SAPIENZA
UNIVERSITÀ DI ROMA

Playing with Light: Future Quantum Technologies

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3D-QUEST

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http://quantumoptics.phys.uniroma1.it

www.3dquest.eu

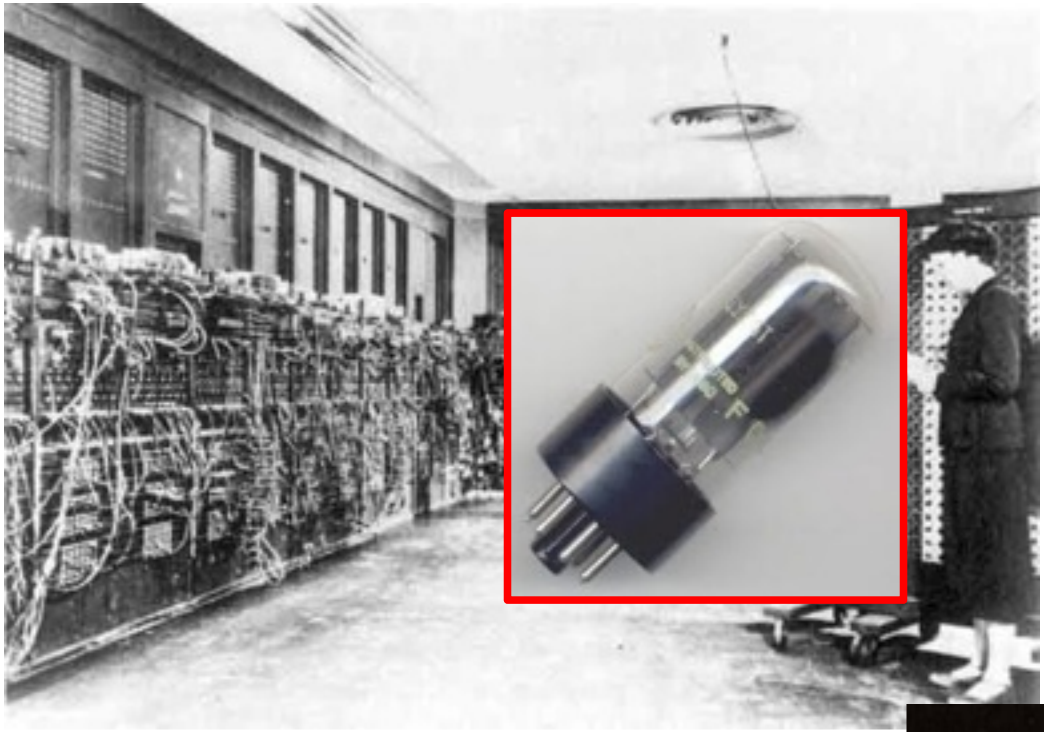
The Turing Machine (1936)

Goal: to decrypt the Enigma codes…

ENIGMA:
1940 II world war

The Turing machine:
abstract model for a machine able to run an algorithm

Movie: The Imitation Game



ENIAC (1946)

Electronic Numerical

Integrator And Computer

18.000 thermionic valves,

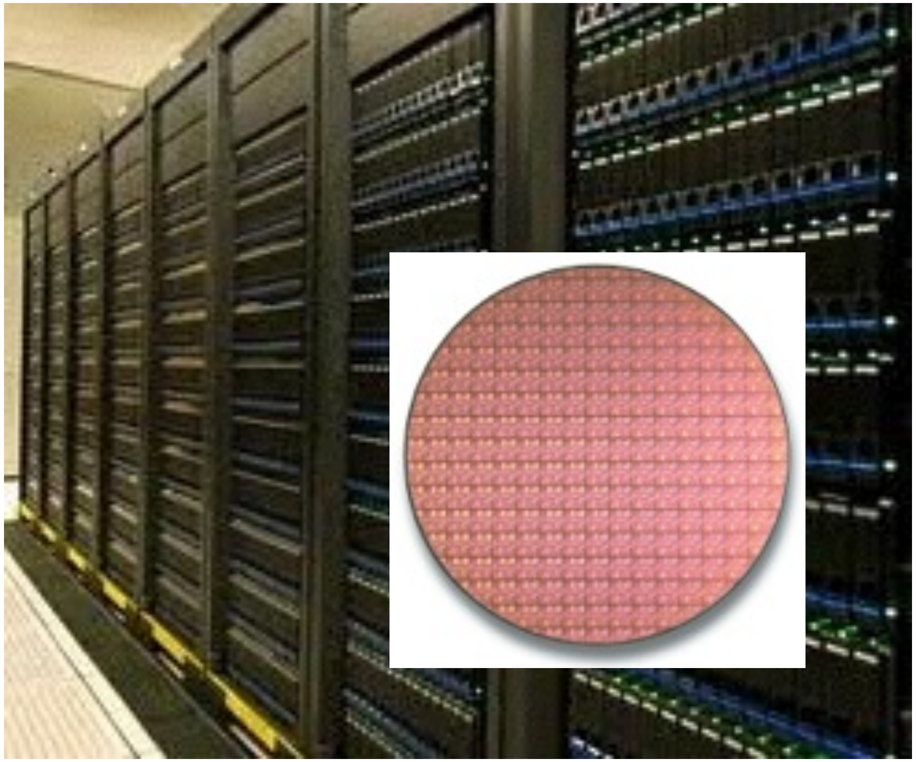
30 tons,

180 mq

Apple I (1976)

.. 4 Kb di Ram...!

TODAY...



Tianhe-1A (2010)

Supercomputer

Operations per second

1 PetaFlops

I-Phone 4s (2012)

RAM 512 Mb

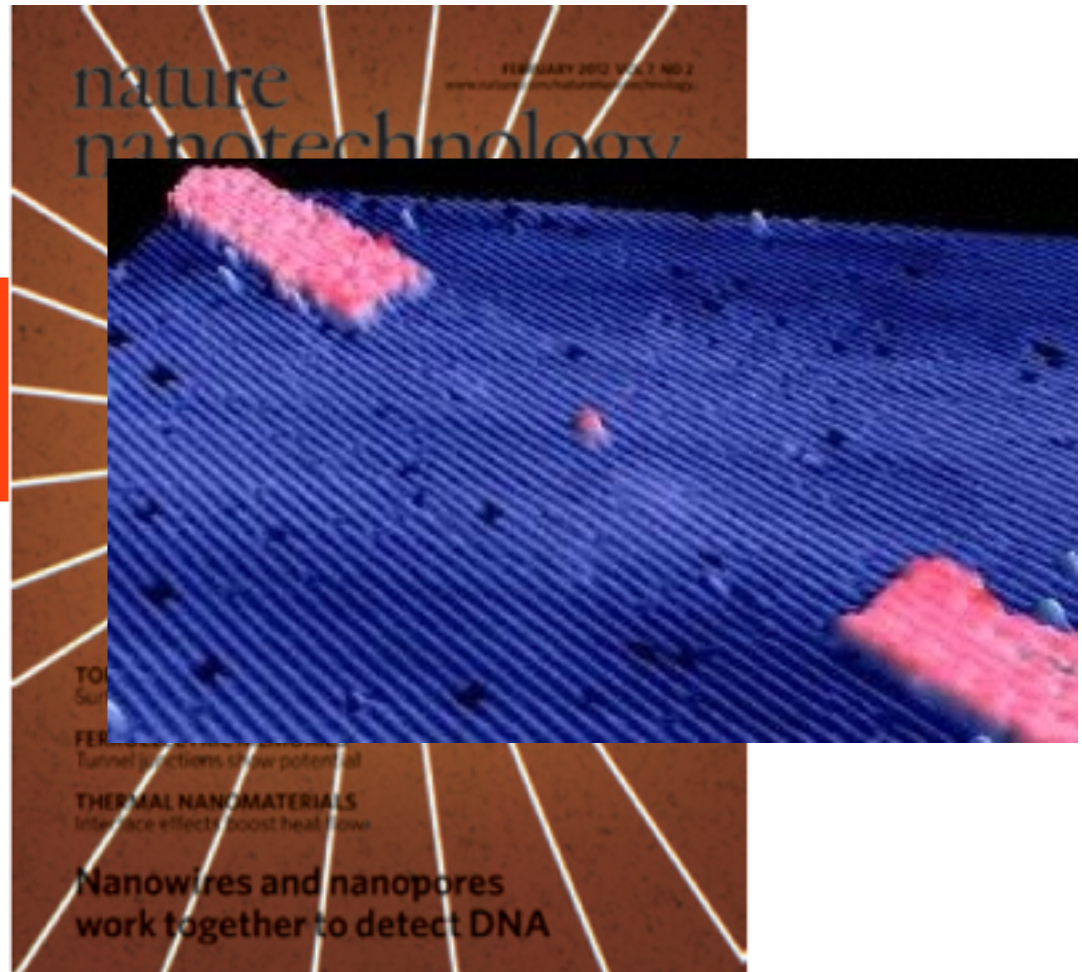
news & views

NANOELECTRONICS

Transistors arrive at the atomic limit

A single-atom transistor has been made by positioning a phosphorus atom between metallic electrodes, also made of phosphorus, on a silicon surface.

Gabriel P. Lansbergen



Breaking news!
19 Febbraio 2012

news & views

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Physicists Create a Working Transistor From a Single Atom

By JOHN MARKOFF

Published: February 19, 2012

Australian and American physicists have built a working transistor from a single phosphorus atom embedded in a silicon crystal.

RECOMMEND

TWITTER

“ […] Un importante passo in avanti verso i super computer quantistici del futuro, realizzato dai fisici dell'università australiana del Nuovo Galles del Sud a Sydney .”

La Repubblica

“ [...] Científicos australianos han construido el transistor más pequeño del mundo a partir de un único átomo, lo que supone un gran paso hacia el desarrollo de los futuros ordenadores cuánticos.”

El Mundo

“ [...]they had laid the groundwork for a futuristic quantum computer that might one day function in a nanoscale world and would be orders of magnitude smaller and quicker than today’s silicon-based machines.”

The New York Times

NANOELECTRONICS

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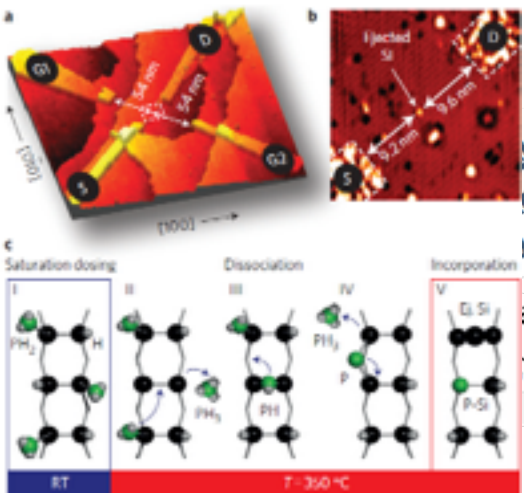

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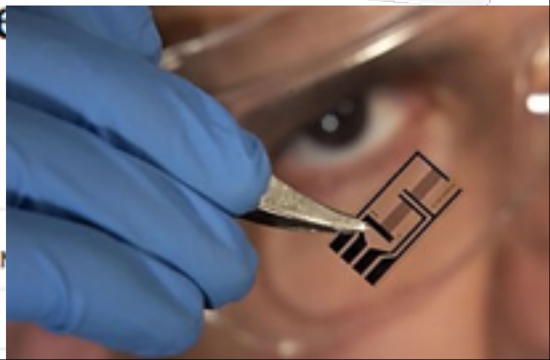
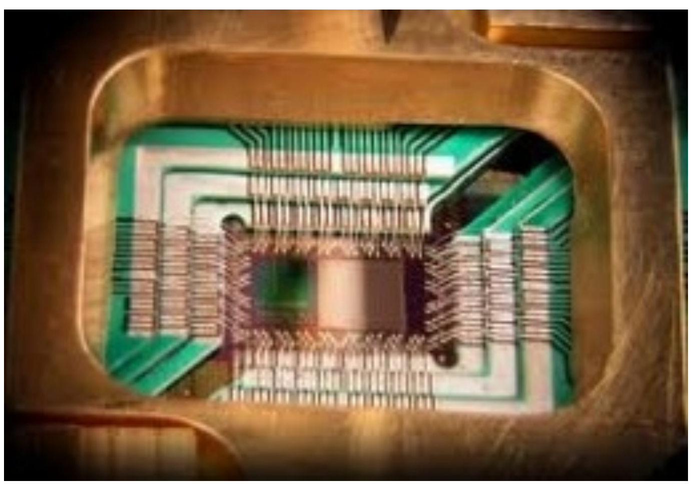
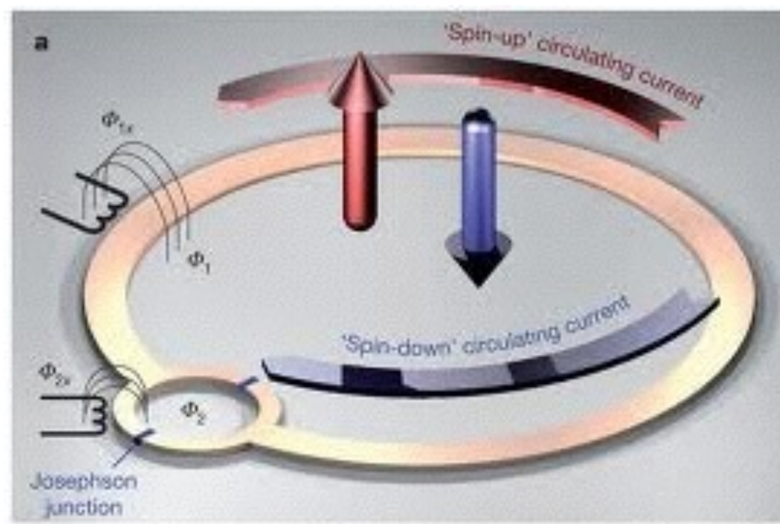


D-wave: a commercial quantum computer…

512 qubit....
Cost: 10.000.0000 $
bought from NASA, google..

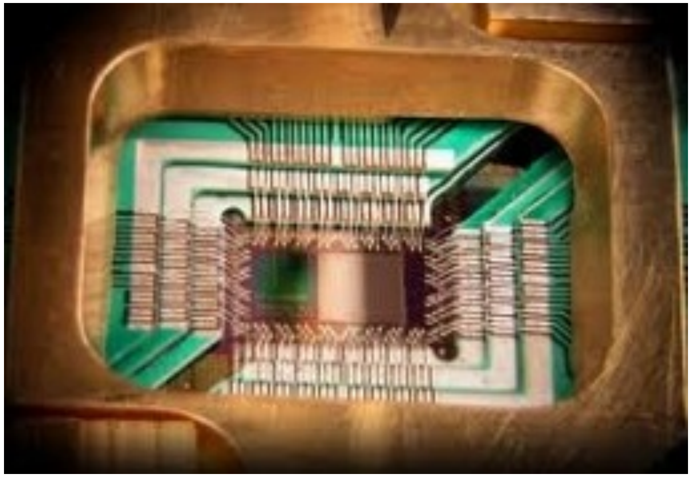





TECH GUYS
TECHNOLOGY AT ITS BEST

D-wave: a commercial quantumcomputer ?!?

512 qubit....
Cost: 15.000.0000 $
Bought from da NASA, google..



Is it"truly" quantum?
And more powerfull
than a classical computer?

Results of Classical Physics:

At the end of 1800…

The predominant physical theory acknowledged as the only constituents of the Universe **matter** and **radiation**

made of particles perfectly localizable, subject to Newton's law

has a wave-like behavior and obeys the laws of electrodynamics of Maxwell;

The equations of classical physics ....

$$\begin{cases} \mathbf{F} = m\mathbf{a} \\ \mathbf{M} = \dfrac{d\mathbf{L}}{dt} \end{cases}$$

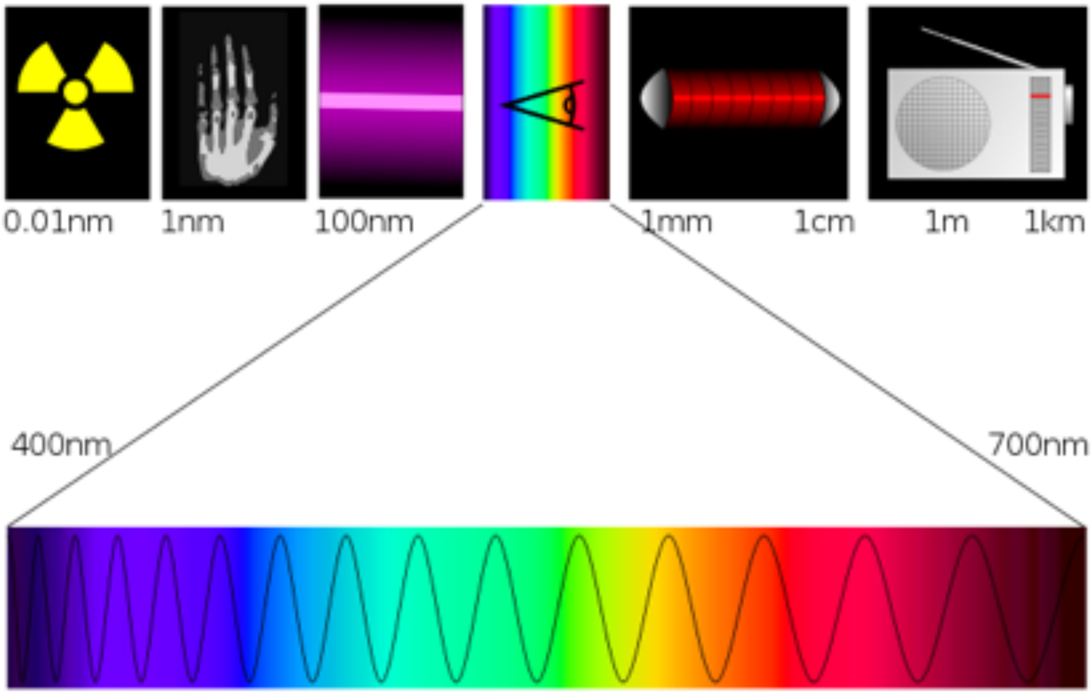
The equations of classical physics ....

The kinematics of the bodies

$$\left\{ \mathbf{F} = m\mathbf{a} \right.$$

Electromagnetism (Maxwell's equations)

$$\begin{cases} \nabla \cdot \mathbf{D} = \rho \\ \nabla \times \mathbf{E} + \dfrac{\partial \mathbf{B}}{\partial t} = 0 \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \times \mathbf{H} - \dfrac{\partial \mathbf{D}}{\partial t} = \mathbf{J} \end{cases}$$



The equations of classical physics ....

Equation | Phenomenon | Description

$$\left\{ \mathbf{F} = m\mathbf{a} \right.$$

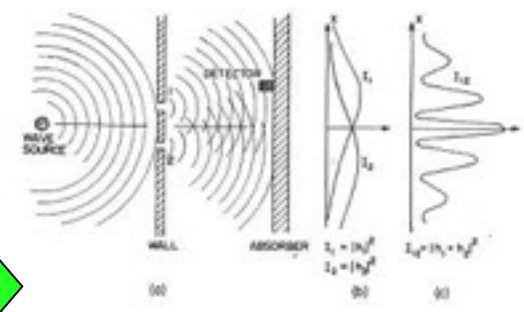
Collision between particles

$$\begin{cases} m_1 v_1 + m_2 v_2 = m_1 V_1 + m_2 V_2 \\ \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{1}{2} m_1 V_1^2 + \frac{1}{2} m_2 V_2^2 \end{cases}$$

Equation | Phenomenon | Description

$$\begin{cases} \nabla \cdot \mathbf{D} = \rho \\ \nabla \times \mathbf{E} + \dfrac{\partial \mathbf{B}}{\partial t} = 0 \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \times \mathbf{H} - \dfrac{\partial \mathbf{D}}{\partial t} = \mathbf{J} \end{cases}$$

Interference between waves



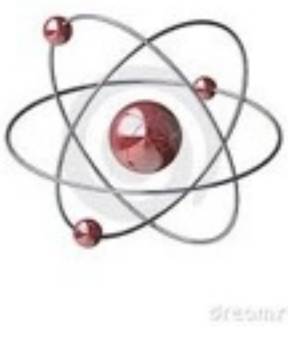
$$I = E^2 = 4 \left| E_A^2 \right| \cos^2 \frac{kd \sin \alpha}{2}$$

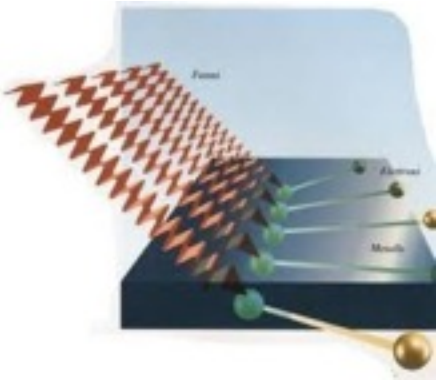
The crisis of classical physics

Classical physics can not explain what happens in the microscopic world …

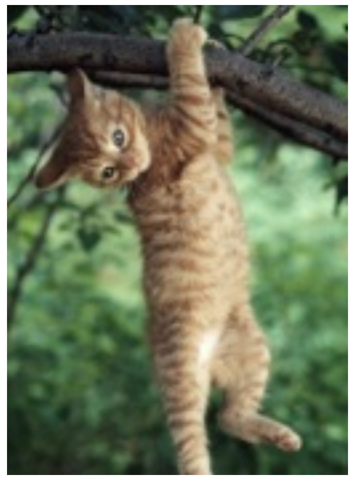
Why an electron does not fall on the nucleus by emitting electromagnetic radiation?

How do you explain the energy emitted from an irradiated metal surface?



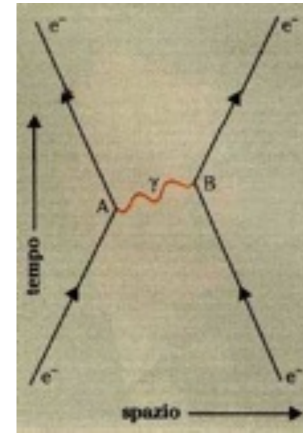


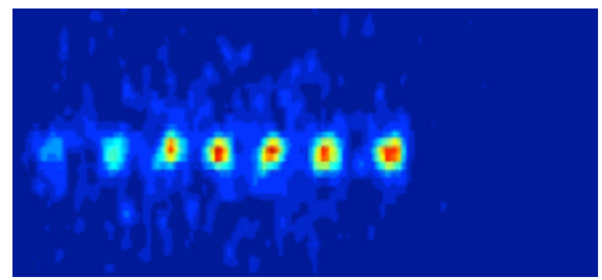
MACROSCOPIC WORLD



CLASSICAL PHYSICS

MICROSCOPIC WORLD



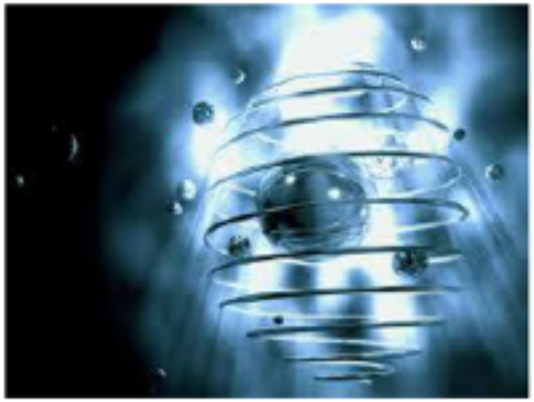


QUANTUM PHYSICS

The answers of Quantum Mechanics ...

The energy, in the same material, has a discontinuous nature being formed by elementary quantity.

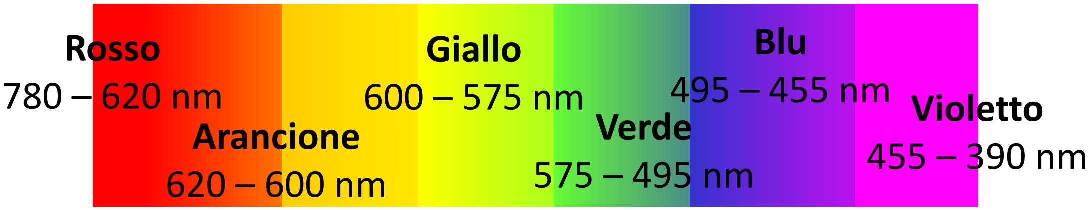
QUANTUM THEORY



All the processes of interaction between bodies (the "force fields") are "quantized" ["Building blocks": photons, electrons, etc..]

The quantum of light: the photon

Electromagnetic wave carries energy
Energy changes in a discrete manner:
as the (unit) of energy is the fundamental PHOTON



Photon:

I) Massless

II) Energy

$$E = h\,\nu$$

Energy

Planck constant

Frequency

The "golden years" of Quantum Mechanics: Solvay Conference (1927)

Quantum physics: Planck, Einstein, Bohr, Dirac, Schroedinger, Heisenberg, Pauli,...

First Principle of dynamic

$$\mathbf{F} = m\,\mathbf{a}$$

Force acting on the system

Mass that describes the system

Acceleration: effect of the force

Schroedinger equation

$$i\hbar\frac{d|\psi(t)\rangle}{dt} = \hat{H}|\psi(t)\rangle$$

h Planck constant

Hamiltonian (describes the system considered)

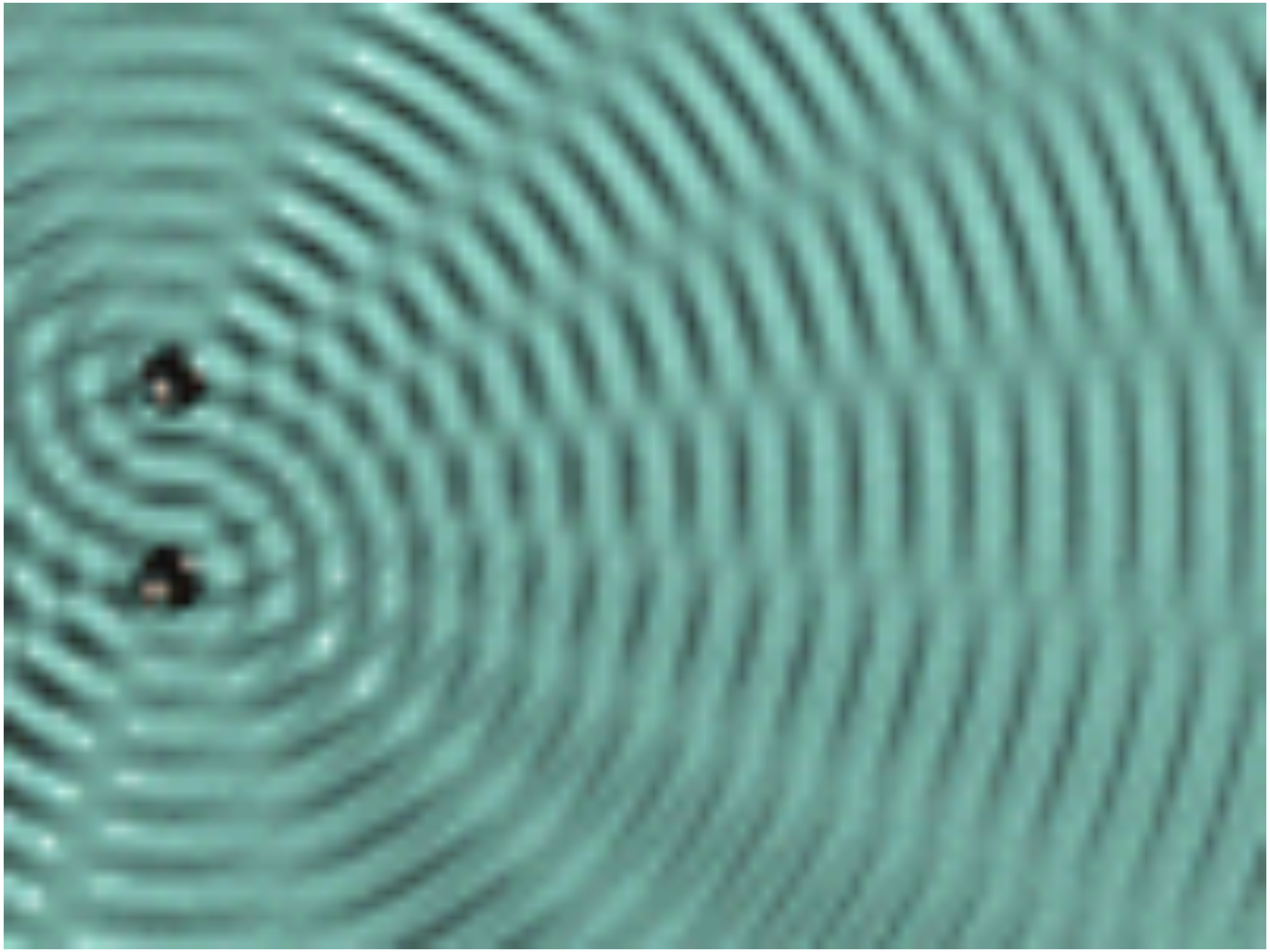
WAVE FUNCTION

Interference

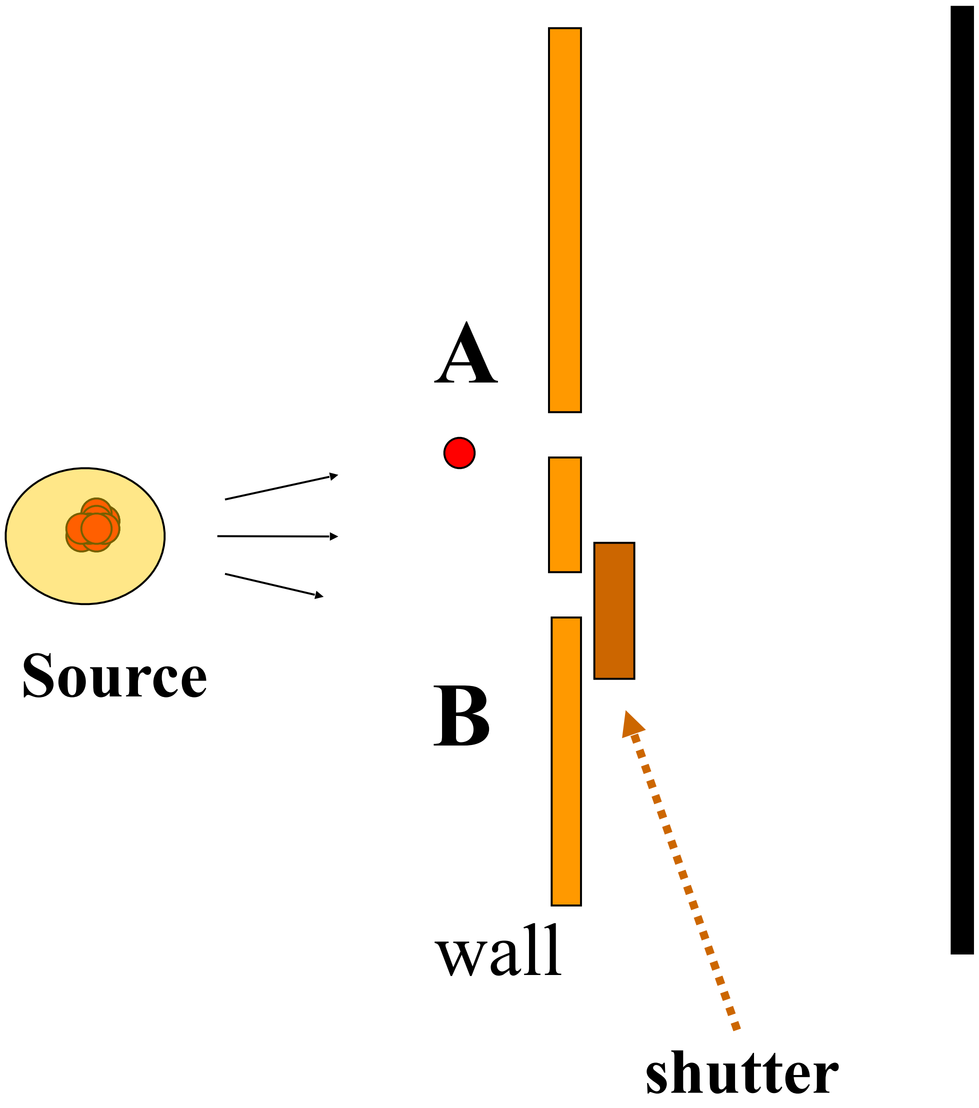
"…the heart of quantum mechanics. In reality it contains the only mystery ..."

R.P. Feynman (1965)

Interference between waves



Single-particle interference



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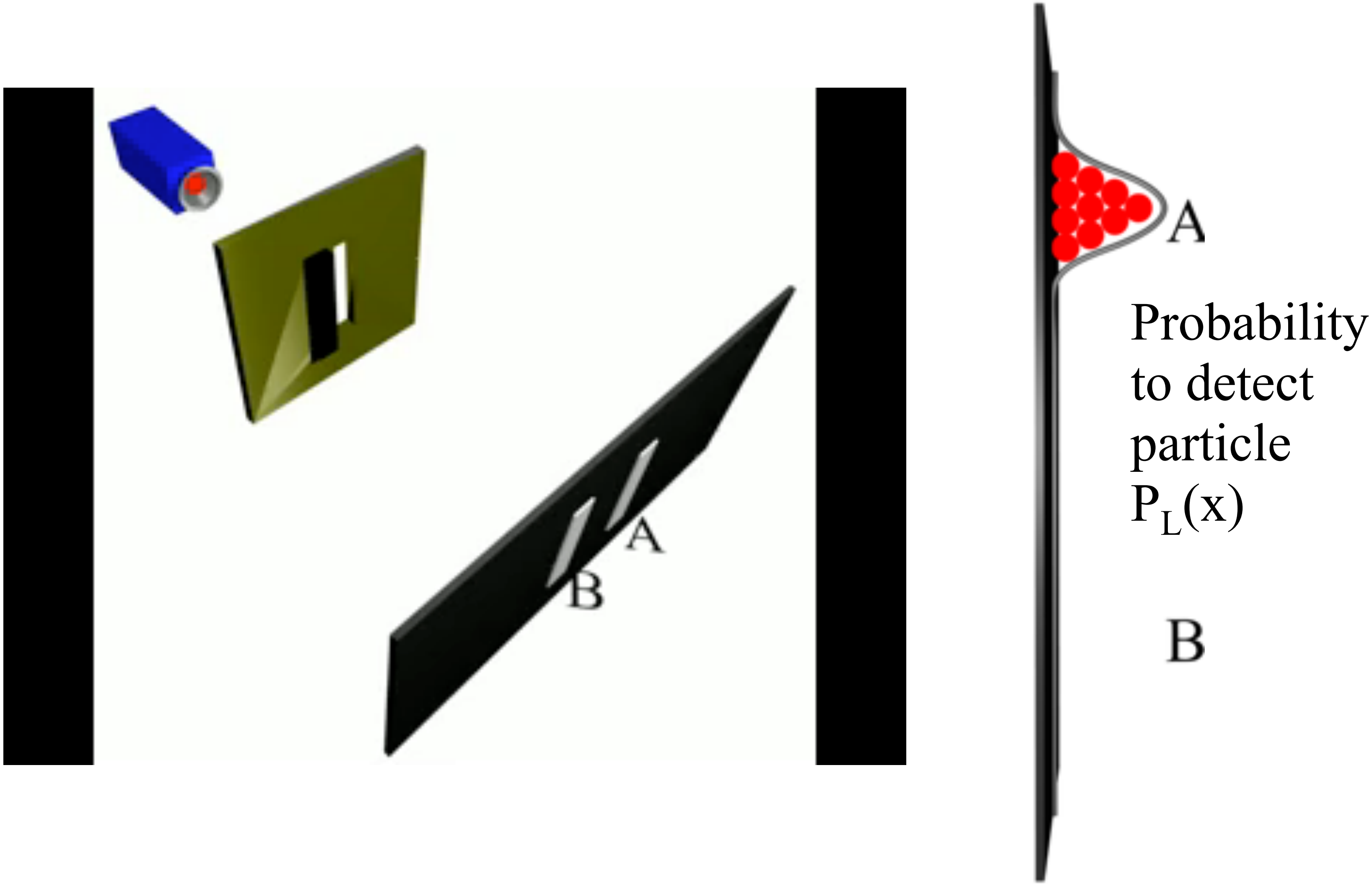

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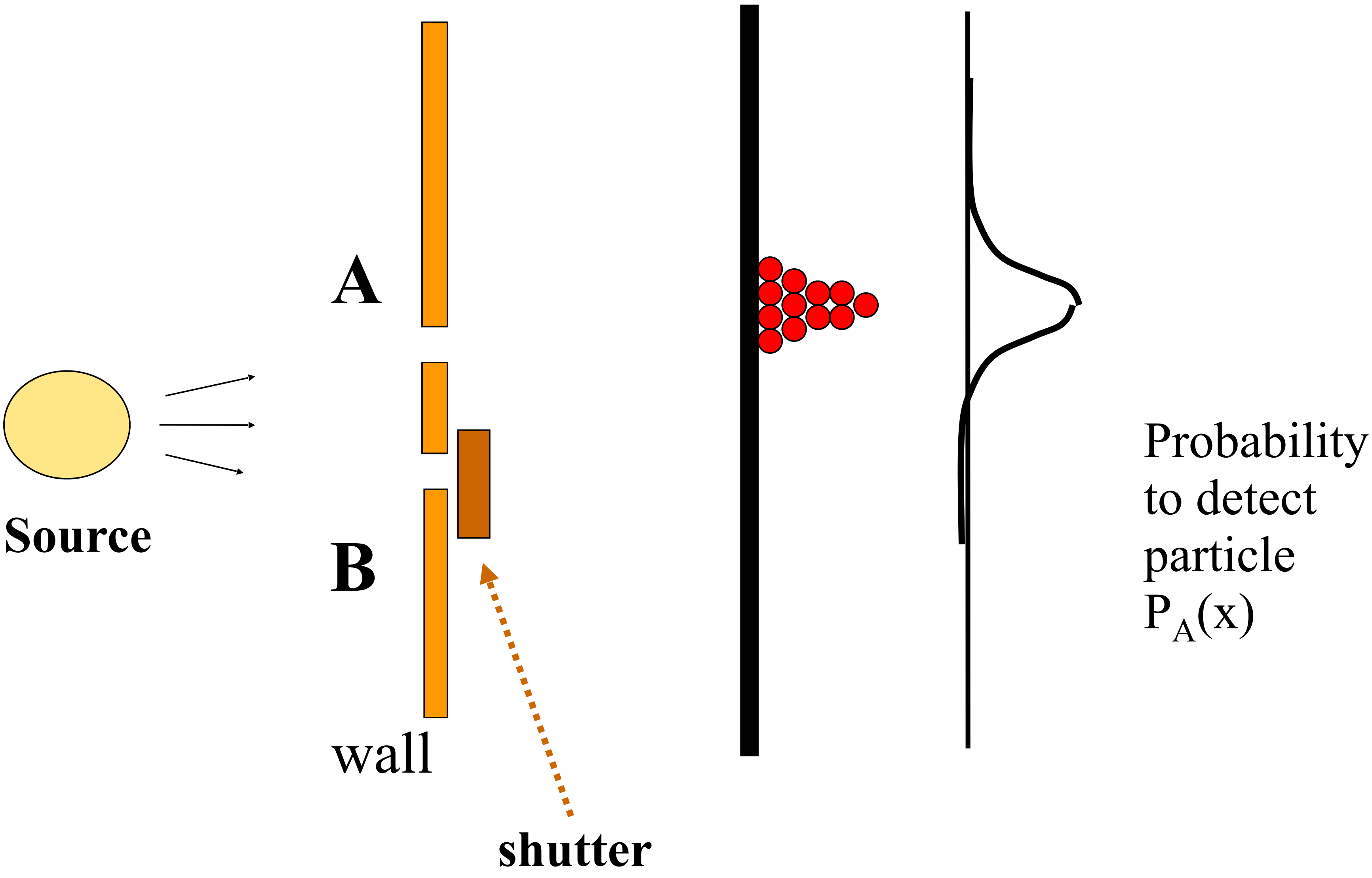

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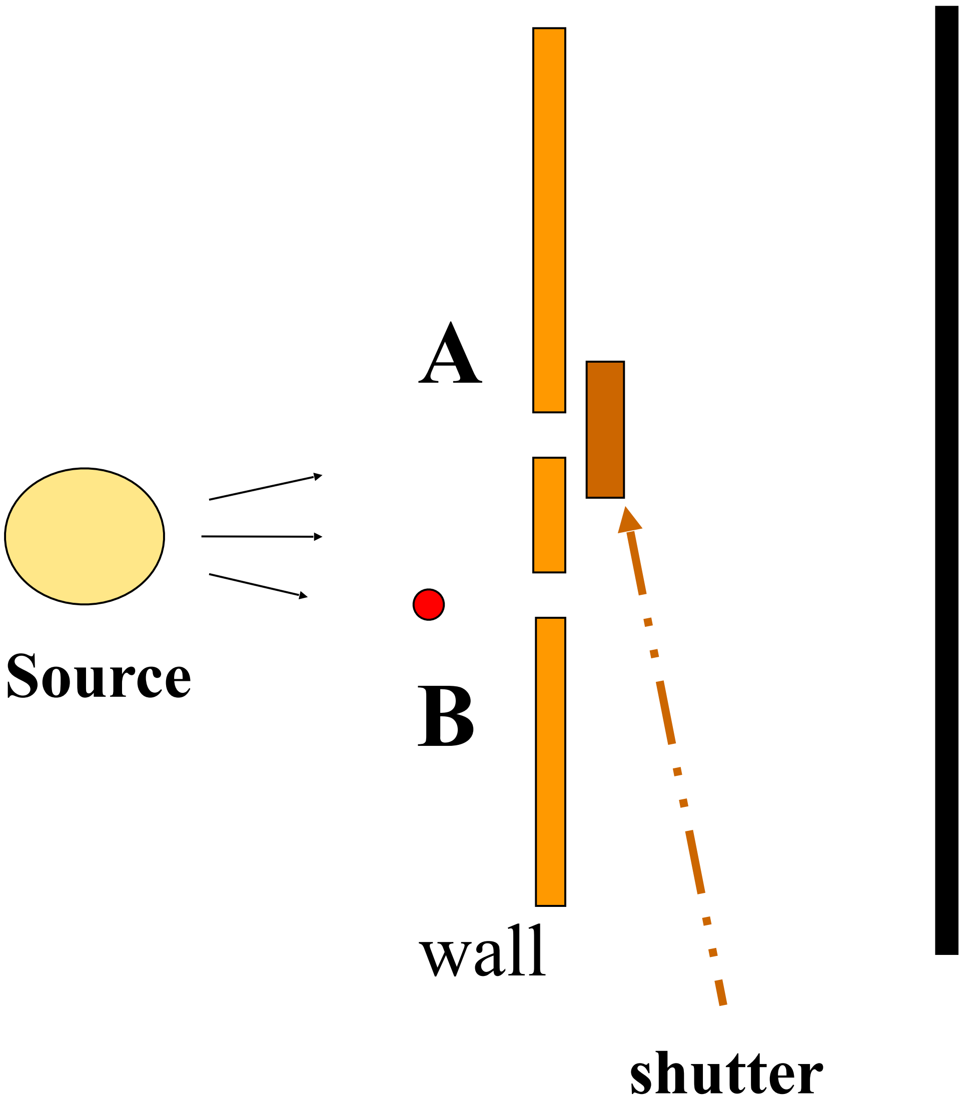
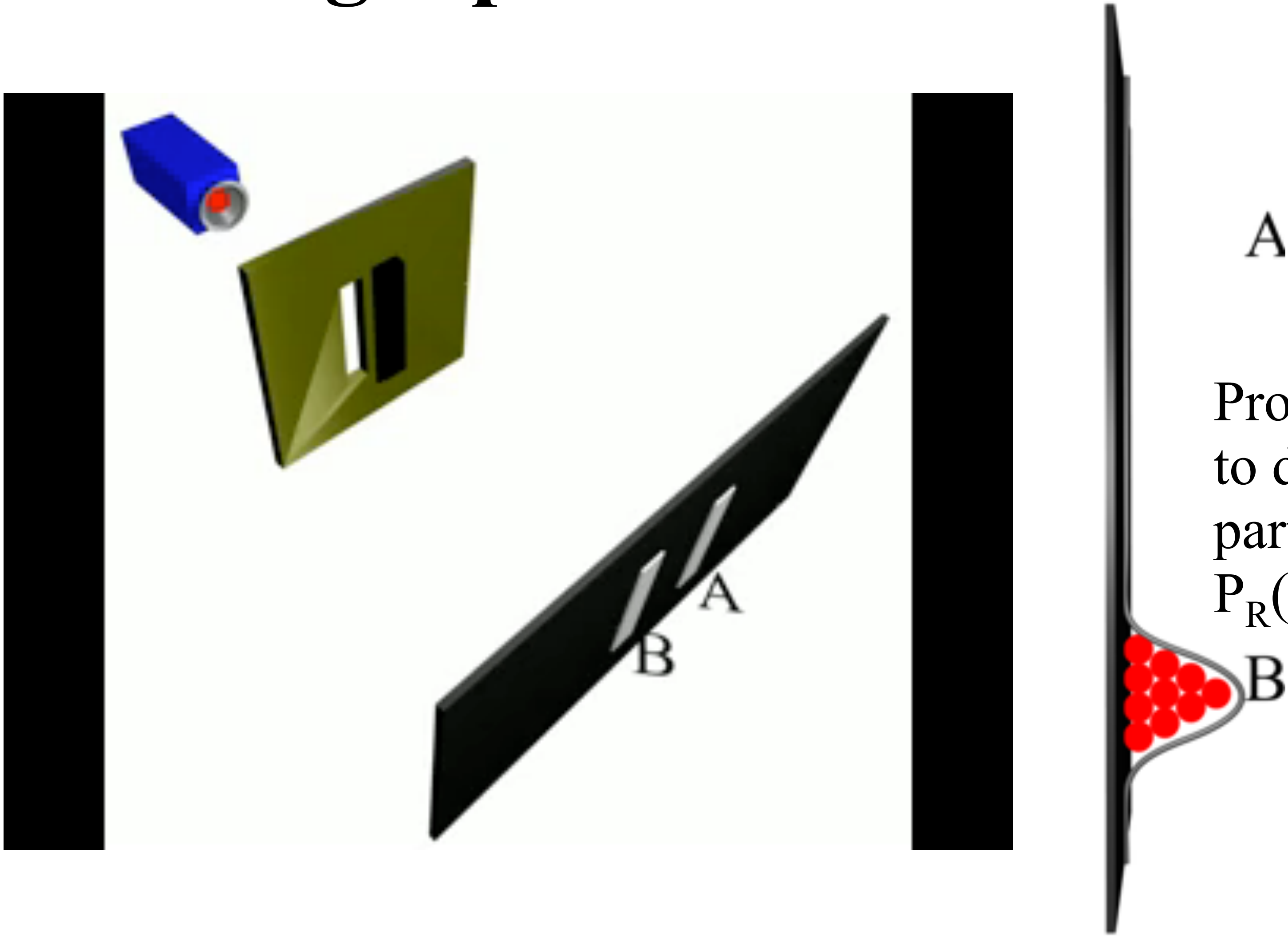
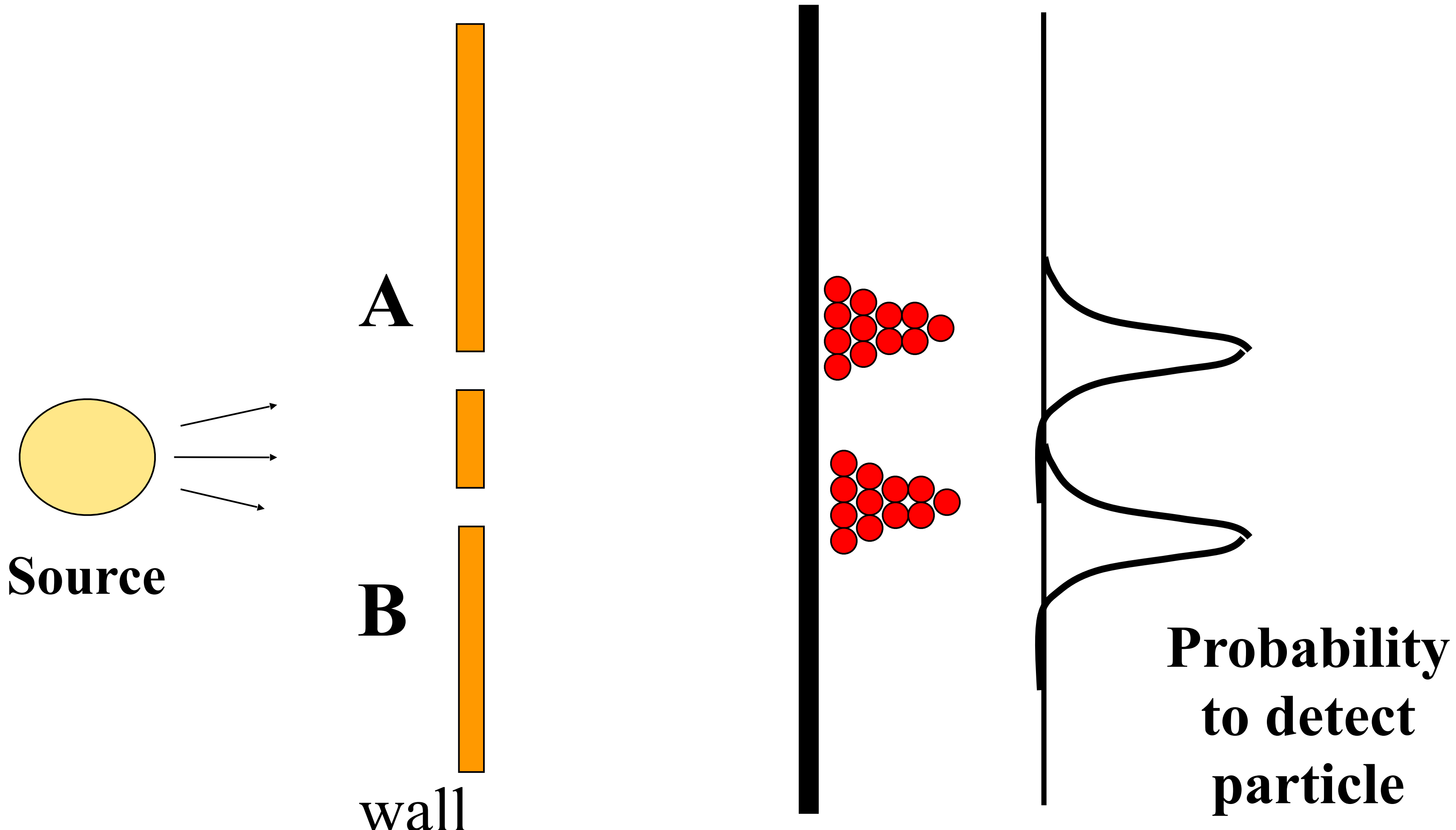


Single-particle interference



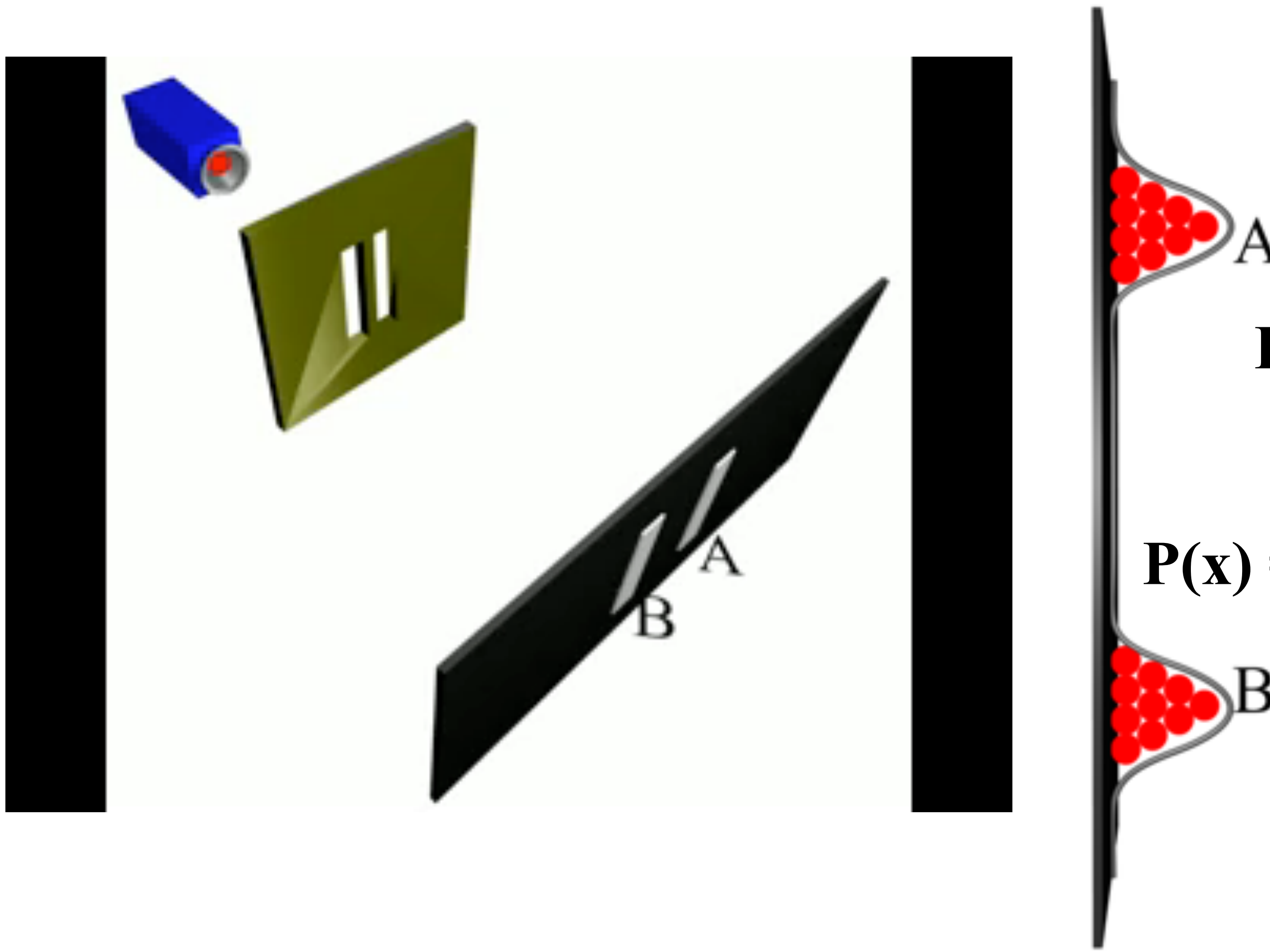
Probability to detect particle $P_R(x)$

“classical” behaviour



$$P(x) = P_A(x) + P_B(x)$$

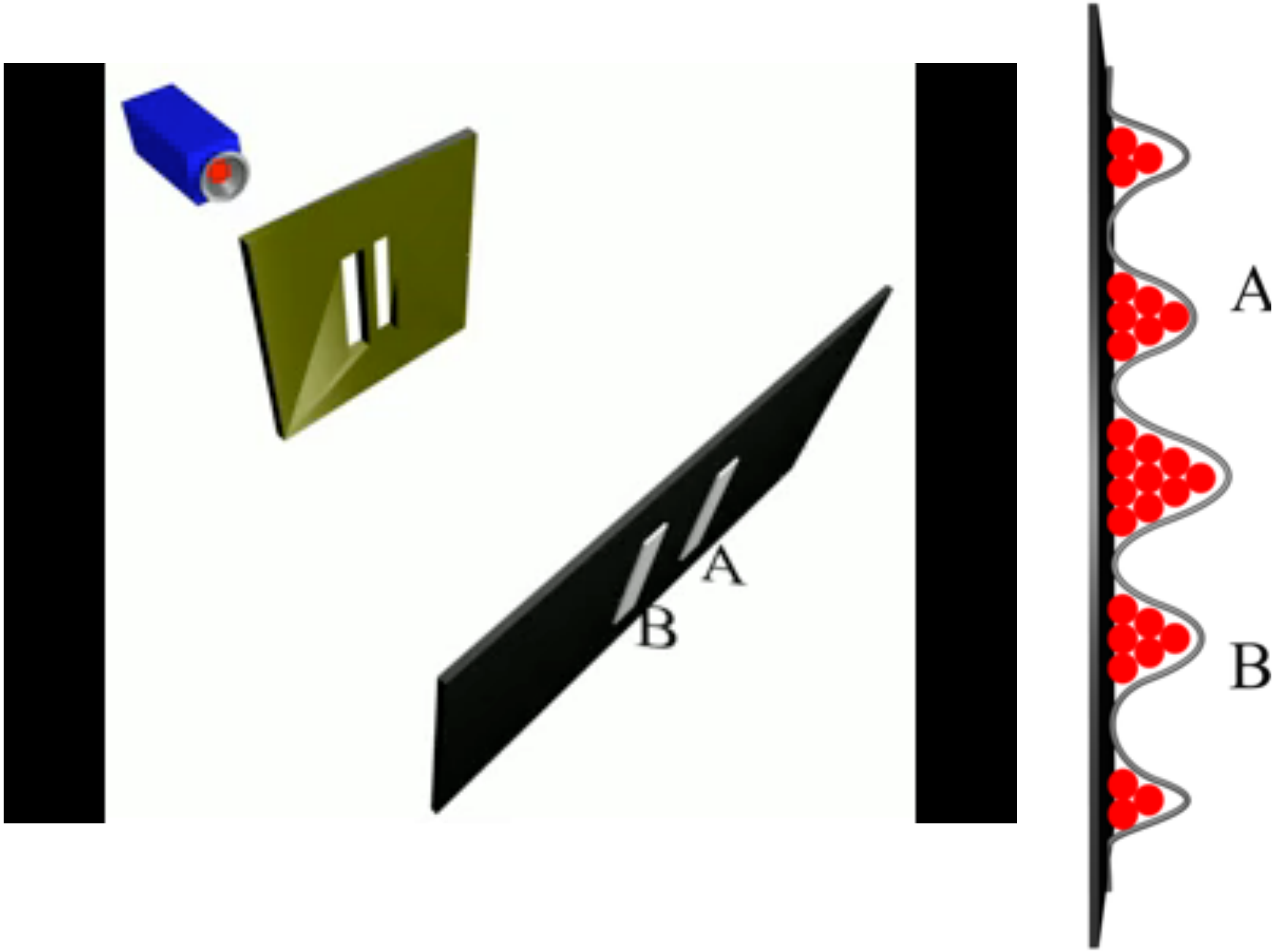
“classical” behaviour



Probability to detect particle

$$P(x) = P_L(x) + P_R(x)$$

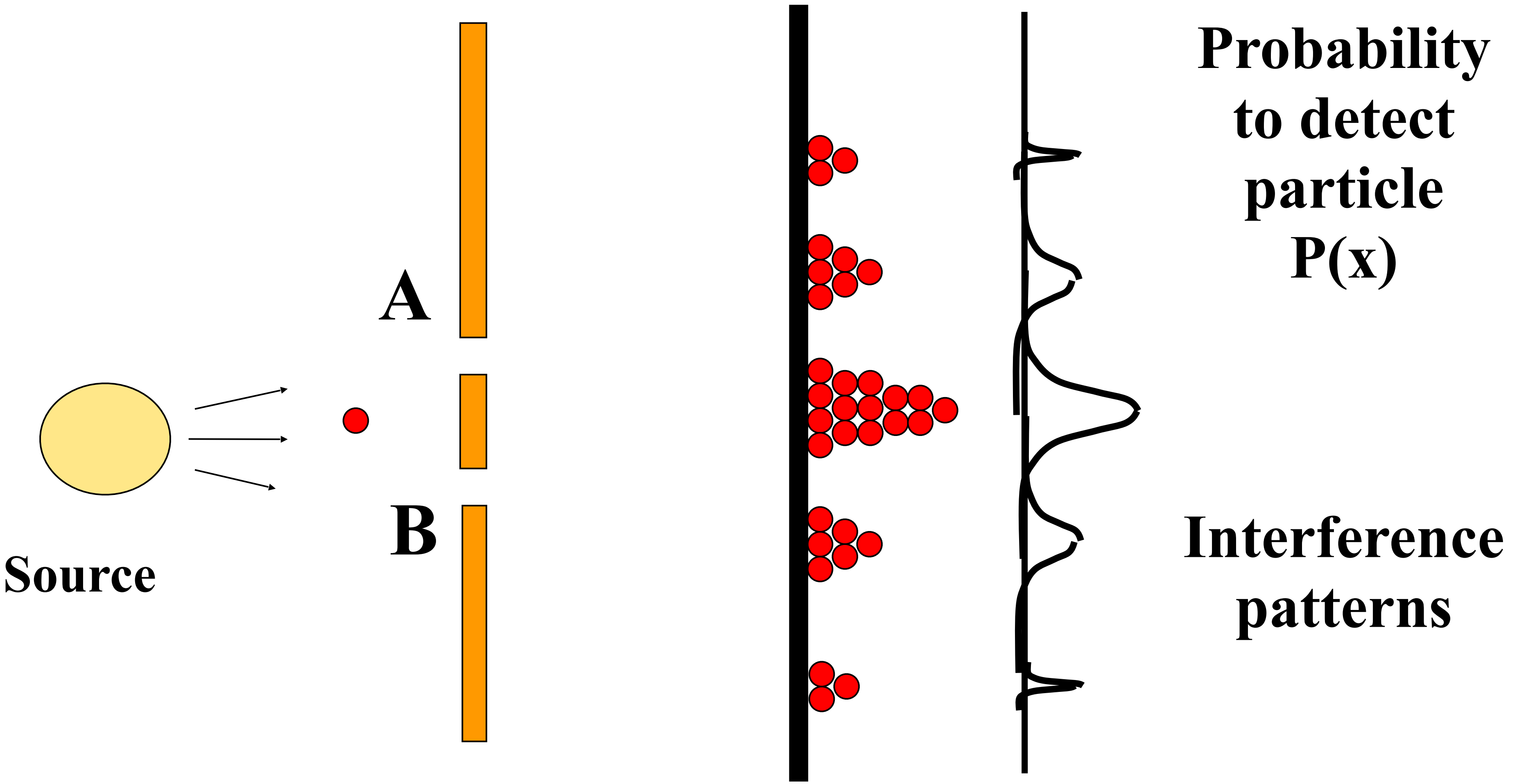
Quantum interference



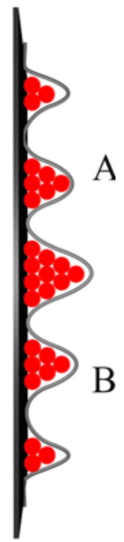
Probability to detect particle P(x)

Interference patterns

Quantum interference



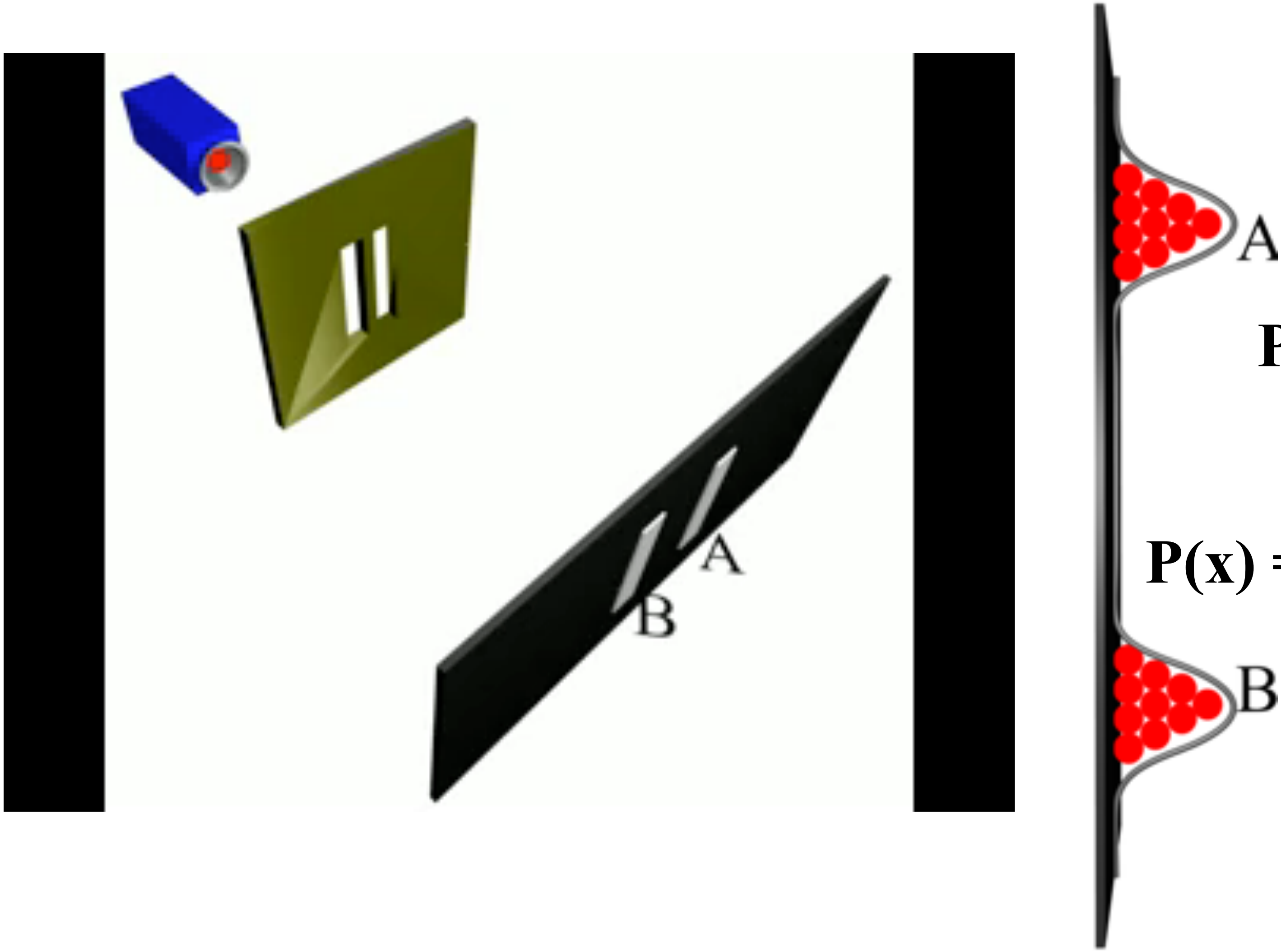
Wavefunction



From which slit the photon is going through ?

It is as if the photon follows the two paths at the same time

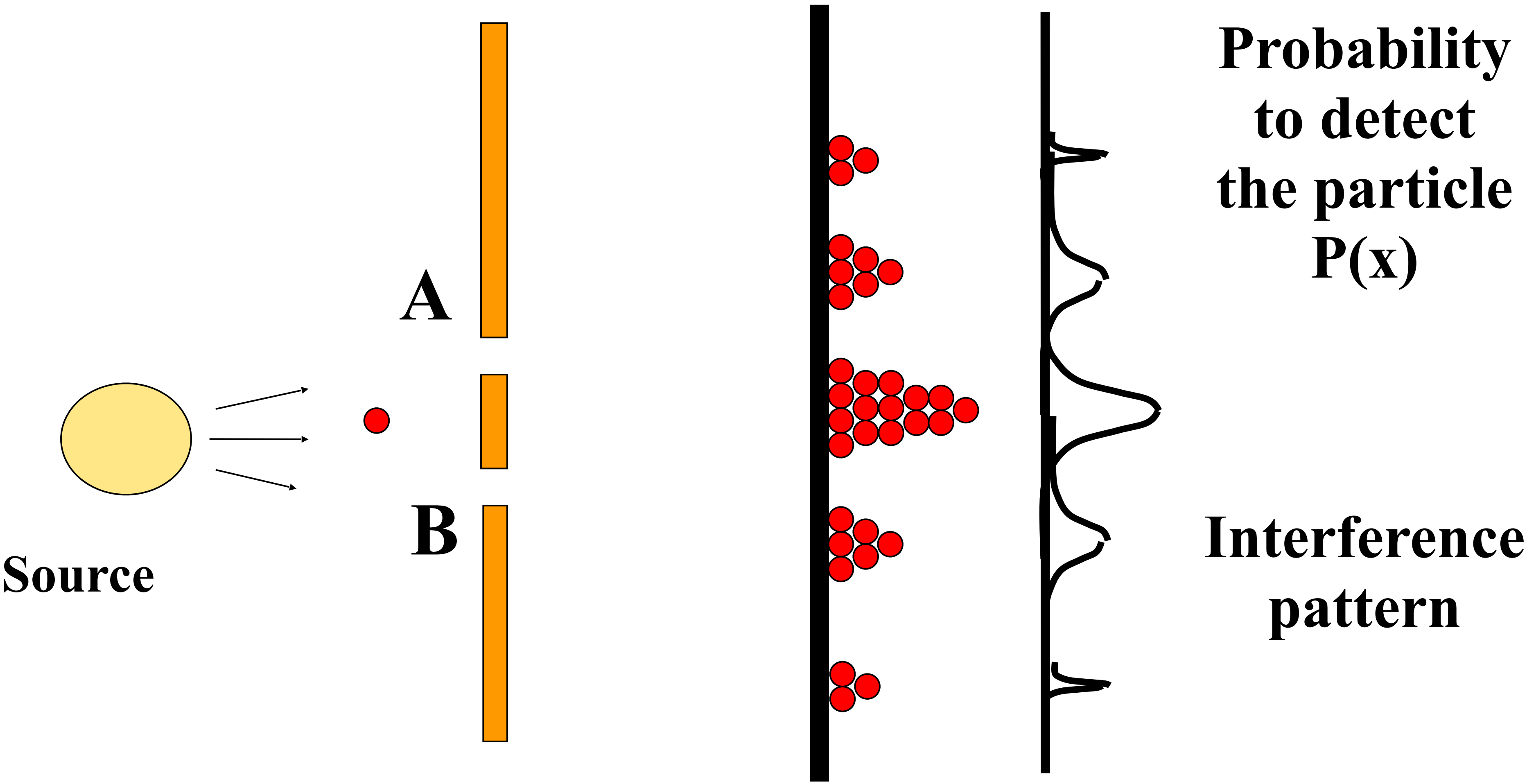
“classical” behaviour



Probability to detect particle

$$P(x) = P_L(x) + P_R(x)$$

Quantum interference

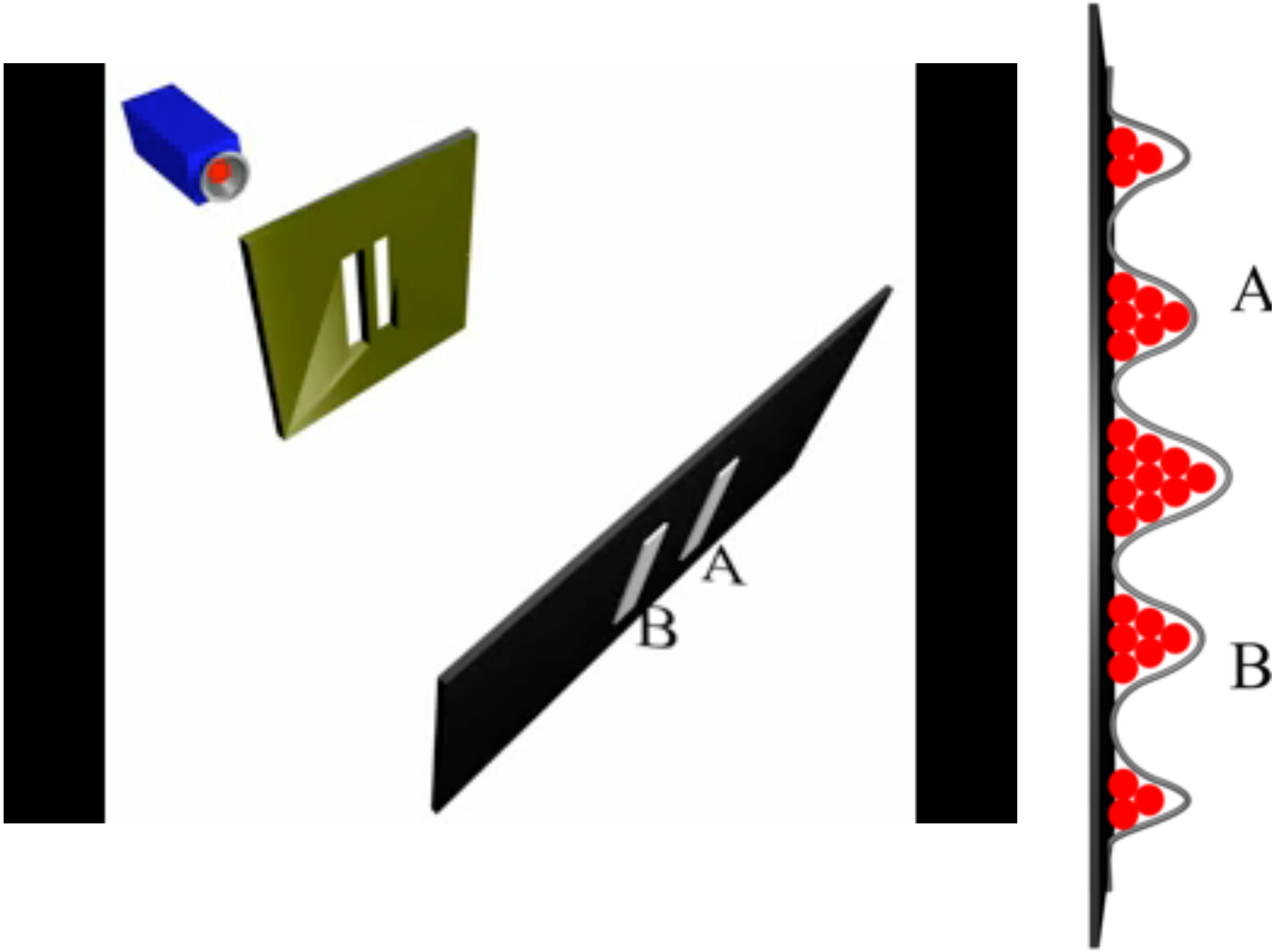


The photon “goes through” the two slits

WAVE FUNCTION

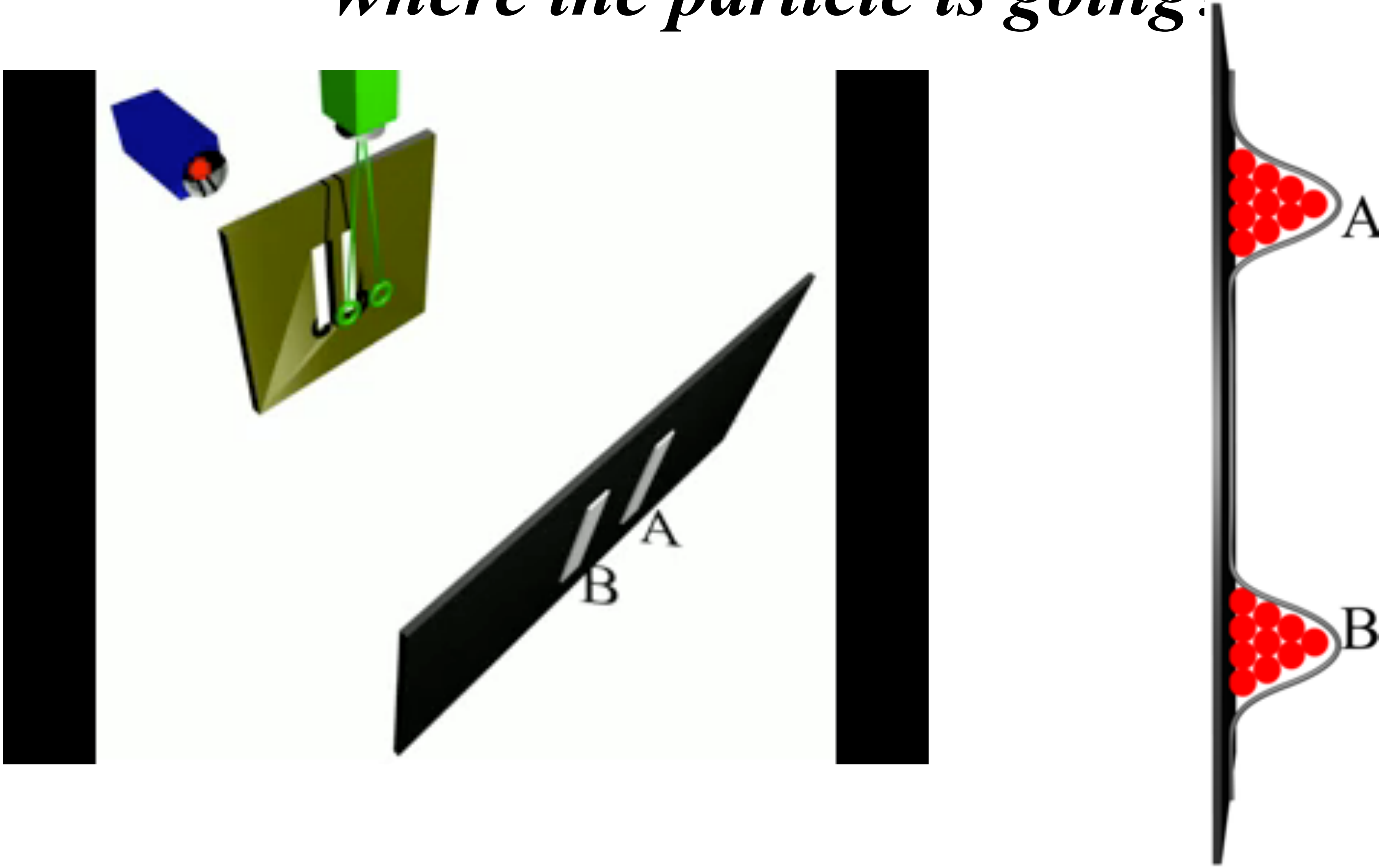
$$\left| fotone\ in\ A \right\rangle + \left| fotone\ in\ B \right\rangle$$

$$|\,fotone\ in\ A\rangle + |\,fotone\ in\ B\rangle$$



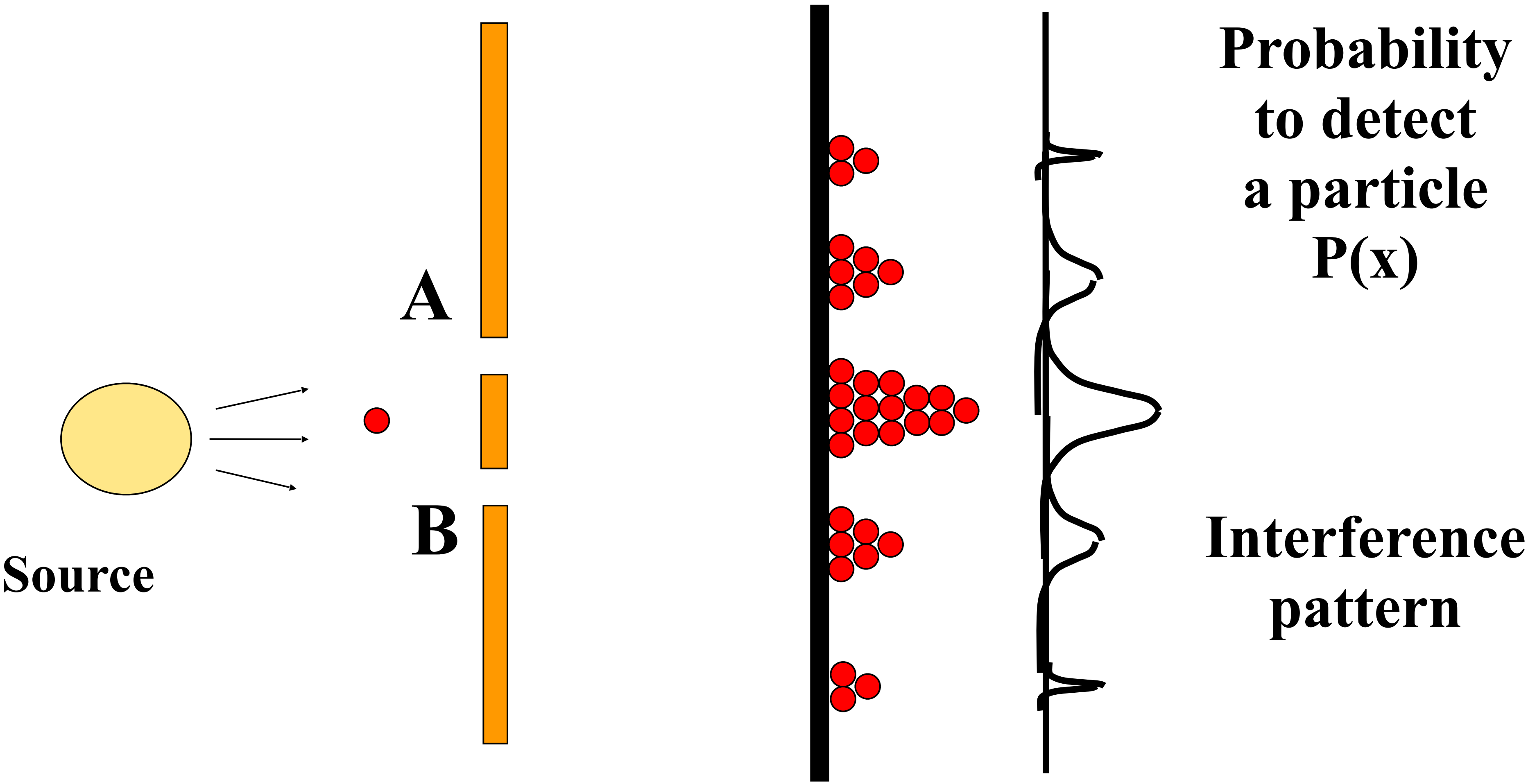
Observation

where the particle is going?



The interference patterns disappear!

Where the particle is going?



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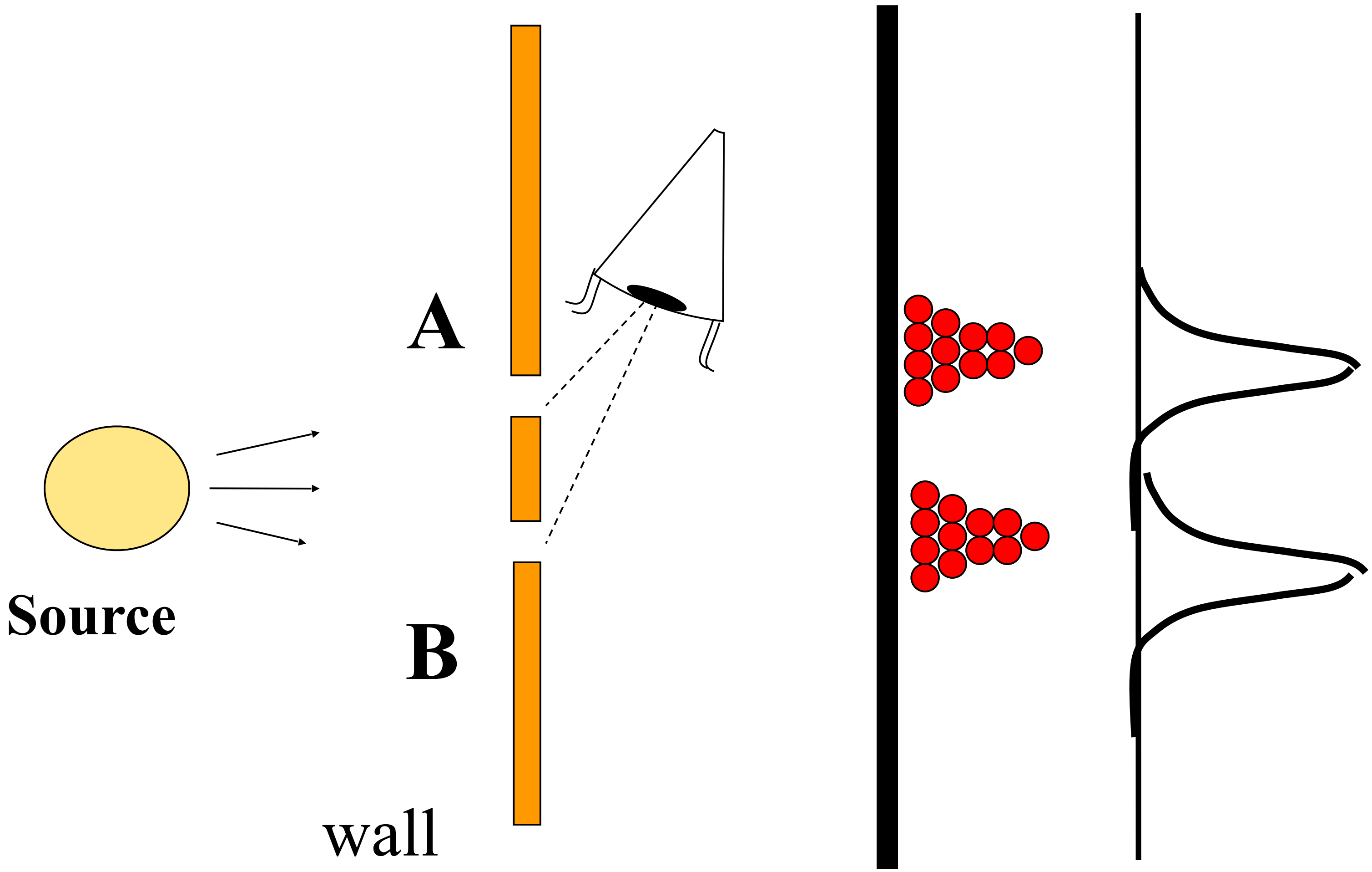

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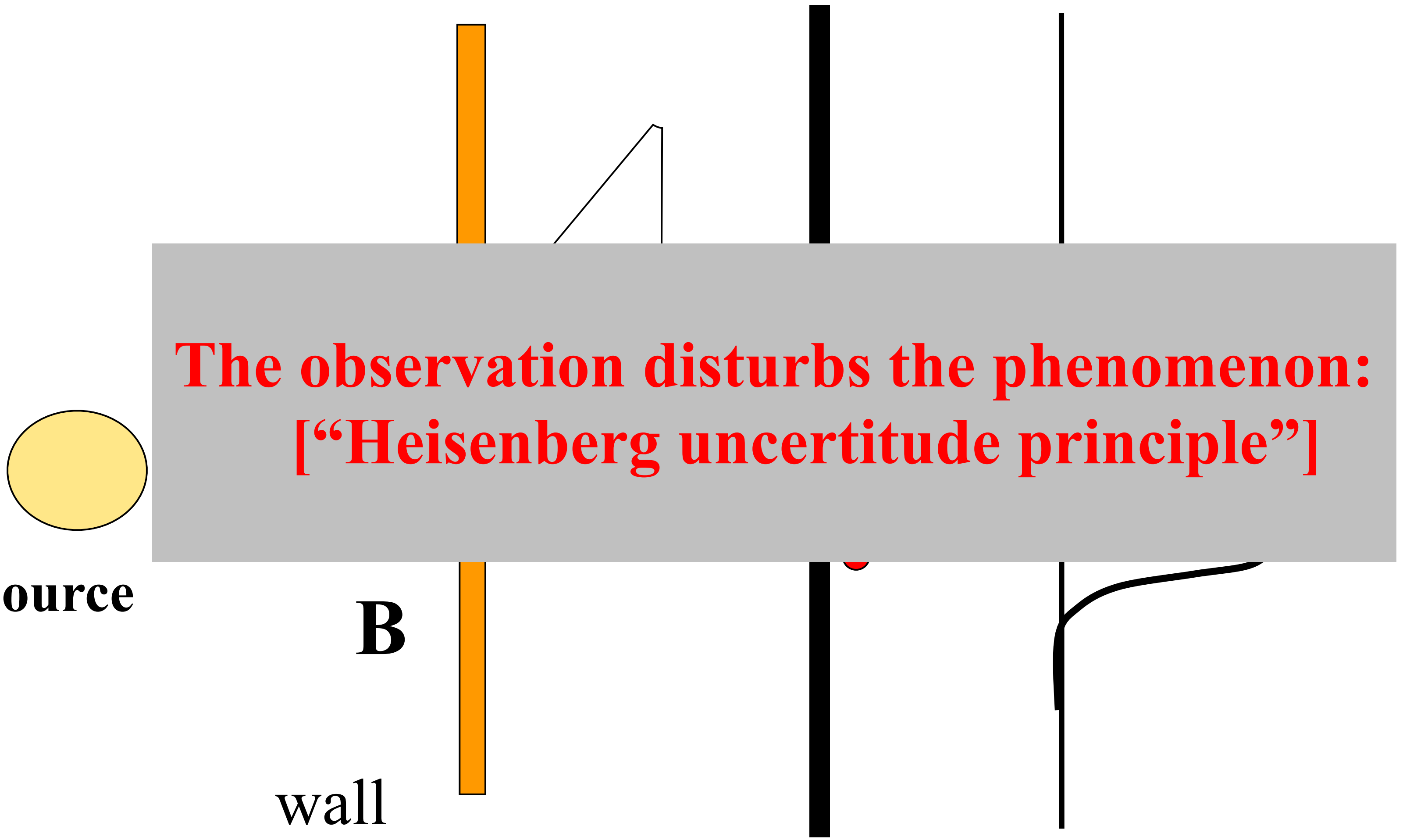
Observation



The observation disturbs the phenomenon: ["Heisenberg uncertitude principle"]

The interference patterns disappear!

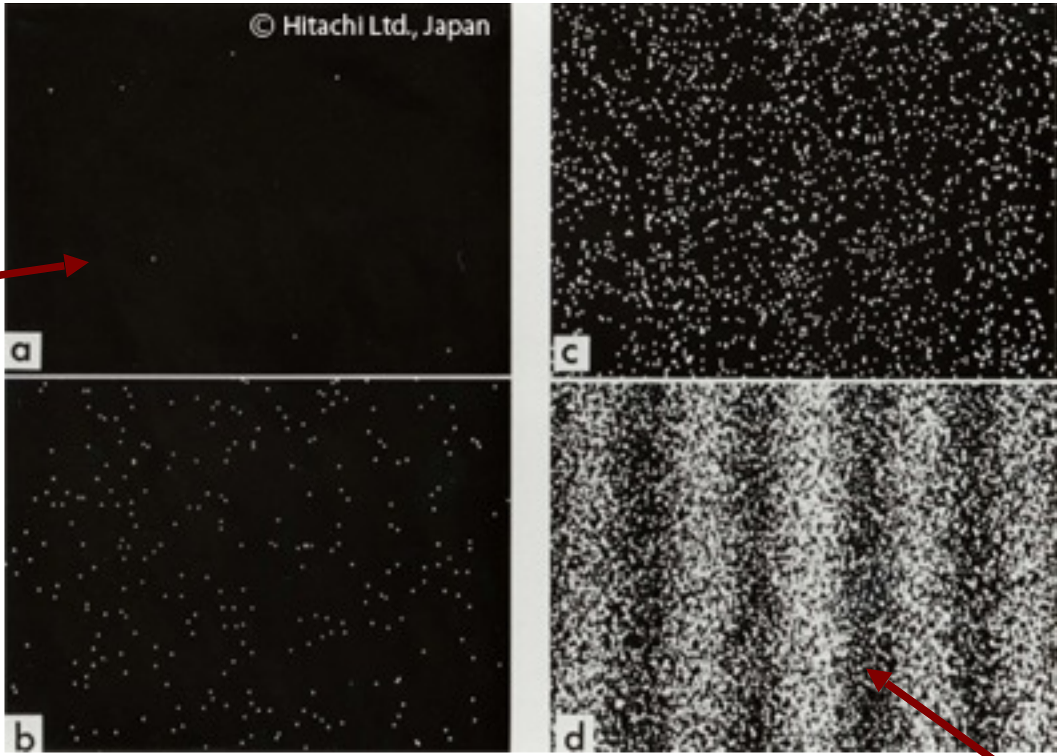
“It from bit”

J.A.Wheeler

The reality is also created by our questions, or from information gained.

The observation disturbs the phenomenon: [“Heisenberg uncertitude principle”]

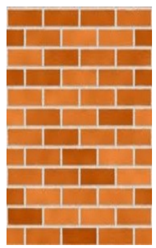
Interference with massive particles: electrons



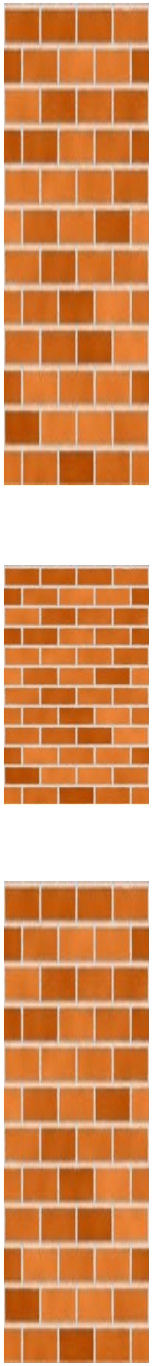
8 electrons

60.000 electrons

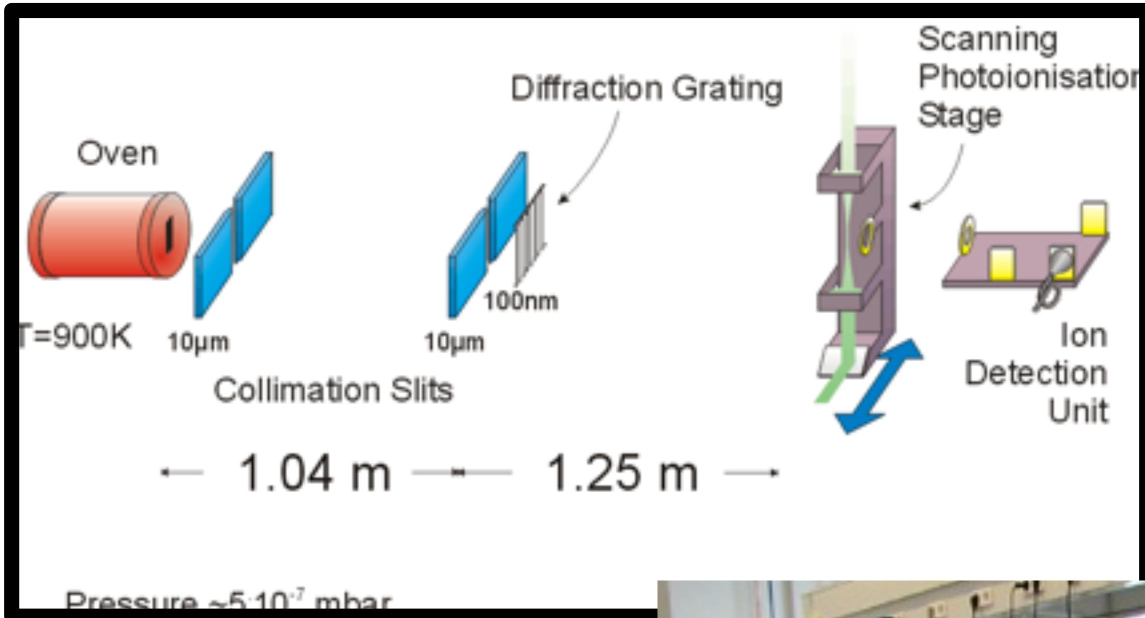

10



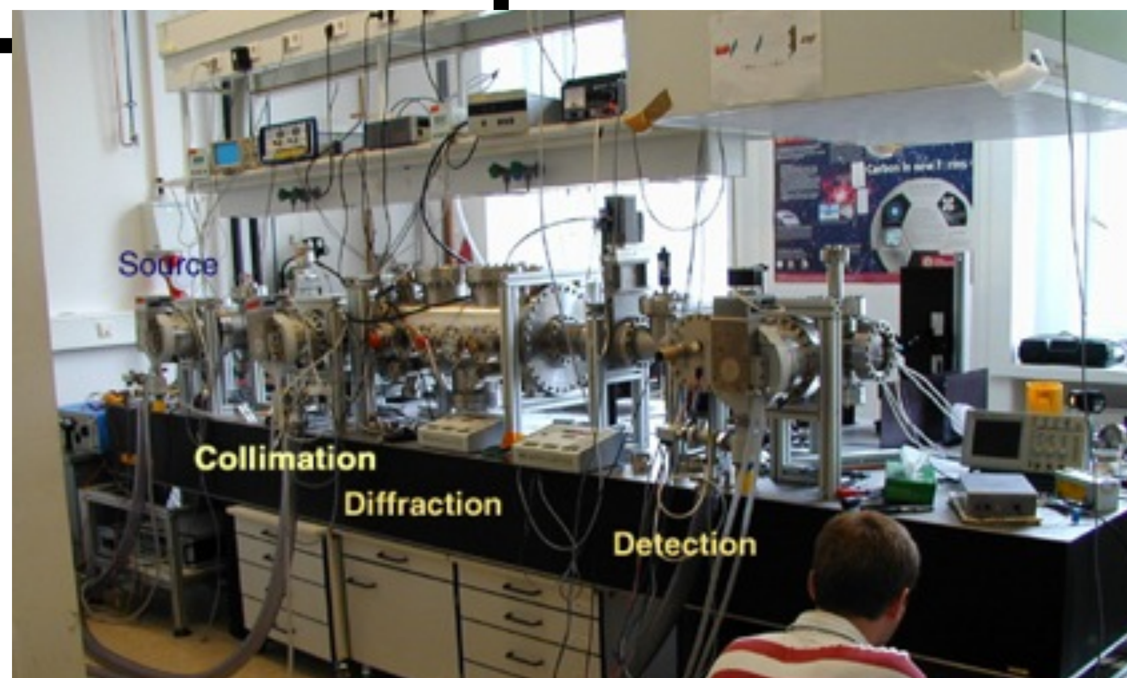
Fullerene C_{60}



?



Scanning
Photoionisation
Stage
Diffraction Grating
Oven
100nm
T=900K
10µm
10µm
Collimation Slits
Ion
Detection
Unit
1.04 m
1.25 m
Pressure ~$5\cdot10^{-7}$ mbar



Source
Collimation
Diffraction
Detection

Fullerene C_{60}

$C_{168}H_{94}F_{152}O_8N_4S_4$

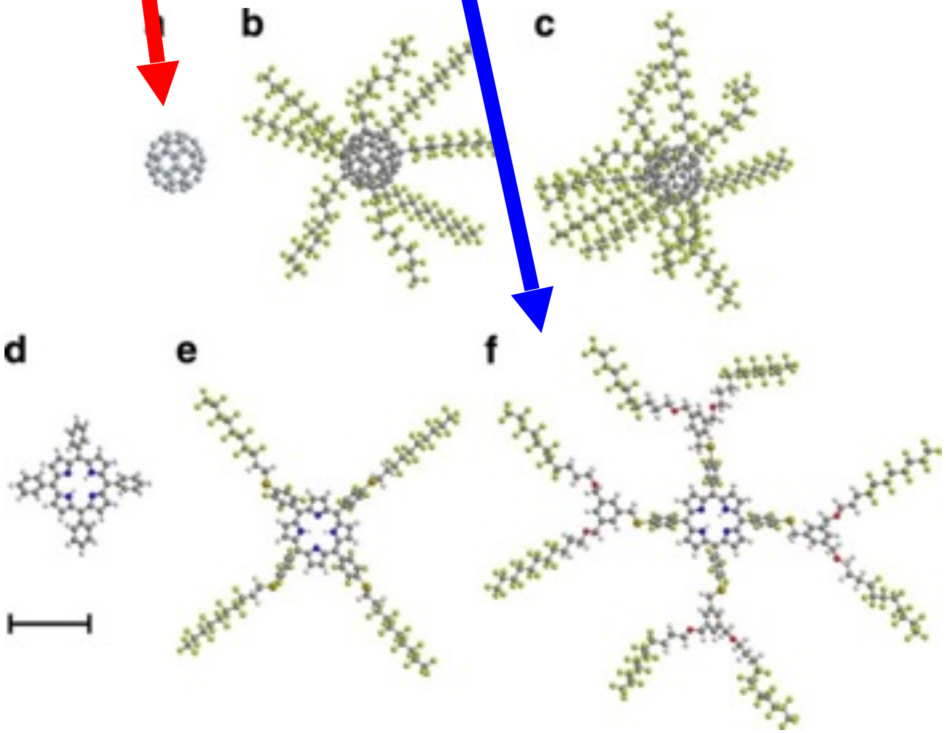
430 atomi

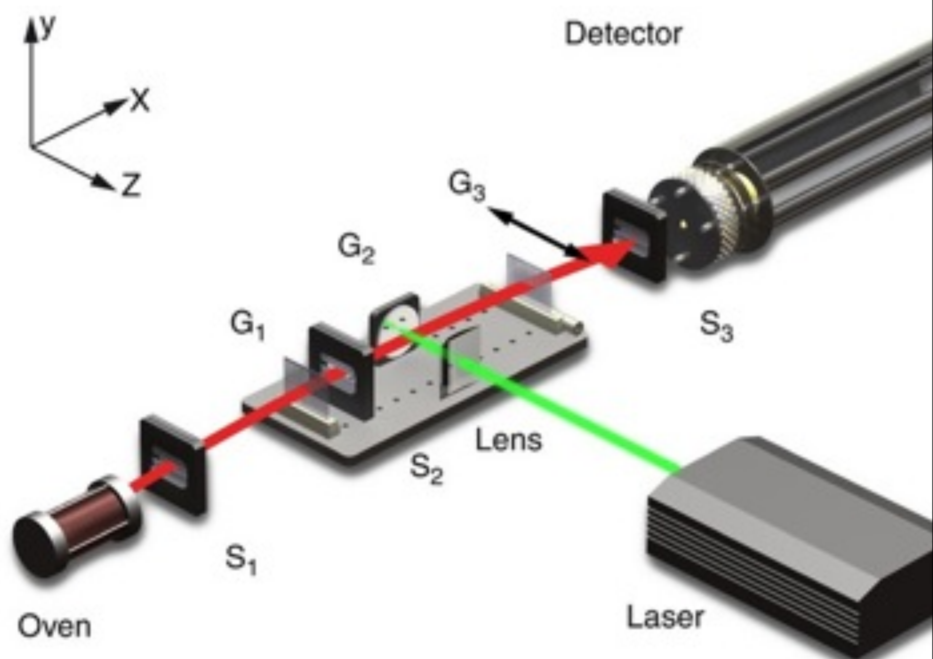
NATURE COMMUNICATIONS | ARTICLE OPEN

Quantum interference of large organic molecules

Stefan Gerlich, Sandra Eibenberger, Mathias Tomandl, Stefan Nimmrichter, Klaus Hornberger, Paul J. Fagan, Jens Tüxen, Marcel Mayor & Markus Arndt

Nature Communications **2**, Article number: 263
doi:10.1038/ncomms1263
Received 05 January 2011 Accepted 02 March 2011

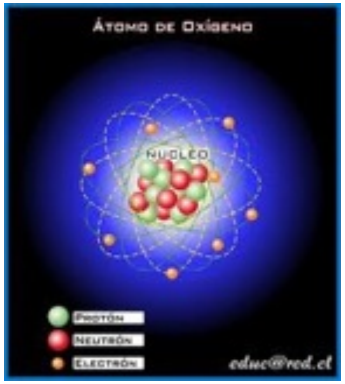


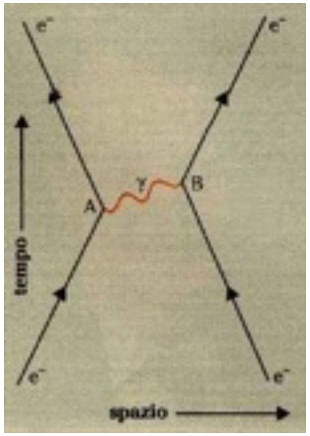


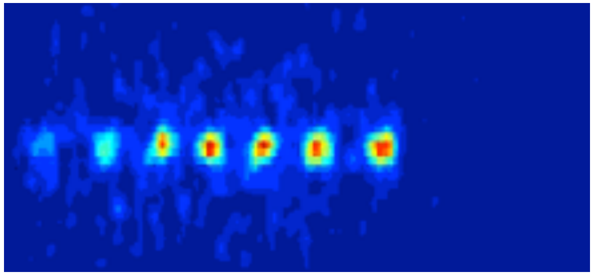
MACROSCOPIC WORLD

CLASSICAL PHYSICS

MICROSCOPIC WORLD



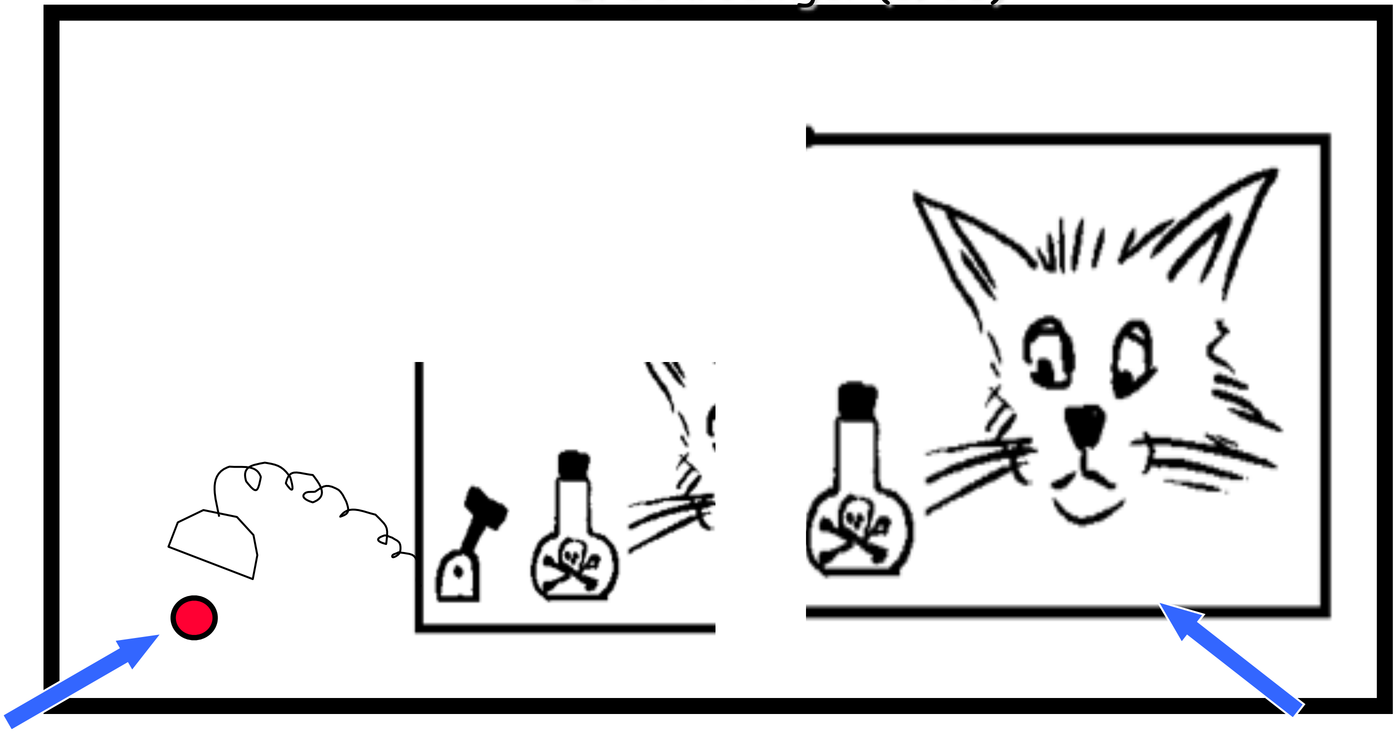




QUANTUM PHYSICS

The paradox of Schroedinger's cat

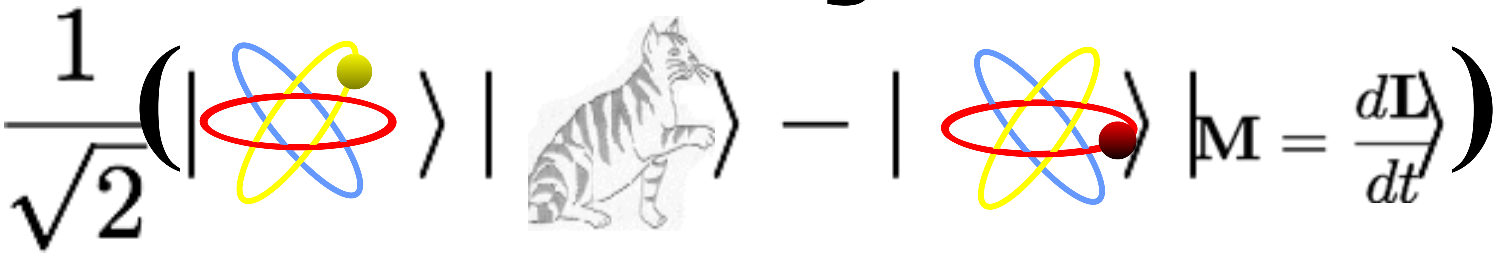
E. Schrödinger (1935)



Oggetto quantistico – particella radioattiva.
50% probabilità di decadimento in un'ora.
Il decadimento causa la rottura della fiala con veleno

Oggetto classico: gatto

The paradox of Schroedinger's cat



Atom not decayed | Alive cat | Atom decayed | Dead cat

Not observed cats living and dead at the same time!

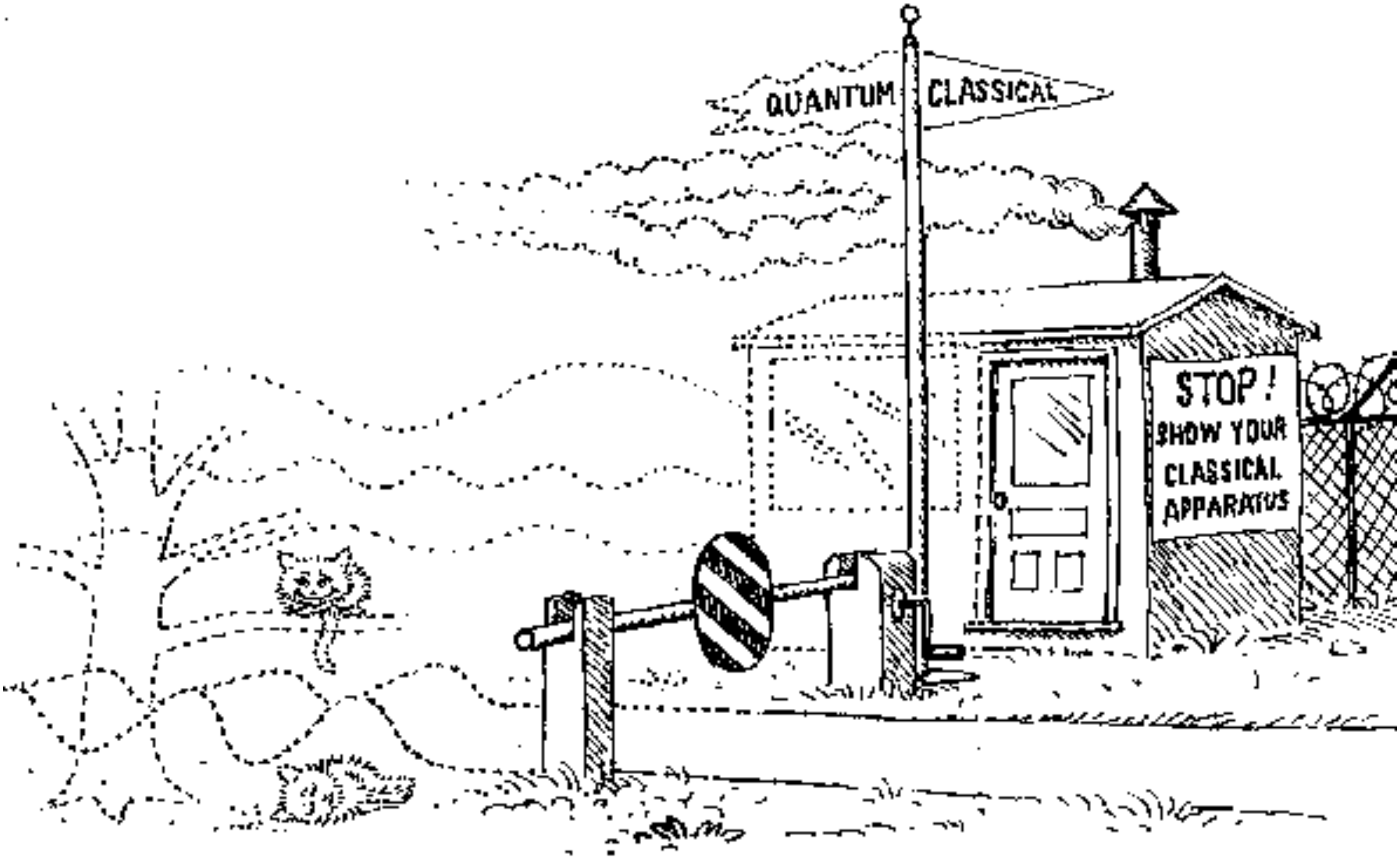
Interaction with the environment: loss of coherence

Superposition state (alive and dead) → Statistical mixture (alive or dead)

Computing: superposition states of many qubits

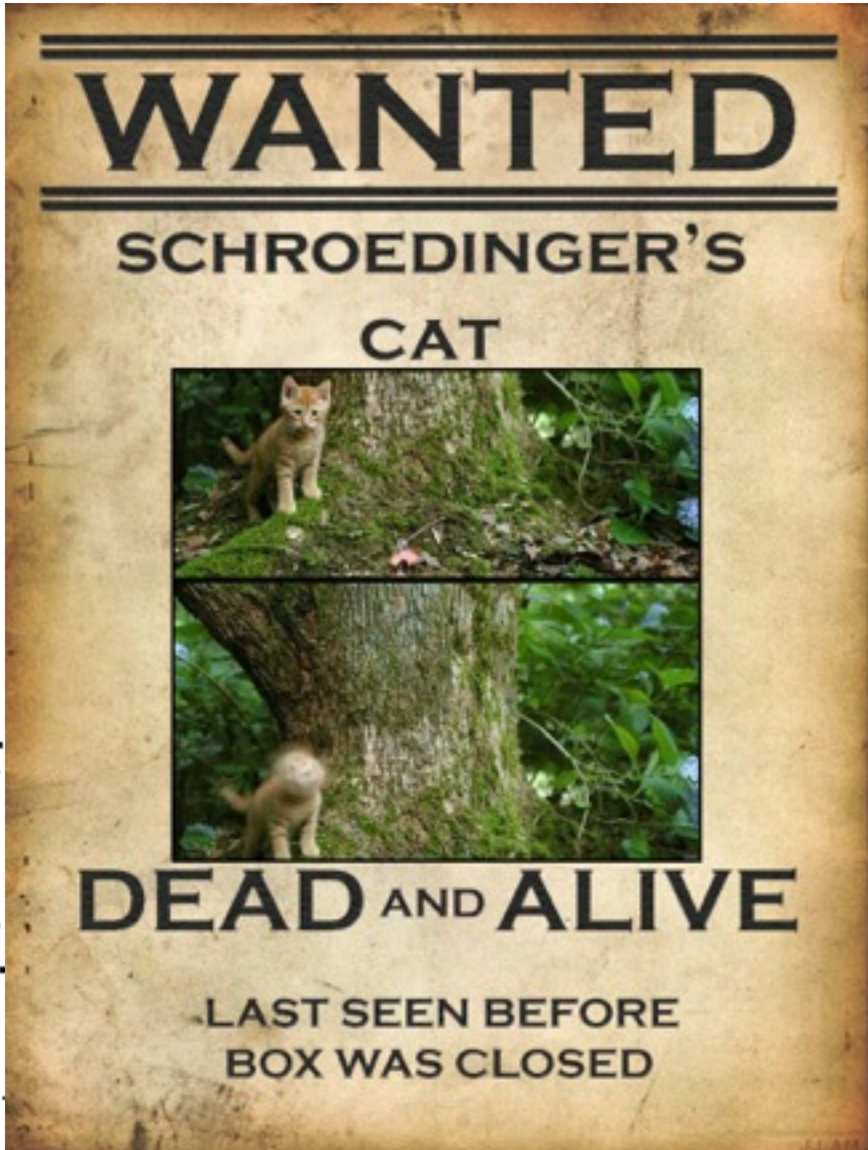
Techniques for Quantum Error Correction

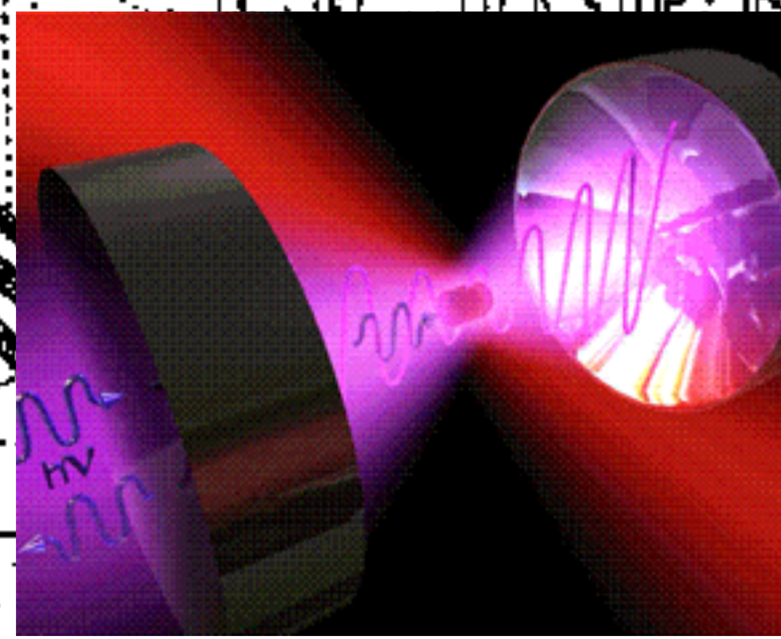
The border between the classical and quantum world



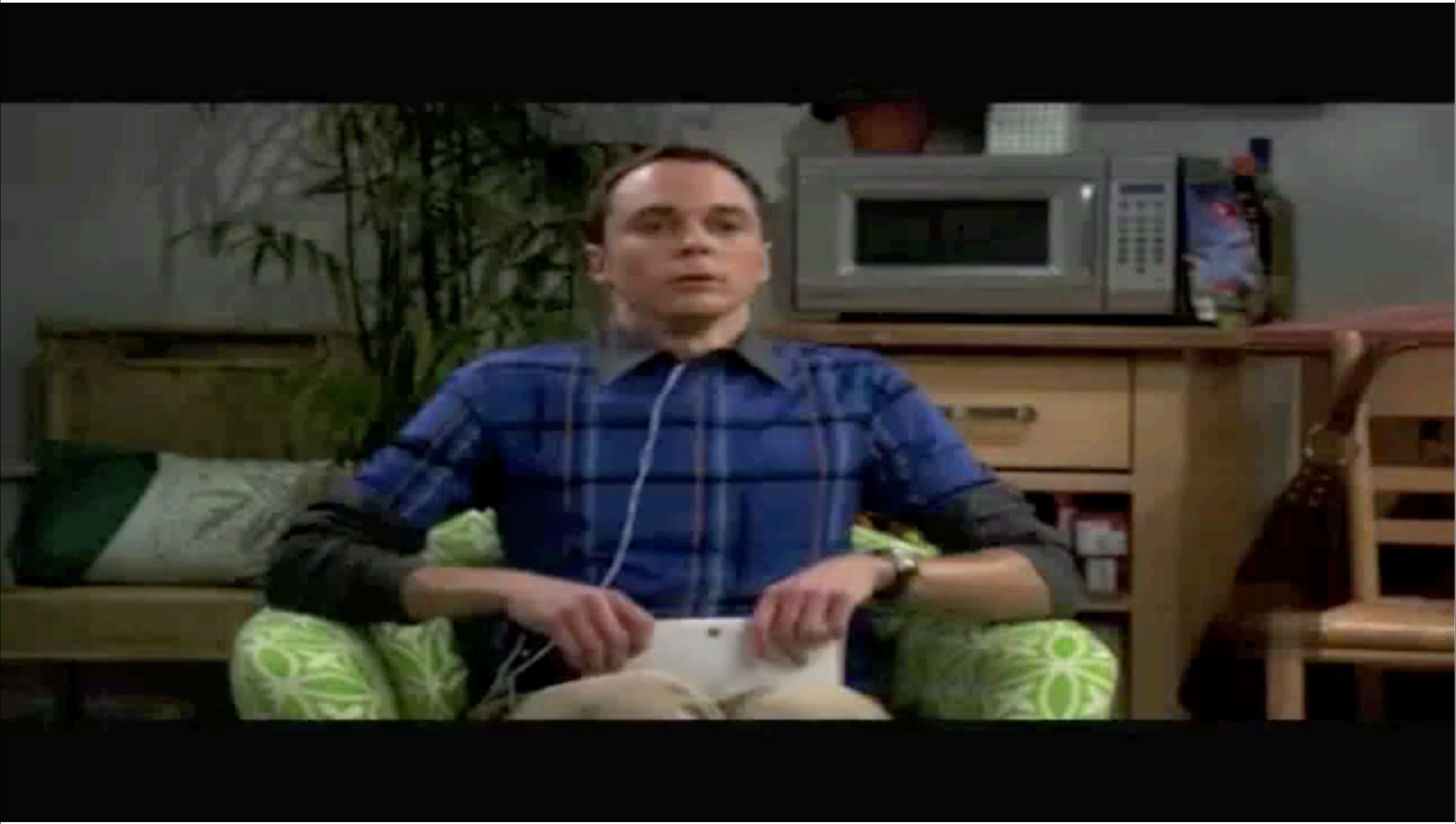
Zurek, Physics Today, October 1991, page 38

The border between the classical and quantum world





Zurek, Physics Today, October 1991, page 38



Quantum Information

Information Theory + Quantum Mechanics:
It exploits the laws of quantum mechanics to communicate, manipulate and process information

Fundamental physics

Non-locality

Micro-macroscopic transition

Applied physics

Criptography

Computation

Metrology

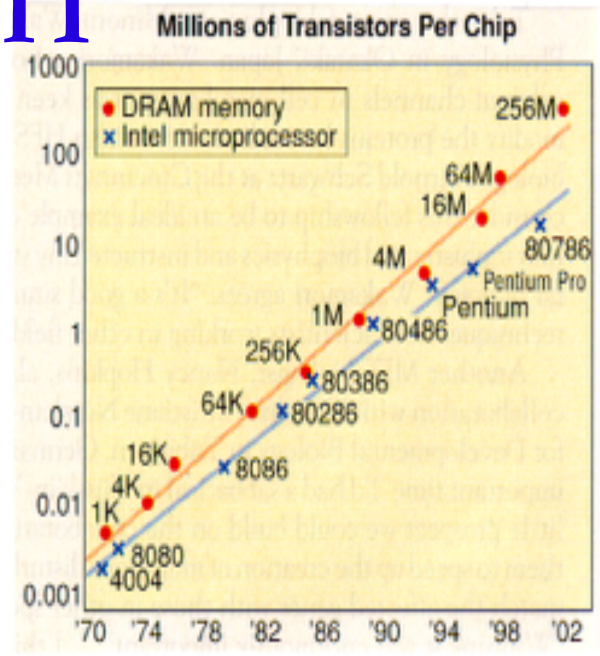
“Information is physics”

R. Landauer

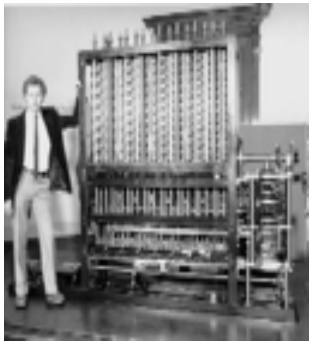
The manipulation of information is governed by the laws of physics..

Evolution of Information Technology

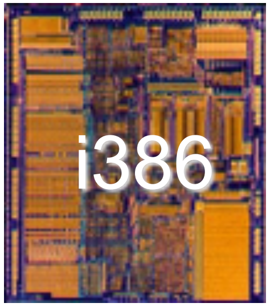
BIT



1879

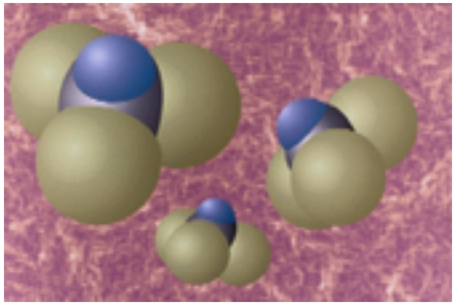


1986



1 micron

2020



1 nanometro

BIT: **Dichotomic variable**

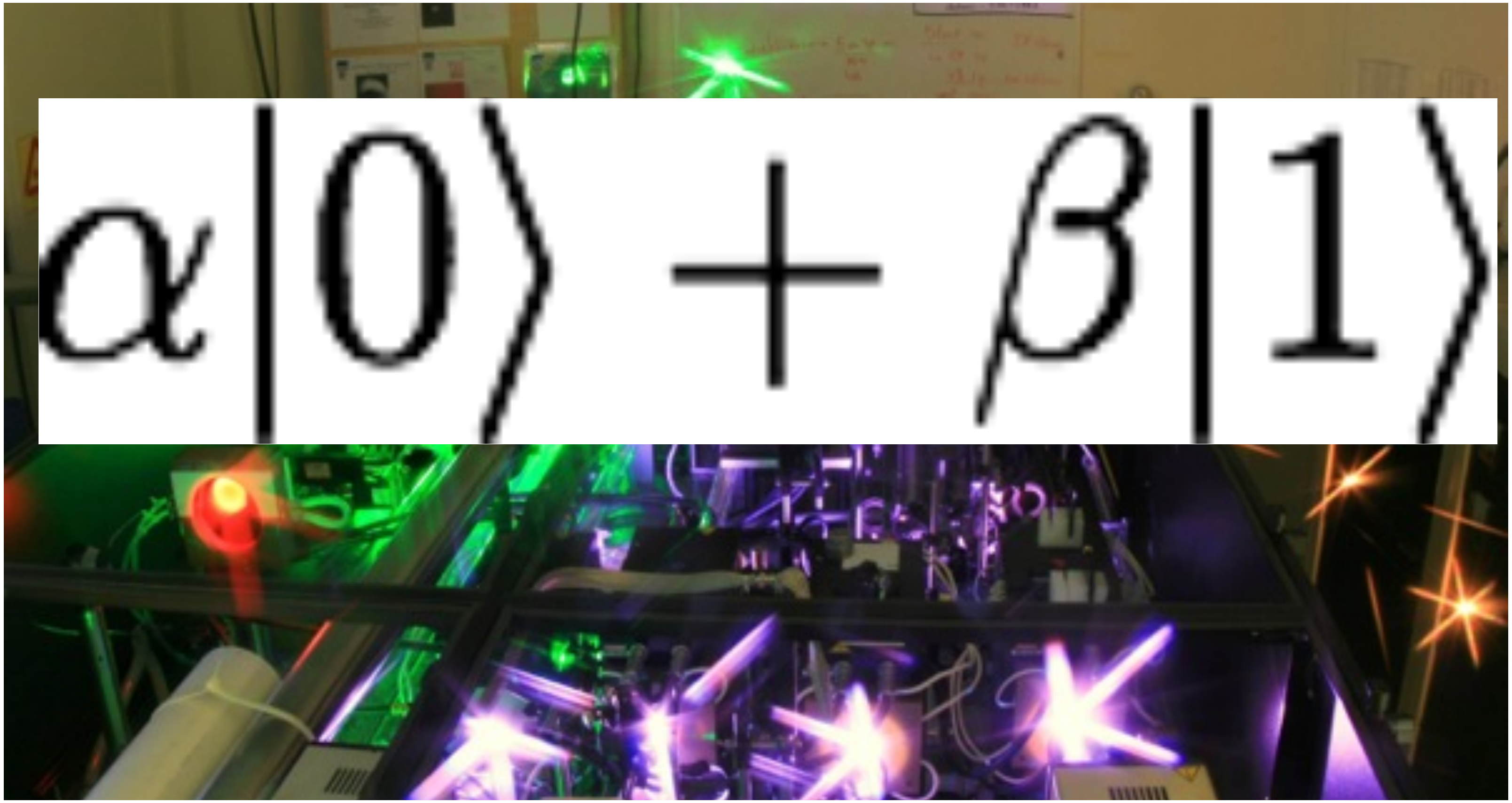
0 *o* 1

QUBIT (Quantum Bit)

$$\alpha|0\rangle + \beta|1\rangle$$

QUANTUM INFORMATION

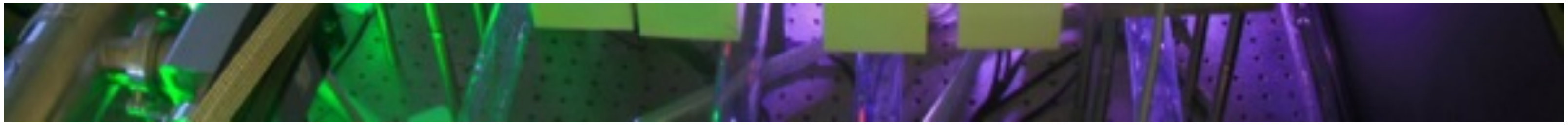
QUBIT (Quantum Bit)



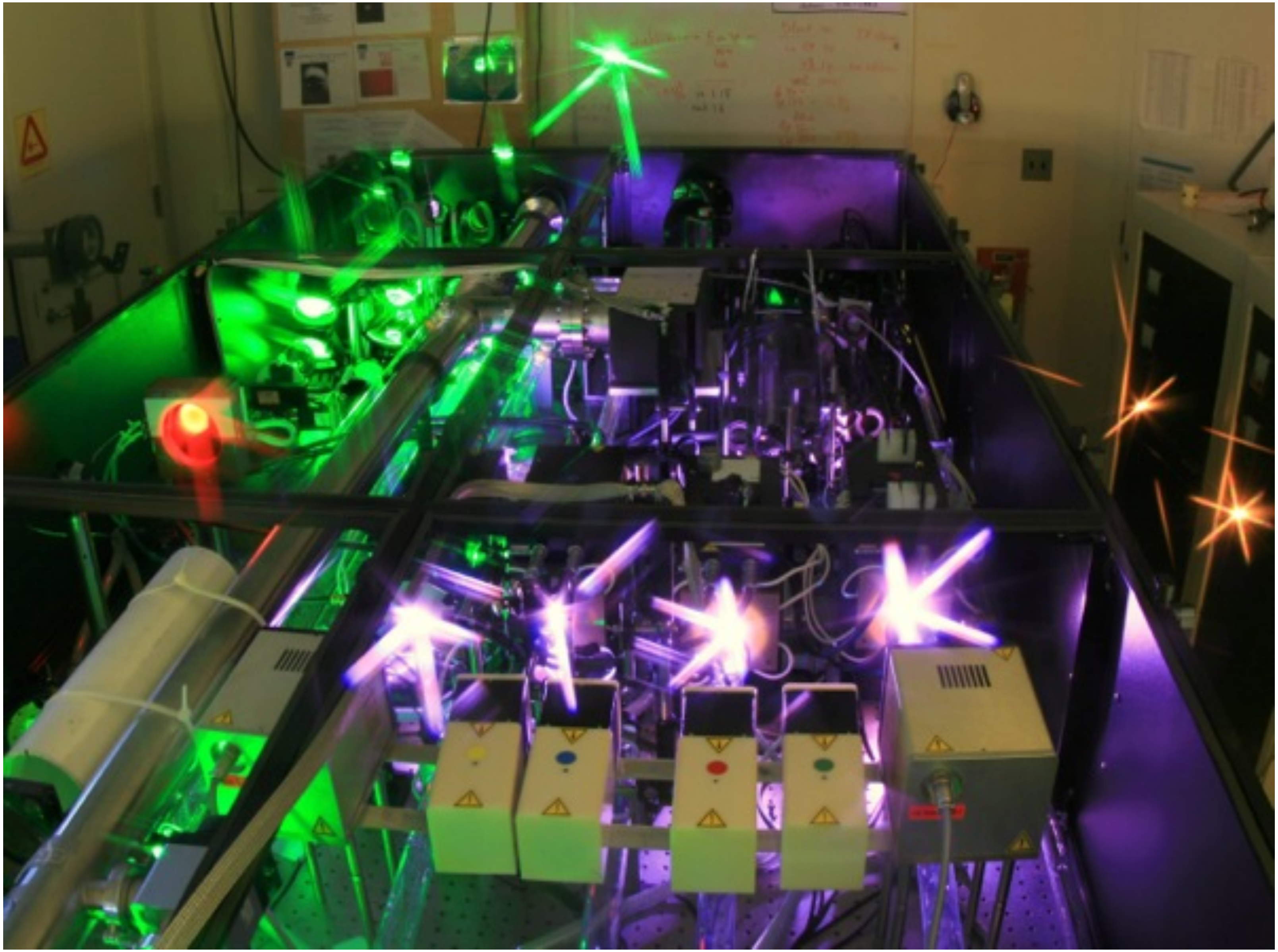
$$\alpha|0\rangle + \beta|1\rangle$$

GOAL:

TO EXPLOIT QUANTUM PARALLELISM

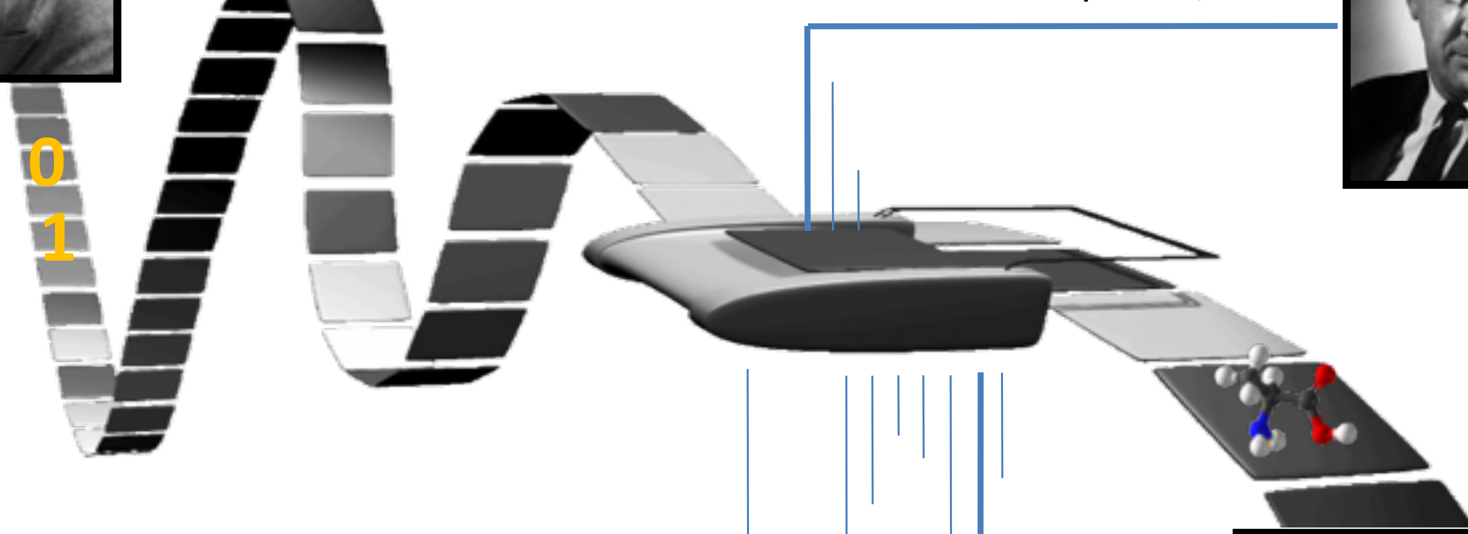


QUBIT (Quantum Bit)



On computable numbers, with an application to the Entscheidungsproblem
A. Turing, 1936

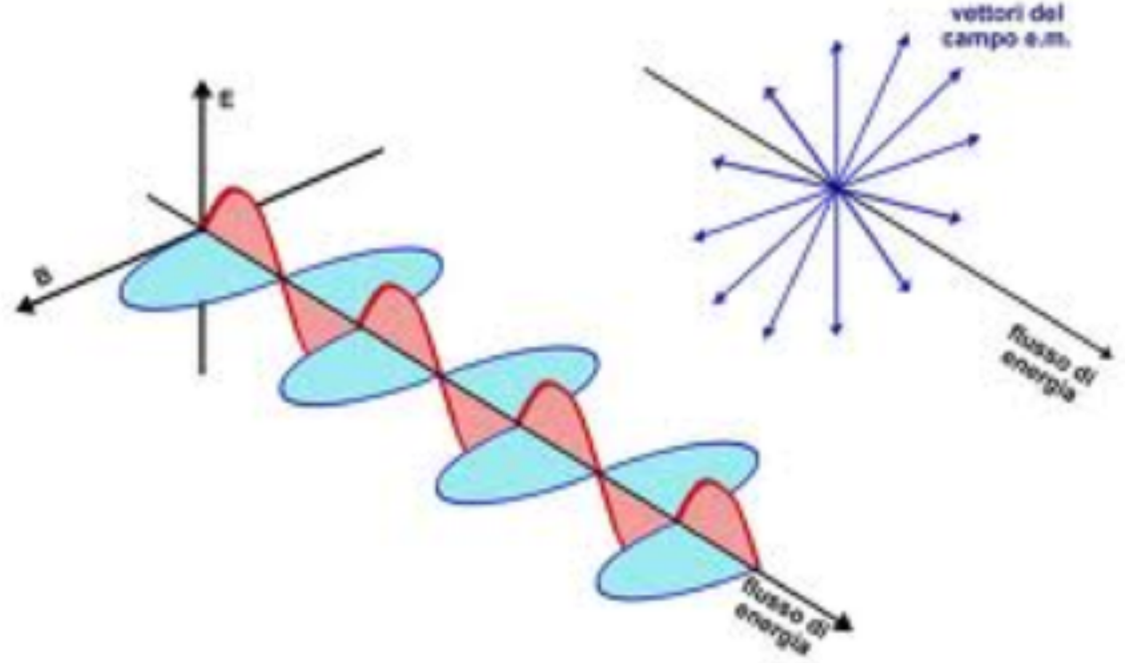
Simulating Physics with Computers
R. Feynman, 1982



Quantum theory, the Church-Turing principle and the universal quantum computer
D. Deutsch, 1984

Algorithms for quantum computation: Discrete log and factoring
P. W. Shor, 1994

Light Polarizzazion



Qubit → **Single photon polarization**

$$\alpha|0\rangle + \beta|1\rangle$$

$$\alpha|H\rangle + \beta|V\rangle$$

H: horizontal
V: vertical

Light Polarization

Polarizzazione: direzione di oscillazione del campo elettromagnetico

Polarizzazione orizzontale $|H\rangle$

Polarizzazione verticale $|V\rangle$

Polarizzazione a + 45° $|H\rangle + |V\rangle$

Polarizzazione a - 45° $|H\rangle - |V\rangle$

Classical cryptography

Cifrario di Cesare:

I sec a.C

Manoscritto di Voynich:

XV sec d.C

ENIGMA:

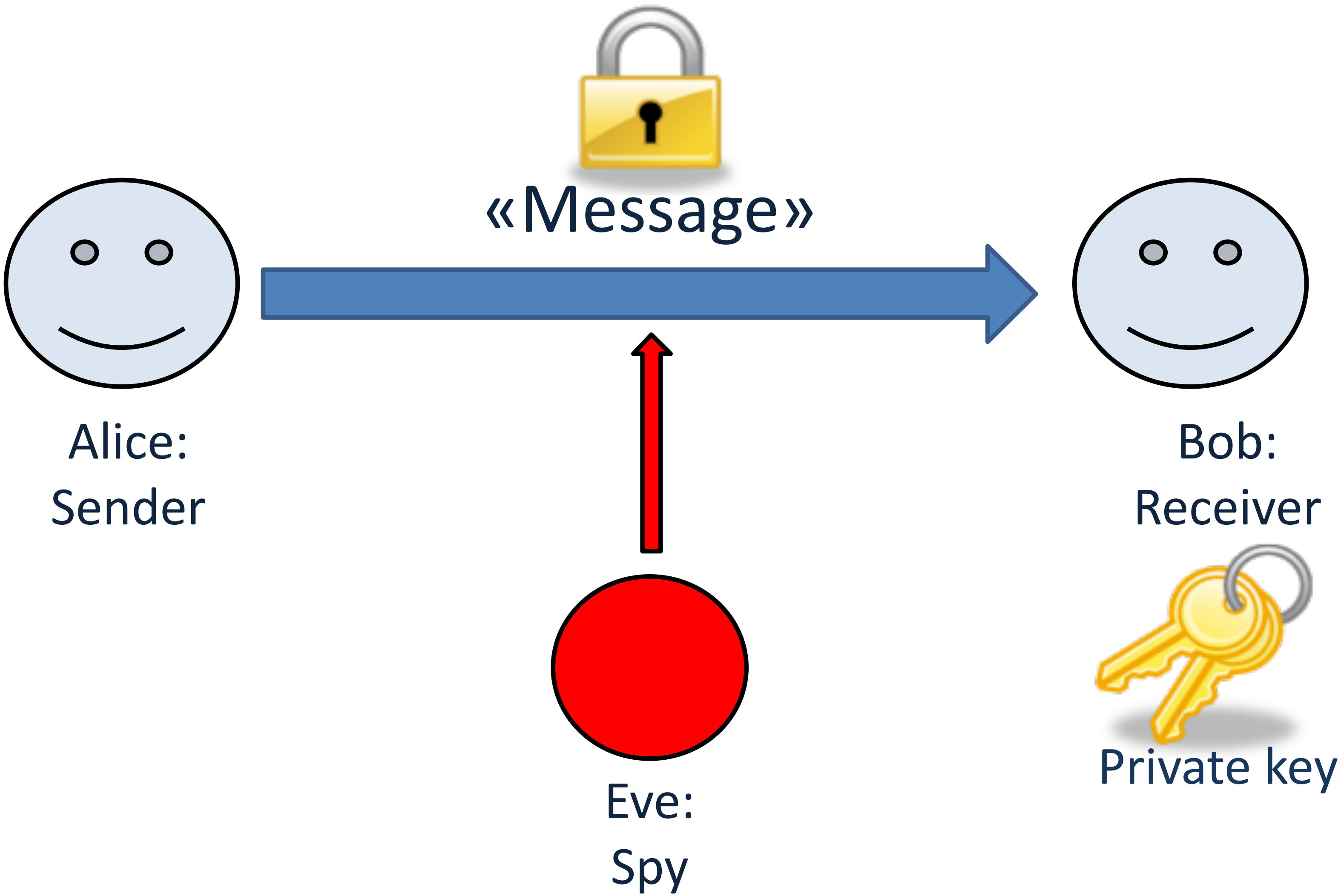
1940 II world war

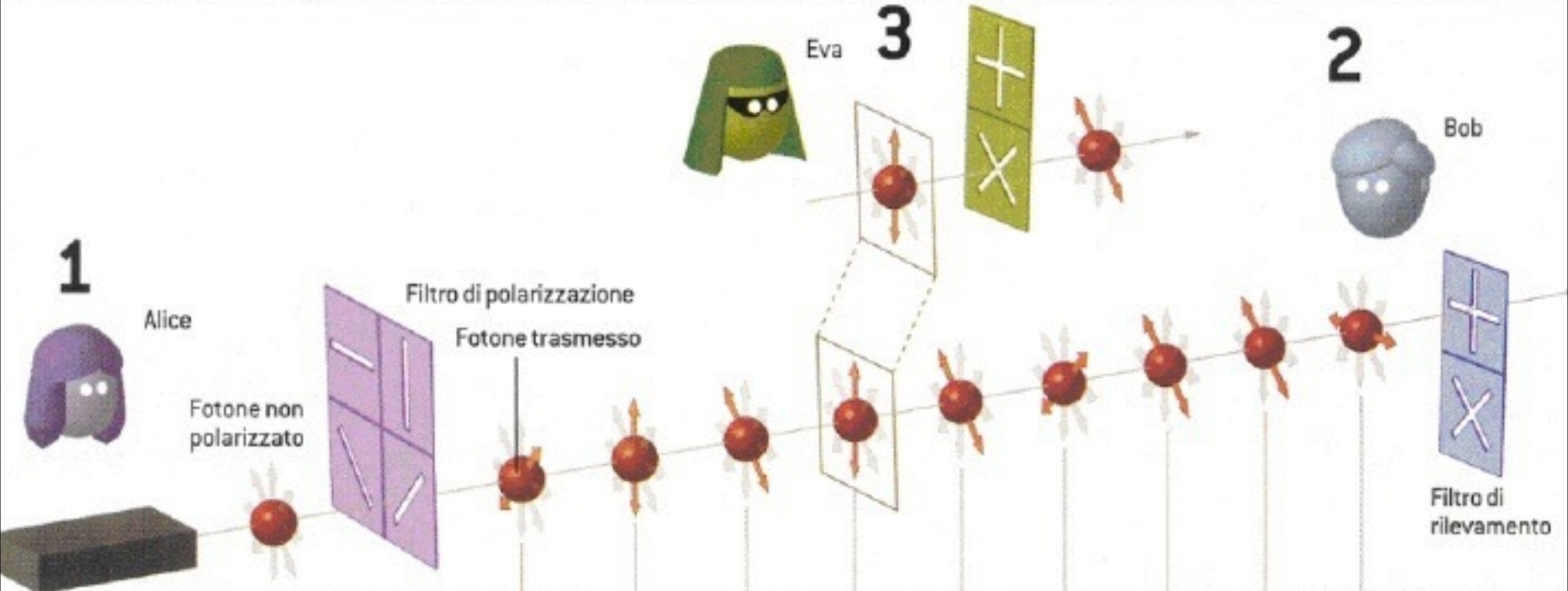
Internet:

1990 - today

Classical cryptography: private key

Need to exchange the secret key of a trusted channel!





Sequenza di bit di Alice:	0	0	1	0	1	0	1	1	1
Schema di filtraggio di Alice:	/	|	\	|	\	/	\	\	—
Schema di rilevamento di Bob:	+	+	+	+	×	+	+	×	+
Misurazione dei bit di Bob:	1	0	1	0	1	0	0	1	1
Sequenza ottenuta (chiave):	–	0	–	0	1	–	–	1	1

Quantum cryptography

“A phenomenon is not a phenomenon until is a measured phenomenon…”

J. A. Wheeler

“Is there a moon in the sky if I do not look at?”

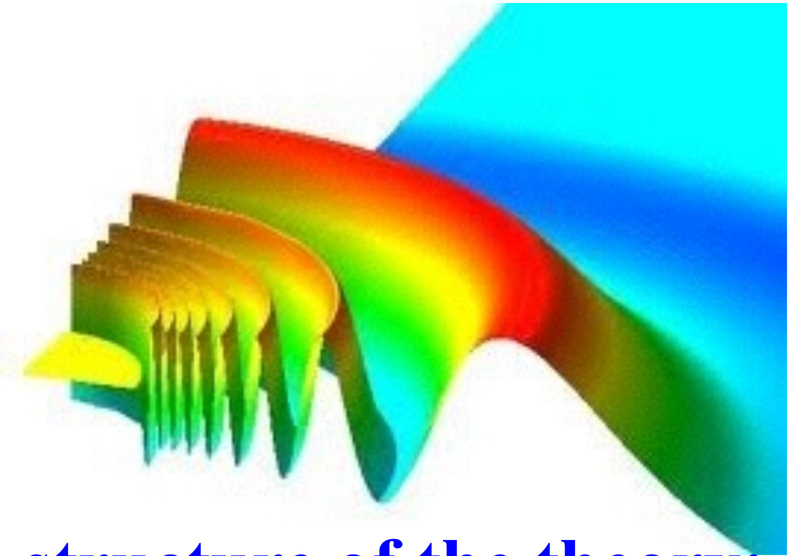
A. Einstein

There are the "objective properties",
the “elements of physical reality” ?

A. Einstein

What is the wave function ?

The **wave function** is a physical state of the quantum system.



Mathematics dominates the structure of the theory:

["Wave function" | Ψ> tool to describe its essence or reality?]

$$|\,fotone\ in\ A\rangle + |\,fotone\ in\ B\rangle$$

The wave function

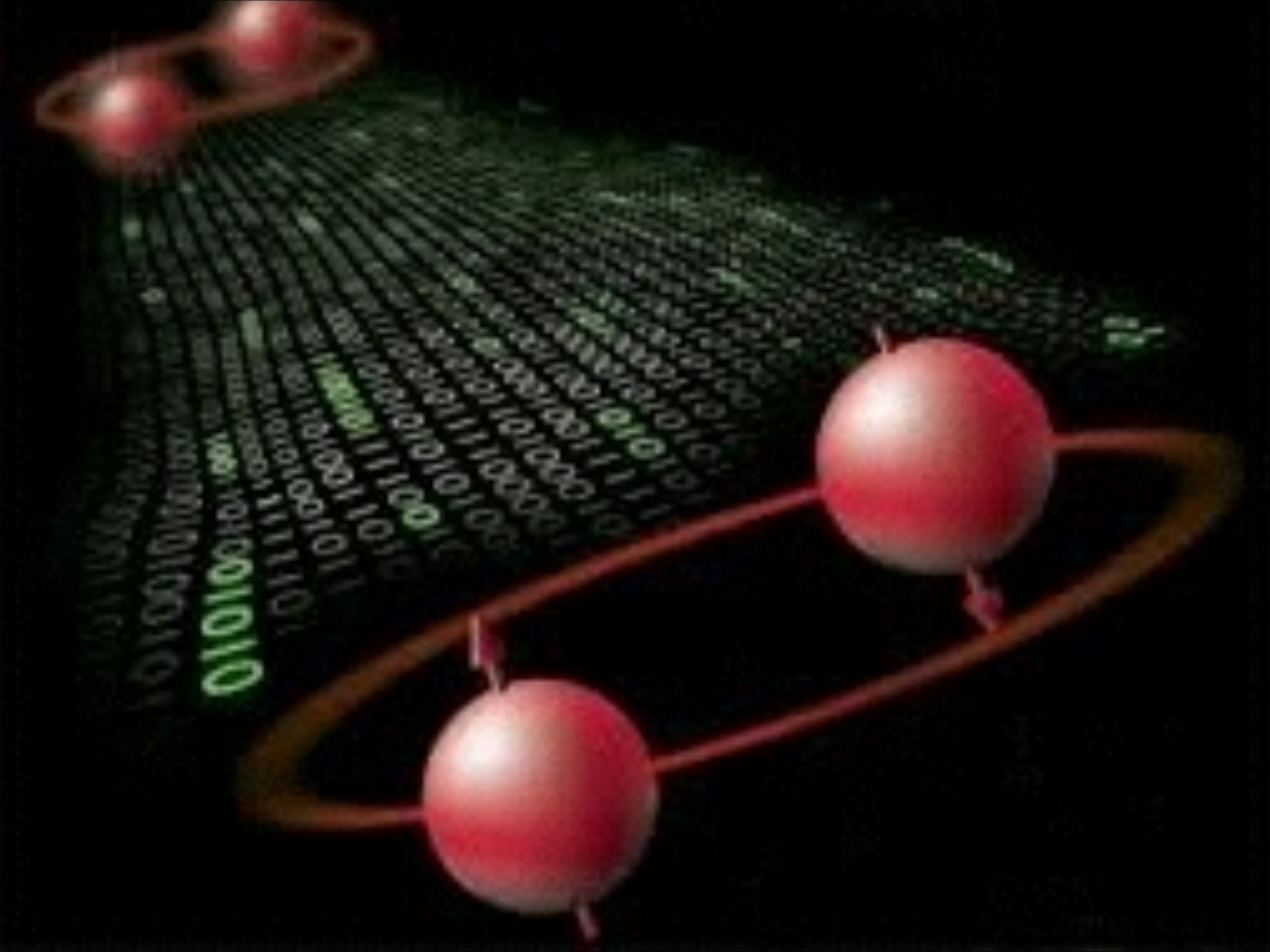
EPISTEMOLOGY

'Discussion on knowledge

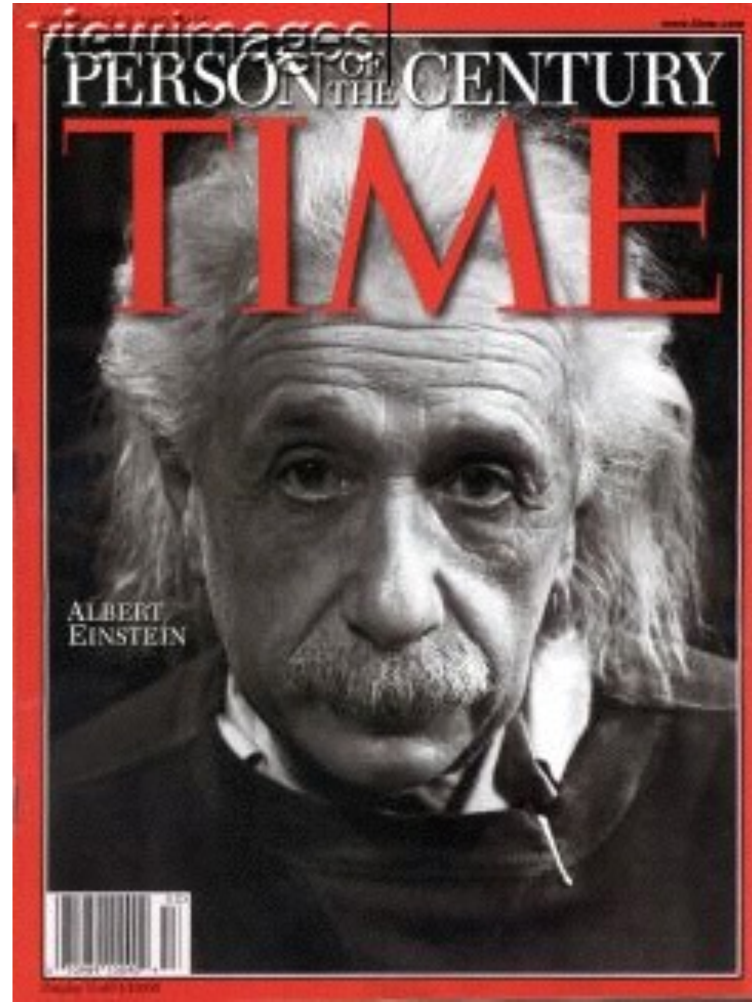
or

ONTOLOGY

'Discussion on essence'



Einstein:
« God does not play dice »



EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

SEE FULLER ONE POSSIBLE

Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.

PRINCETON, N. J., May 3.—Professor Albert Einstein will attack science's important theory of quantum mechanics, a theory of which he was a sort of grandfather. He concludes that while it is "correct" it is not "complete."

With two colleagues at the Institute for Advanced Study here, the noted scientist is about to report to the American Physical Society what is wrong with the theory of quantum mechanics, it has been learned exclusively by Science Service.

The quantum theory, with which science predicts with some success inter-atomic happenings, does not meet the requirements for a satisfactory physical theory, Professor Einstein will report in a joint paper with Dr. Boris Podolsky and Dr. N. Rosen.

In the quantum theory as now used, the latest Einstein paper will point out that where two physical quantities such as the position of a particle and its velocity interact, a knowledge of one quantity precludes knowledge about the other. This is the famous principle of uncertainty put forward by Professor Werner Heisenberg and incorporated in the quantum theory. This very fact, Professor Einstein feels, makes the quantum theory fail in the requirements necessary for a satisfactory physical theory.

Two Requirements Listed.

These two requirements are:

1. The theory should make possible a calculation of the facts of nature and predict results which can be accurately checked by experiment; the theory should be, in other words, correct.

2. Moreover, a satisfactory theory should, as a good image of the objective world, contain a counterpart for things found in the objective world; that is, it must be a complete theory.

Quantum theory, Professor Einstein and his colleagues will report, fulfills the correctness requirement but fails in the completeness requirement.

While proving that present quantum theory does not give a complete description of physical reality, Professor Einstein believes some later, still undeveloped, theory will make this possible. His conclusion is:

"While we have thus shown that the wave function [of quantum theory] does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible."

The development of quantum mechanics has proved very useful in exploring the atom. Six Nobel Prizes in physics, including one to Einstein, have been awarded for various phases of the researches leading up to quantum mechanics. The names of Planck, Bohr, de Broglie, Heisenberg, Dirac and Schroedinger, as well as Einstein, are linked with quantum mechanics.

The exact title of the Einstein-Podolsky-Rosen paper is: "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?"

Explanation by Podolsky.

In explaining the latest view of the physical world as revealed in their researches Dr. Podolsky, one of the authors, said:

"Physicists believe that there exist real material things independent of our minds and our theories. We construct theories and invent words (such as electron, positron, &c.) in an attempt to explain to ourselves what we know about our external world and to help us to obtain further knowledge of it. Before a theory can be considered to be satisfactory it must pass two very severe tests. First, the theory must enable us to calculate facts of nature, and these calculations must agree very accurately with observations and experiments. Second, we expect a satisfactory theory, as a good image of objective reality, to contain a counterpart for every element of the physical world. A theory satisfying the first requirement may be called a correct theory while, if it satisfies the second requirement, it may be called a complete theory.

"Hundreds of thousands of experiments and measurements have shown that, at least in cases when matter moves much slower than light, the theory of Planck, Einstein, Bohr Heisenberg and Schroedinger known as quantum mechanics is a correct theory. Einstein, Podolsky and Rosen now discuss the question of the completeness of quantum mechanics. They arrive at the conclusion that quantum mechanics, in its present form, is not complete.

"In quantum mechanics the condition of any physical system, such as an electron, an atom, &c., is supposed to be completely described by a formula known as a 'wave function.' Suppose that we know the wave function for each of two physical systems, and that these two systems come together, interact, and again separate (as when two particles collide and move apart). Quantum mechanics, although giving us considerable information about such a process, does not enable us to calculate the wave function of each physical system after the separation. This fact is made use of in showing that the wave function does not give a complete description of physical reality. Since, however, description of physical systems by wave functions is an essential step of quantum mechanics, this means that quantum mechanics is not a complete theory."

Raises Point of Doubt.

Special to THE NEW YORK TIMES.

PRINCETON, N. J., May 3.—Asked to comment on the new ideas of Professor Einstein and his collaborators, Professor Edward U. Condon, mathematical physicist of Princeton University, said tonight:

"Of course, a great deal of the argument hinges on just what meaning is to be attached to the word 'reality' in connection with physics. They have certainly discussed an interesting point in connection with the theory. Dr. Einstein has never been satisfied with the statistical causality which in the new theories replaces the strict causality of the old physics.

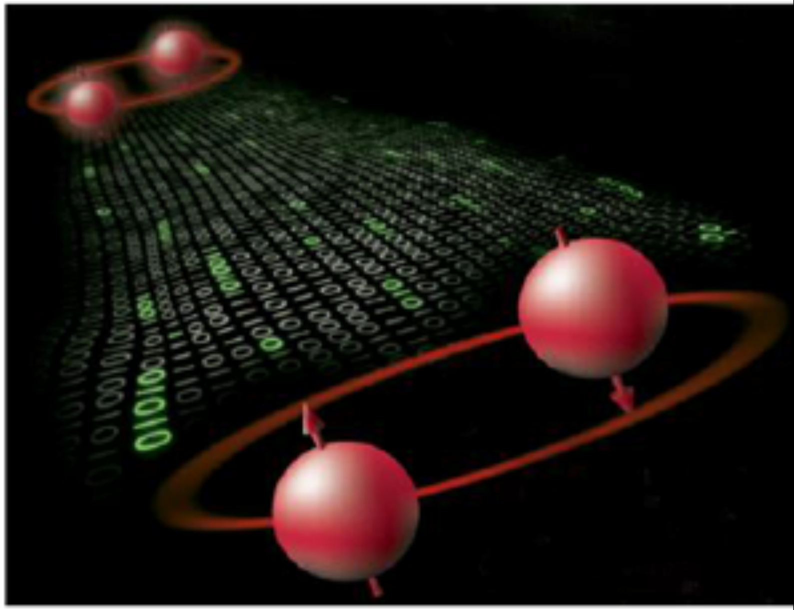
"It is reported that when he first learned of the work of Schroedinger and Dirac, he said, 'Der lieber Gott wuerfelt nicht. [the good Lord does not throw dice]. For the last five years he has subjected the quantum mechanical theories to very searching criticism from this standpoint. But I am afraid that thus far the statistical theories have withstood criticism."

Paradox of Einstein-Podolsky-Rosen

To demonstrate that quantum mechanics is NOT a complete theory, they introduce the concept of

Entanglement

$$\boxed{\left|\Psi\right\rangle_{AB} = \frac{\left|0\right\rangle_A\left|1\right\rangle_B - \left|1\right\rangle_A\left|0\right\rangle_B}{\sqrt{2}}}$$



THE NEW YORK TIMES, SATURDAY, MAY 4, 1935.

EINSTEIN ATTAC[K] QUANTUM THE[ORY]

Scientist and Two Colle[agues] Find It Is Not 'Comple[te'] Even Though 'Correct'

SEE FULLER ONE POSS[IBLE]

Believe a Whole Descripti[on of] 'the Physical Reality' Can Be Provided Eventually.

MAY 15, 1935 PHYSICAL REVIEW VOLUME 47

Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?

A. Einstein, B. Podolsky and N. Rosen, *Institute for Advanced Study, Princeton, New Jersey*

(Received March 25, 1935)

In a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system. In quantum mechanics in the case of two physical quantities described by non-commuting operators, the knowledge of one precludes the knowledge of the other. Then either (1) the description of reality given by the wave function in quantum mechanics is not complete or (2) these two quantities cannot have simultaneous reality. Consideration of the problem of making predictions concerning a system on the basis of measurements made on another system that had previously interacted with it leads to the result that if (1) is false then (2) is also false. One is thus led to conclude that the description of reality as given by a wave function is not complete.

other words, correct.

2. Moreover, a satisfactory theory should, as a good image of the objective world, contain a counterpart for things found in the ...

external world and to help us to obtain further knowledge of it. Before a theory can be considered to be satisfactory it must pass two very severe tests. First, the theory ...

that quantum mechanics is not a complete theory."

Raises Point of Doubt.

« While we have shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists.

We believe, however, that such a theory is possible. »

N. Rosen.

In the quantum theory as now used, the latest Einstein paper will

prizes in physics, including one to Einstein, have been awarded for various phases of the researches leading up to quantum mechanics.

quantum mechanics, in its present form, is not complete.

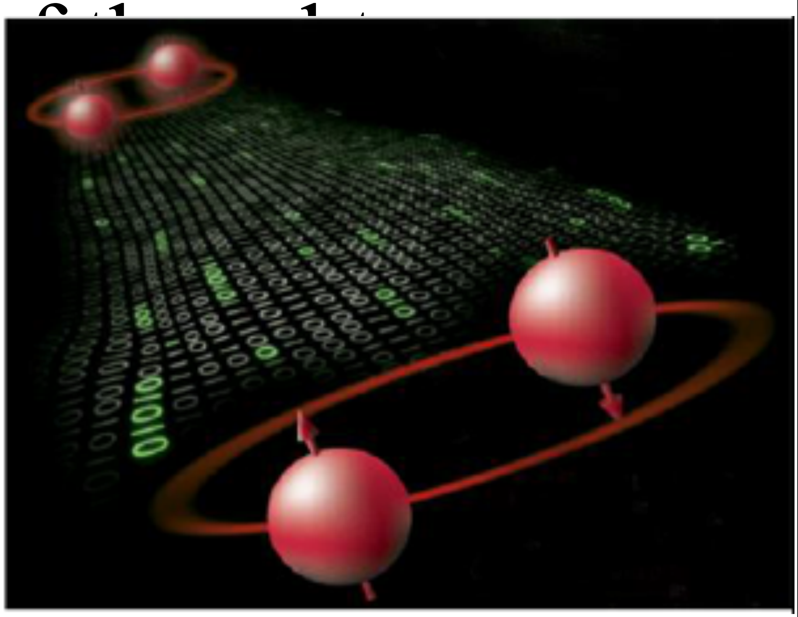
"In quantum mechanics the condition of any physical system, such

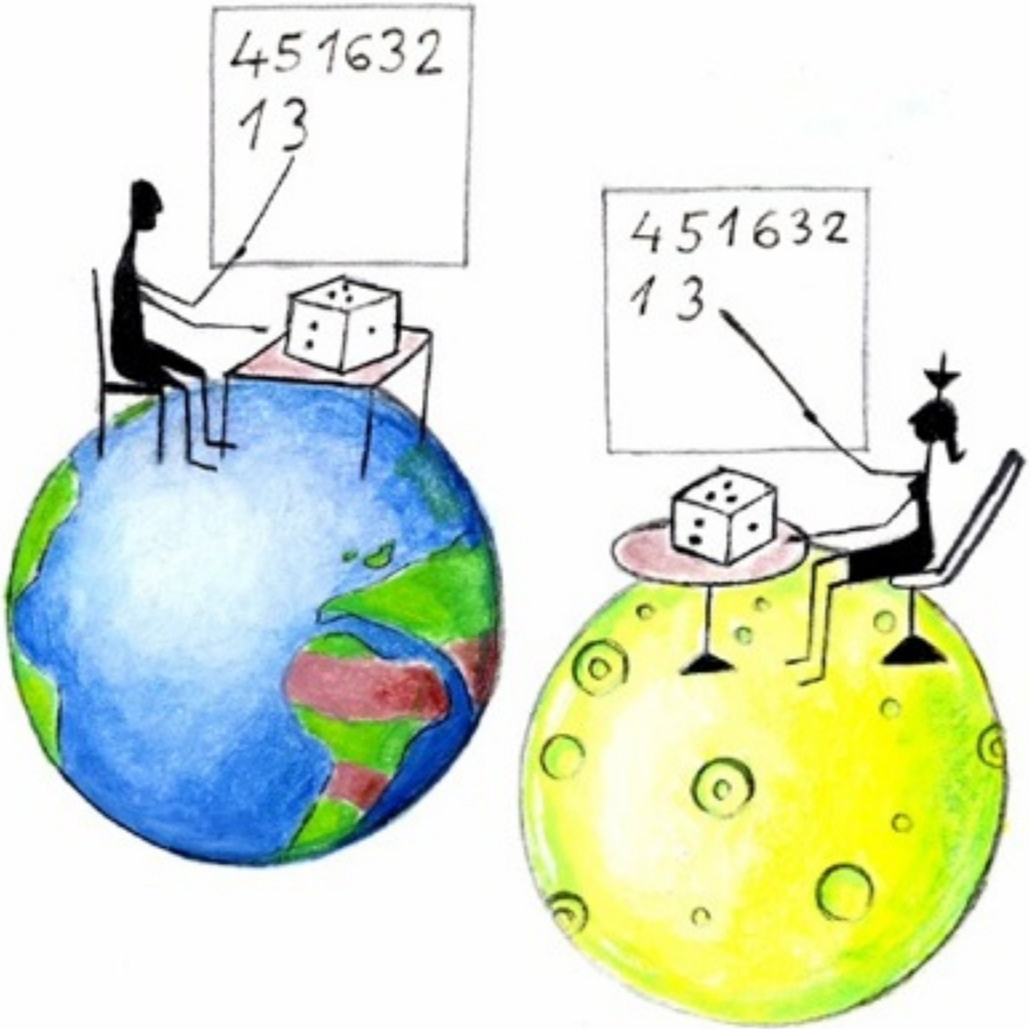
standpoint. But I am afraid that thus far the statistical theories have withstood criticism."

$$|\Psi\rangle_{AB} = \frac{|0\rangle_A|1\rangle_B - |1\rangle_A|0\rangle_B}{\sqrt{2}}$$

« I would not call **entanglement** one but rather the **characteristic trait of quantum mechanics**,
the one that enforces its entire departure from classical lines

E. Schroedinger

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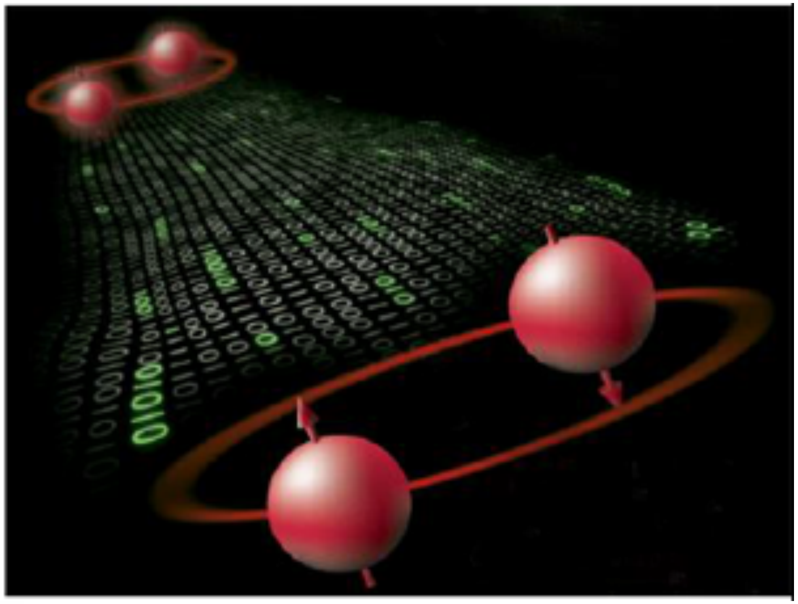
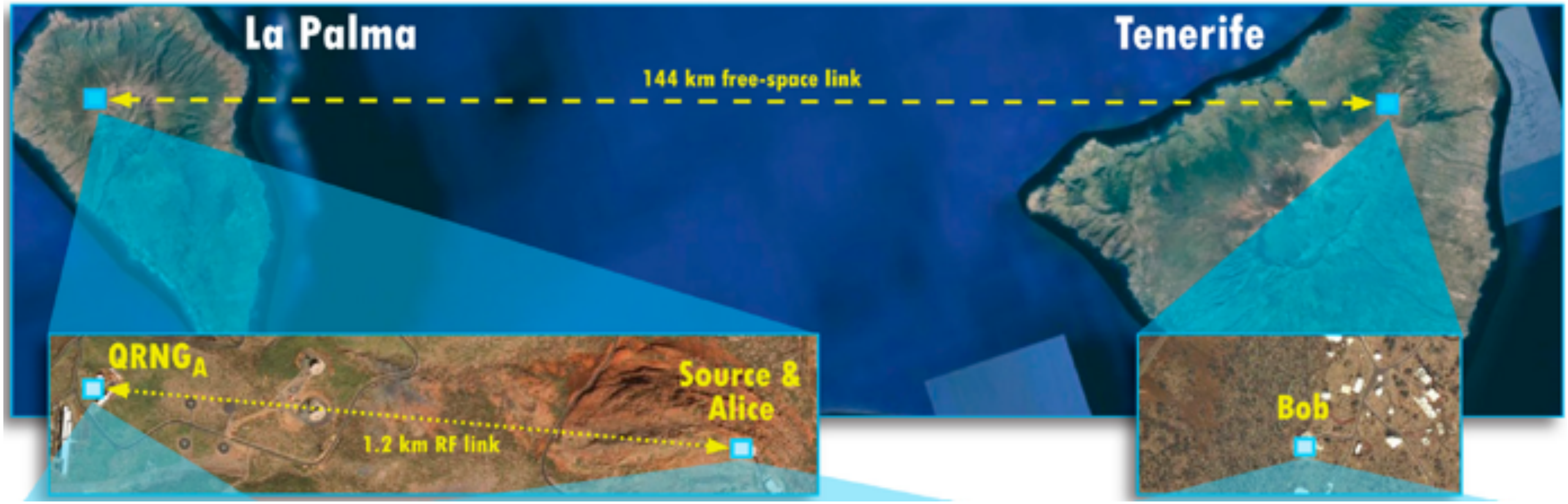


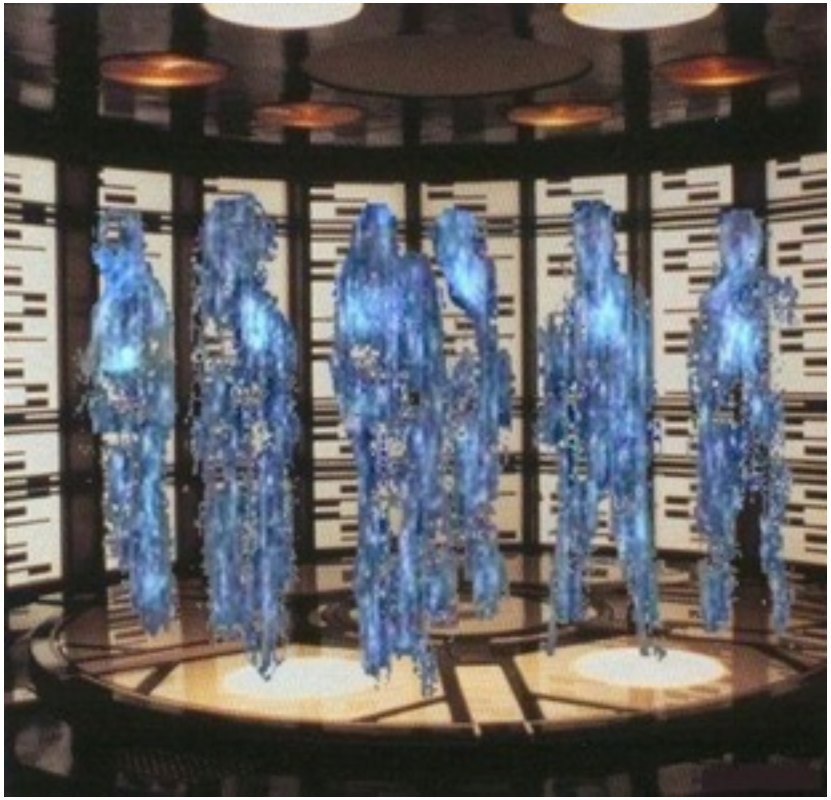
Violation of local realism with freedom of choice

Thomas Scheidl[a], Rupert Ursin[a], Johannes Kofler[a,b,1], Sven Ramelow[a,b], Xiao-Song Ma[a,b], Thomas Herbst[b], Lothar Ratschbacher[a,2], Alessandro Fedrizzi[a,3], Nathan K. Langford[a,4], Thomas Jennewein[a,5], and Anton Zeilinger[a,b,1]

[a]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria; and [b]Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria



… up to Quantum Teleportation...

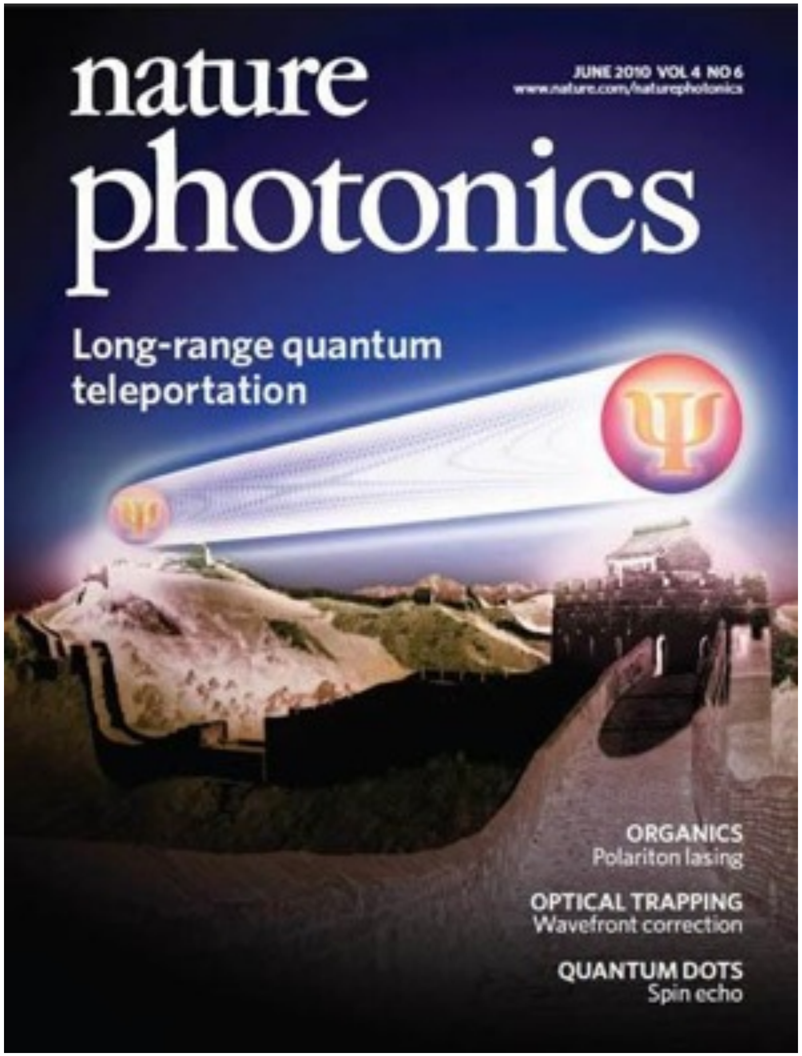


What is teleported ?

$$\Psi$$

The wavefunction

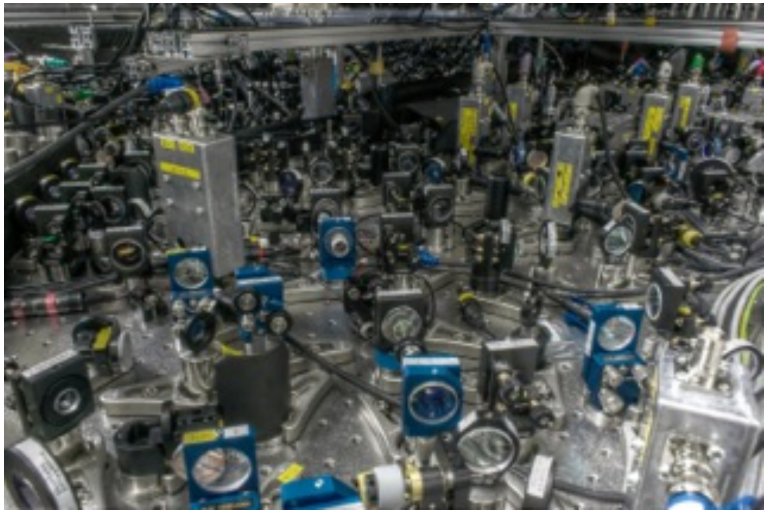
… up to Quantum Teleportation...



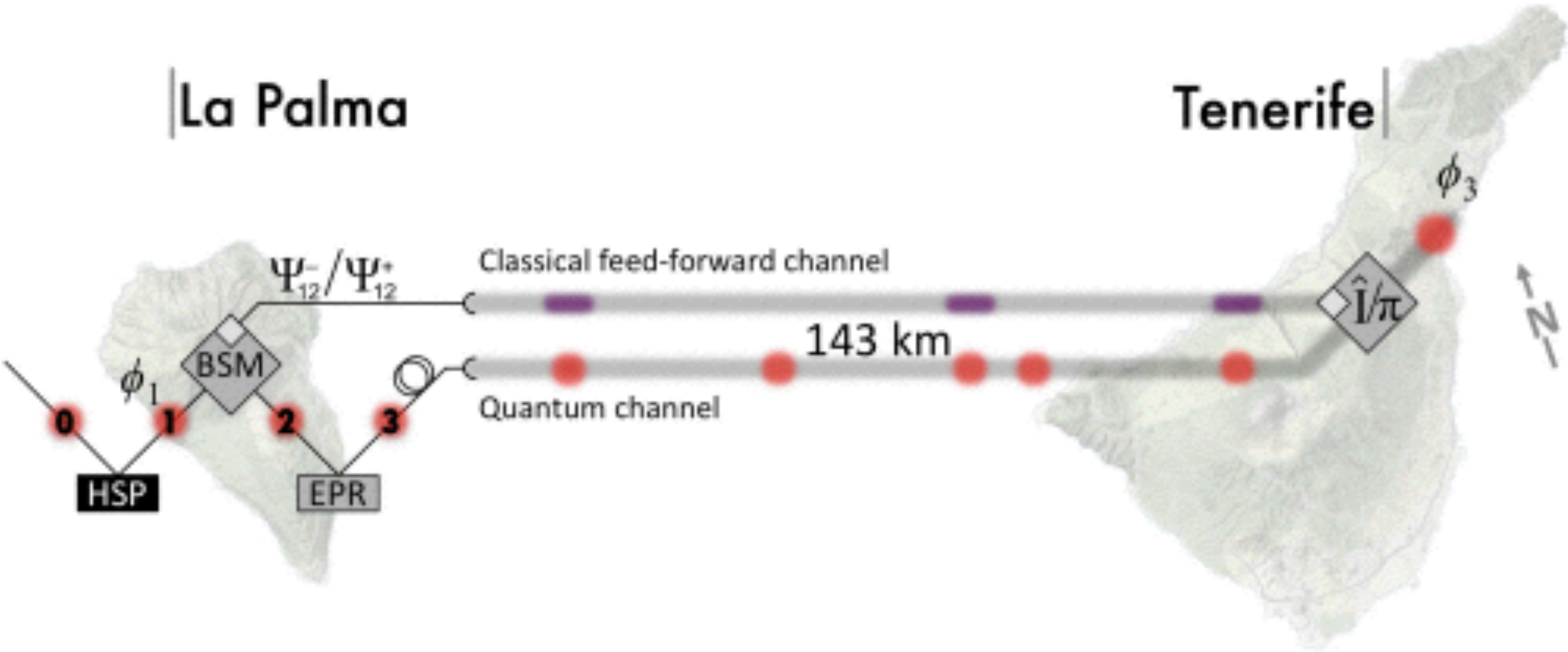
LETTERS
PUBLISHED ONLINE: 16 MAY 2010 | DOI: 10.1038/NPHOTON.2010.87
nature photonics

Experimental free-space quantum teleportation

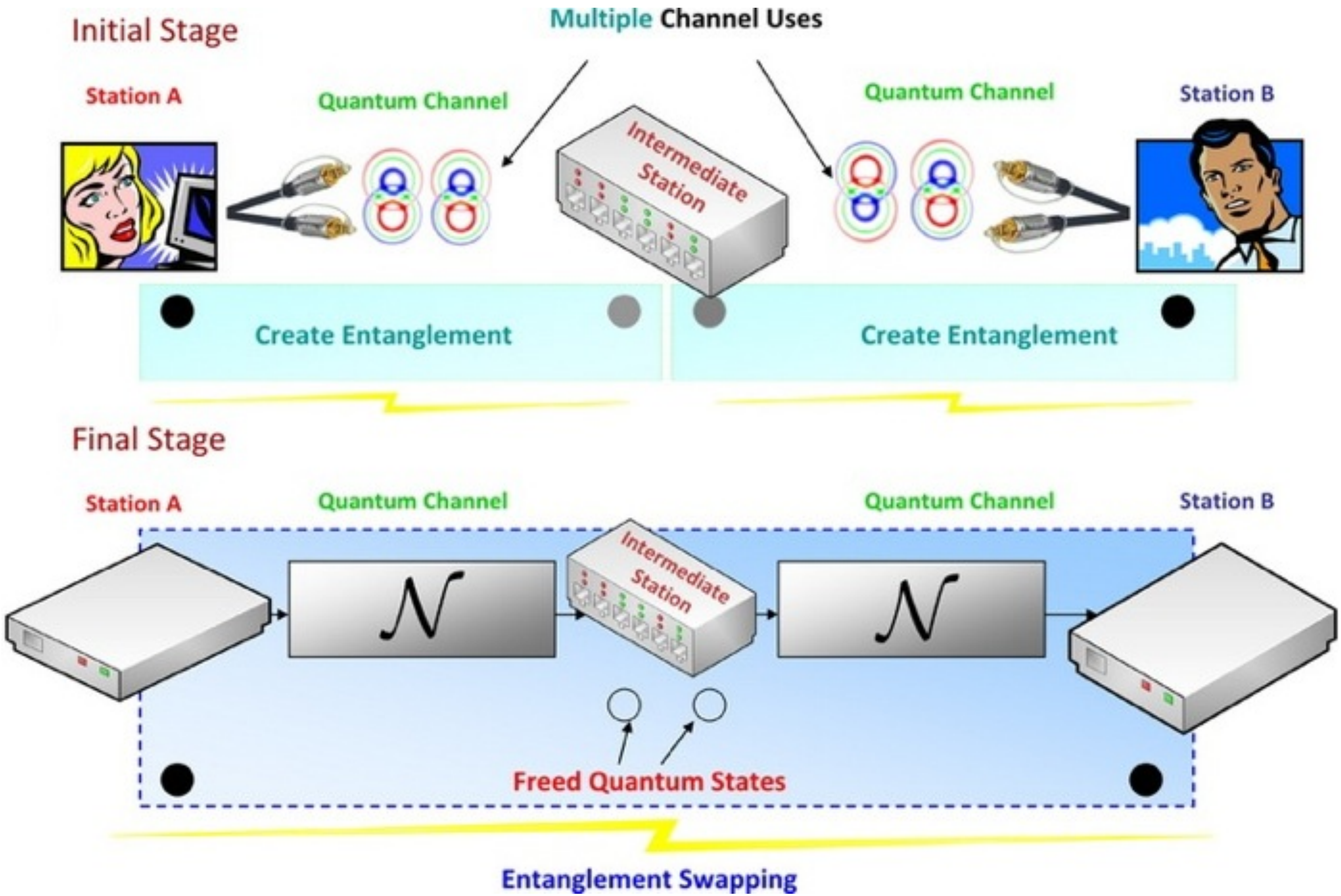
Xian-Min Jin[1,†], Ji-Gang Ren[1,2,†], Bin Yang[1], Zhen-Huan Yi[2], Fei Zhou[2], Xiao-Fan Xu[1], Shao-Kai Wang[2], Dong Yang[2], Yuan-Feng Hu[1], Shuo Jiang[2], Tao Yang[1], Hao Yin[1], Kai Chen[1], Cheng-Zhi Peng[2]* and Jian-Wei Pan[1,2]*




La Palma
143 km
Tenerife


La Palma
Tenerife
ϕ_3
Classical feed-forward channel
$\Psi_{12}^{-}/\Psi_{12}^{+}$
$\hat{I}/\pi$
BSM
143 km
ϕ_1
Quantum channel
0
1
2
3
HSP
EPR
N

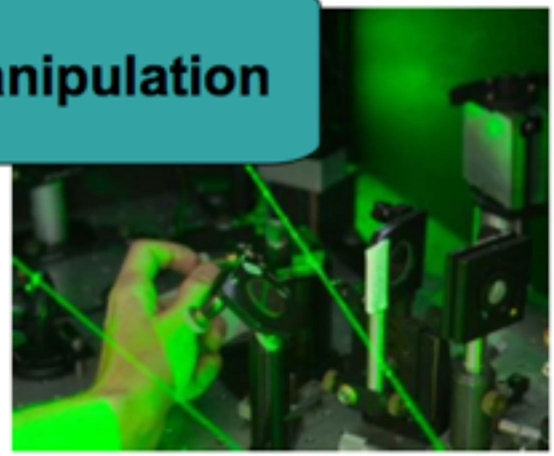
Quantum teleportation: quantum repeater



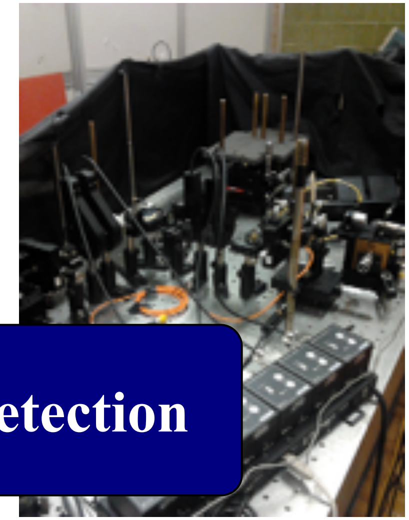
Integrated quantum photonics

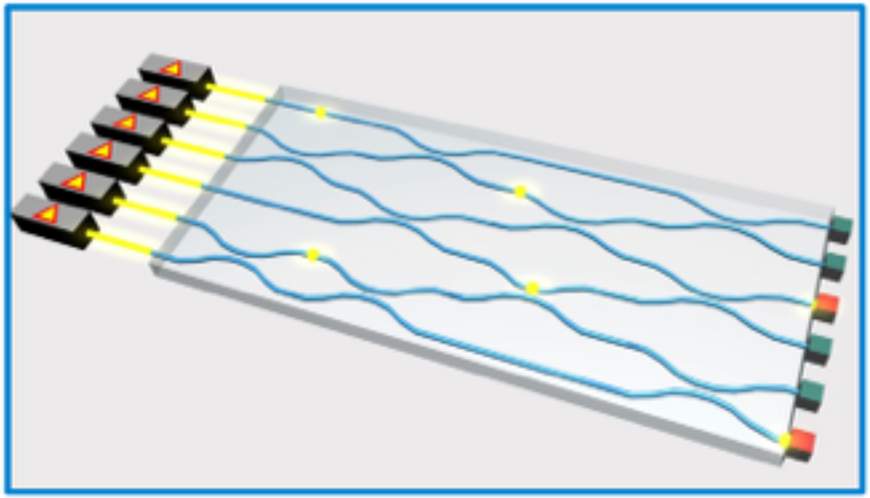
Preparation

Manipulation



Detection



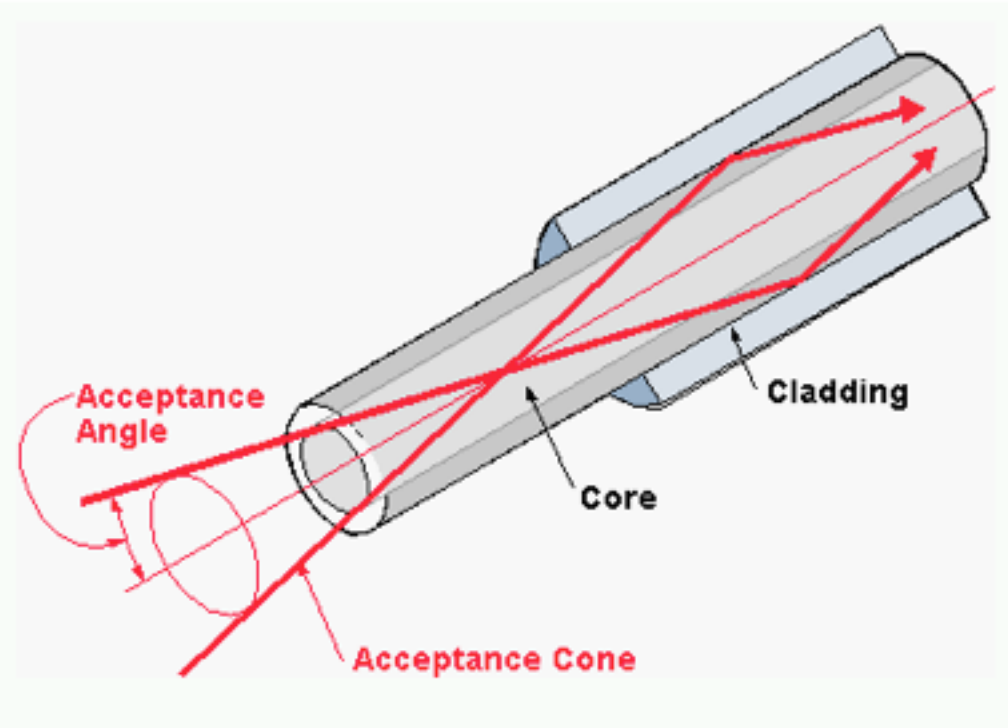


- Single photon sources
- Manipulation
- Single photon detectors

ON THE SAME CHIP

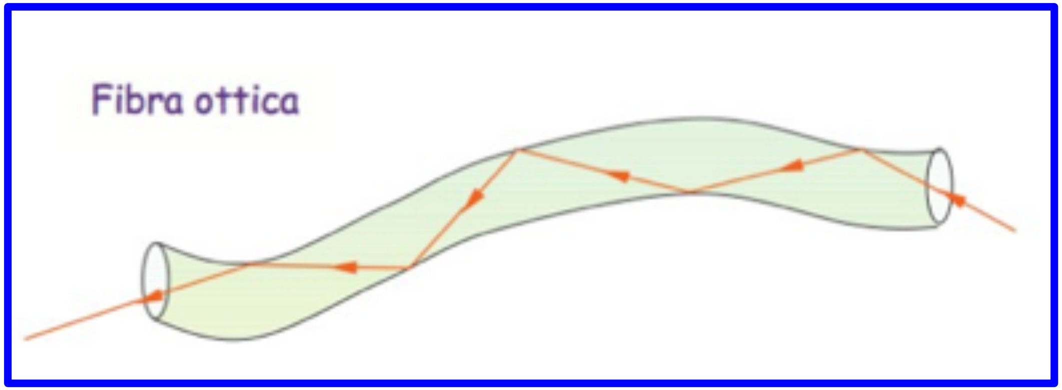
How to guide light inside the chip ?

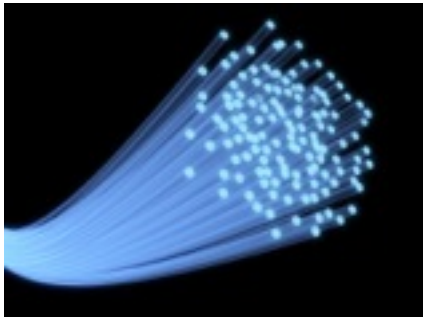
From Computer Desktop Encyclopedia
© 1999 The Computer Language Co. Inc.



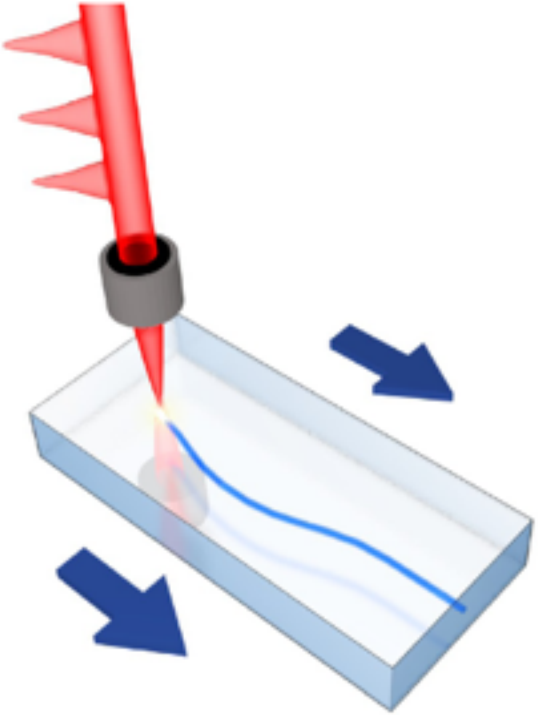
Optical fibre:

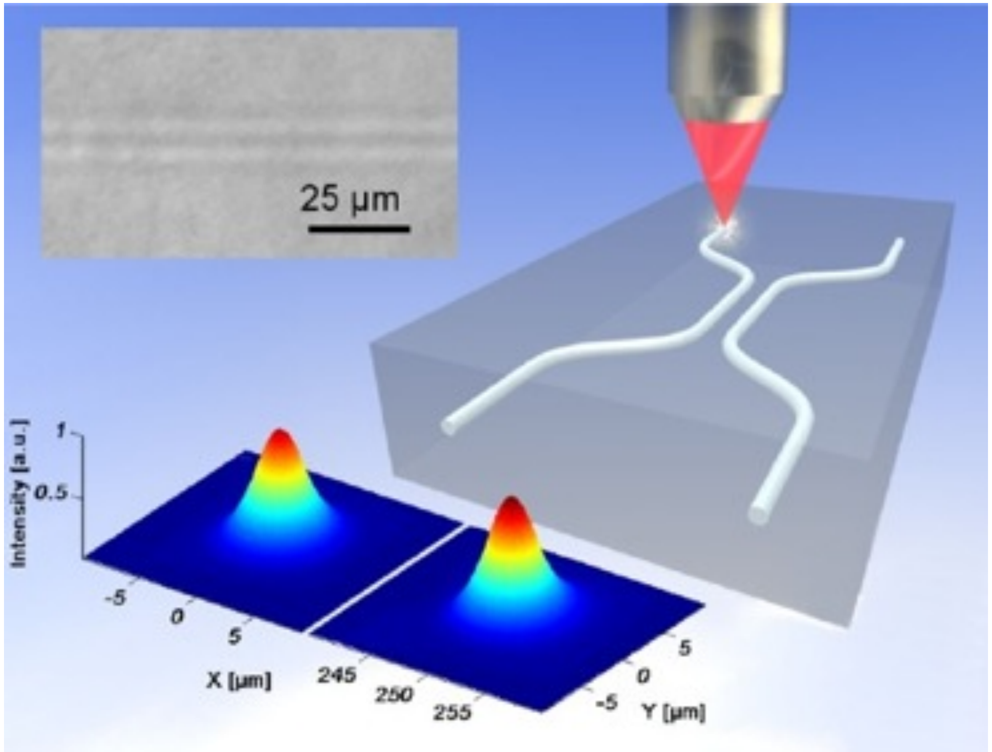
Guide the light

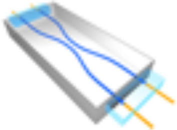




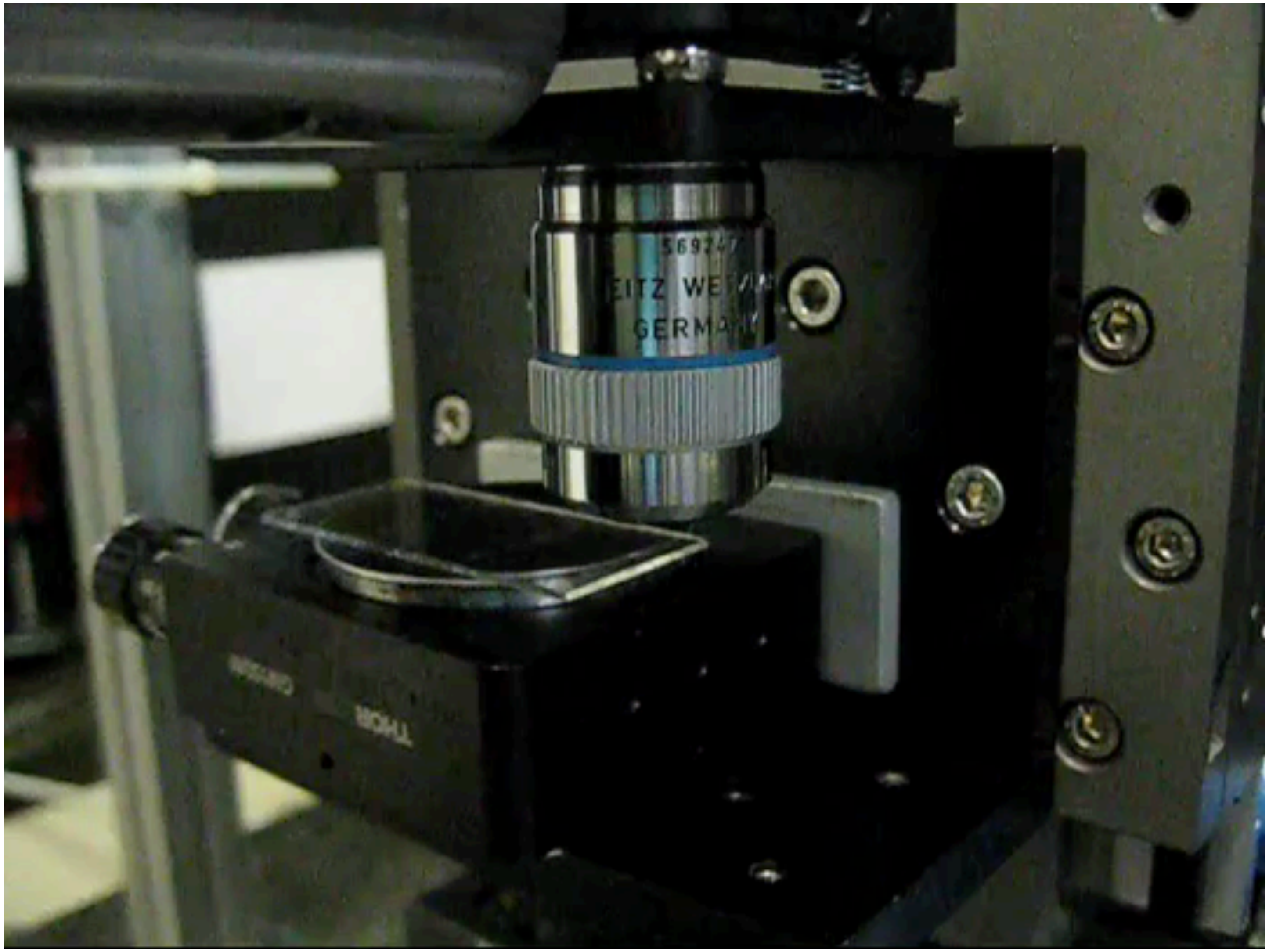
Laser written integrated circuit



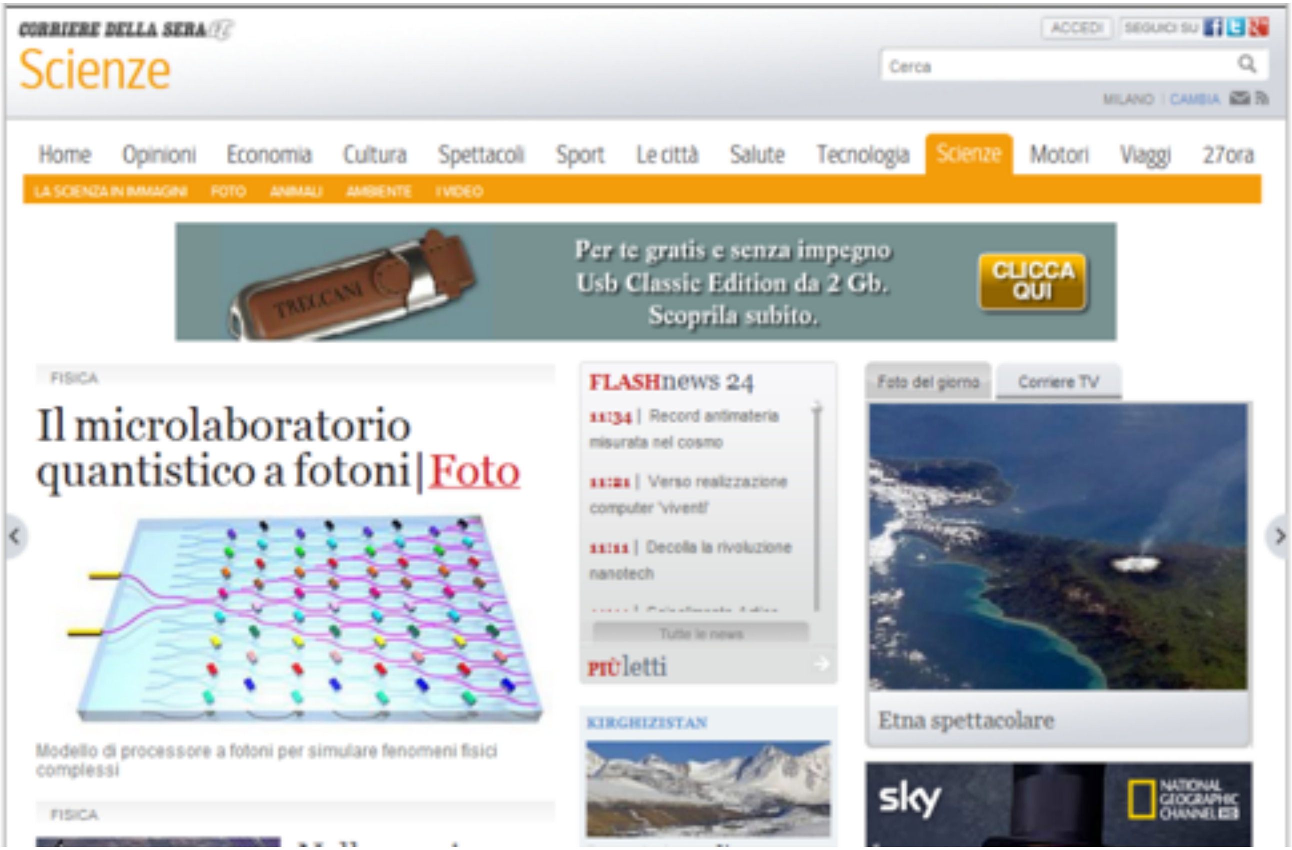




Laser writing technique



Towards integrated quantum information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Modello di processore a fotoni per simulare fenomeni fisici complessi

FLASHnews 24

11:34 | Record antimateria misurata nel cosmo

11:21 | Verso realizzazione computer 'viventi'

11:11 | Decolla la rivoluzione nanotech

Foto del giorno Corriere TV

Etna spettacolare

KIRGHIZISTAN

ISTITUTO NAZIONALE DI OTTICA

INO-CNR

POLITECNICO MILANO

Thank you!

QUANTUM OPTICS GROUP

Dipartimento di Fisica, Sapienza Università di Roma

PICQUE

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erc

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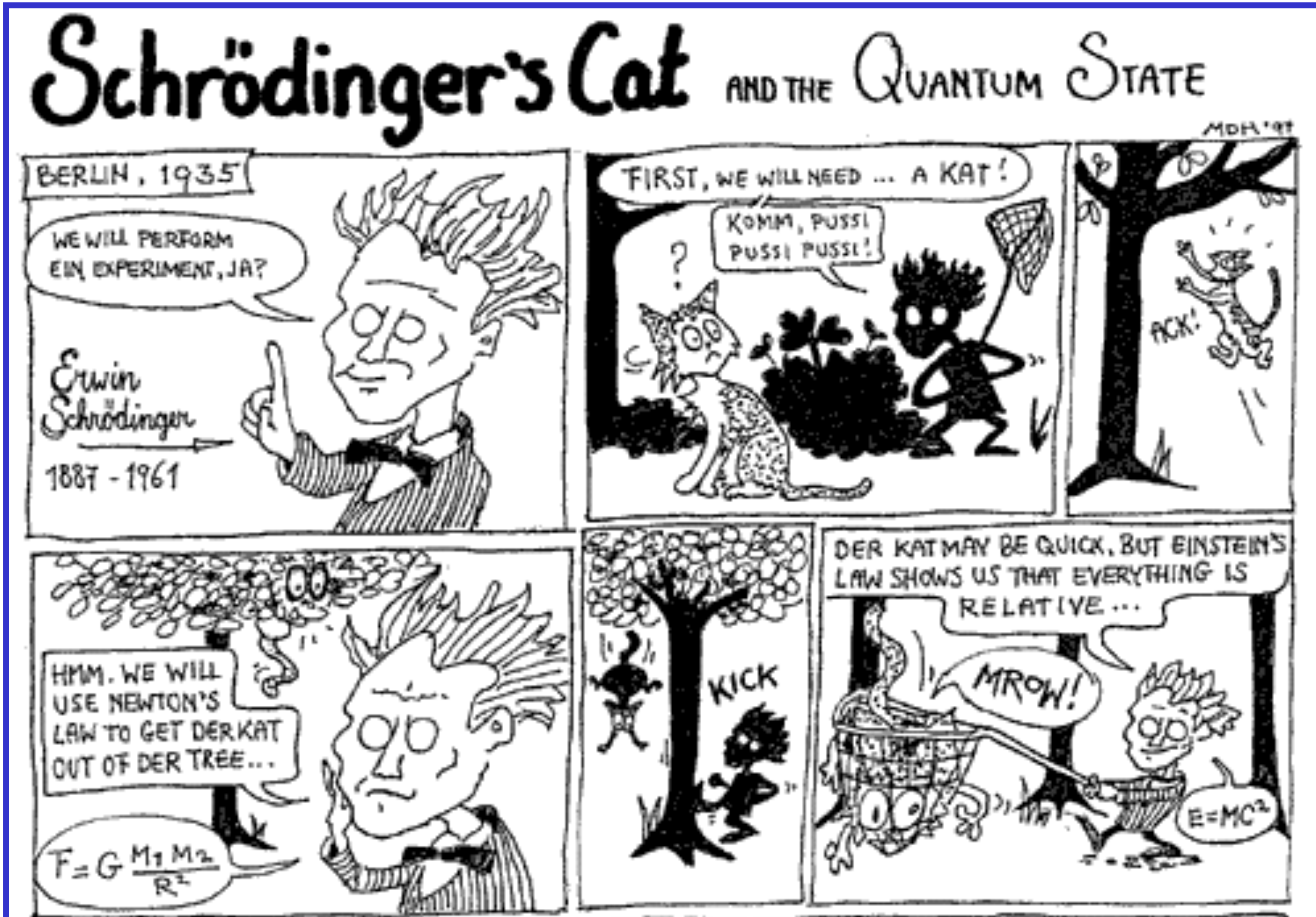
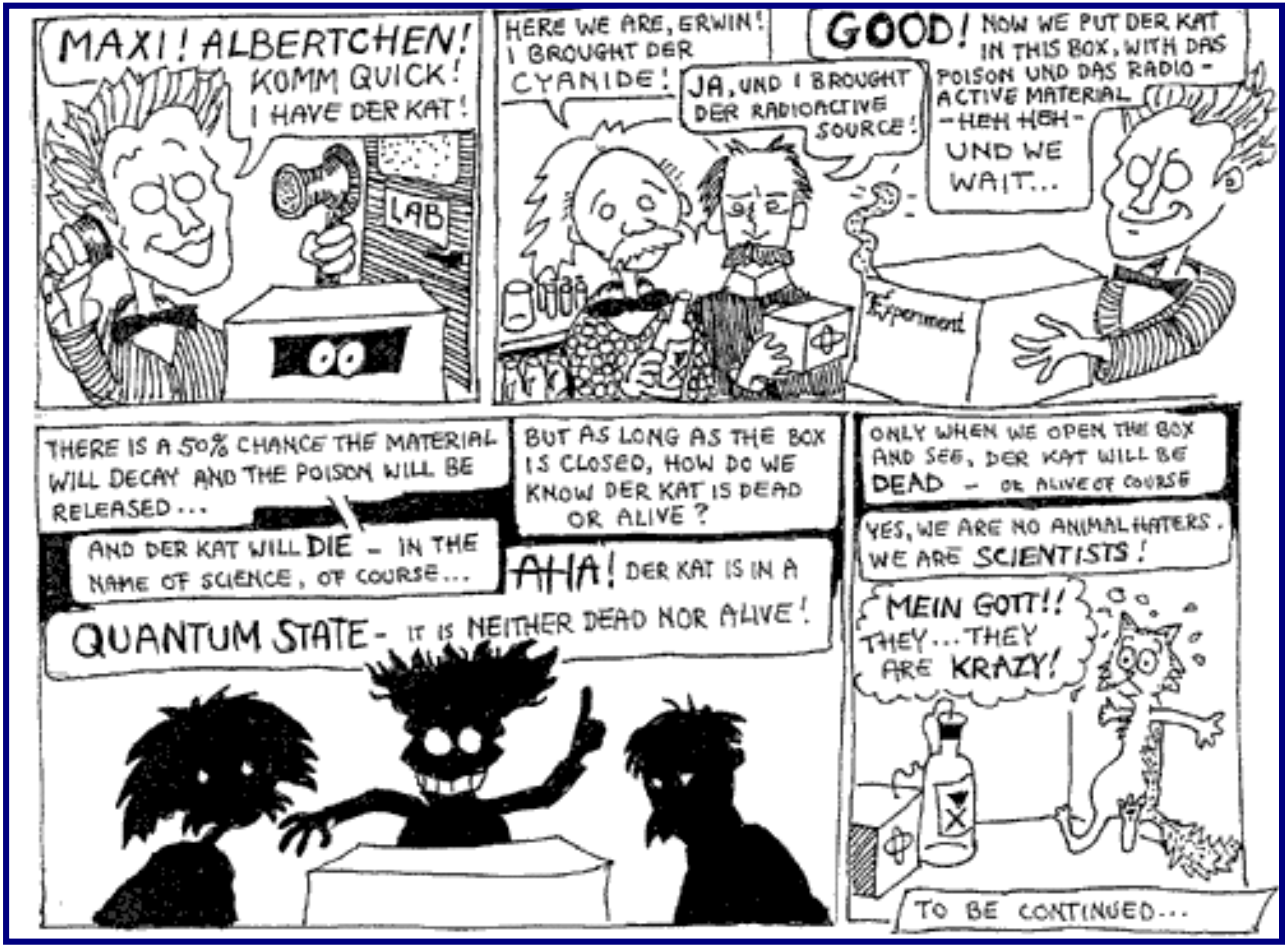
Enjoy life, enjoy quantum



Schrödinger's Cat AND THE QUANTUM STATE
BERLIN, 1935
WE WILL PERFORM EIN EXPERIMENT, JA?
Erwin Schrödinger
1887 - 1961
FIRST, WE WILL NEED ... A KAT!
?
KOMM, PUSSI PUSSI PUSSI!
ACK!
HMM. WE WILL USE NEWTON'S LAW TO GET DER KAT OUT OF DER TREE...
$F = G \frac{M_1 M_2}{R^2}$
KICK
DER KAT MAY BE QUICK, BUT EINSTEIN'S LAW SHOWS US THAT EVERYTHING IS RELATIVE...
MROW!
$E=MC^2$



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