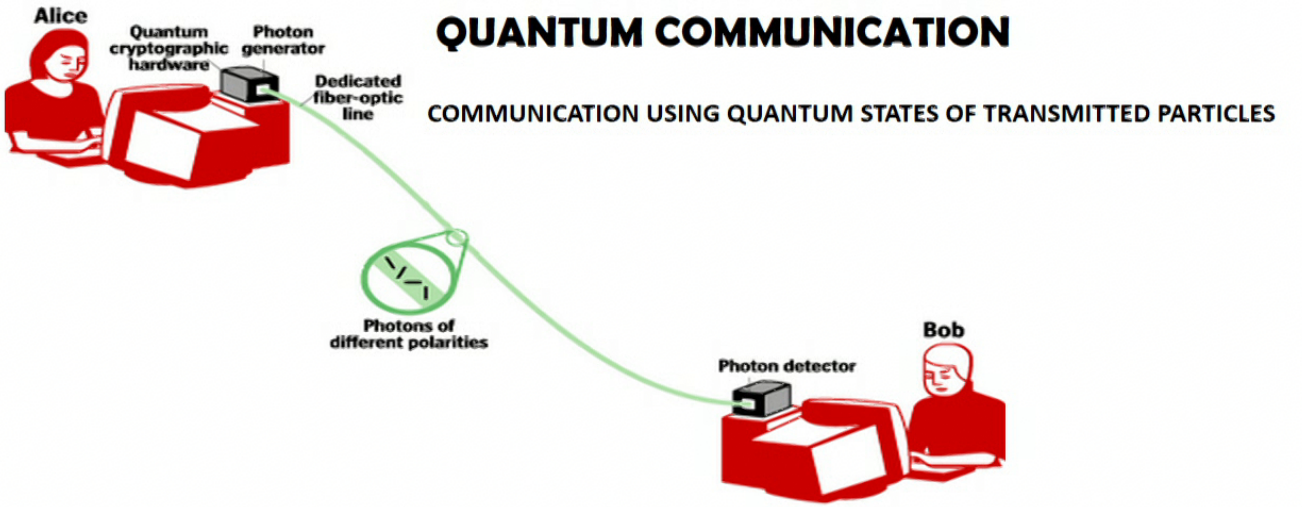
Adding quantum Zeno effect

Direct counterfactual communication

QUANTUM COMMUNICATION

COMMUNICATION USING QUANTUM STATES OF TRANSMITTED PARTICLES





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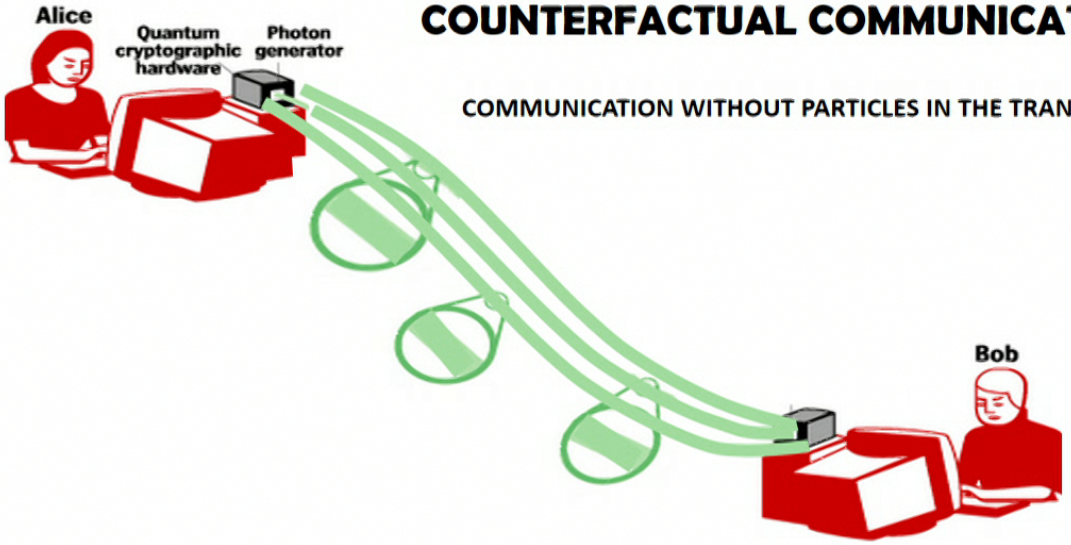

COUNTERFACTUAL COMMUNICATION

COMMUNICATION WITHOUT PARTICLES IN THE TRANSMITION CHANNEL

frontiers in Physics | Optics and Photonics

Counterfactual transmission of a quantum state: a new teleportation?

< Archive

arXiv:1404.2200 (2014)

ORIGINAL RESEARCH ARTICLE

Front. Phys., 26 January 2016 | http://dx.doi.org/10.3389/fphy.2015.00094

Protocol for Counterfactually Transporting an Unknown Qubit

Hatim Salih*

Independent Researcher, London, UK

Quantum teleportation circumvents the uncertainty principle using dual channels: a quantum one consisting of previously-shared entanglement, and a classical one, together allowing the disembodied transport of an unknown quantum state over distance. It has recently been shown that a classical bit can be counterfactually communicated between two parties in empty space, "Alice" and "Bob." Here, by using our "dual" version of the chained quantum Zeno effect to achieve a counterfactual CNOT gate, we propose the first protocol for transporting an unknown qubit counterfactually, that is without any physical particles traveling between Alice and Bob—no classical channel and no previously-shared entanglement.

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PHYSICAL REVIEW A **92**, 052315 (2015)

Counterfactual transmission of a quantum state: a new teleportation?

Direct counterfactual transmission of a quantum state

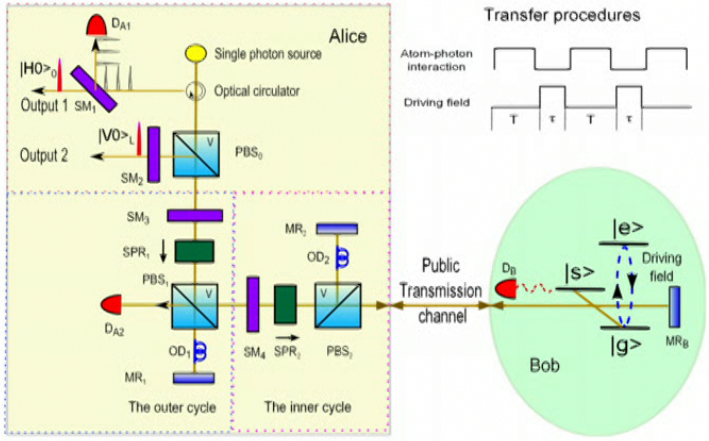
Zheng-Hong Li,[1,2] M. Al-Amri,[1,2] and M. Suhail Zubairy[1]

itute for Quantum Science and Engineering (IQSE) and Department of Physics and Astronomy, Texas A&M University, College Station, Texas 77843-4242, USA

[2]*The National Center for Applied Physics, KACST, P.O. Box 6086, Riyadh 11442, Saudi Arabia*

(Received 8 June 2015; revised manuscript received 27 September 2015; published 11 November 2015)

We show that an unknown quantum state can be transferred with neither quantum nor classical particle traveling in the transmission channel. Our protocol does not require prearranged entangled photon pairs and Bell measurements. By utilizing quantum Zeno effect and counterfactuality, we can entangle and disentangle a photon and an atom by nonlocal interaction. It is shown that quantum information is completely transferred from an atom to photon due to controllable disentanglement processes. There is no need to cross-check the result via classical channels.



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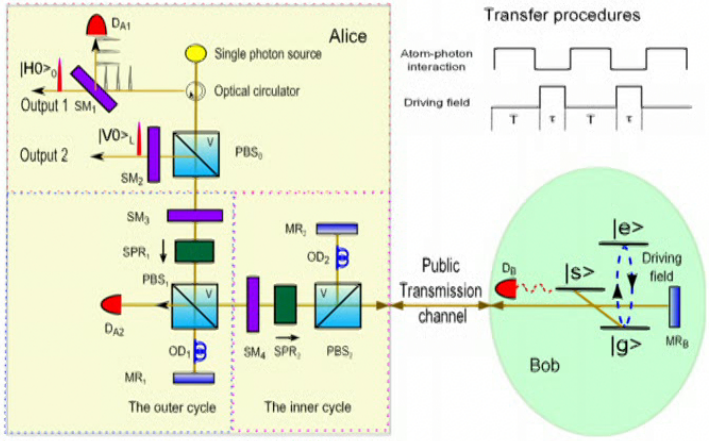

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Comment on "Direct counterfactual transmission of a quantum state"

L. Vaidman

Phys. Rev. A **93**, 066301 – Published 2 June 2016

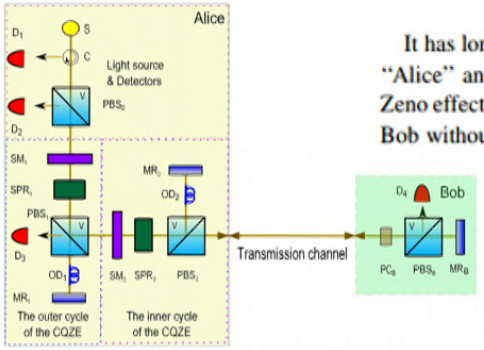
Protocol for Direct Counterfactual Quantum Communication

Hatim Salih,[1,*] Zheng-Hong Li,[1,2] M. Al-Amri,[1,2] and M. Suhail Zubairy[2]

[1]*The National Center for Mathematics and Physics, KACST, P.O. Box 6086, Riyadh 11442, Saudi Arabia*

[2]*Institute for Quantum Science and Engineering (IQSE) and Department of Physics and Astronomy, Texas A&M University, College Station, Texas 77843-4242, USA*

(Received 1 January 2013; published 23 April 2013)



It has long been assumed in physics that for information to travel between tw es 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.

PRL 110, 170502 (2013) PHYSICAL REVIEW LETTERS week ending 26 APRIL 2013

Protocol for Direct Counterfactual Quantum Communication

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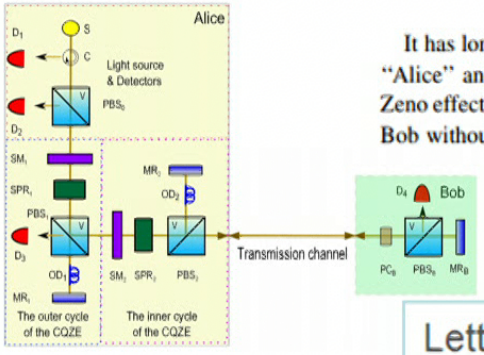


Letter

Nature **439**, 949-952 (23 February 2006) | doi:10.1038/nature04523

Counterfactual quantum computation through quantum interrogation

Onur Hosten[1], Matthew T. Rakher[1,2], Julio T. Barreiro[1], Nicholas A. Peters[1] and Paul G. Kwiat[1]

The logic underlying the coherent nature of quantum information processing often deviates from intuitive reasoning, leading to surprising effects. Counterfactual computation constitutes a striking example: the potential outcome of a quantum computation can be inferred, even if the computer is not run[1]. Relying on similar arguments to interaction-free

Counterfactual Quantum Cryptography

Tae-Gon Noh (노태곤)
Phys. Rev. Lett. **103**, 230501 – Published 1 December 2009

Quantum cryptography allows one to distribute a secret key between two remote parties using the fundamental principles of quantum mechanics. The well-known established paradigm for the quantum key distribution relies on the actual transmission of signal particle through a quantum channel. In this Letter, we show that the task of a secret key distribution can be accomplished even though a particle carrying secret information is not in fact transmitted through the quantum channel. The proposed protocols can be implemented with current technologies and provide practical security advantages by eliminating the possibility that an eavesdropper can directly access the entire quantum system of each signal particle.

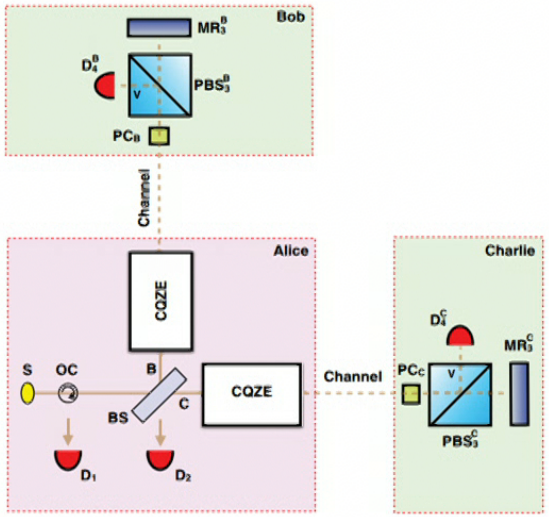
PHYSICAL REVIEW A **90**, 012333 (2014)

Tripartite counterfactual quantum cryptography

Hatim Salih*
Qubet Research, London NW6 1RE, United Kingdom
(Received 22 April 2014; published 24 July 2014)

We show how two distrustful parties, "Bob" and "Charlie," can share a secret key with the help of a mutually trusted "Alice" counterfactually; that is, with no information-carrying particles traveling between any of the three.

DOI: 10.1103/PhysRevA.90.012333 PACS number(s): 03.67.Dd, 03.67.Hk, 03.65.Ta



Experimental Realization of High-Efficiency Counterfactual Computation

Fei Kong,[1] Chenyong Ju,[1,2,*] Pu Huang,[1,2] Pengfei Wang,[1,2] Xi Kong,[1,2] Fazhan Shi,[1,2] Liang Jiang,[3,†] and Jiangfeng Du[1,2,‡]

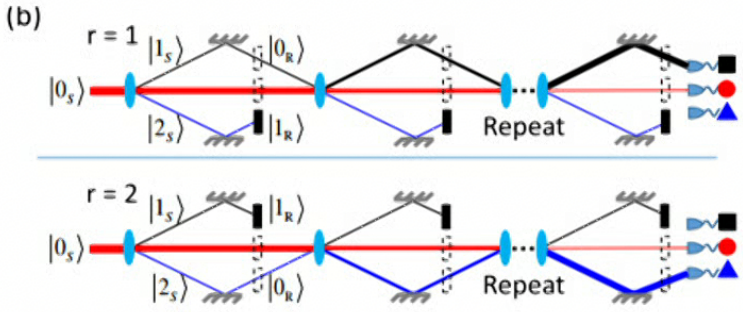
[1]*Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China*

[2]*Synergetic Innovation Center of Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei 230026, China*

[3]*Department of Applied Physics, Yale University, New Haven, Connecticut 06511, USA*

(Received 5 January 2015; published 21 August 2015)

Counterfactual computation (CFC) exemplifies the fascinating quantum process by which the result of a computation may be learned without actually running the computer. In previous experimental studies, the counterfactual efficiency is limited to below 50%. Here we report an experimental realization of the generalized CFC protocol, in which the counterfactual efficiency can break the 50% limit and even approach unity in principle. The experiment is performed with the spins of a negatively charged nitrogen-vacancy color center in diamond. Taking advantage of the quantum Zeno effect, the computer can remain in the not-running subspace due to the frequent projection by the environment, while the computation result can be revealed by final detection. The counterfactual efficiency up to 85% has been demonstrated in our experiment, which opens the possibility of many exciting applications of CFC, such as high-efficiency quantum integration and imaging.



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Quantum counterfactual communication without a weak trace

D. R. M. Arvidsson-Shukur and C. H. W. Barnes
Phys. Rev. A **94**, 062303 – Published 5 December 2016

Institution: KEK

Proceedings of the National Academy of Sciences of the United States of America

PNAS

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> Current Issue > vol. 114 no. 19 > Yuan Cao, 4920–4924, doi: 10.1073/pnas.1614560114

Check for updates

Direct counterfactual communication via quantum Zeno effect

Yuan Cao[a,b,1], Yu-Huai Li[a,b,1], Zhu Cao[c], Juan Yin[a,b], Yu-Ao Chen[a,b], Hua-Lei Yin[a,b], Teng-Yun Chen[a,b], Xiongfeng Ma[c], Cheng-Zhi Peng[a,b,2], and Jian-Wei Pan[a,b,2]

This Issue

May 9, 2017
vol. 114 no. 19
Masthead (PDF)
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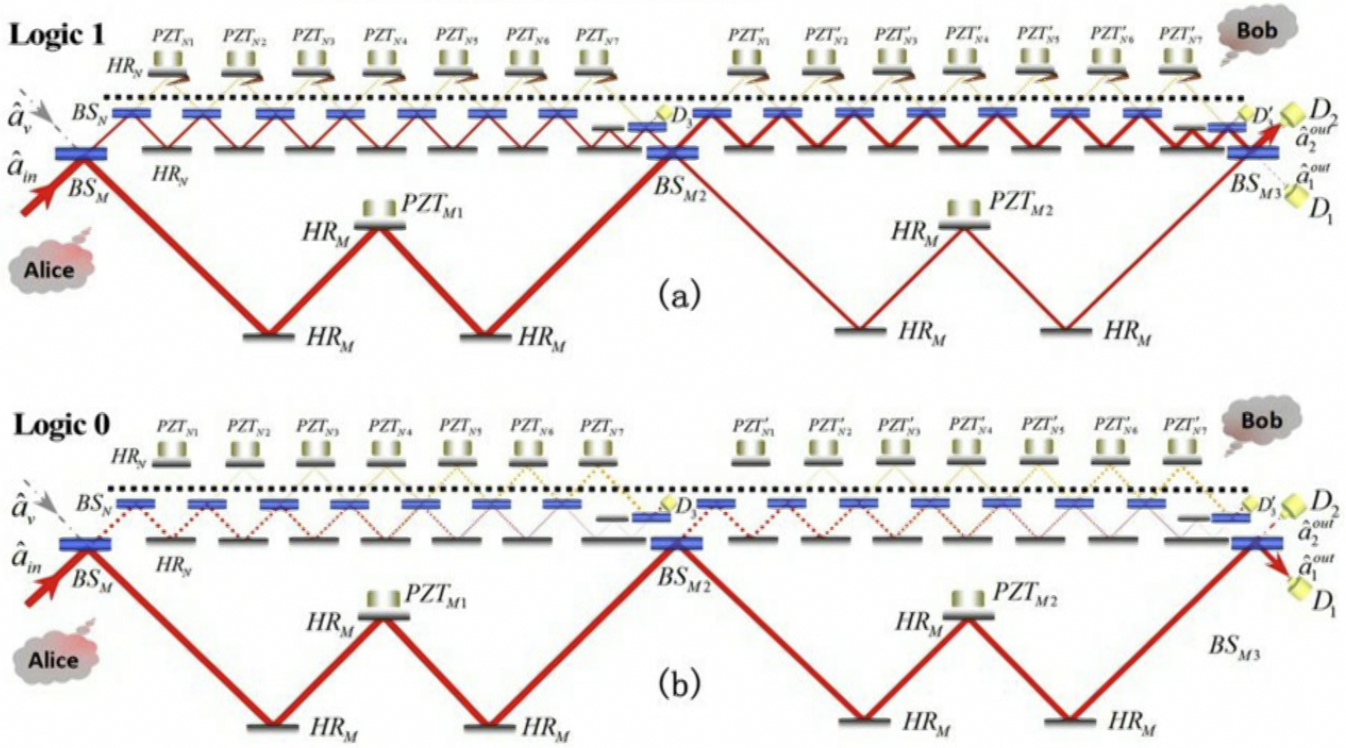
SCIENTIFIC REPORTS

Article | OPEN | Published: 07 September 2017

The Experimental Demonstration of High Efficiency Interaction-free Measurement for Quantum Counterfactual-like Communication

Chao Liu, Jinhong Liu, Junxiang Zhang & Shiyao Zhu



Counterfactuals are things that might have happened, although they did not in fact happen.

R. Penrose: *Shadows of the Mind* (1994)

Interaction-free measurement

A. Elitzur and L. Vaidman
Found. Phys. **23**, 987 (1993) .

BOMB: explodes when any particle “touches” it

interacts only through explosion

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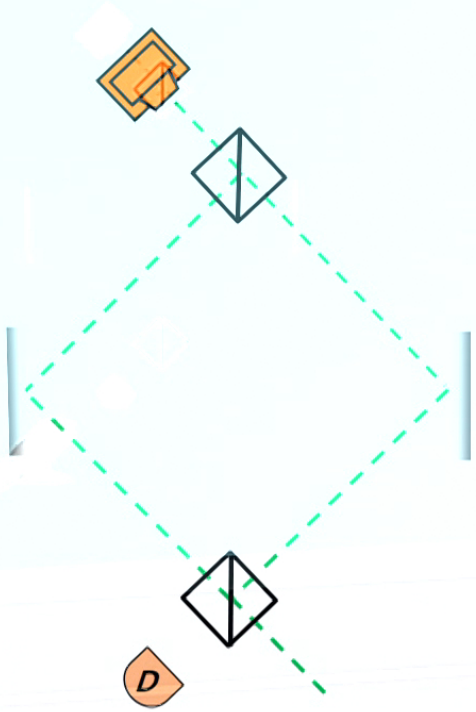

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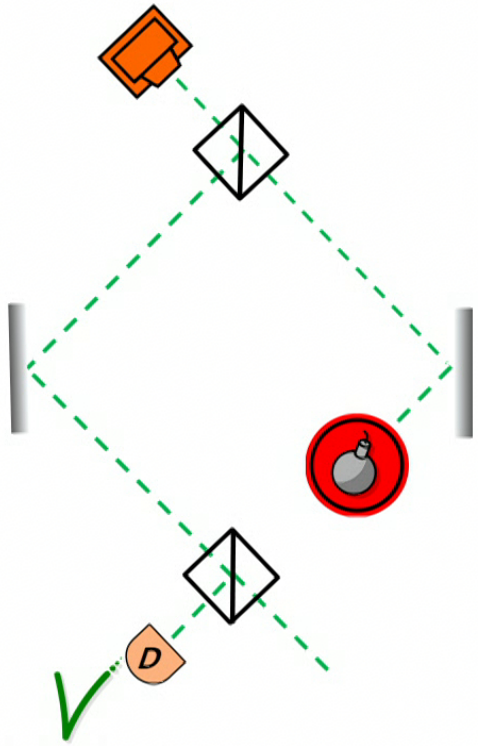
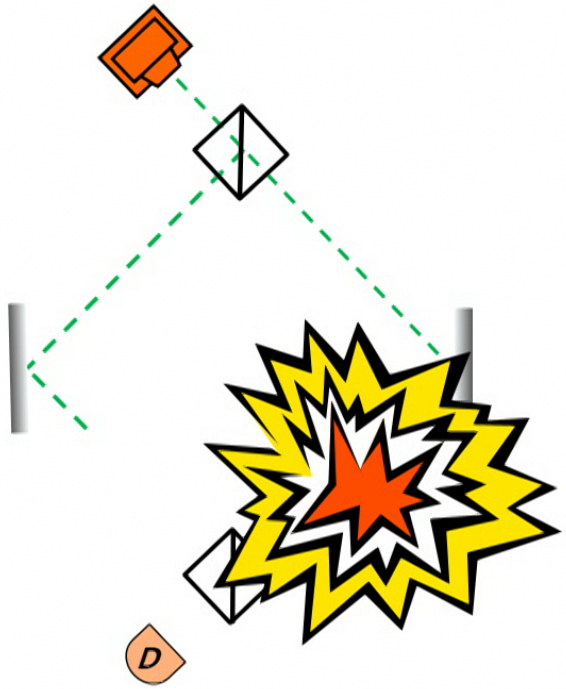


We know that the bomb is there
but the photon was not there

Interaction-free measurement



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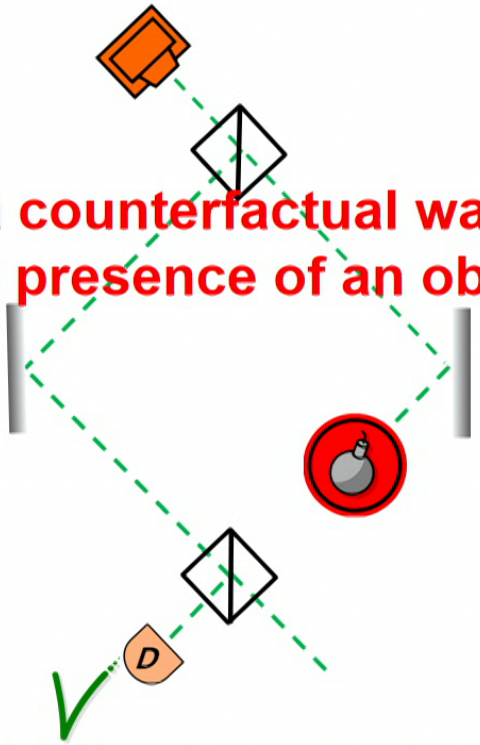
Interaction-free measurement

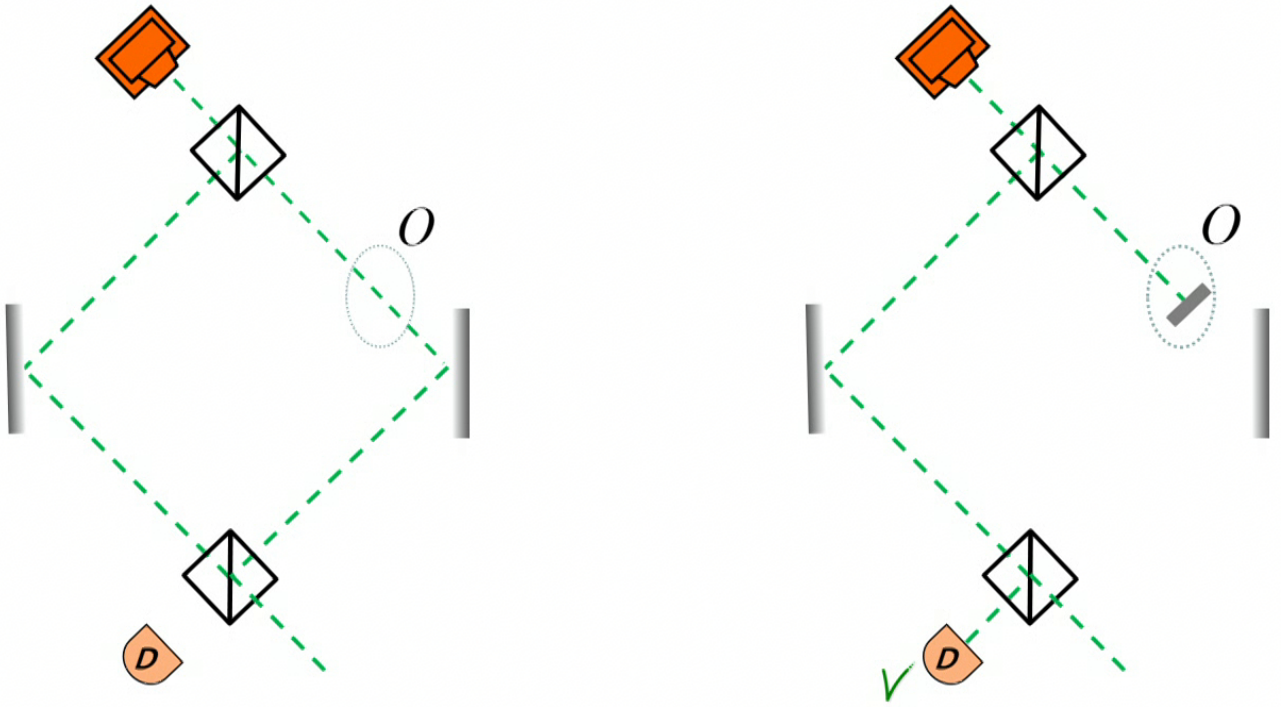


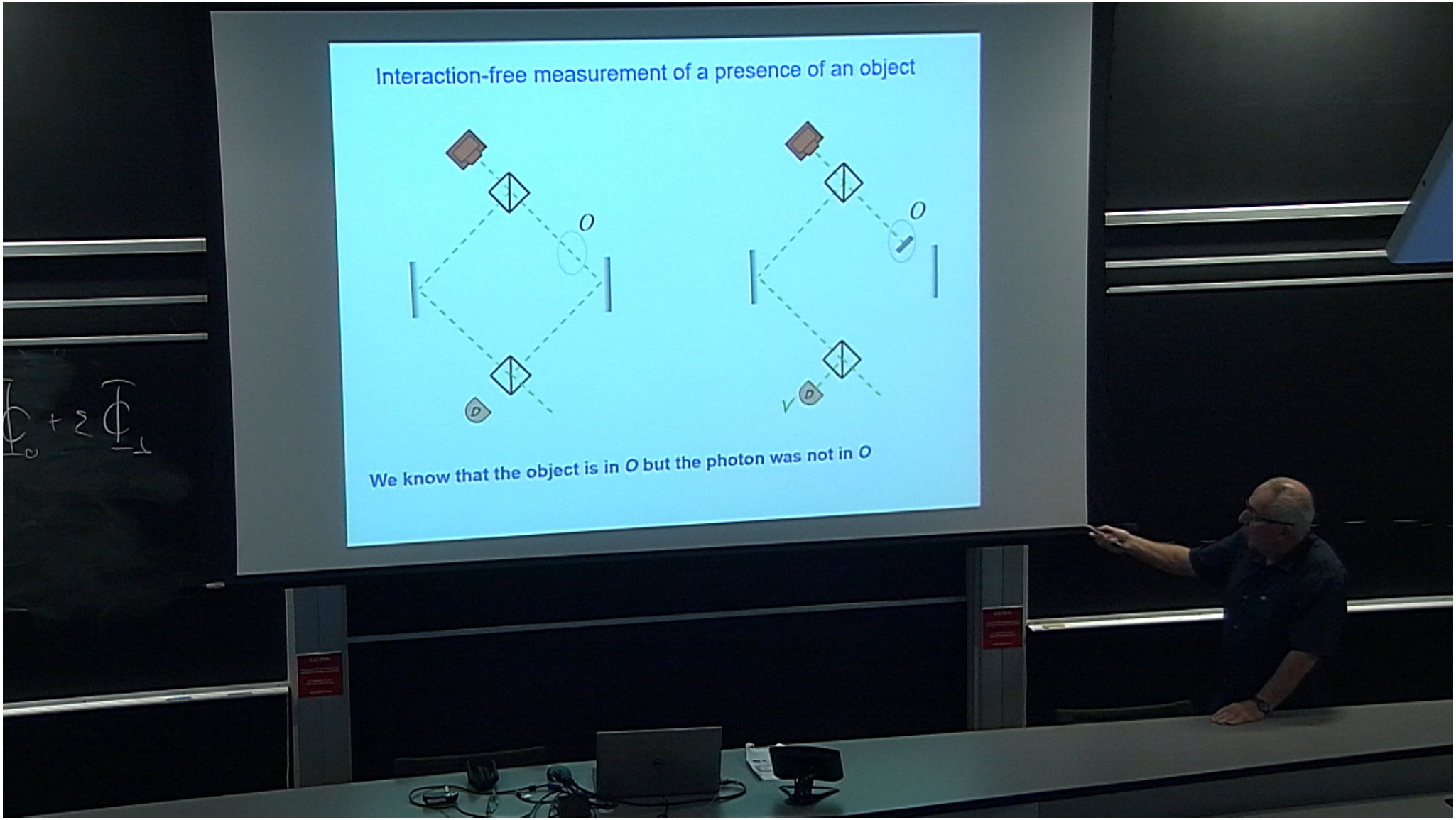
IFM is a counterfactual way to find the presence of an object

We know that the bomb is there but the photon was not there

It could have been there

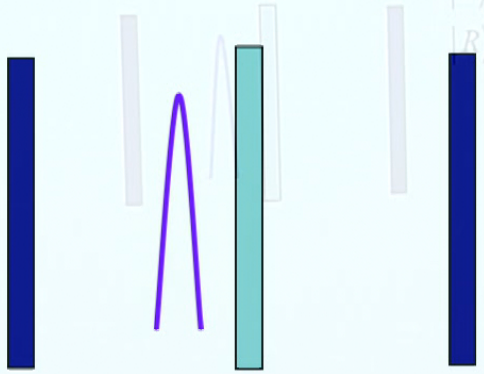
Interaction-free measurement of a presence of an object




Interaction-free measurement of a presence of an object
O
D
O
D
We know that the object is in O but the photon was not in O

Efficient IFM (Zeno Effect)

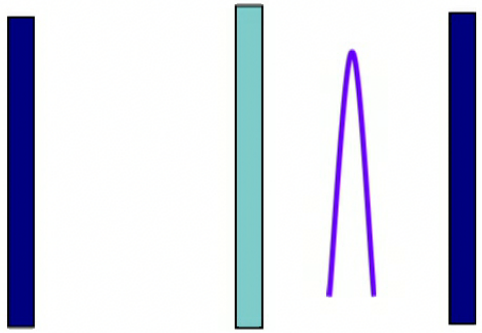
Kwiat et al, PRL 83, 4725 (1999).



$$|L\rangle \rightarrow \cos\alpha\,|L\rangle + \sin\alpha\,|R\rangle,$$
$$|R\rangle \rightarrow -\sin\alpha\,|L\rangle + \cos\alpha\,|R\rangle$$

Efficient IFM (Zeno Effect)

Kwiat et al, PRL 83, 4725 (1999).



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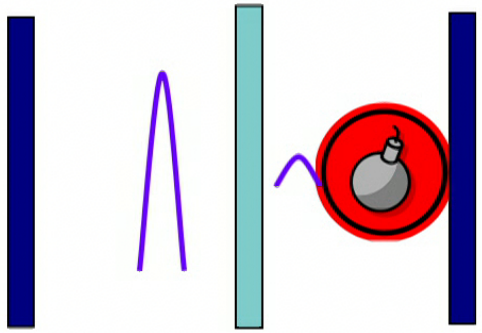
$$|L\rangle \rightarrow \cos\alpha\,|L\rangle + \sin\alpha\,|R\rangle \quad \rightarrow \cos 2\alpha\,|L\rangle + \sin 2\alpha\,|R\rangle$$

$$\rightarrow \cos k\alpha\,|L\rangle + \sin k\alpha\,|R\rangle \quad \rightarrow |R\rangle$$

$$K\alpha = \frac{\pi}{2}$$

Efficient IFM (Zeno Effect)

Kwiat et al, PRL 83, 4725 (1999).

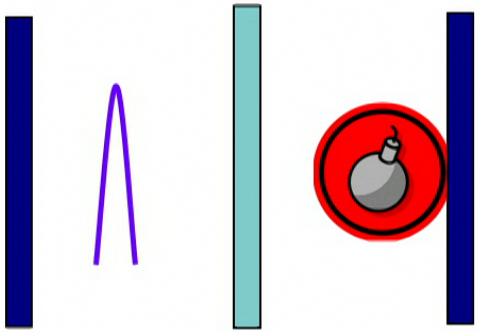


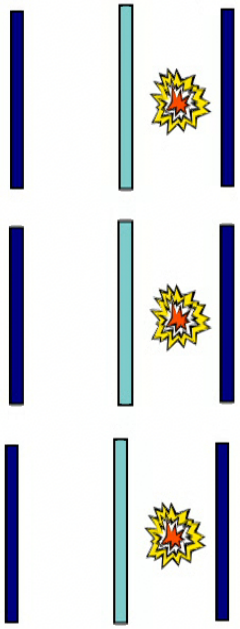
$$|L\rangle \rightarrow \cos\alpha\,|L\rangle + \sin\alpha\,|\otimes_1\rangle$$

$$\rightarrow \cos\alpha\left(\cos\alpha\,|L\rangle + \sin\alpha\,|\otimes_2\rangle\right) + \sin\alpha\,|\otimes_1\rangle$$

Efficient IFM (Zeno Effect)

Kwiat et al, PRL 83, 4725 (1999).





$$|L\rangle \rightarrow \cos\alpha\,|L\rangle + \sin\alpha\,|\otimes_1\rangle$$

$$\rightarrow \cos\alpha\left(\cos\alpha\,|L\rangle + \sin\alpha\,|\otimes_2\rangle\right) + \sin\alpha\,|\otimes_1\rangle$$

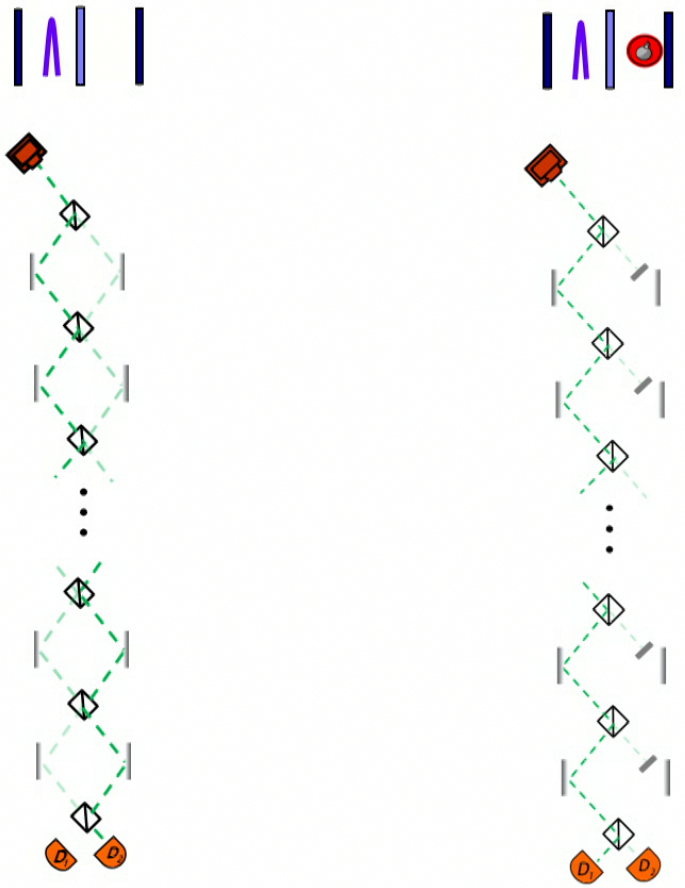
$$\rightarrow \cos\alpha\left[\cos\alpha\left(\cos\alpha\,|L\rangle + \sin\alpha\,|\otimes_3\rangle\right) + \sin\alpha\,|\otimes_2\rangle\right] + \sin\alpha\,|\otimes_1\rangle \ldots$$

$$K\alpha = \frac{\pi}{2}$$

$$\rightarrow \cos^K\alpha\,|L\rangle + \sum_i c_i\,|\otimes_i\rangle$$

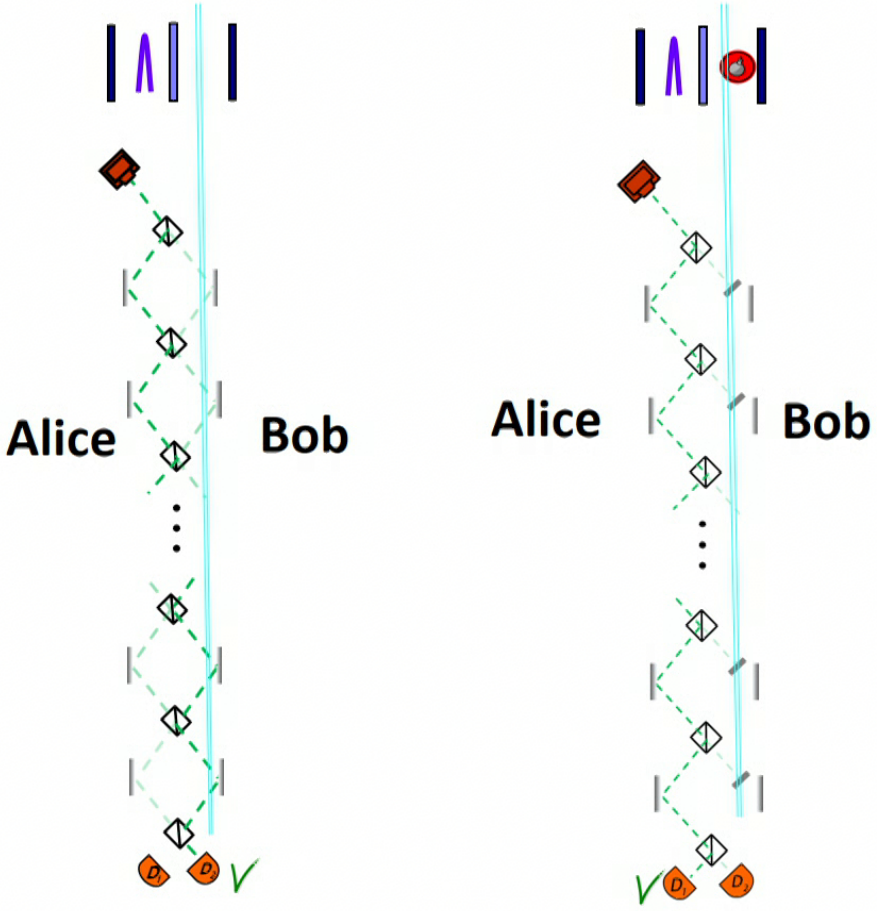
$$\cos^{2K}\frac{\pi}{2K} \simeq 1 - \frac{\pi^2}{4K}$$

Efficient IFM (Zeno Effect)



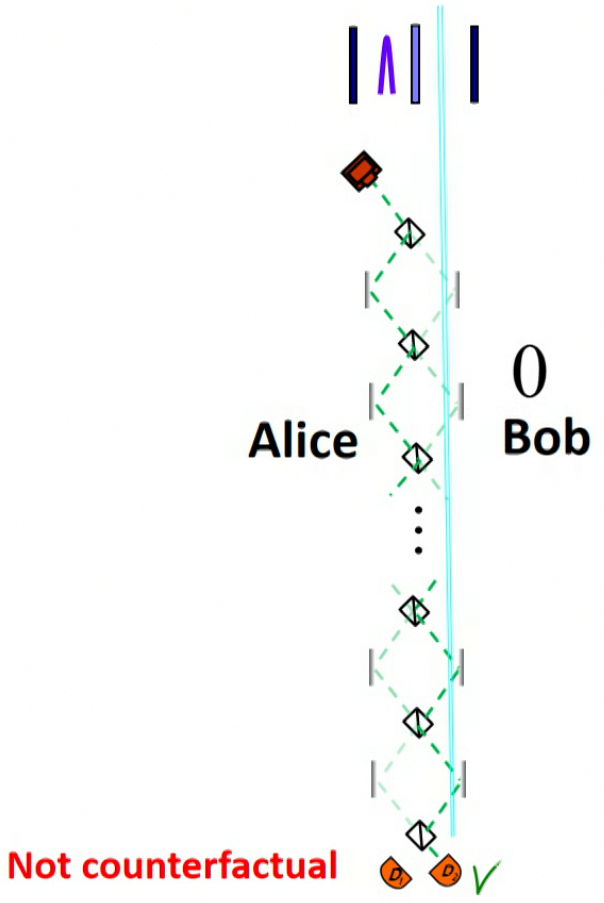
Efficient IFM (Zeno Effect)

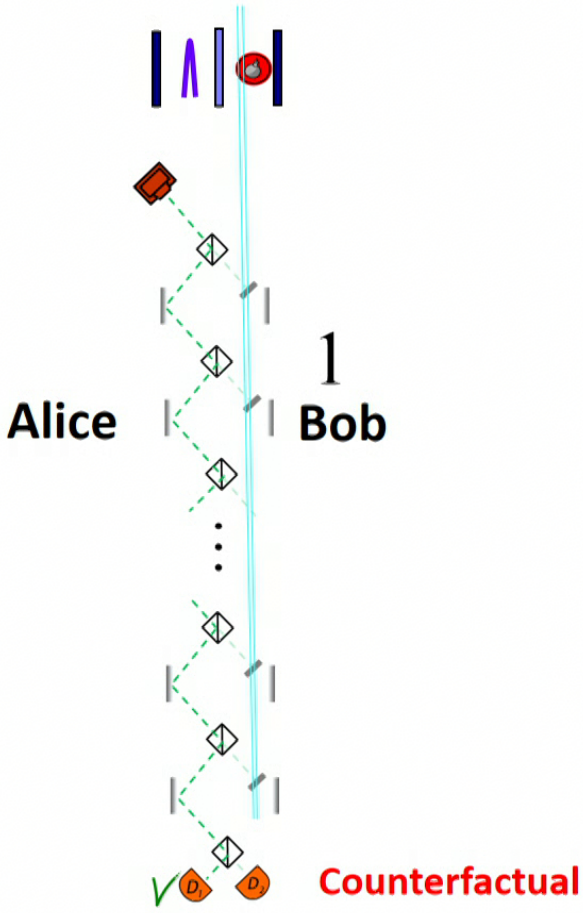
Counterfactual detection of an object



Efficient IFM (Zeno Effect)

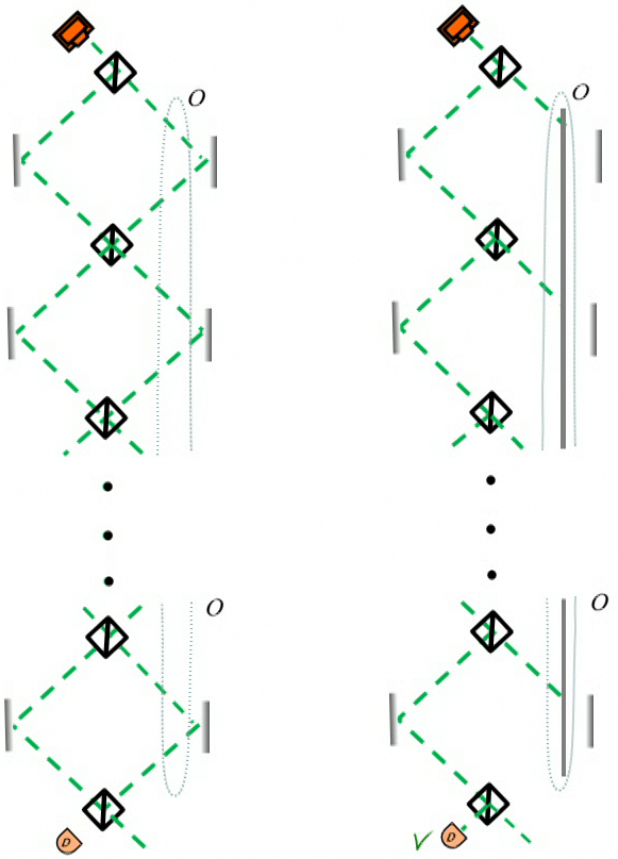
Counterfactual communication of one bit value





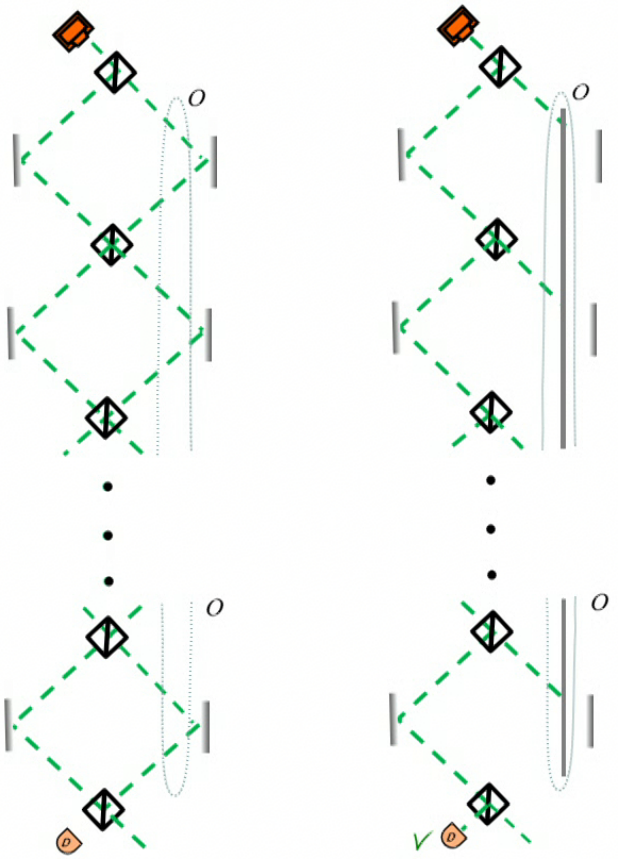
Efficient Interaction-free measurement

IFM of a presence of an object

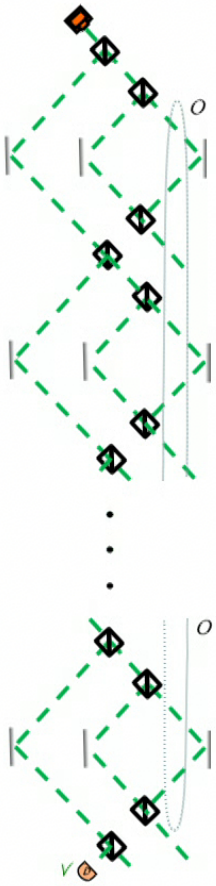


Efficient Interaction-free measurement

IFM of a presence of an object



IFM of an absence of an object



Efficient Interaction-free measurement

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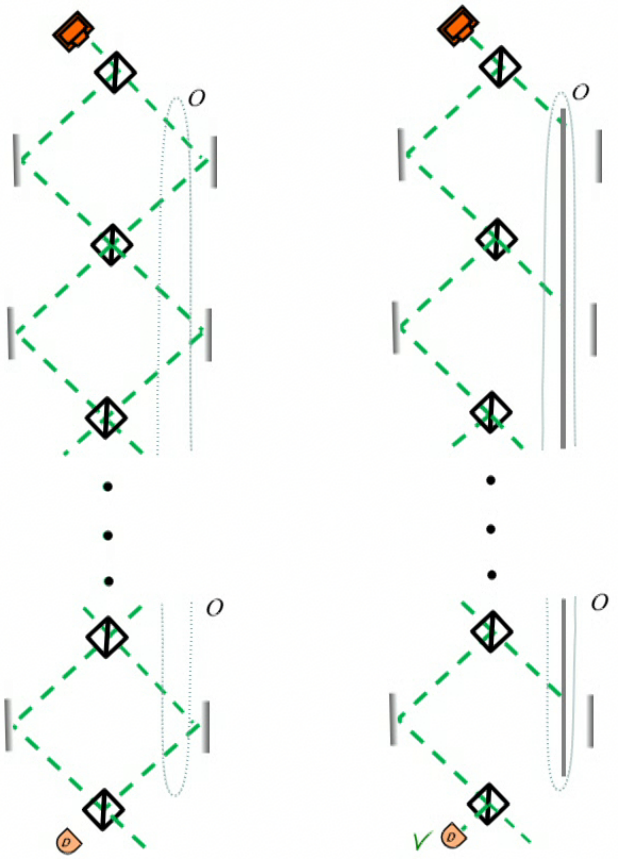
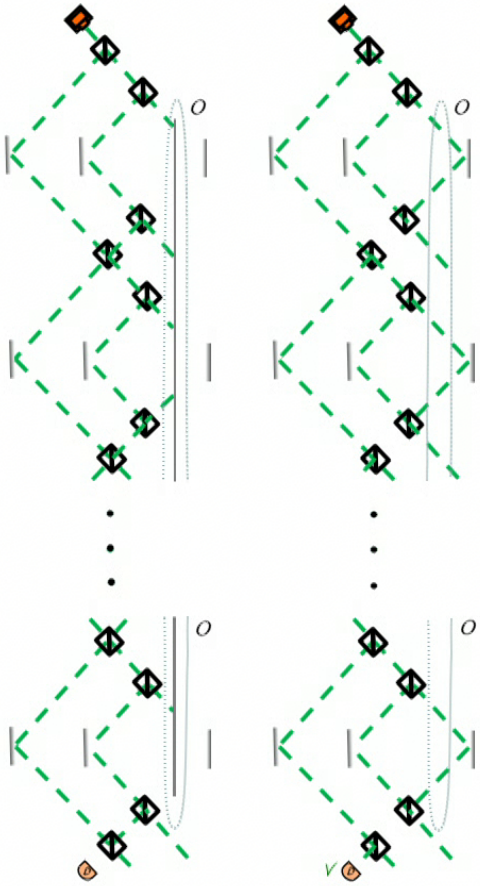
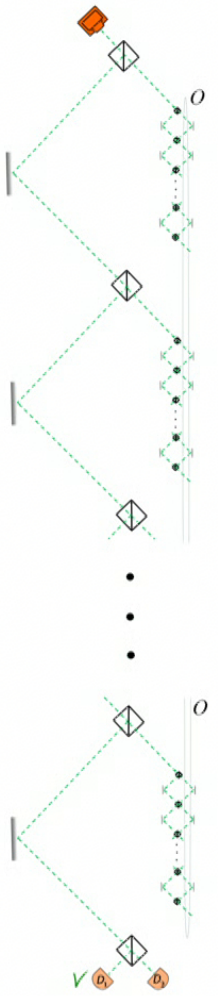


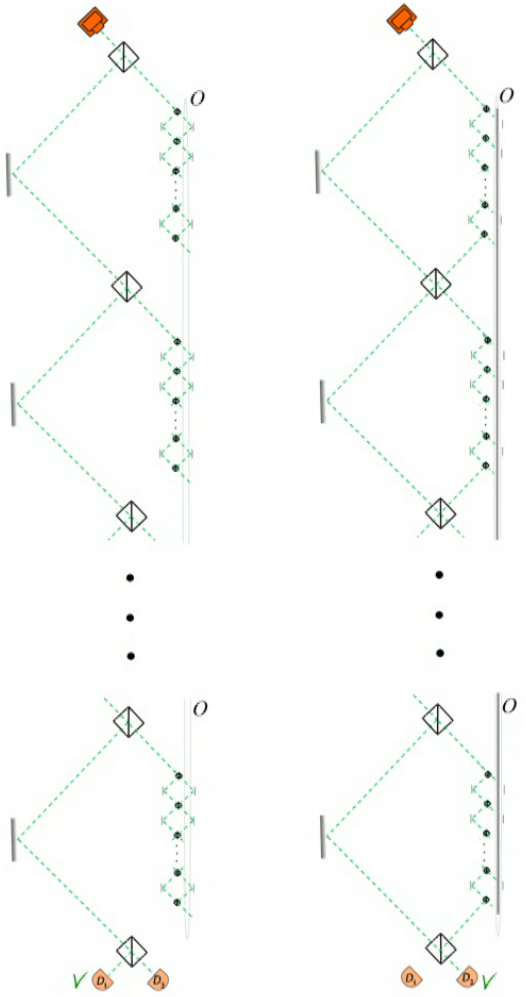
IFM of an absence of an object



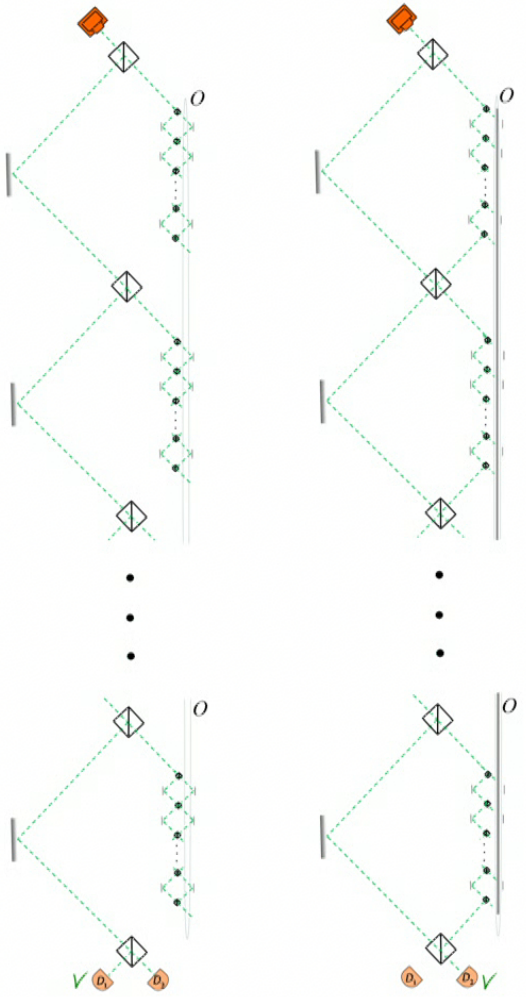
Efficient counterfactual communication



Efficient counterfactual communication

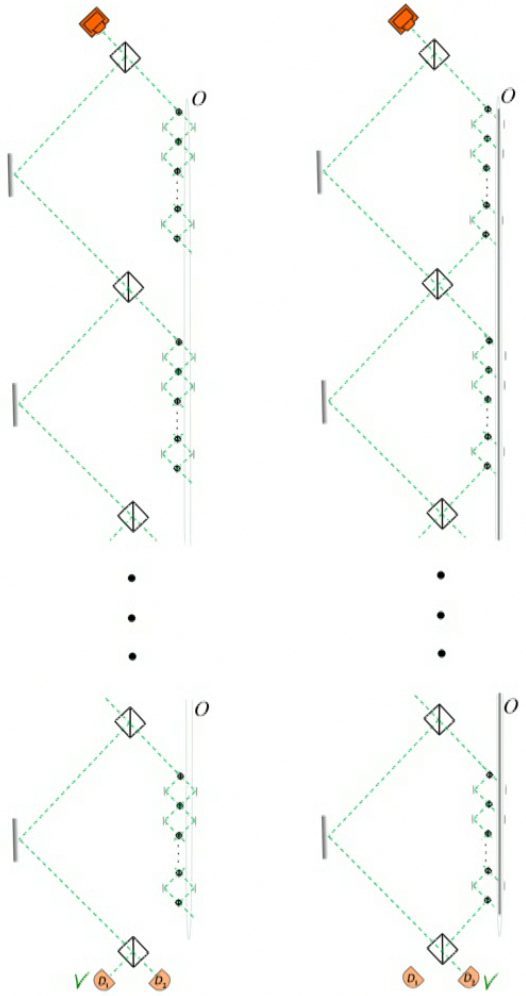


Efficient counterfactual communication



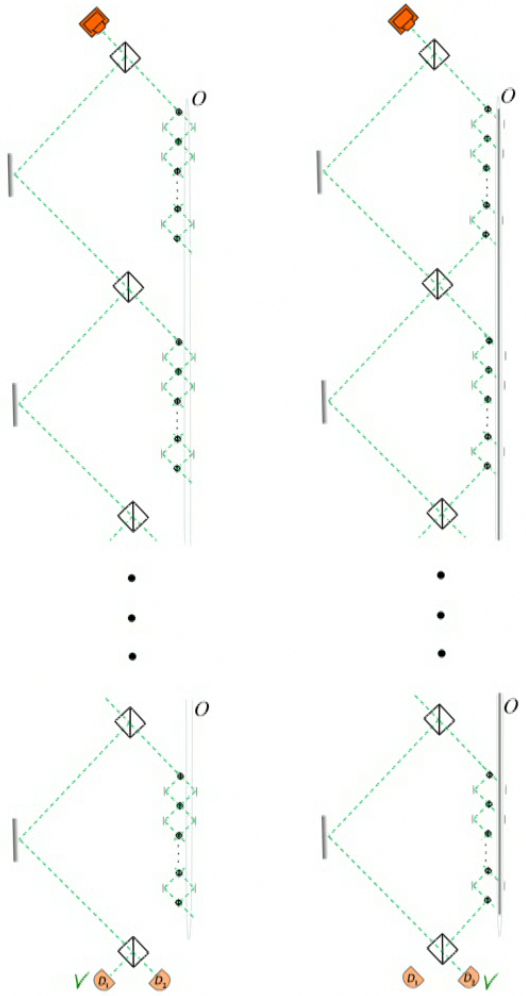
$$|R\rangle_A|1\rangle_B \rightarrow |1\rangle_A|1\rangle_B$$
$$|R\rangle_A|0\rangle_B \rightarrow |0\rangle_A|0\rangle_B$$

Direct counterfactual transmission of a quantum state



$$|R\rangle_A|1\rangle_B \rightarrow |1\rangle_A|1\rangle_B$$
$$|R\rangle_A|0\rangle_B \rightarrow |0\rangle_A|0\rangle_B$$
$$|\psi\rangle_B = \alpha|1\rangle_B + \beta|0\rangle_B$$
$$|R\rangle_A|\psi\rangle_B \rightarrow \alpha|1\rangle_A|1\rangle_B + \beta|0\rangle_A|0\rangle_B$$

Direct counterfactual transmission of a quantum state



$$|R\rangle_A|1\rangle_B \rightarrow |1\rangle_A|1\rangle_B$$
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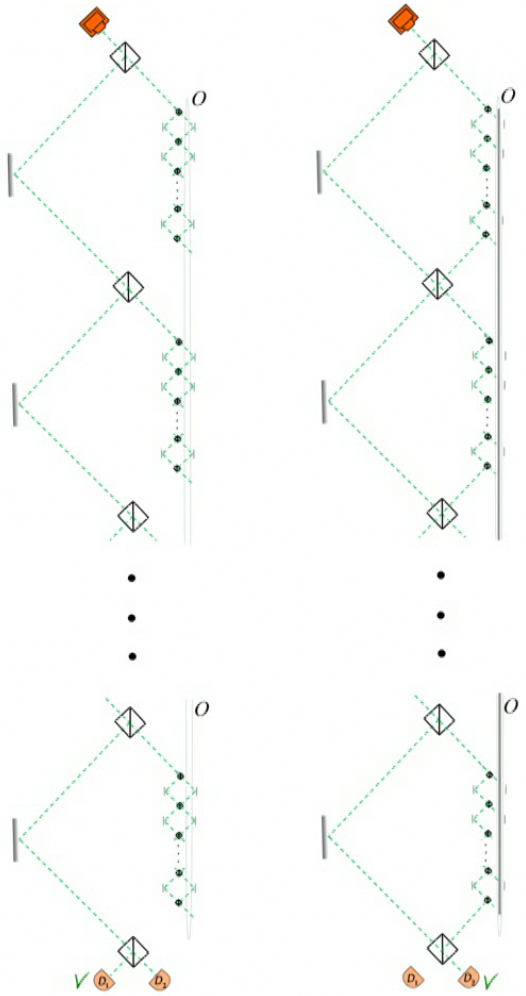
$$|R\rangle_A|\psi\rangle_B \rightarrow \alpha|1\rangle_A|1\rangle_B + \beta|0\rangle_A|0\rangle_B$$

Time reversal + Alice ↔ Bob

$$\alpha|1\rangle_A|1\rangle_B + \beta|0\rangle_A|0\rangle_B \rightarrow |\psi\rangle_A|R\rangle_B$$

Direct counterfactual transmission of a quantum state



$$|R\rangle_A|1\rangle_B \rightarrow |1\rangle_A|1\rangle_B$$
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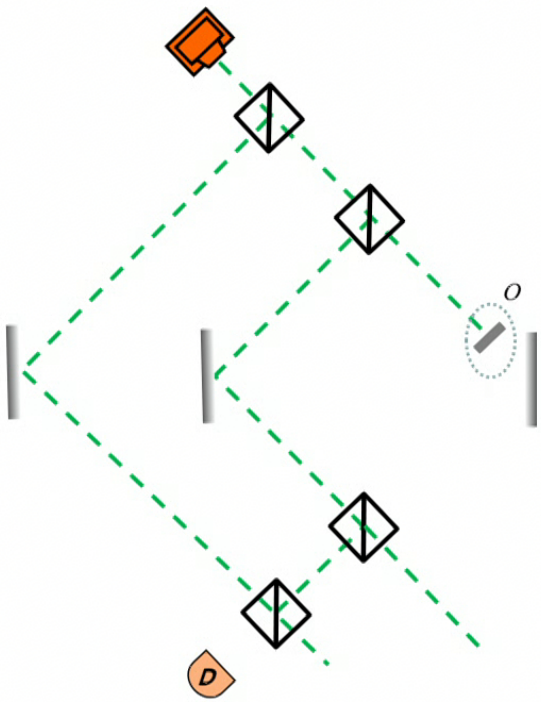
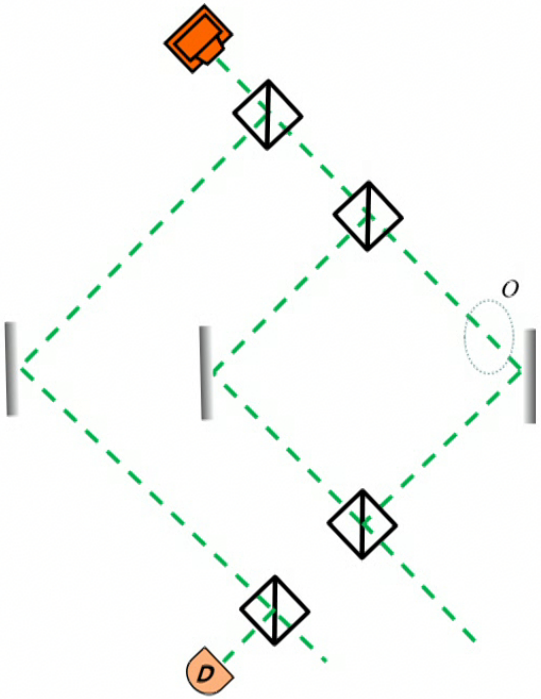
Time reversal + Alice ↔ Bob

$$\alpha|1\rangle_A|1\rangle_B + \beta|0\rangle_A|0\rangle_B \rightarrow |\psi\rangle_A|R\rangle_B$$

$$|R\rangle_A|\psi\rangle_B \rightarrow |\psi\rangle_A|R\rangle_B$$

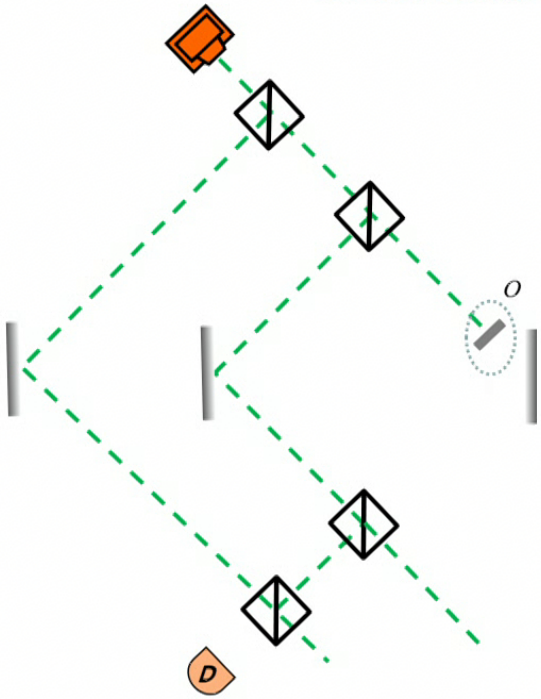
Interaction-free measurement of an absence of an object

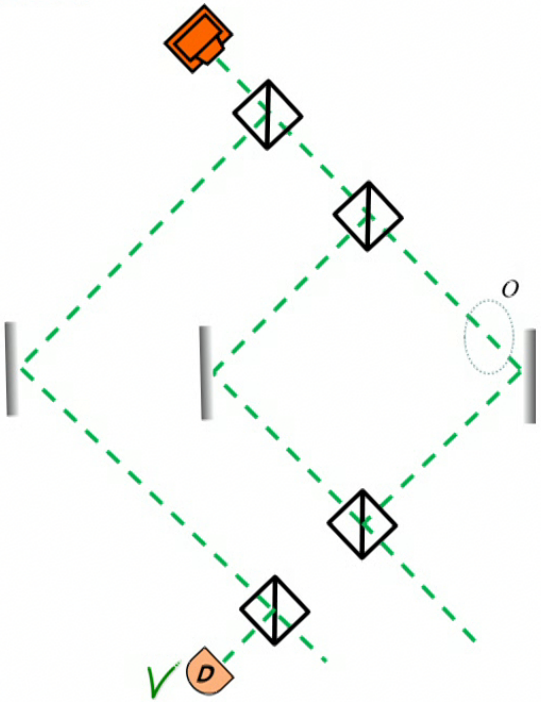




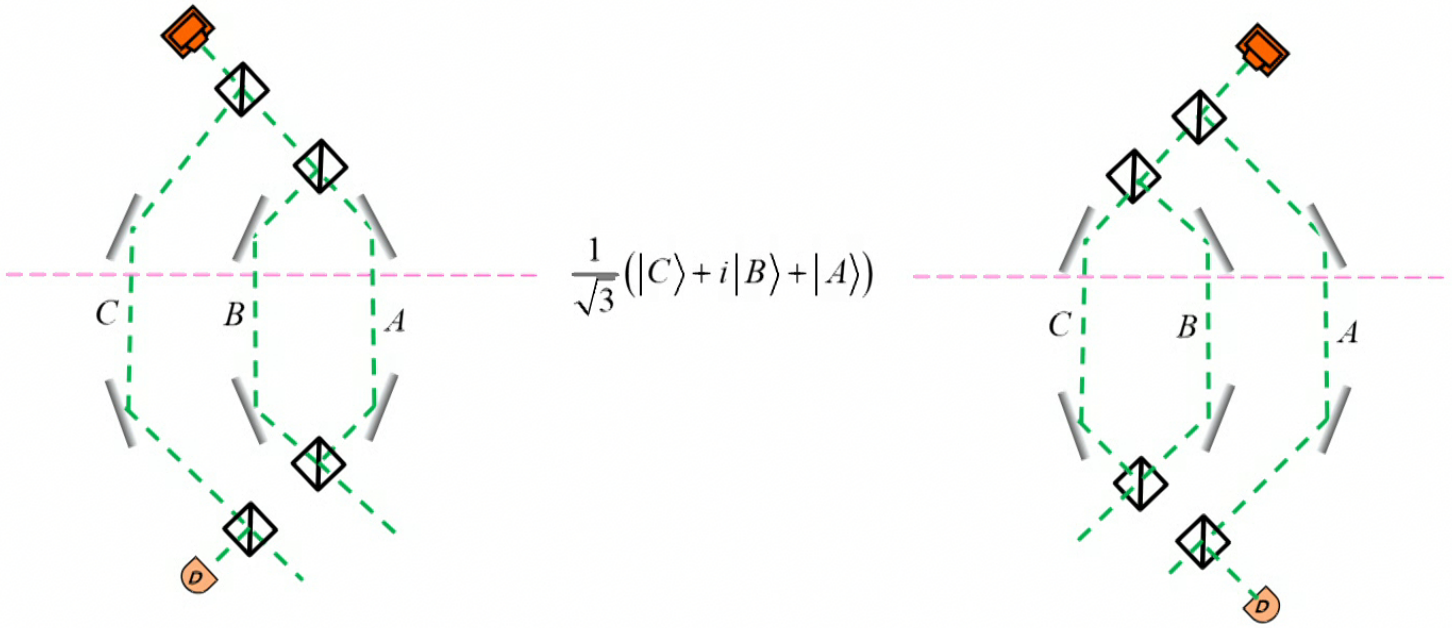
Interaction-free measurement of an absence of an object

Is it really interaction-free?

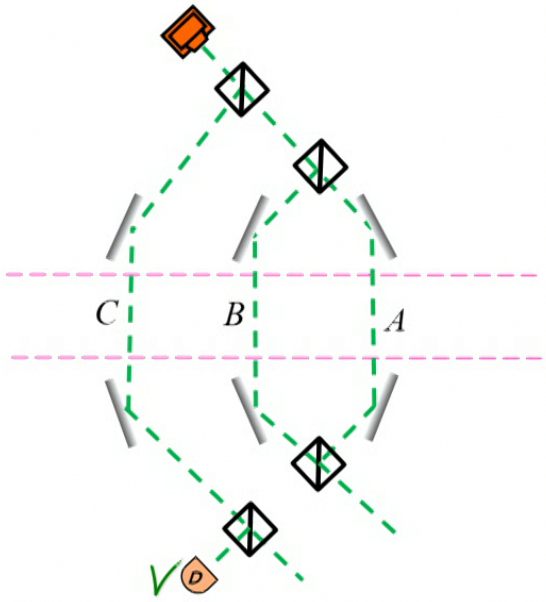




Paradox

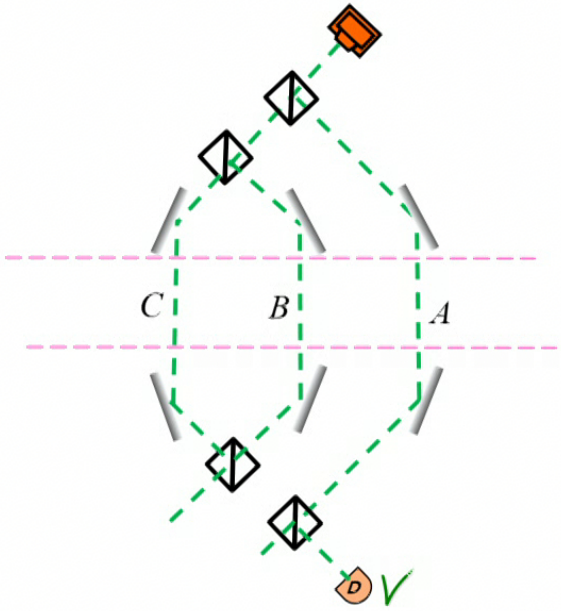


Paradox

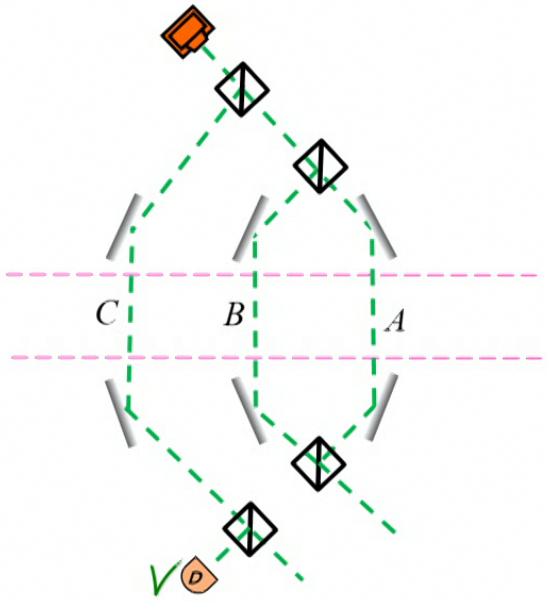


$$\frac{1}{\sqrt{3}}\left(|C\rangle + i|B\rangle + |A\rangle\right)$$

$$\frac{1}{\sqrt{3}}\left(|C\rangle - i|B\rangle + |A\rangle\right)$$

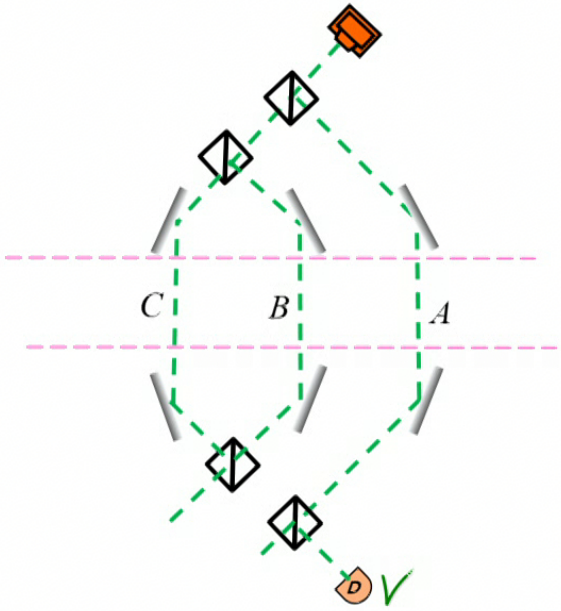


Paradox



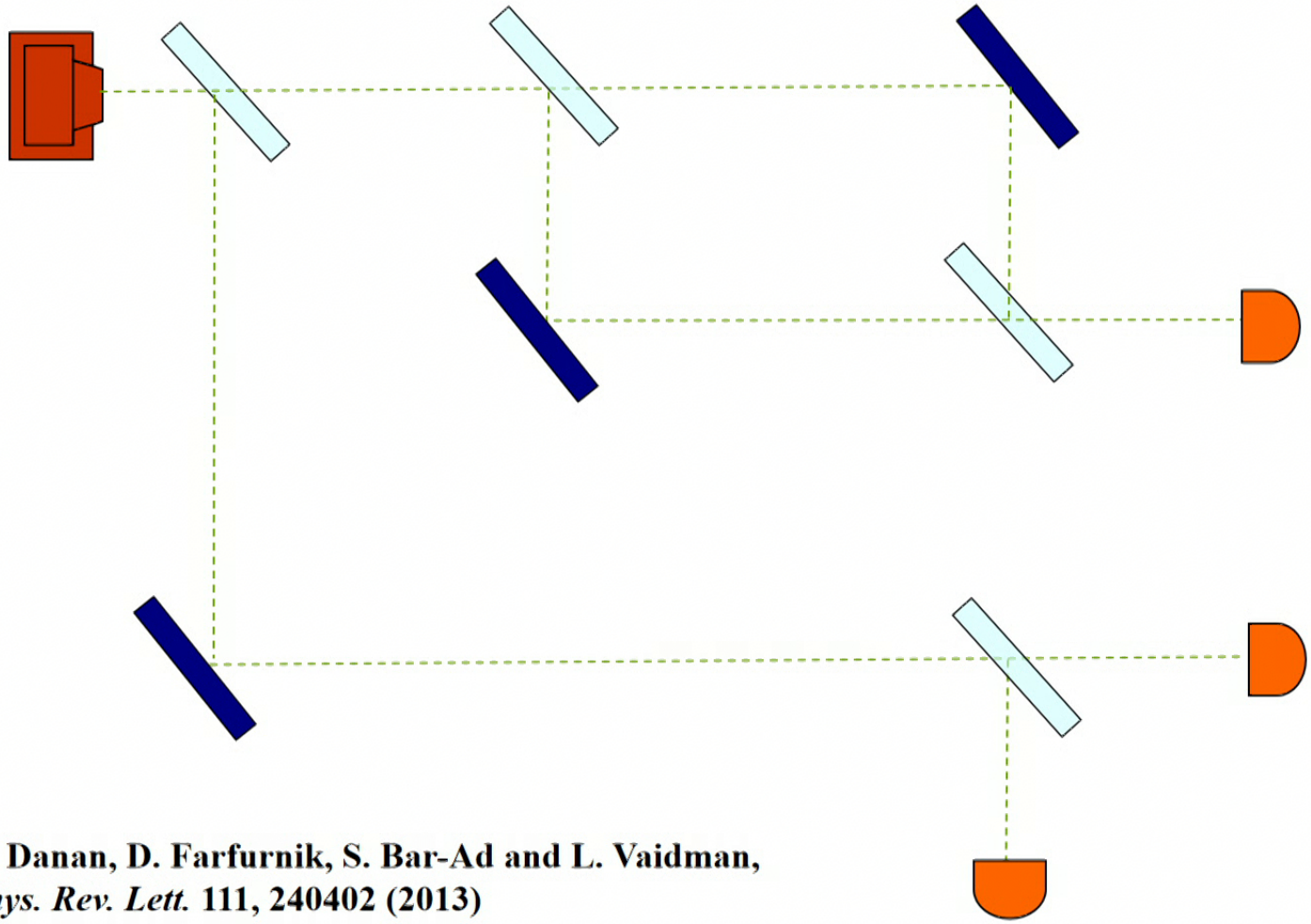
$$\frac{1}{\sqrt{3}}\left(|C\rangle + i|B\rangle + |A\rangle\right)$$

$$\frac{1}{\sqrt{3}}\left(|C\rangle - i|B\rangle + |A\rangle\right)$$



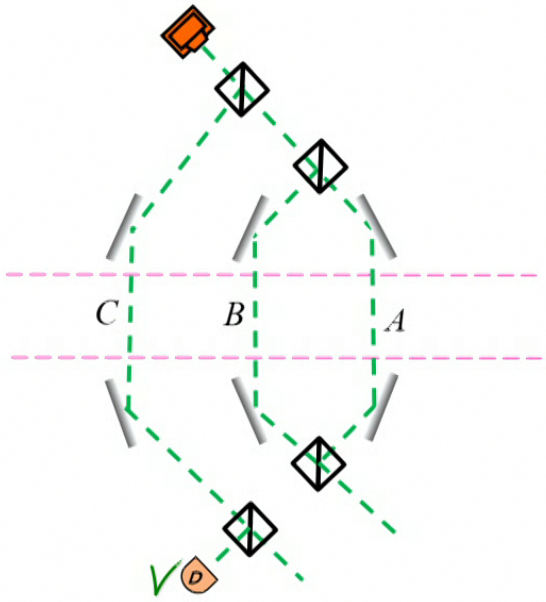
Wheeler: photon was in C

Asking photons where have they been



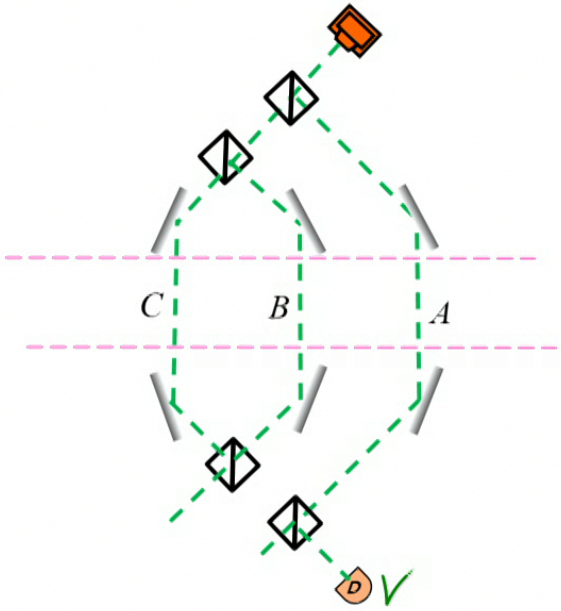
A. Danan, D. Farfurnik, S. Bar-Ad and L. Vaidman,
Phys. Rev. Lett. 111, 240402 (2013)

Paradox



$$\frac{1}{\sqrt{3}}\left(|C\rangle + i|B\rangle + |A\rangle\right)$$

$$\frac{1}{\sqrt{3}}\left(|C\rangle - i|B\rangle + |A\rangle\right)$$

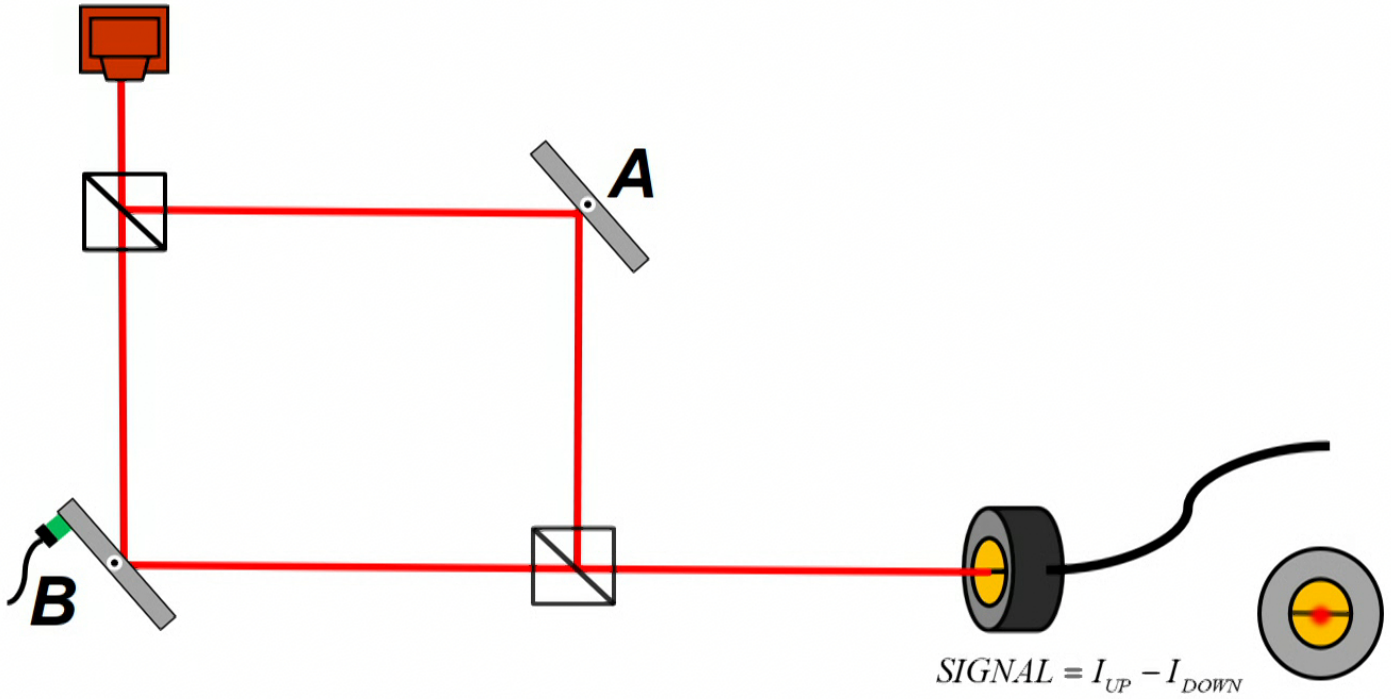


Wheeler: photon was in *C*

Wheeler: photon was in *A*

Quantum description is symmetric between *A* and *C*

Asking photons where have they been



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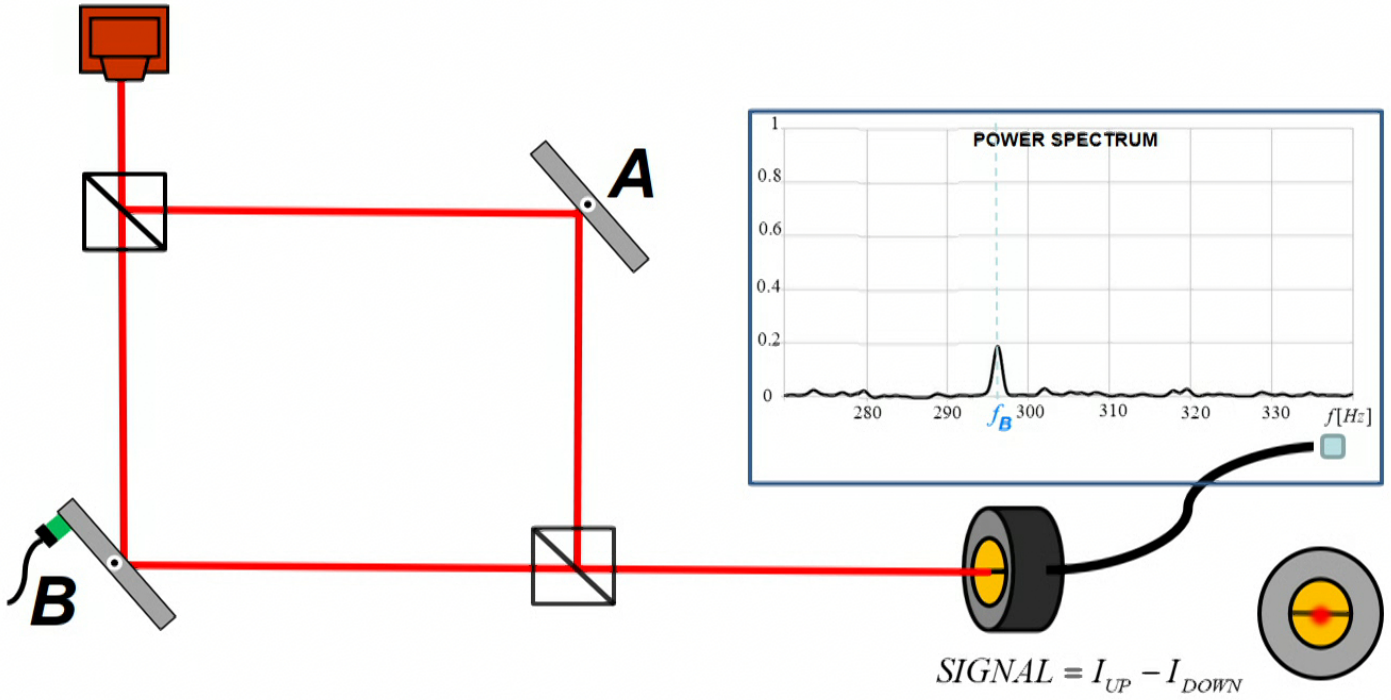
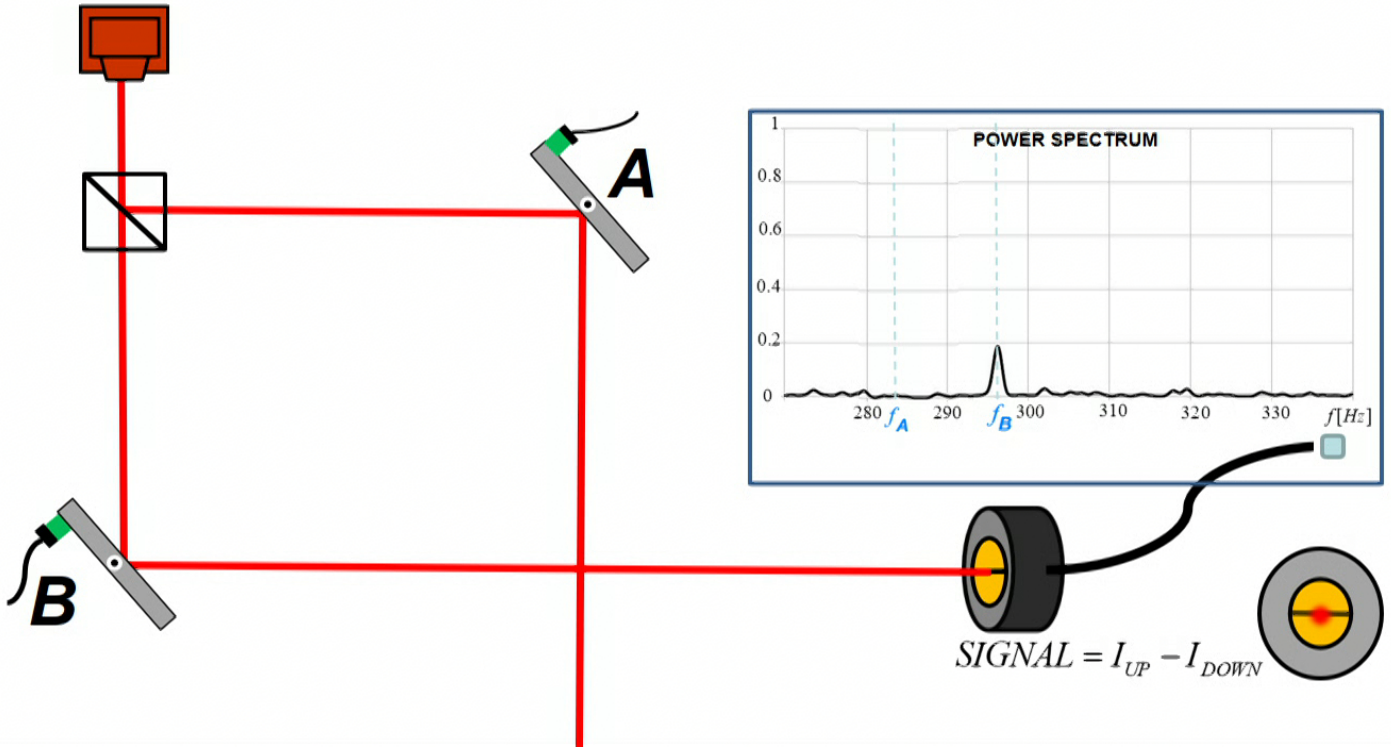
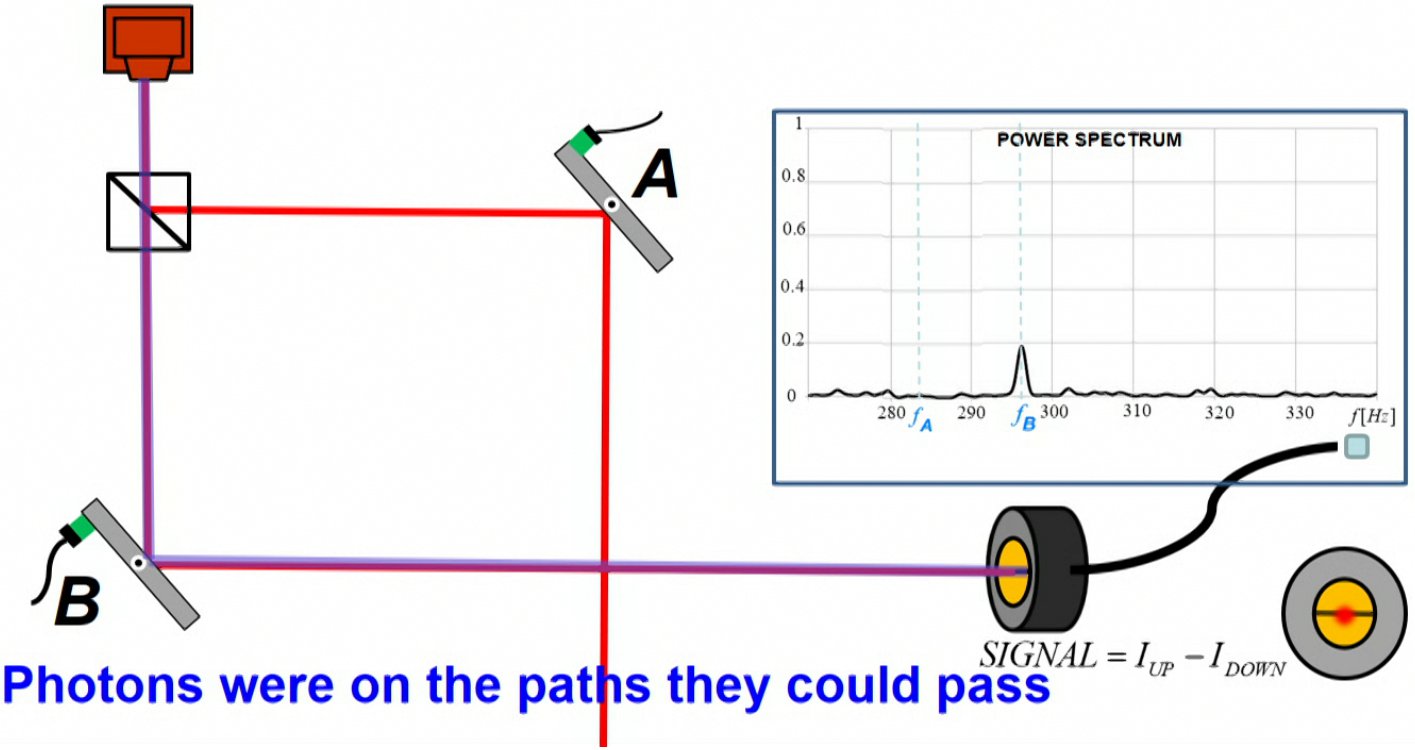


Asking photons where have they been

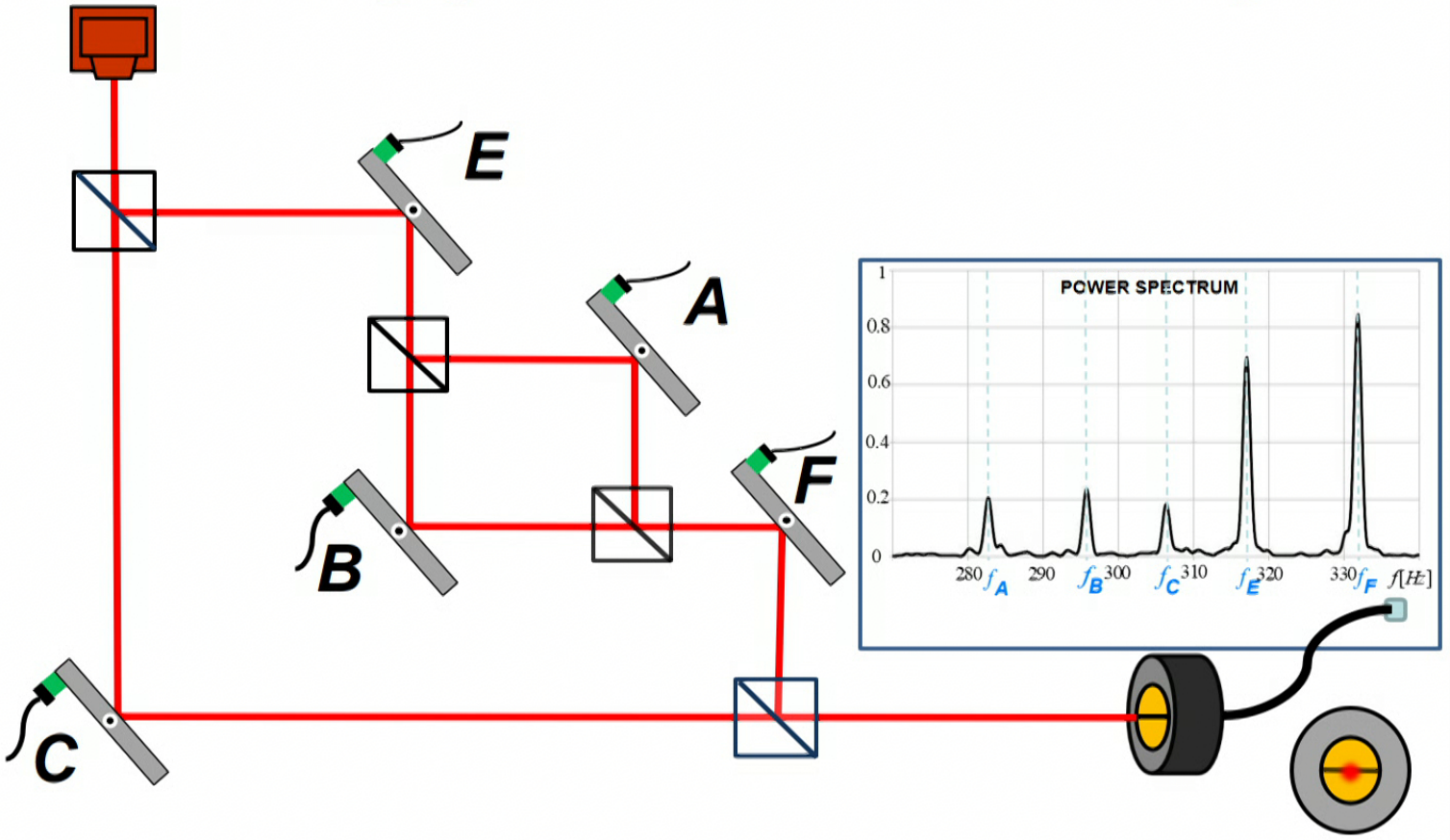


Asking photons where have they been



Photons were on the paths they could pass

Asking photons where have they been

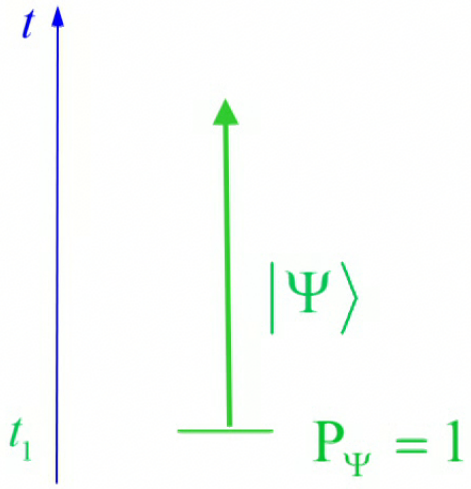


The two-state vector formalism of quantum mechanics

The pre- and post-selected particle is described by the two-state vector

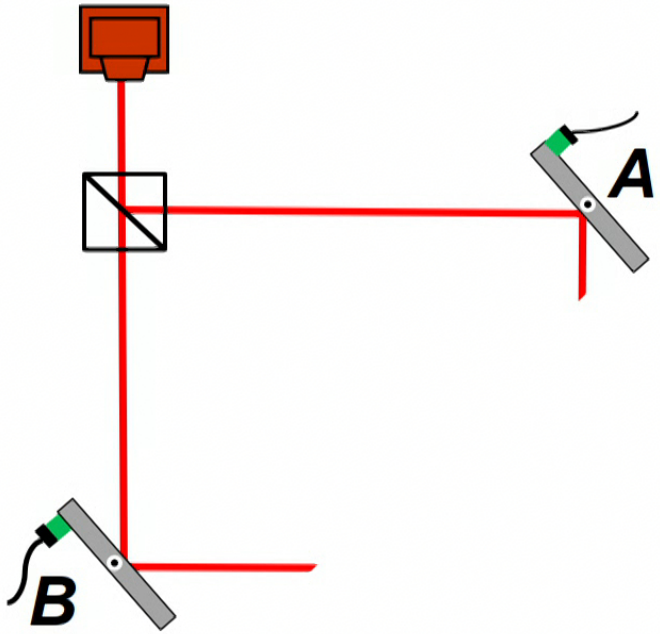
$$\langle \Phi | \quad | \Psi \rangle$$

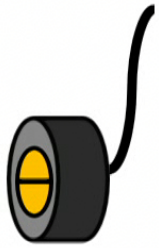
The two-state vector



The two-state vector formalism explanation

The pre- and post-selected photon was in the overlap of the forward and backward evolving states





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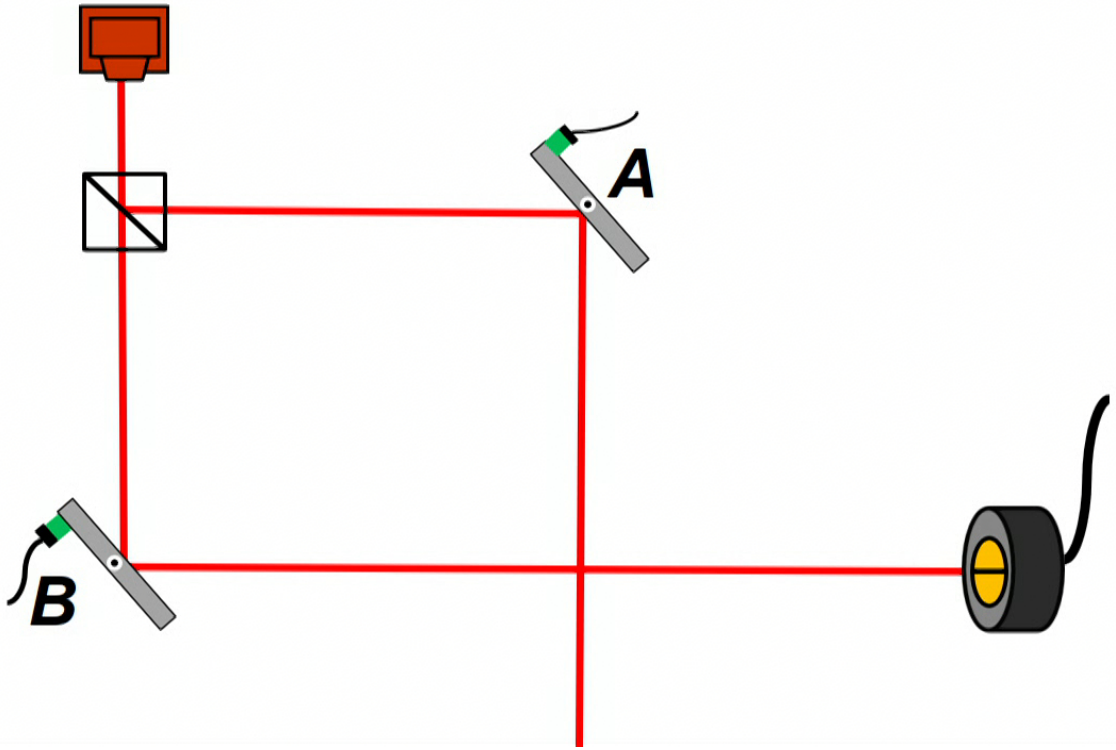

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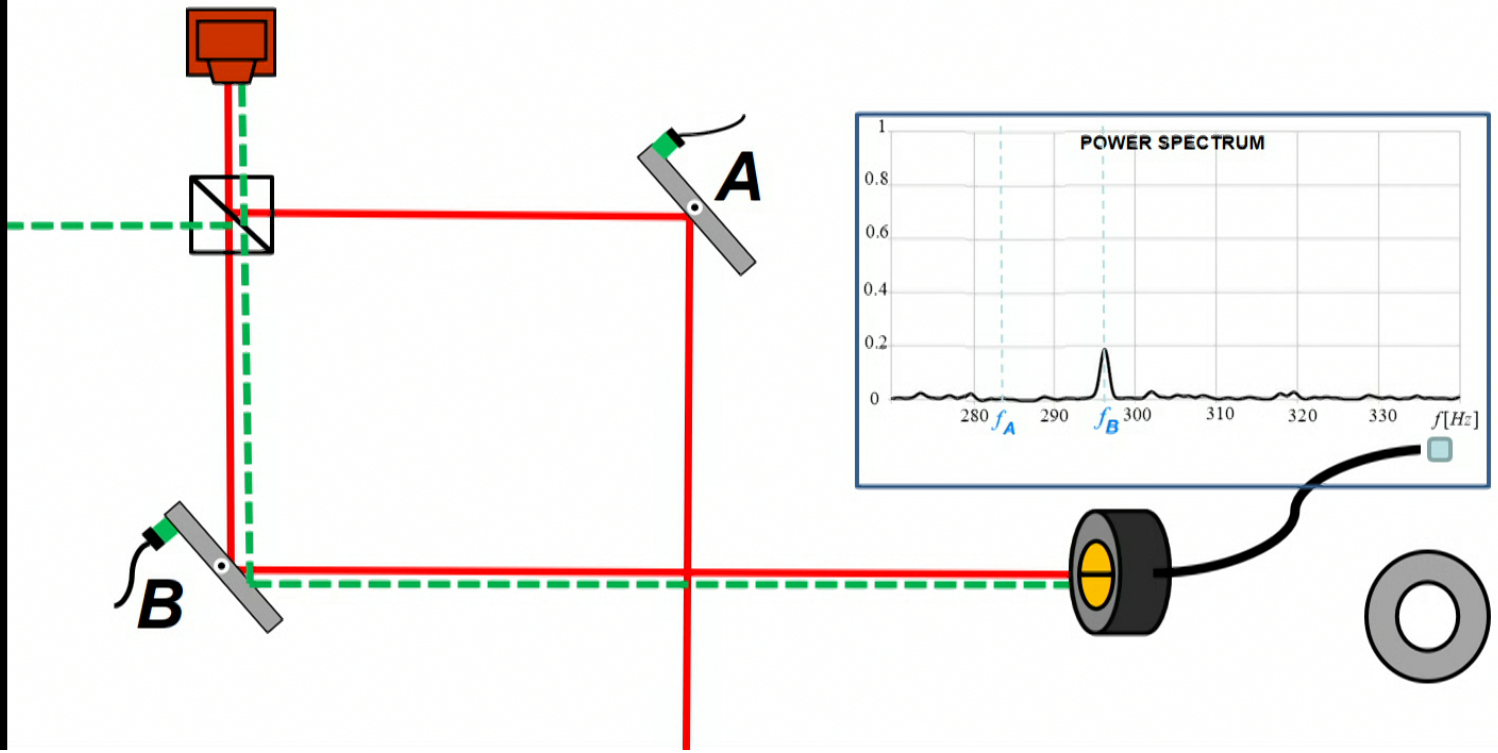

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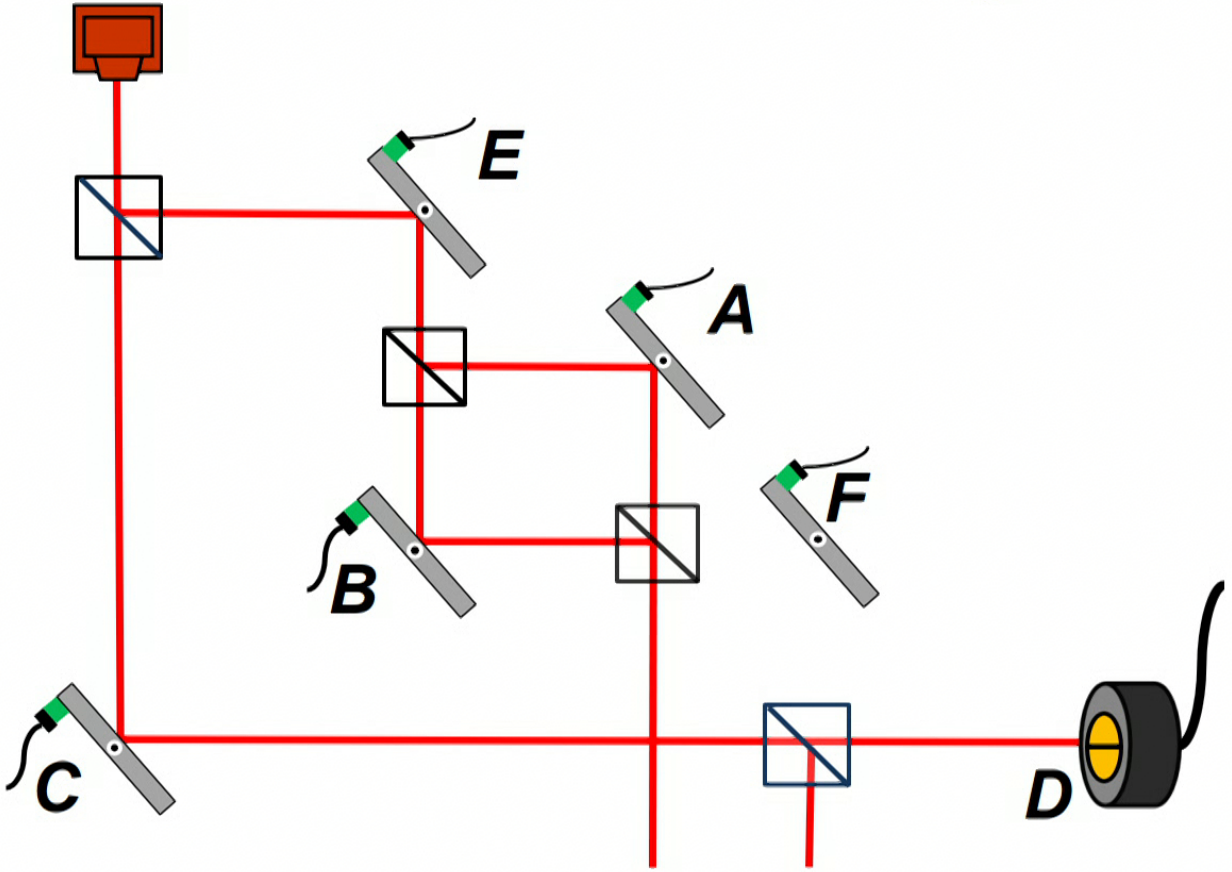

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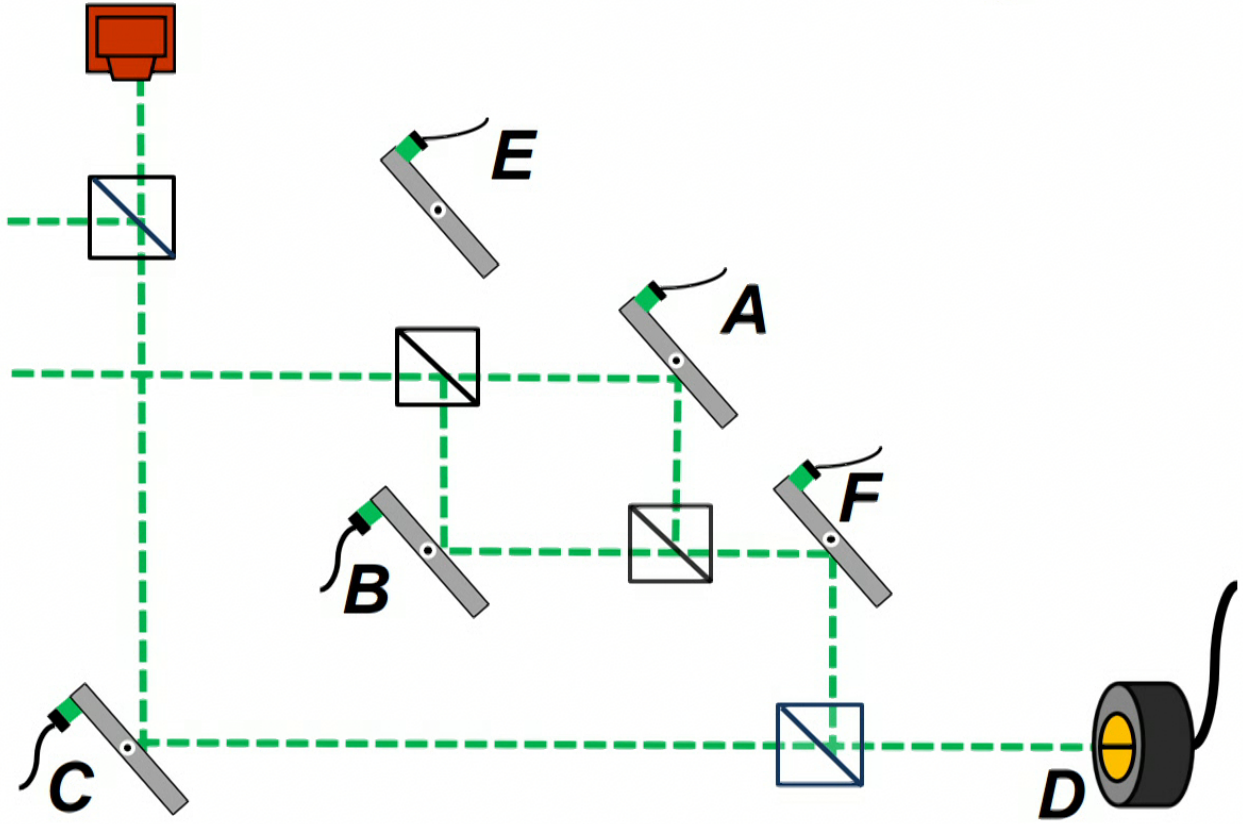

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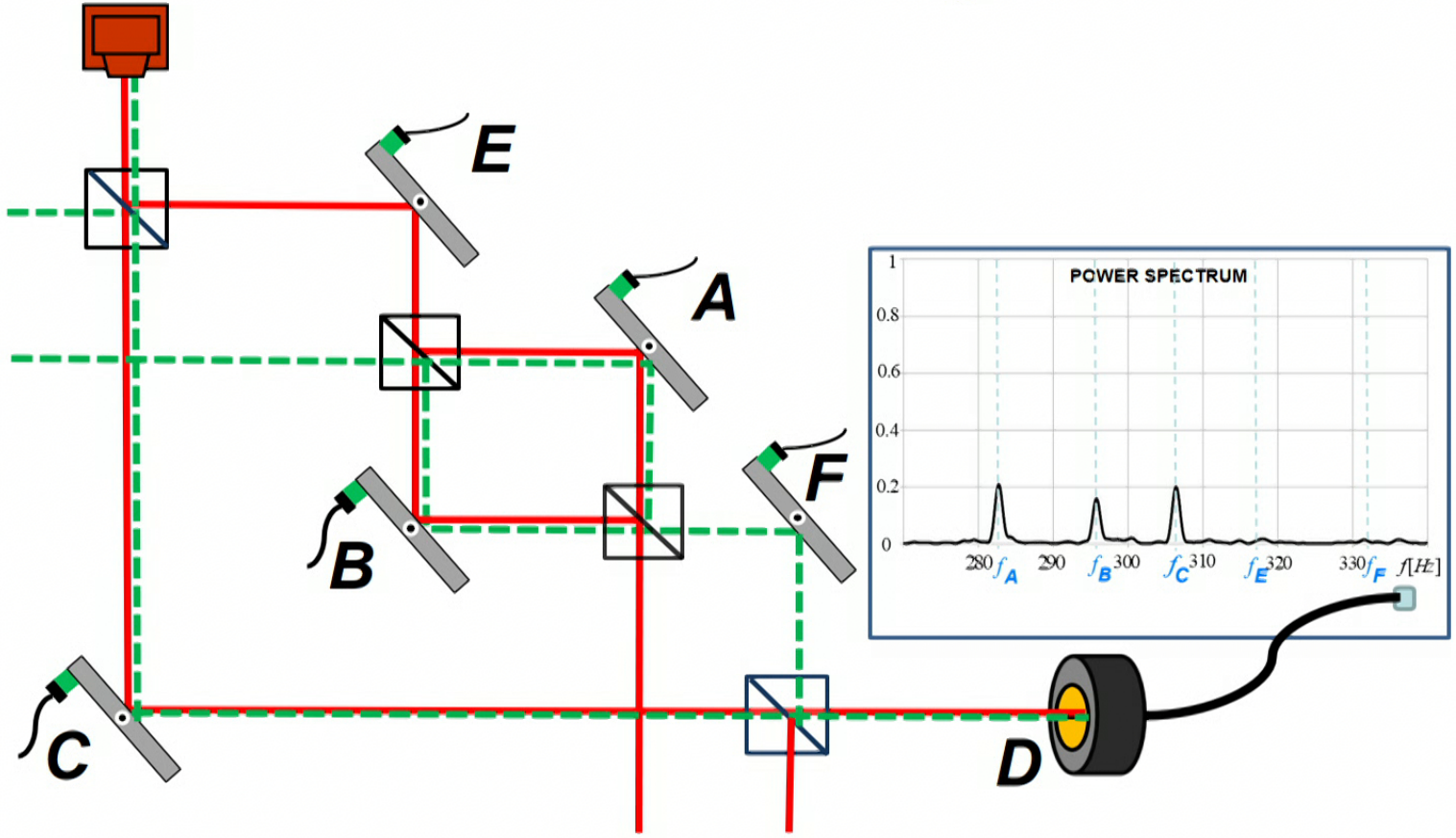
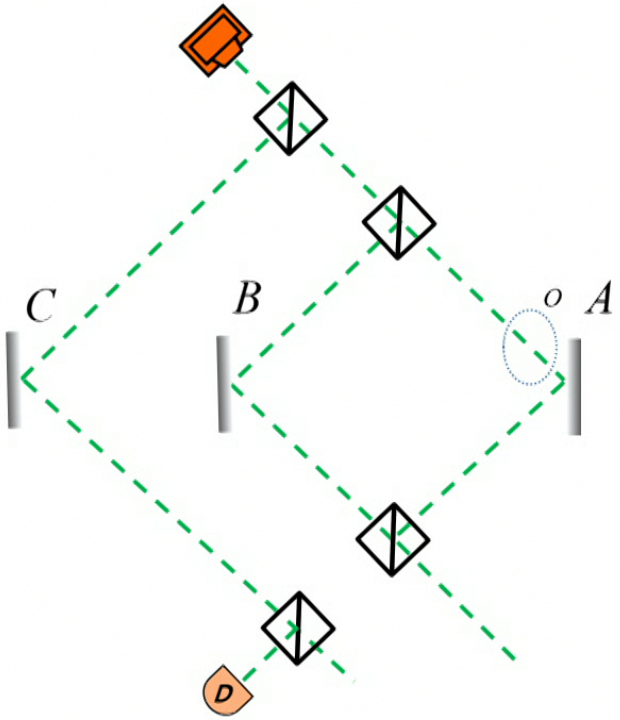
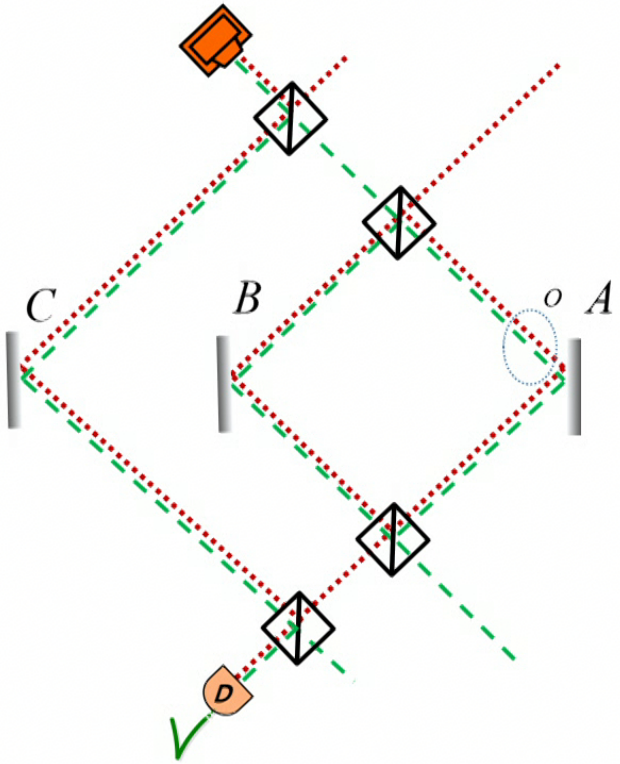


Interaction-free measurement of the absence of an object

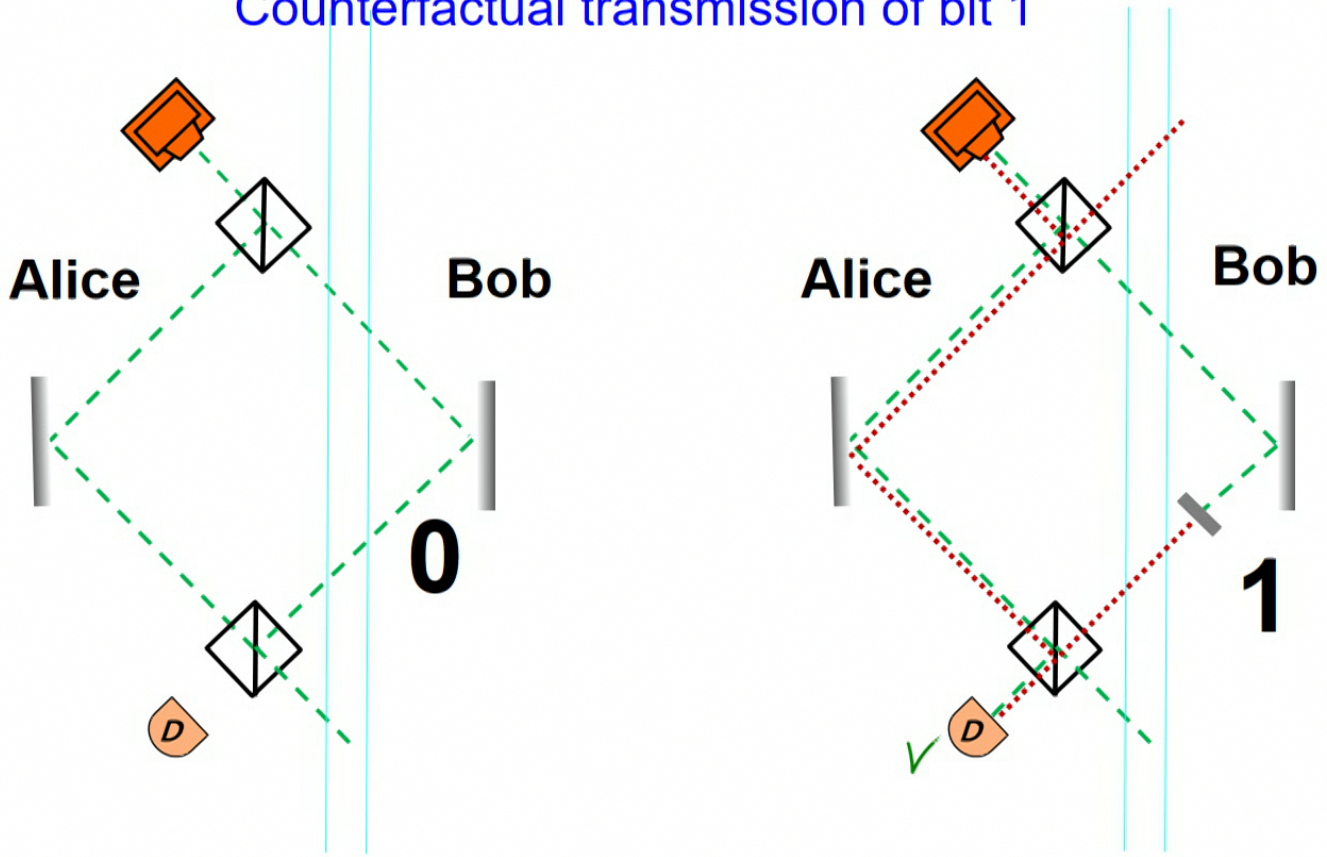


Interaction-free measurement of the absence of an object



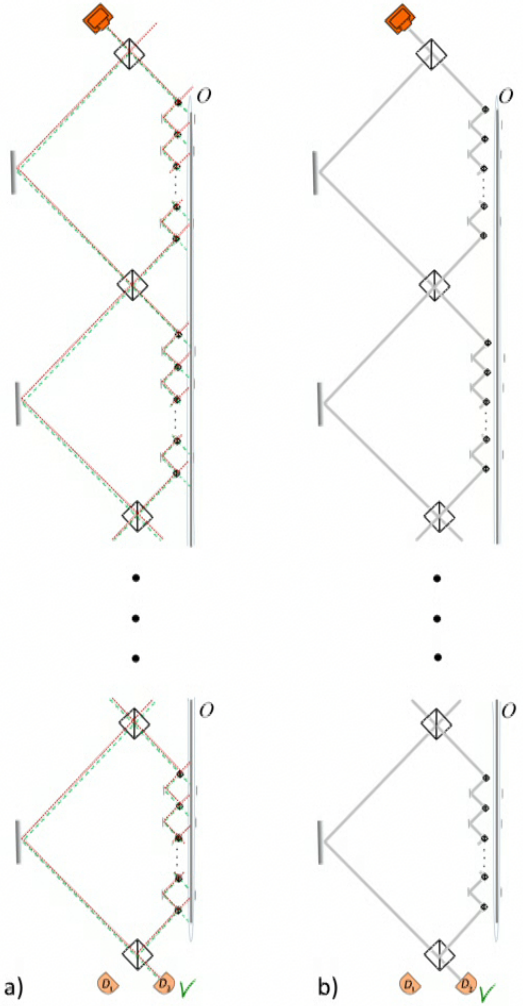
Interaction-free measurement of the presence of an object

Counterfactual transmission of bit 1

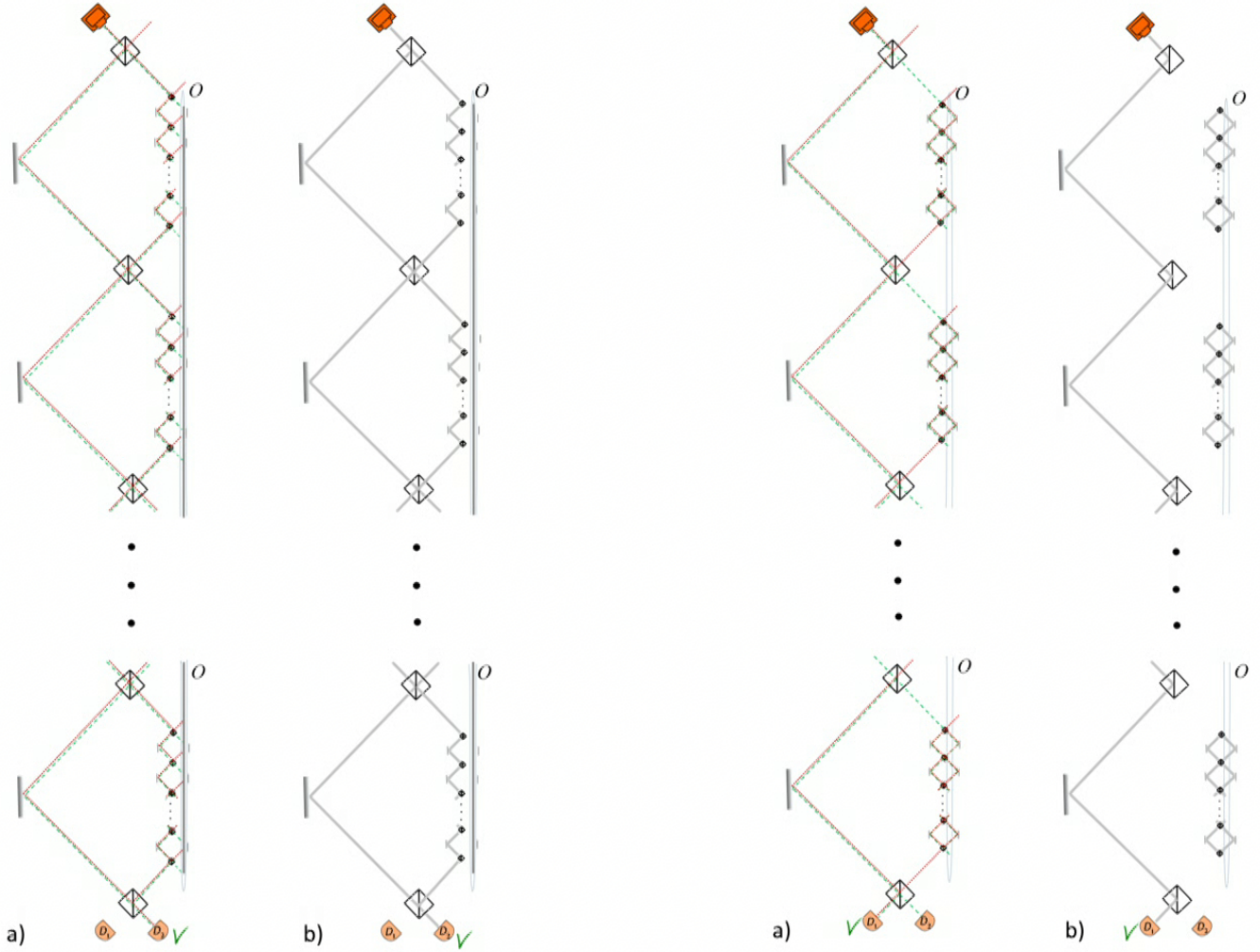


Alice knows that the bit is 1 without photon reaching Bob

Direct counterfactual communication



Direct counterfactual communication



Conclusions

We can create a secret key without particles being present in the transmission channel

We cannot transfer a message without particles being present in the transmission channel

“Being present” means leaving a trace. The trace is left in the overlap of the forward and backward evolving wave functions

Trace left in the transmission channel in the process of “Direct counterfactual communication” is larger than the trace left by a single particle passing through this channel

Conclusions

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Trace left in the transmission channel in the process of "Direct counterfactual communication" is larger than the trace left by a single particle passing through this channel

Quantum Physics

Modification of "Counterfactual communication protocols" which makes them truly counterfactual

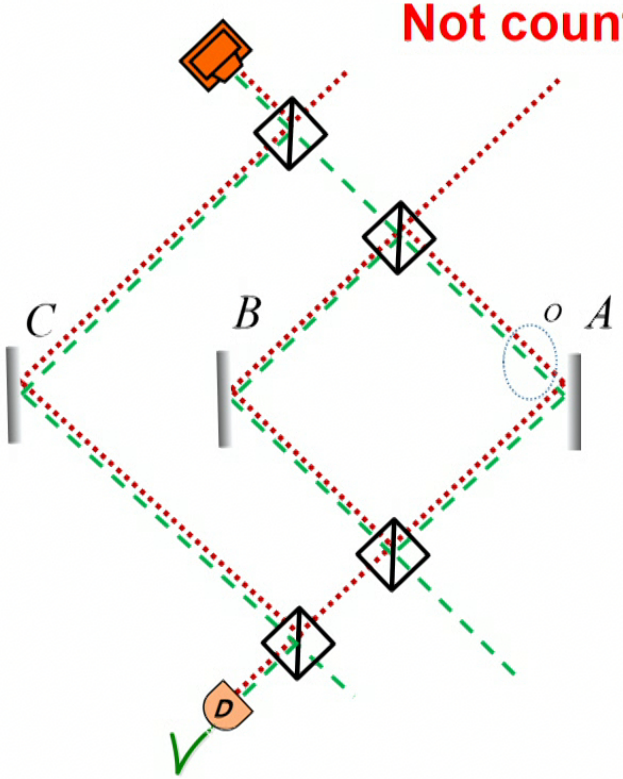
Yakir Aharonov, Lev Vaidman

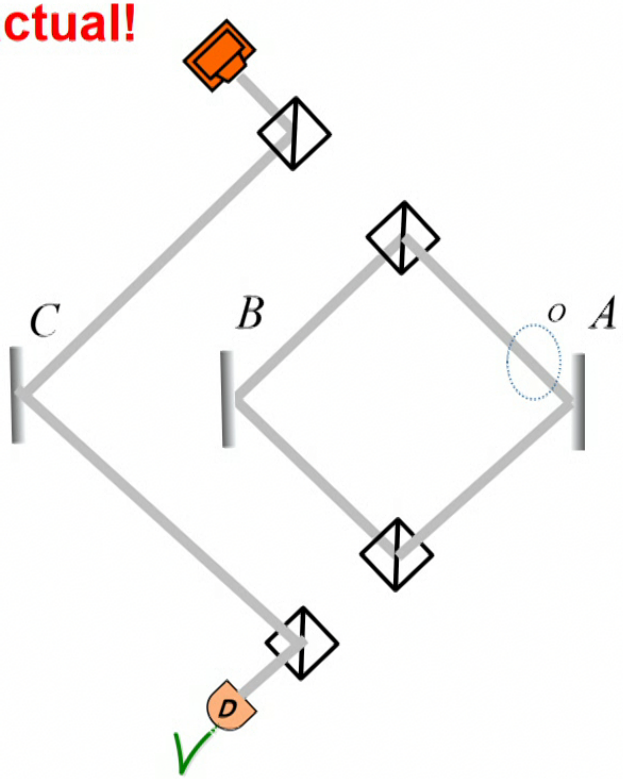
(Submitted on 27 May 2018)

Possibility to communicate between spatially separated regions, without even a single photon passing between the two parties, is an amazing quantum phenomenon. The possibility of transmitting one value of a bit in such a way, the interaction-free measurement, was known for quarter of a century. The protocols of full communication, including transmitting unknown quantum states were proposed only few years ago, but it was shown that in all these protocols the particle was leaving a weak trace in the transmission channel, the trace larger than the trace left by a single particle passing through the channel. This made the claim of counterfactuality of these protocols at best controversial. However, a simple modification of these recent protocols eliminates the trace in the transmission channel and makes all these protocols truly counterfactual.

Interaction-free measurement of the absence of an object

Not counterfactual!

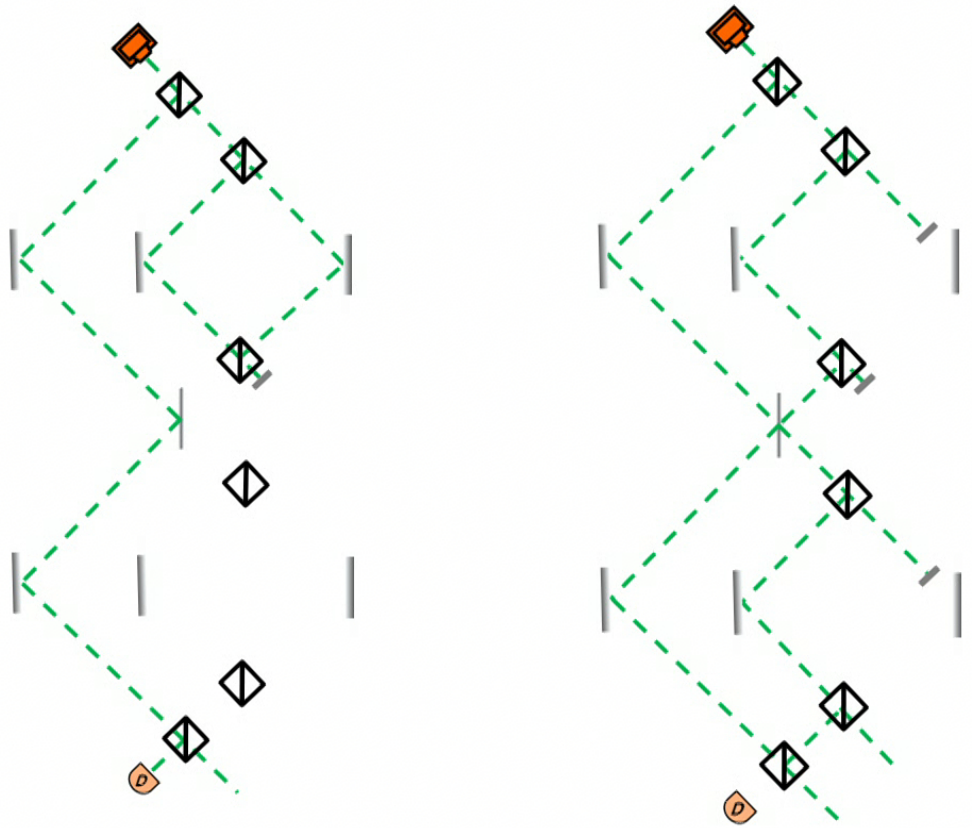




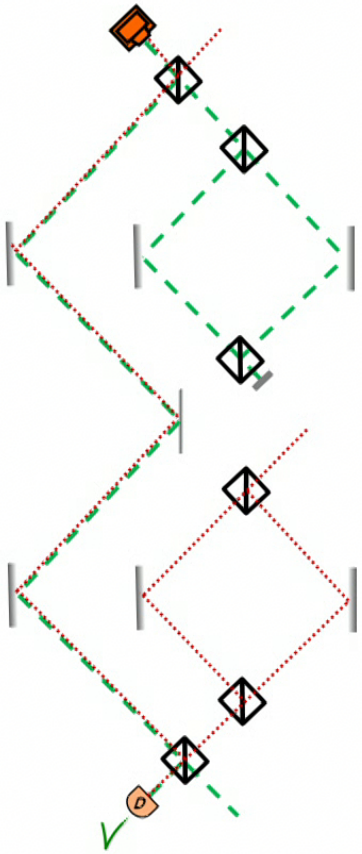
Both forward and backward evolving wave functions are present *O*

The photons left a trace in *O*

Modified Interaction-free measurement of the absence of an object

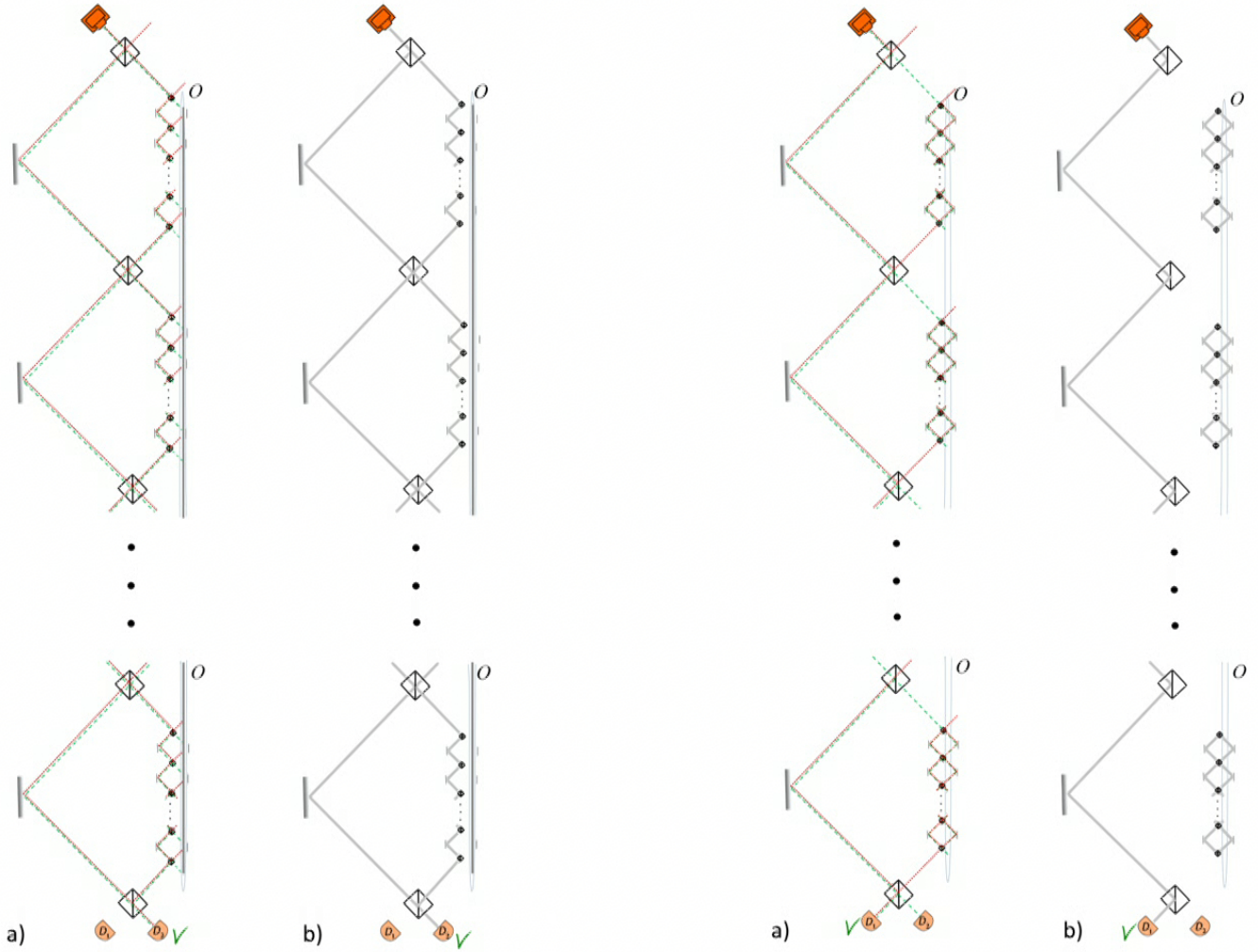


Modified Interaction-free measurement of the absence of an object

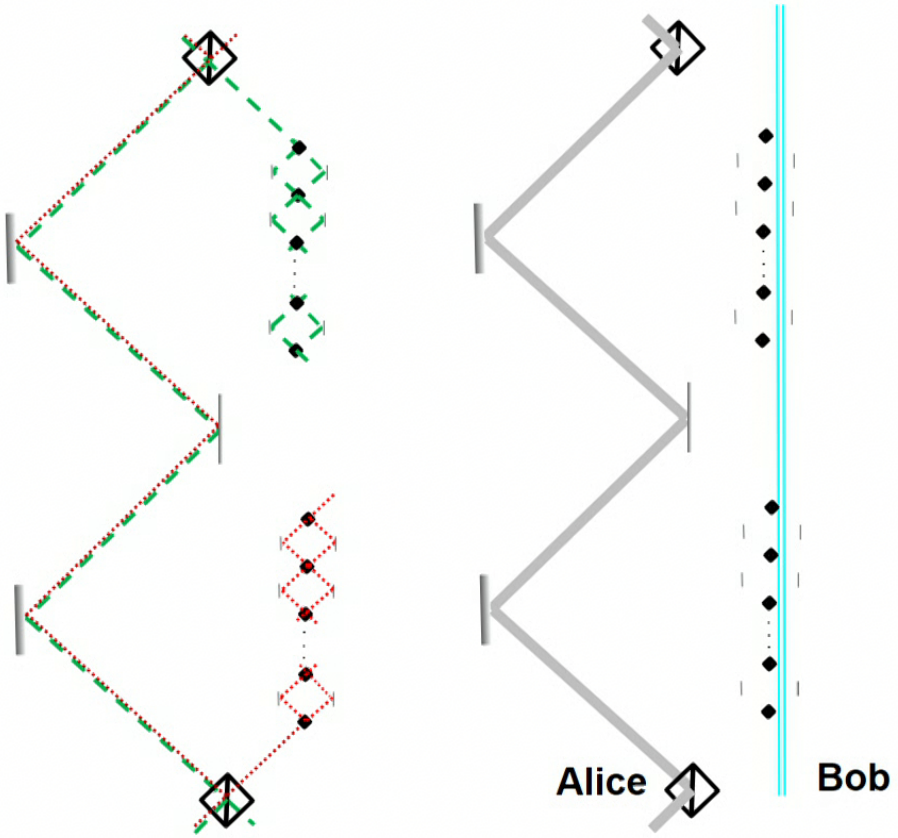


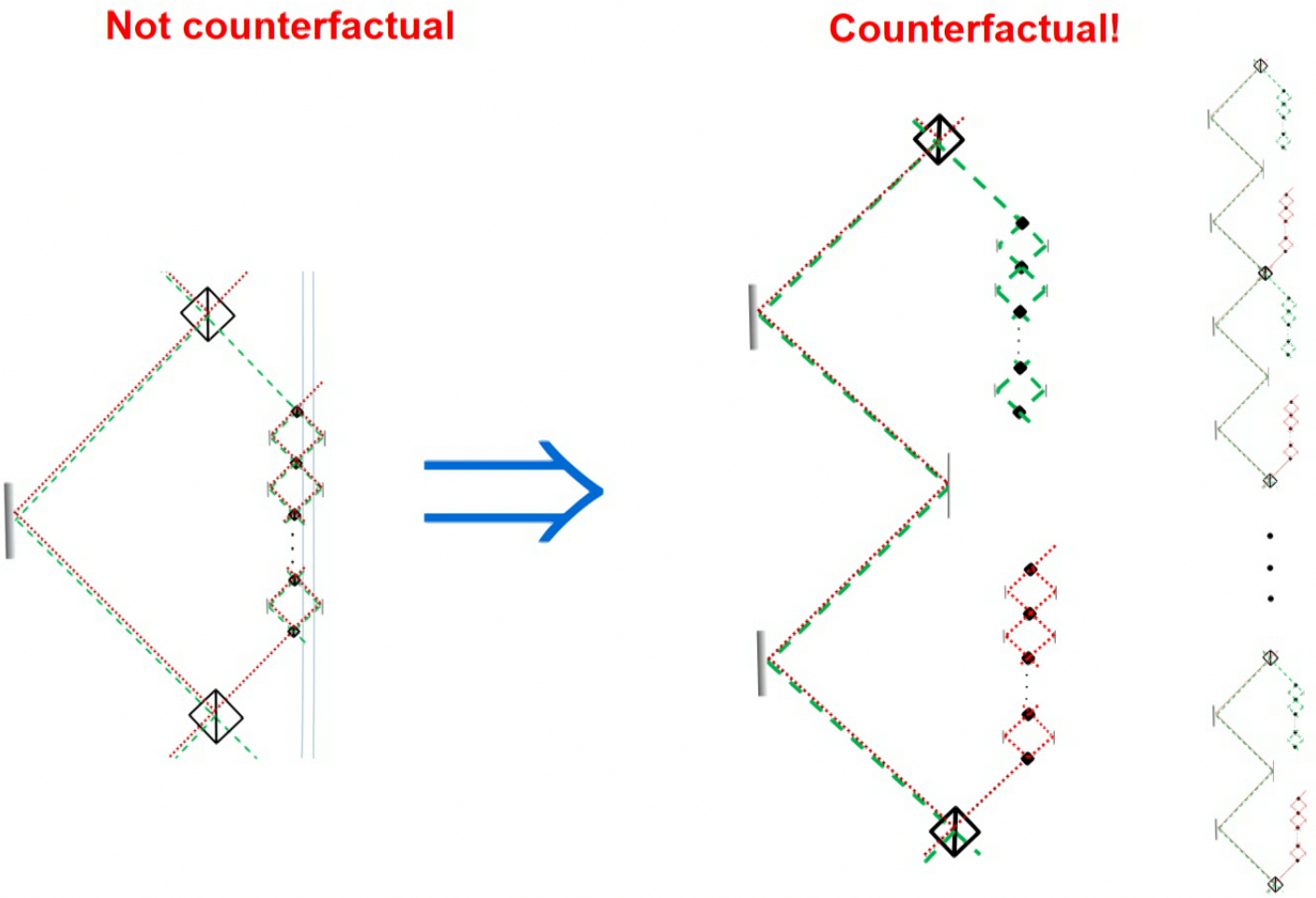
Direct counterfactual transmission of a quantum state

Not counterfactual!



Counterfactual!




Not counterfactual
Counterfactual!

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We can transfer a message without particles being present in the transmission channel!

"Being present" means leaving a trace. The trace is left in the overlap of the forward and backward evolving wave functions

Trace left in the transmission channel in the process of "Direct counterfactual communication" is larger than the trace left by a single particle passing through this channel