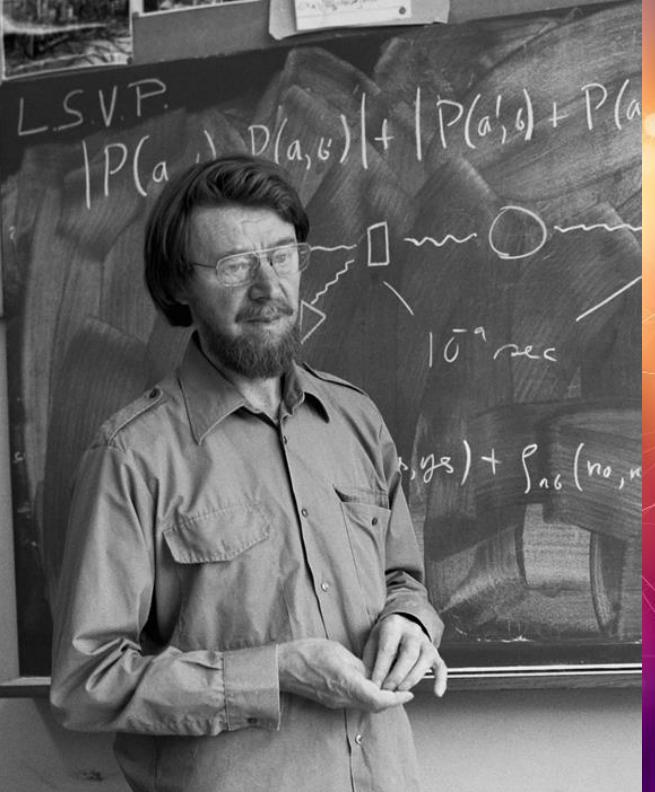




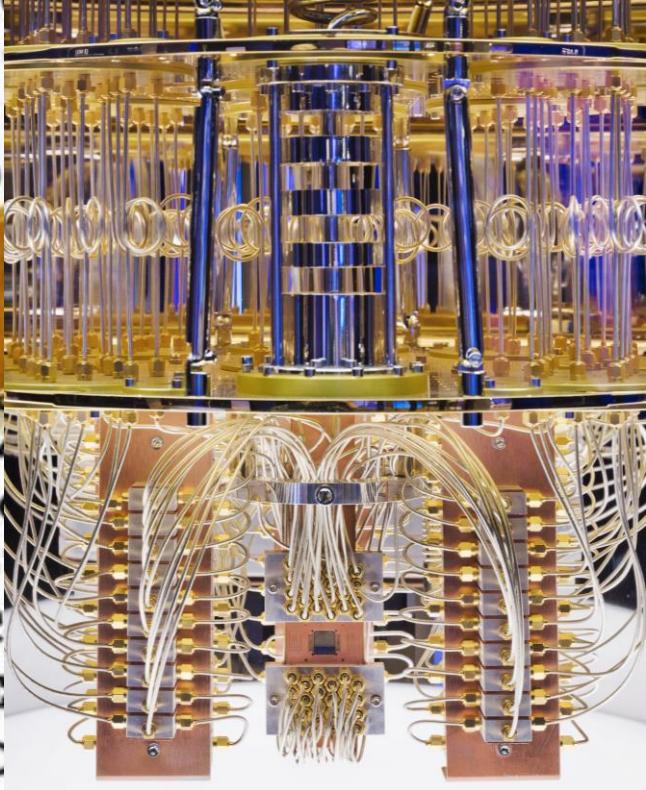
Entanglement

Giovanni Della Lunga





G0030200	0120860
024FG002	53D03C0
387525C1	01A0770
024FG002	53D03C0
387525C1	4F553E
242434E	3D4A6
53D4553	414
0312E30	3424
C0000000	024E4E
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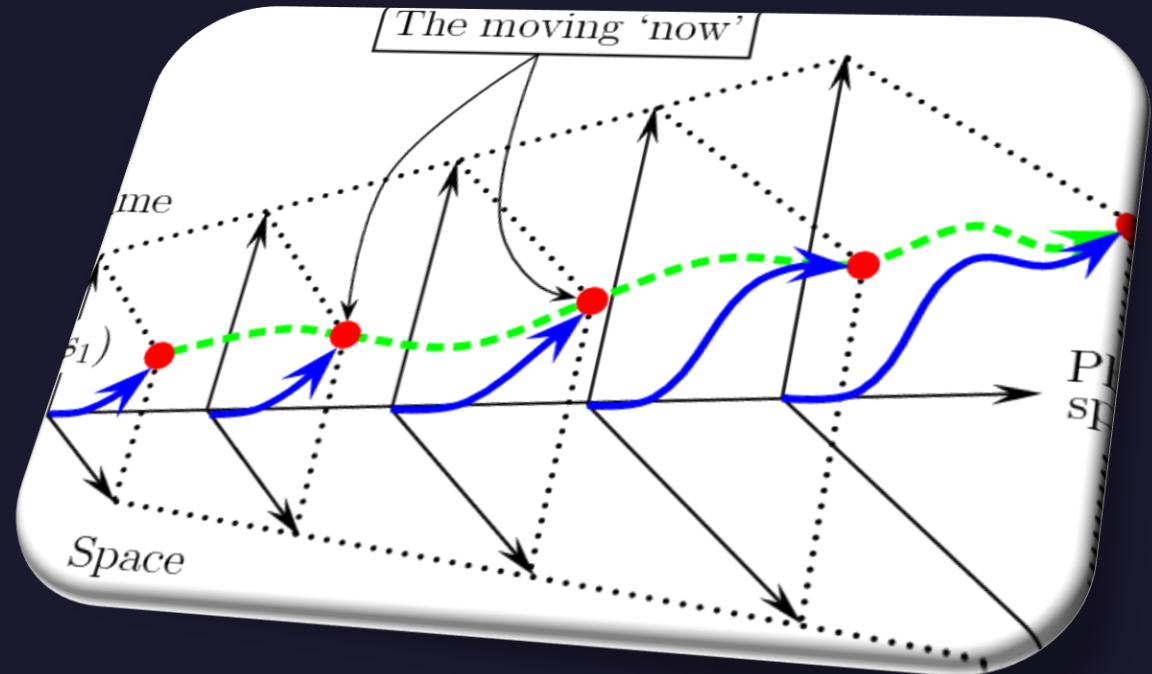
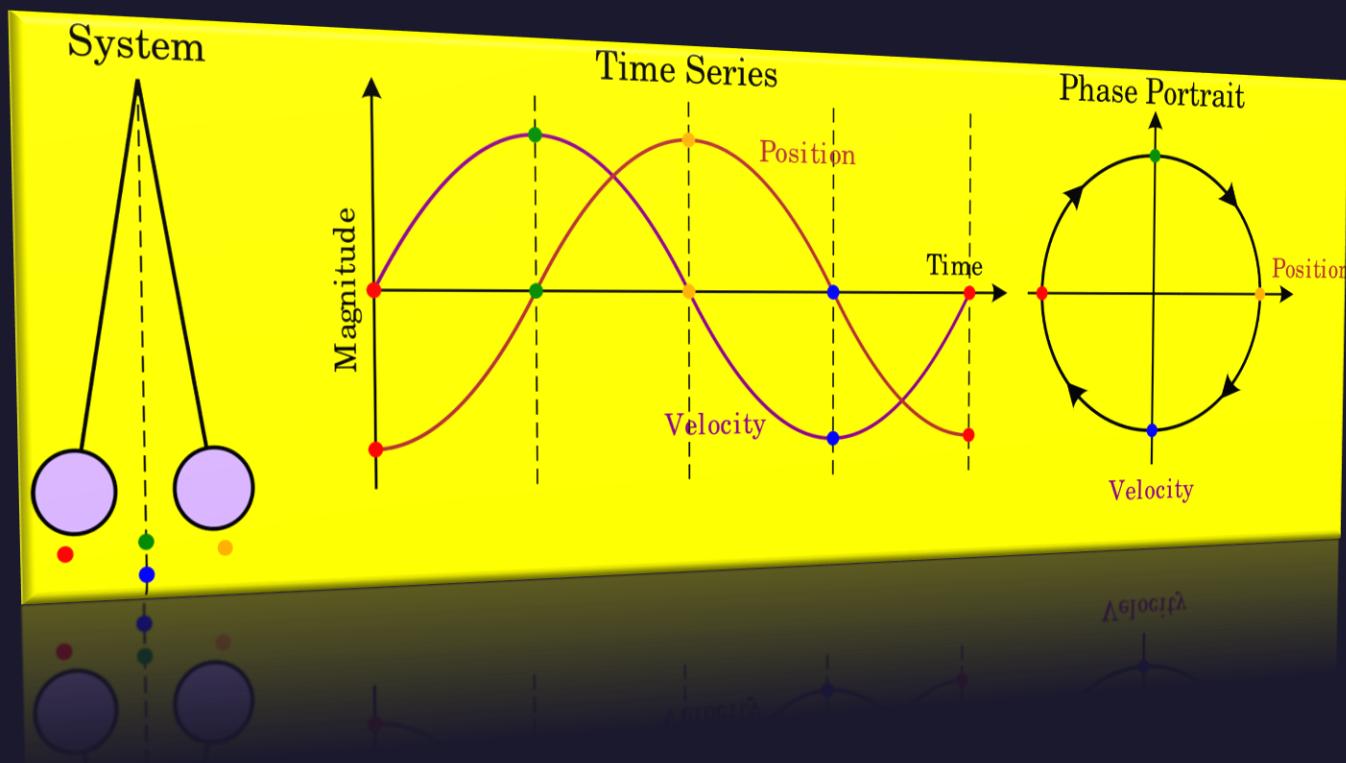


Introduzione

- In italiano **entanglement** significa semplicemente legato o aggrovigliato attorcigliato.
- In meccanica quantistica **entanglement** significa una cosa precisa, abbastanza semplice da enunciare, indica che due o più particelle sono connesse tra loro, cioè hanno proprietà che sono correlate. In altre parole, lo stato di ciascuna particella non può essere descritto senza tenere conto dell'insieme delle particelle.

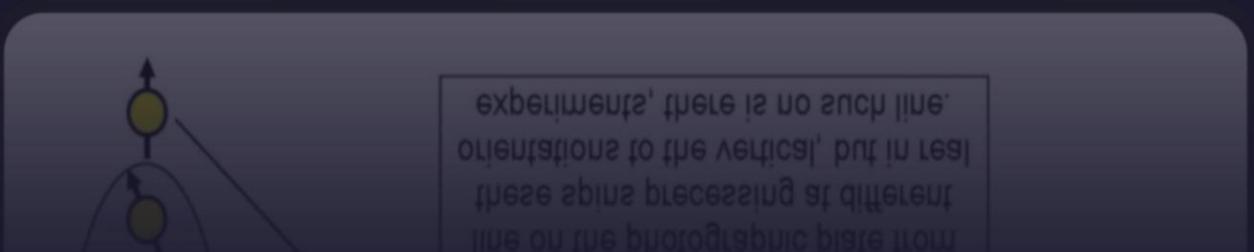
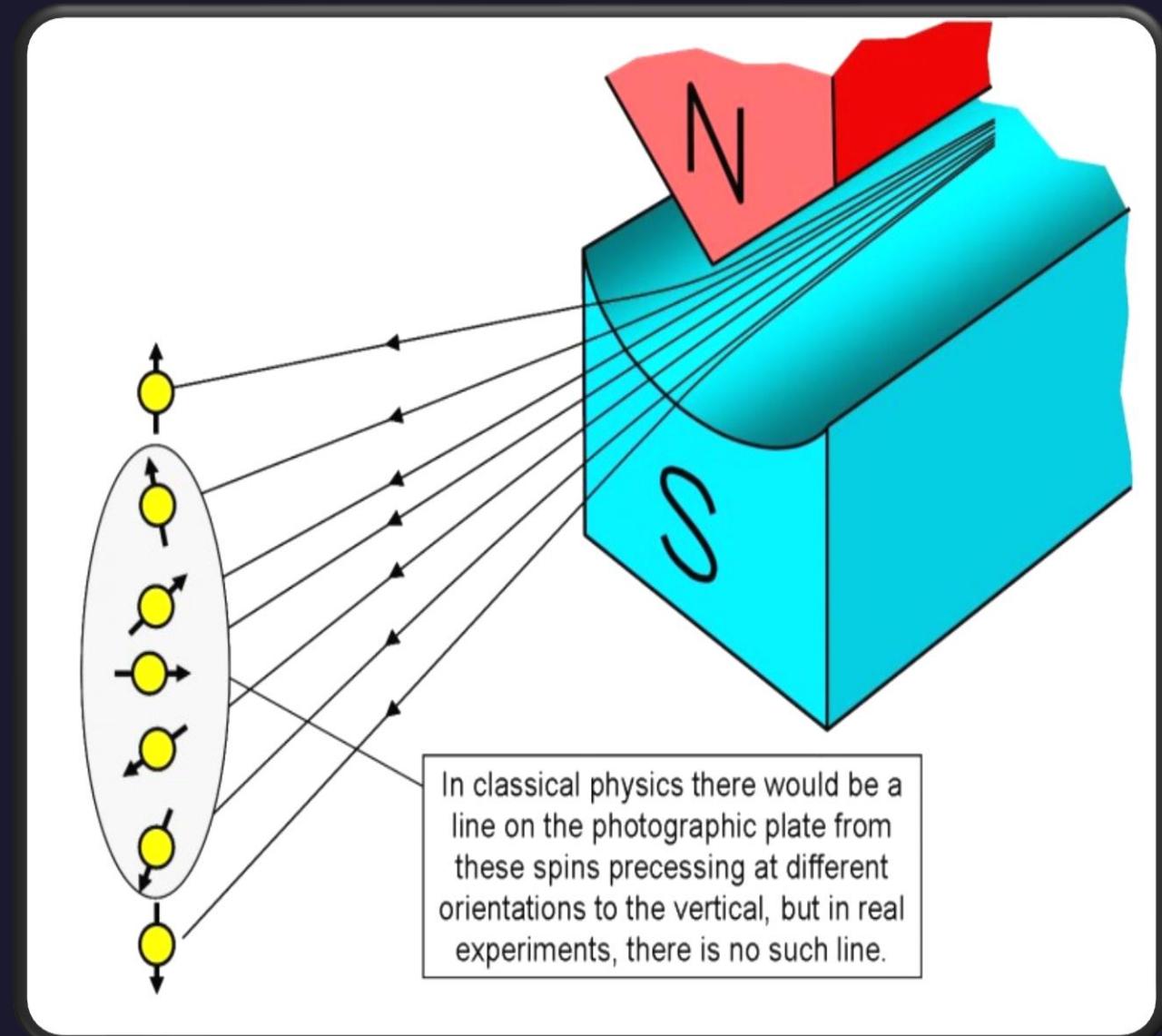
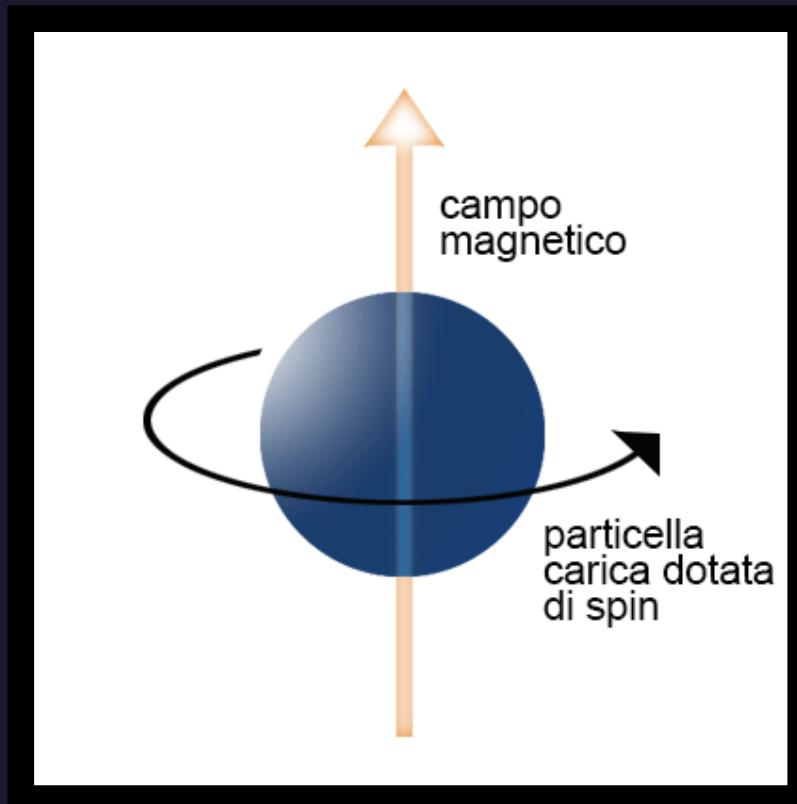
Introduzione

- Proprietà e Stato di un Sistema Fisico
- In generale lo stato di un sistema è la specificazione di tutte le grandezze fisiche caratteristiche del sistema.



Introduzione

- Gli elettroni hanno una proprietà quantistica che ha una certa somiglianza con la rotazione di un oggetto macroscopico per esempio una trottola e infatti è stata chiamata **spin** che significa appunto rotazione

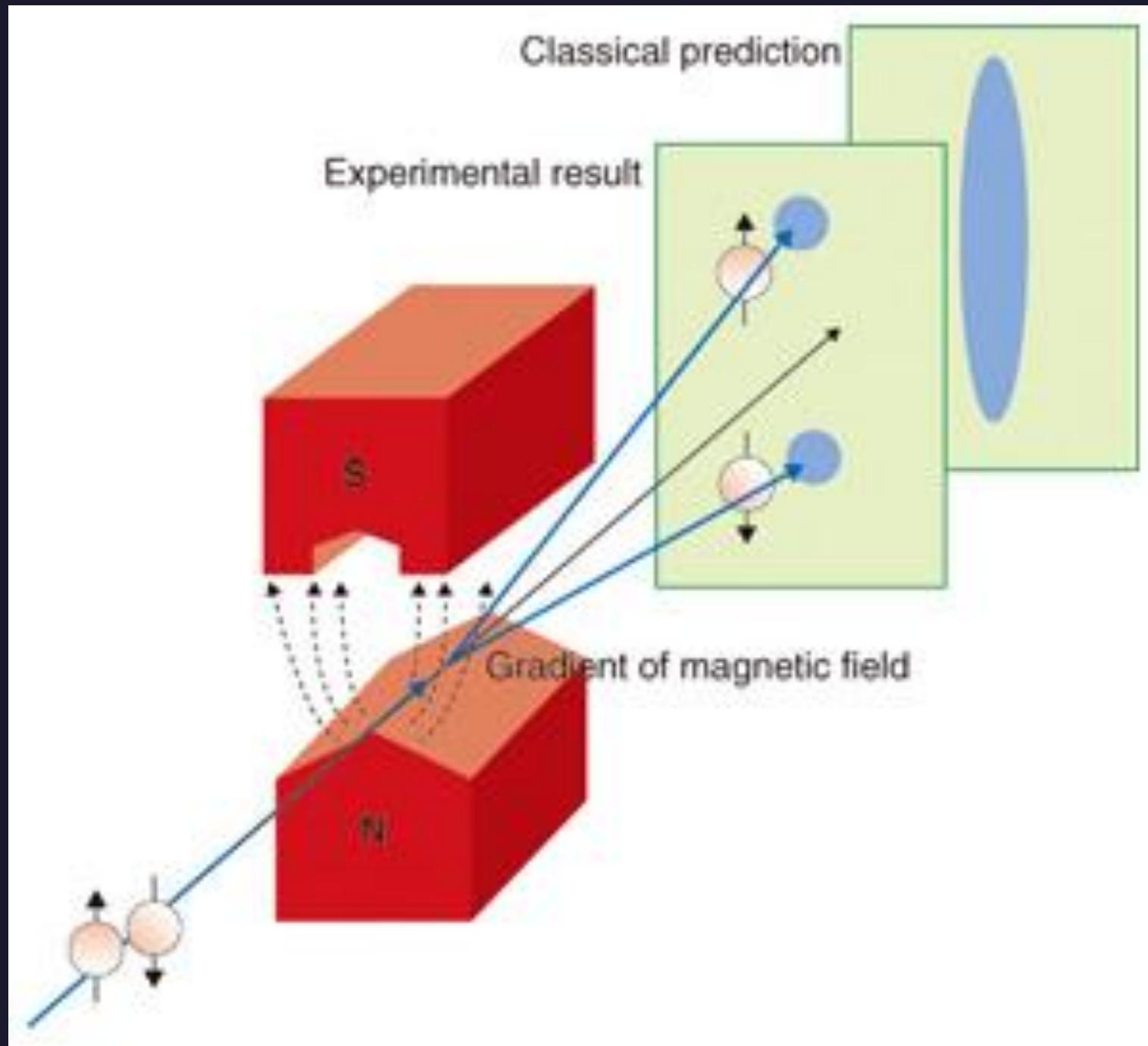
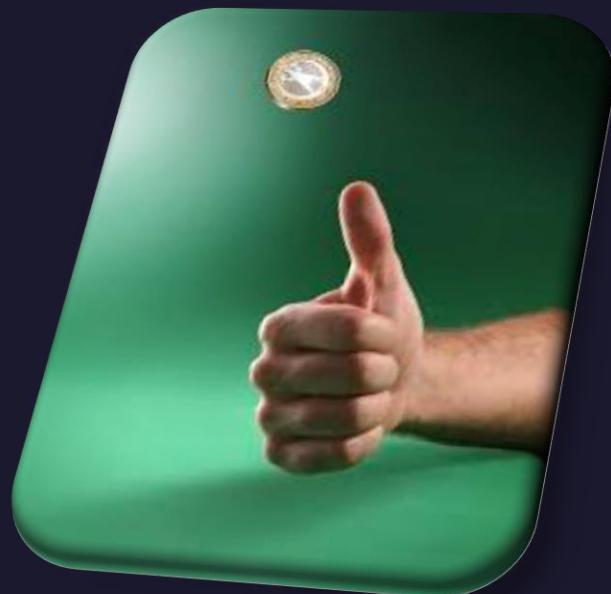


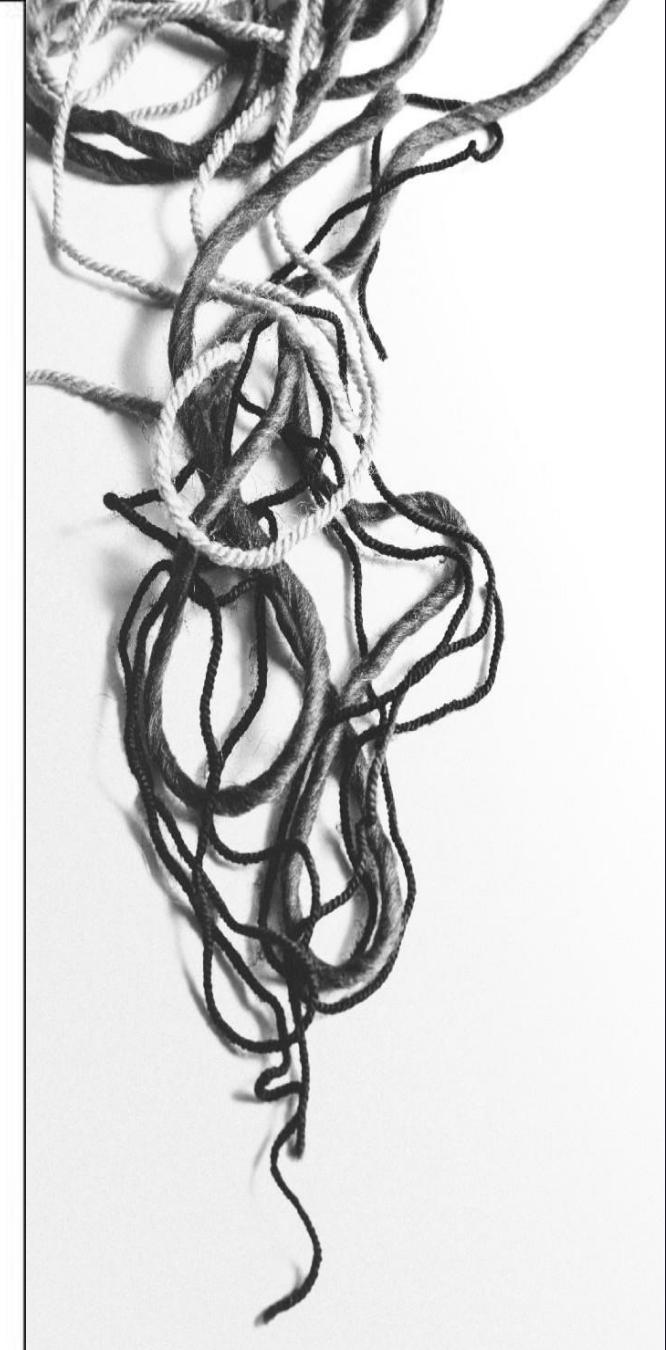
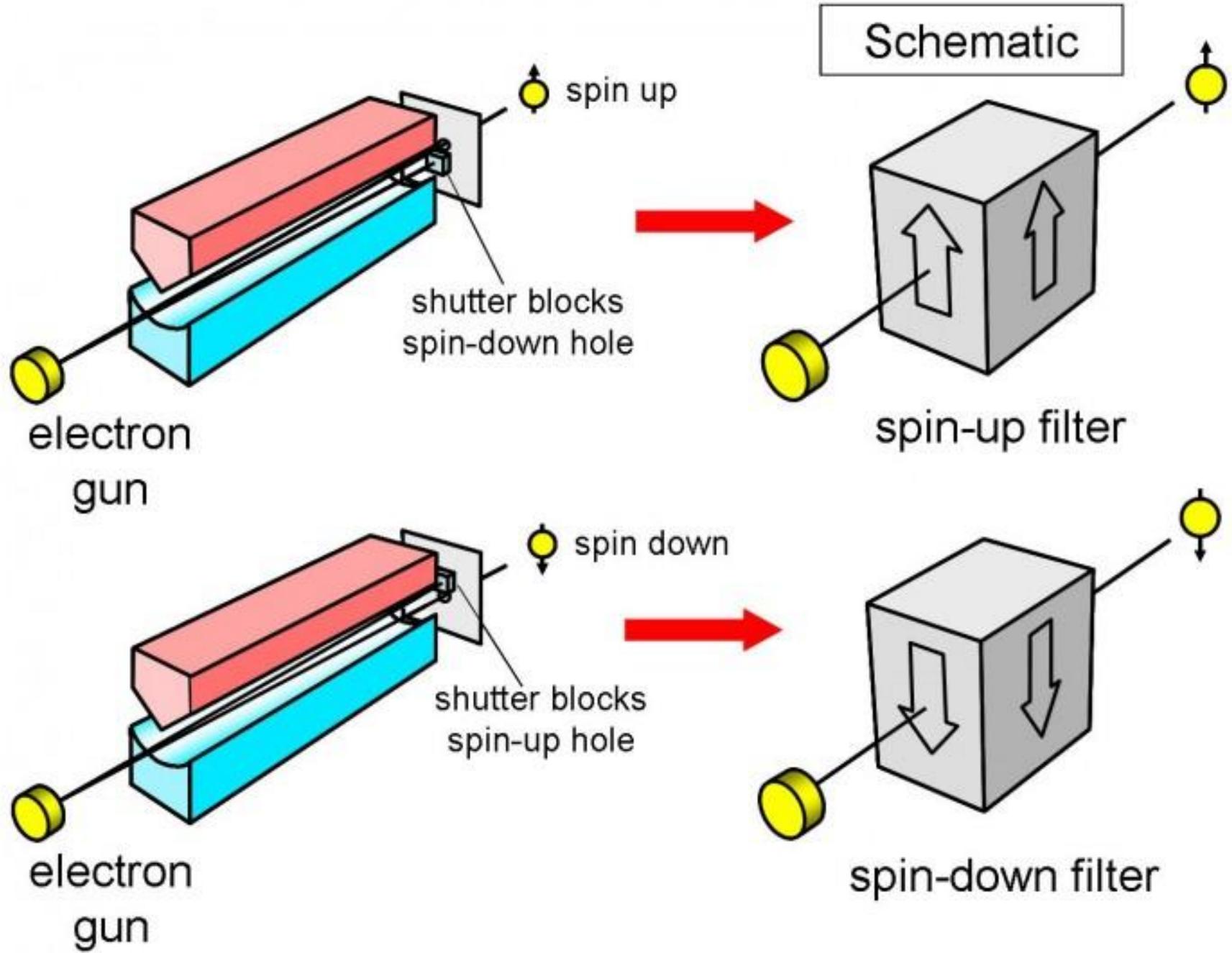
Quantizzazione



Esperimento di Stern-Gerlach

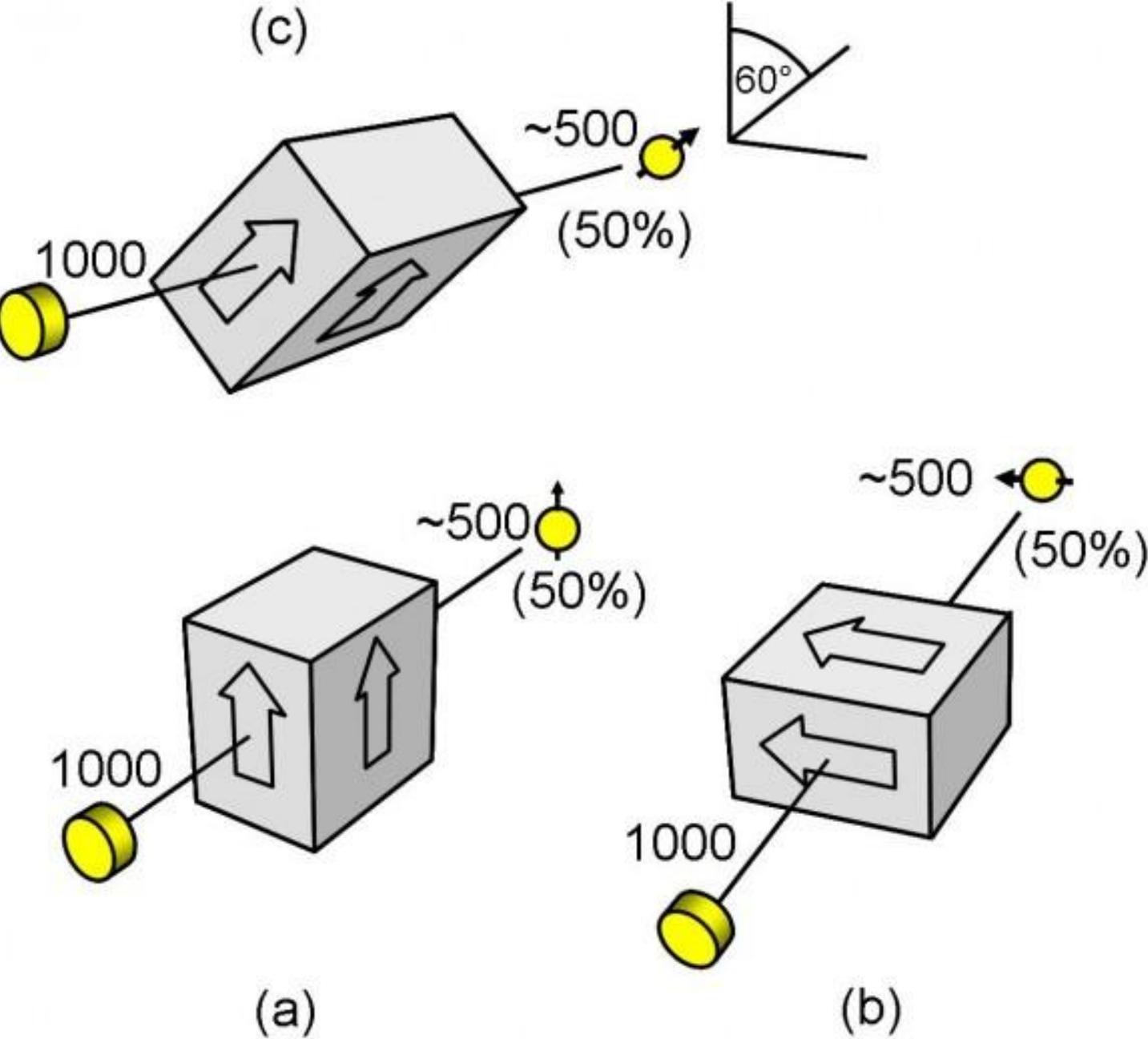
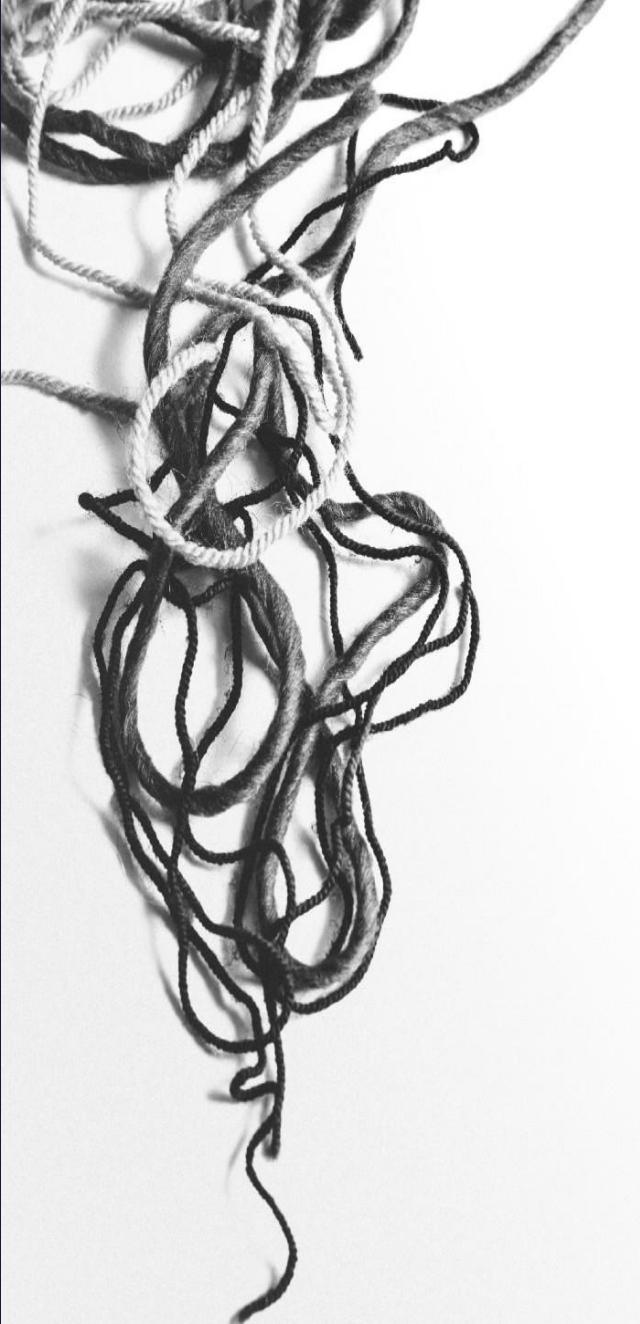
Lo spin degli elettroni può avere solo due valori più o meno un mezzo oppure se vogliamo rendere le cose ancora più semplici **su** e **giù**

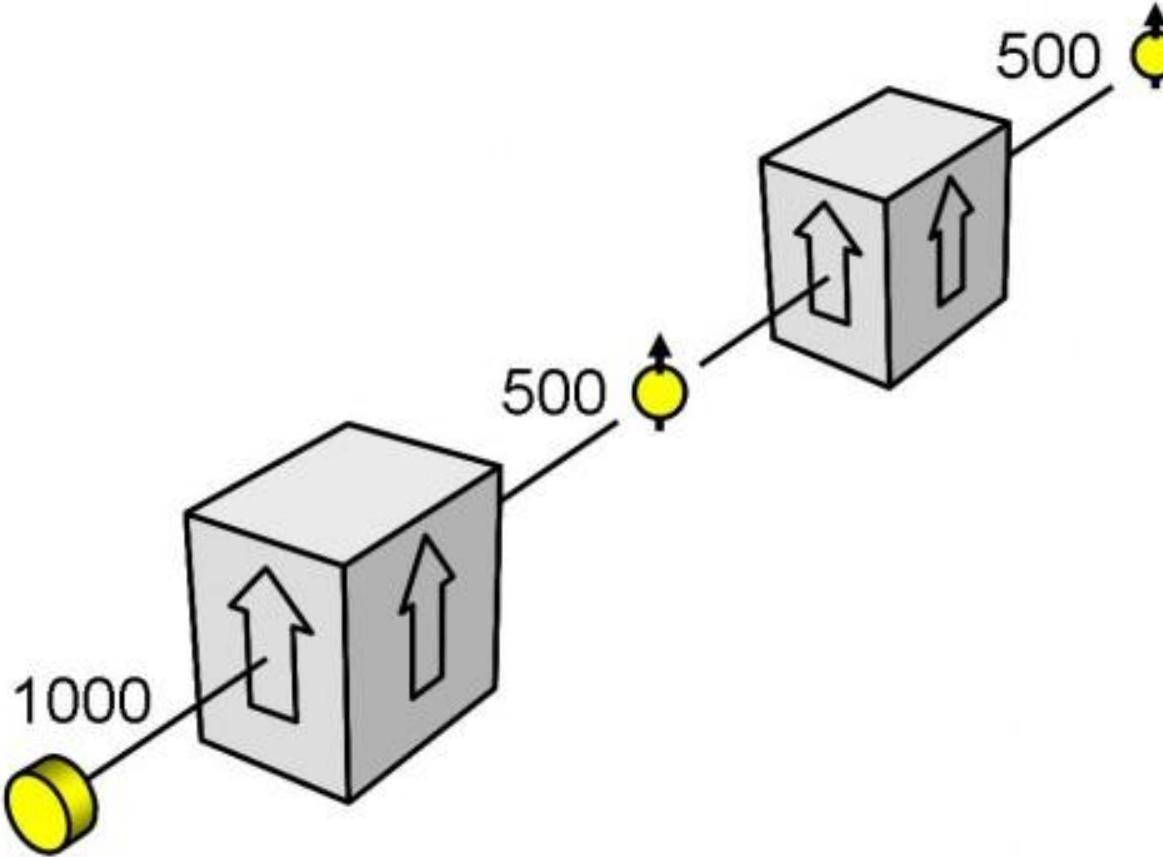
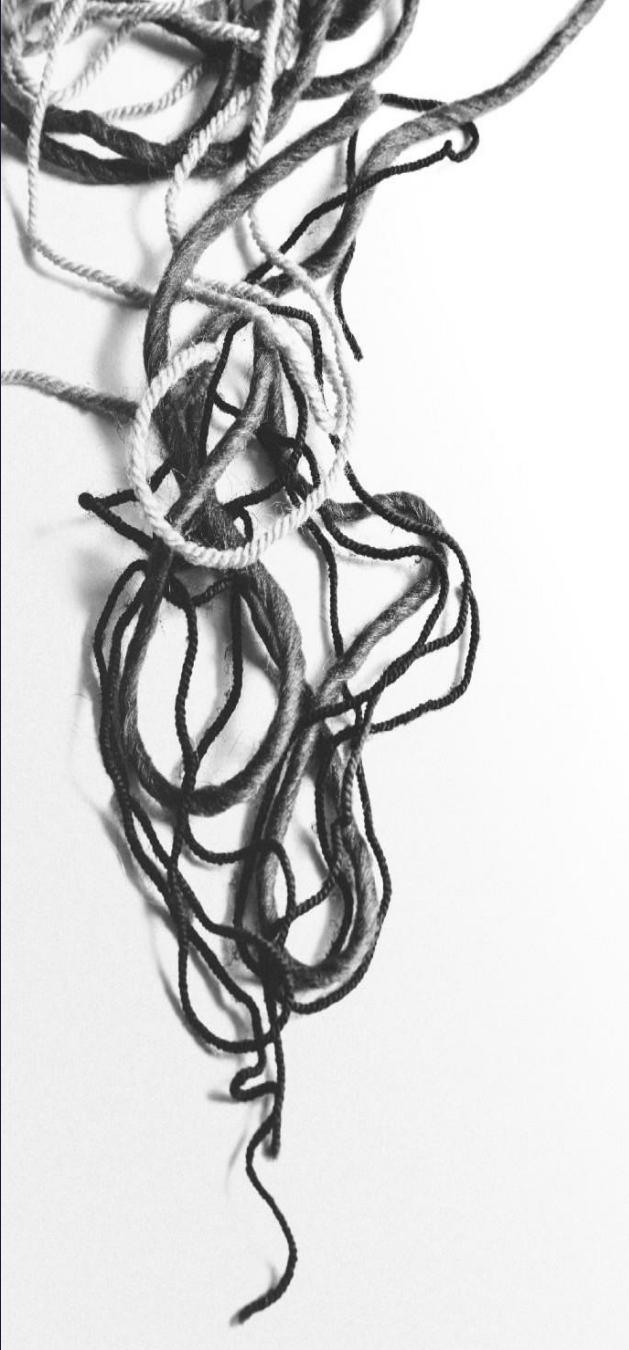


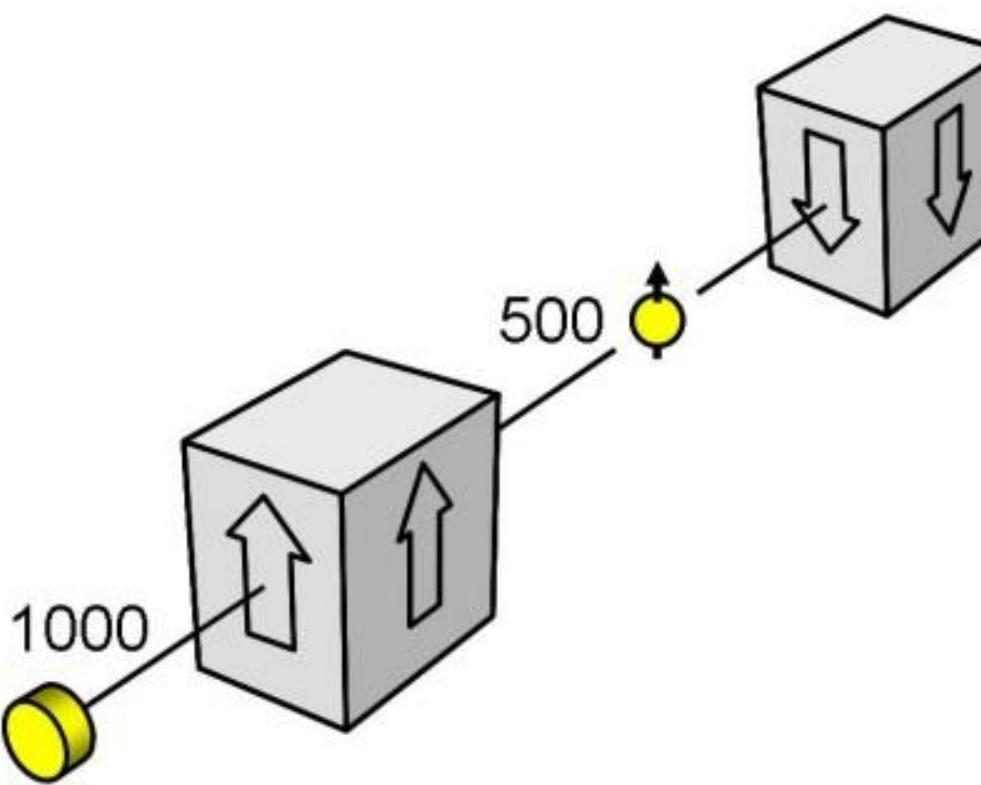
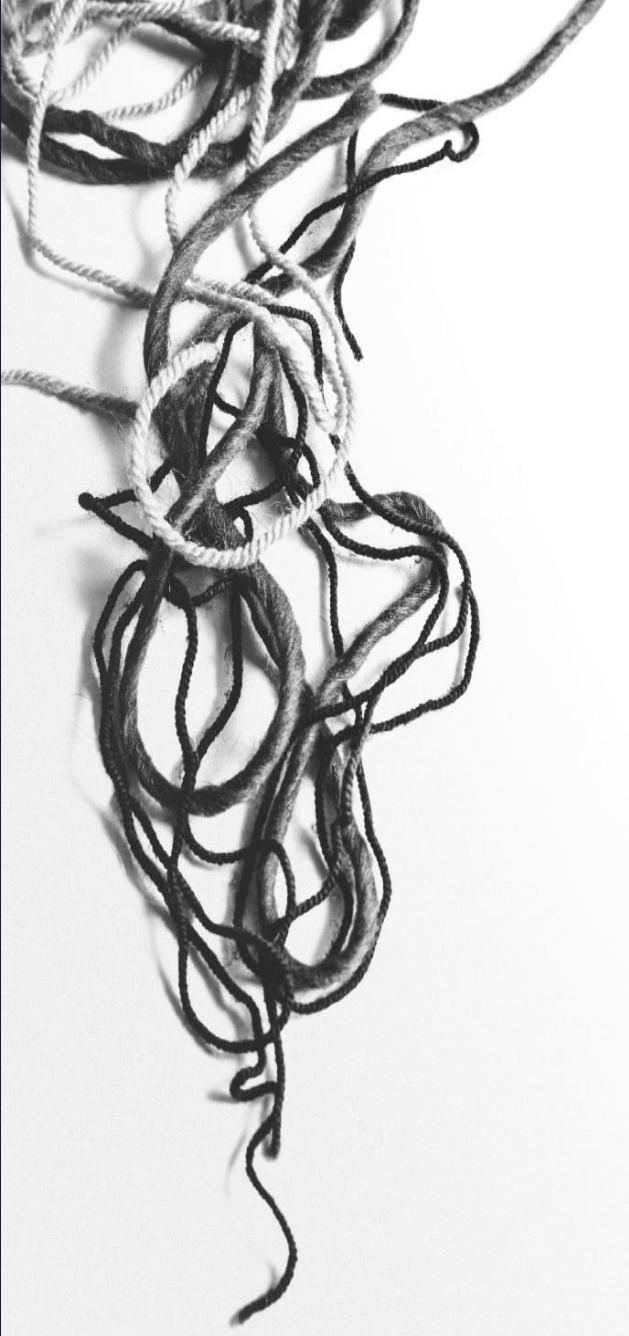


A collection of black, twenty-sided dice (D20s) are scattered across a white background. The dice are oriented in various ways, with some showing faces like 1, 3, 5, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20. The lighting creates highlights on the raised edges of the dice.

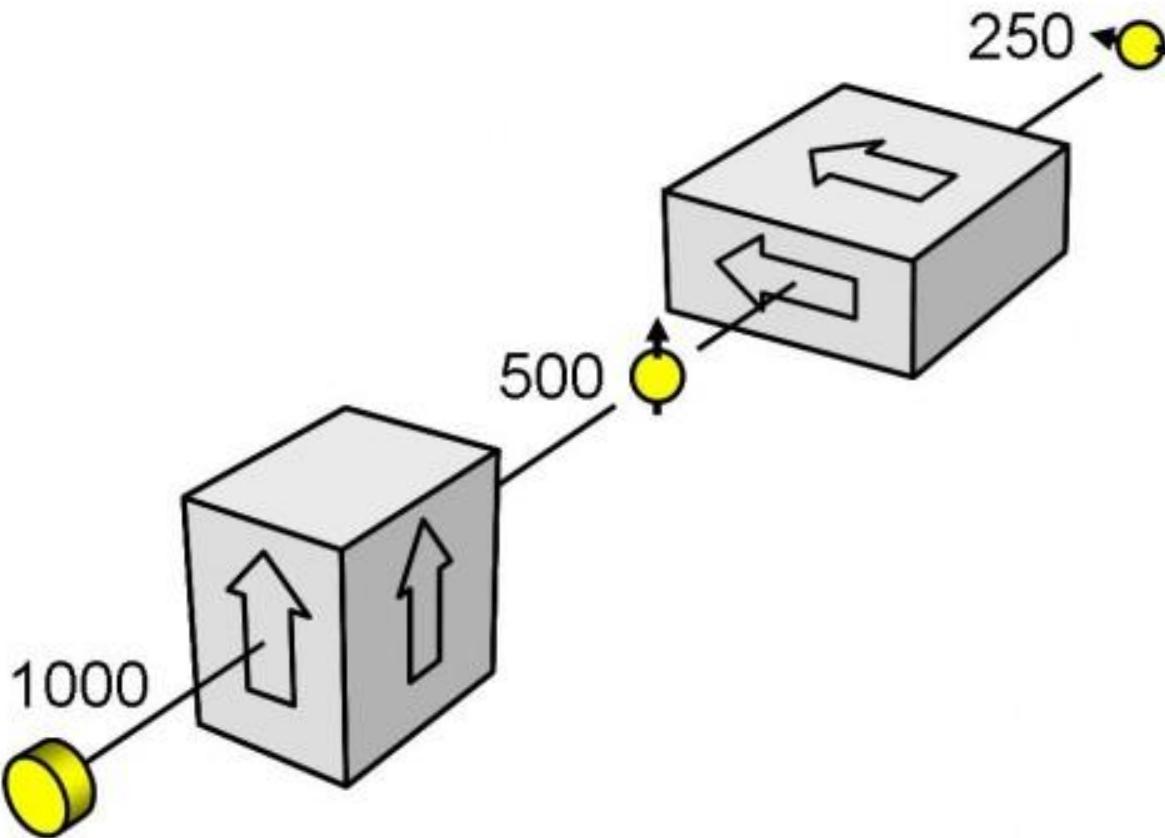
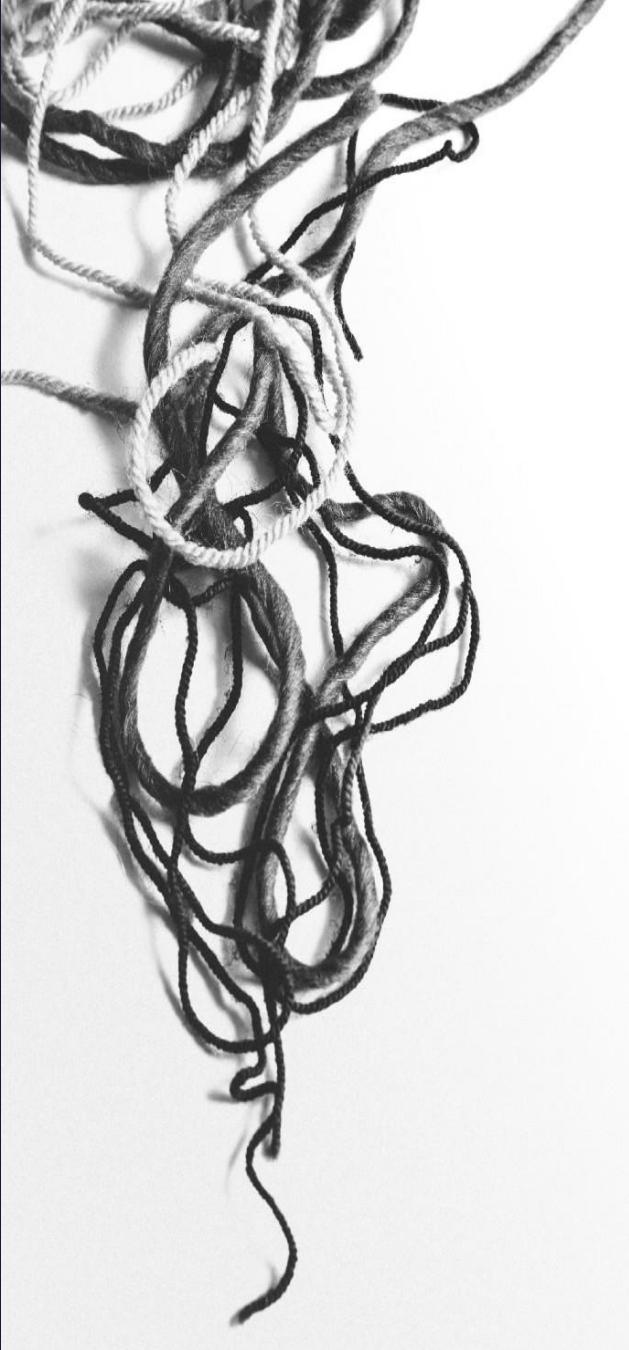
Causalità

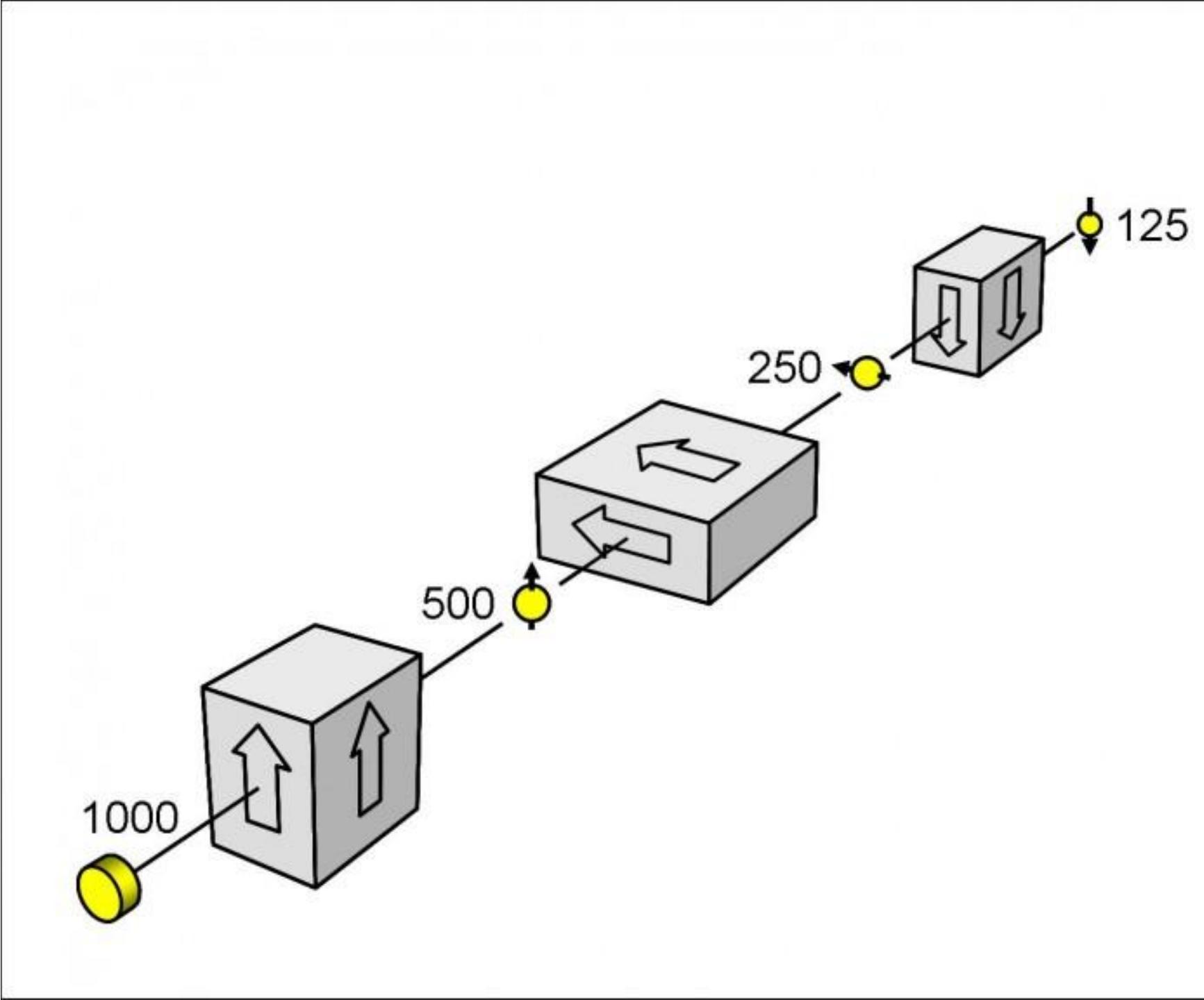
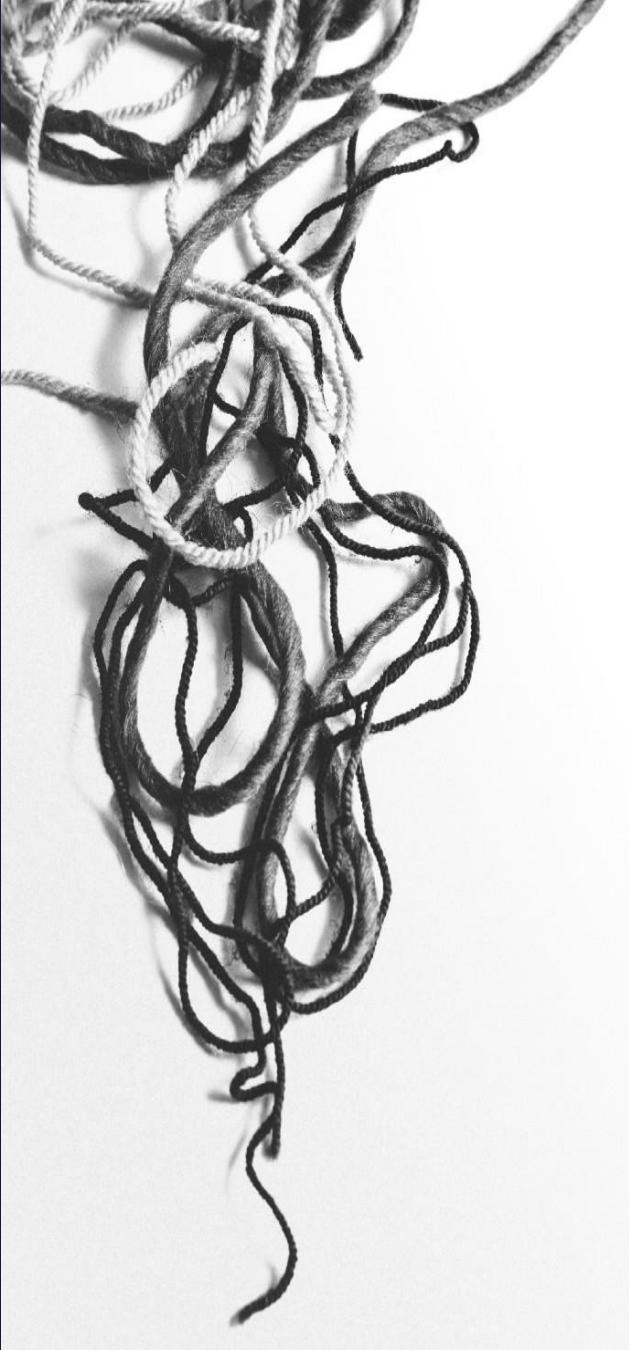






no electrons
emerge from
second filter



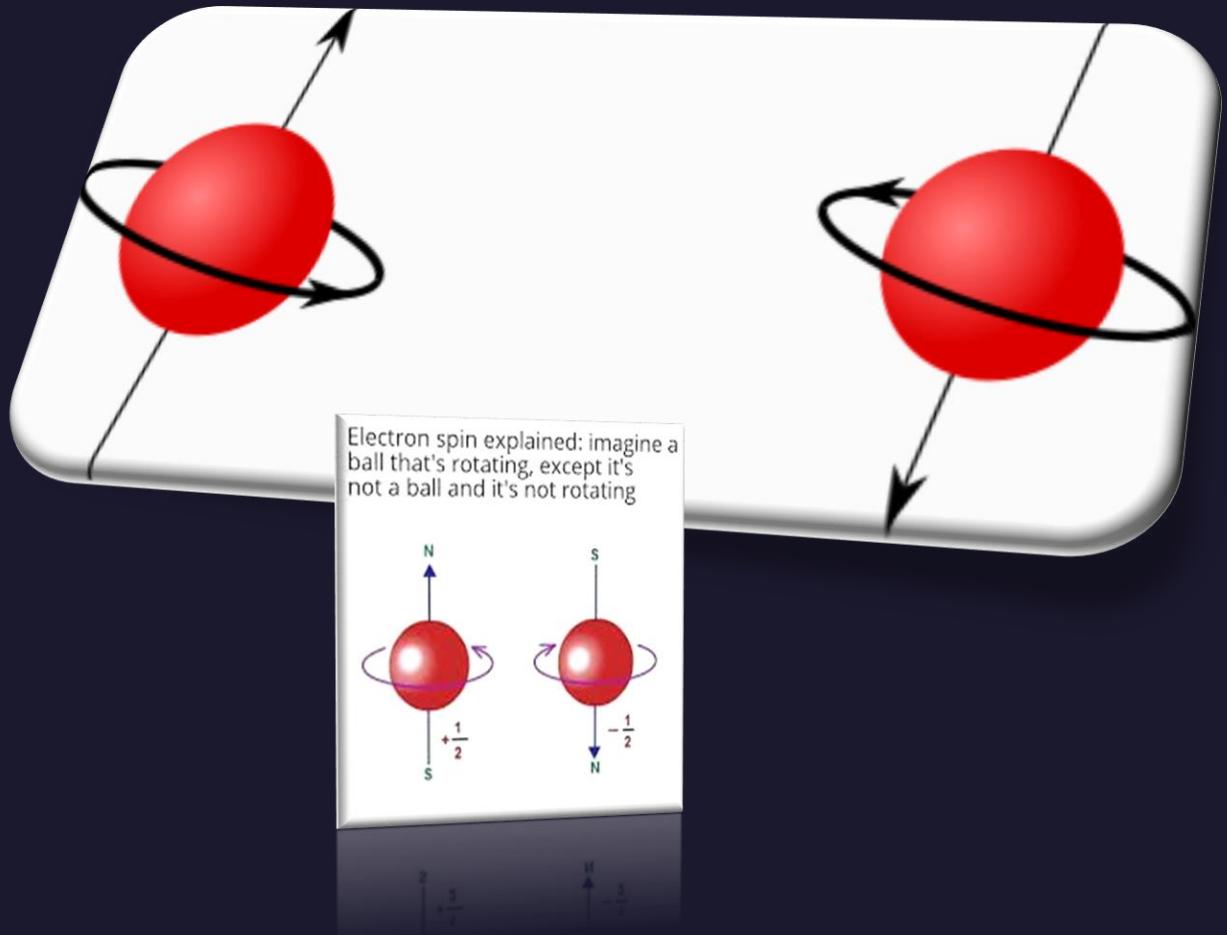


Conservazione

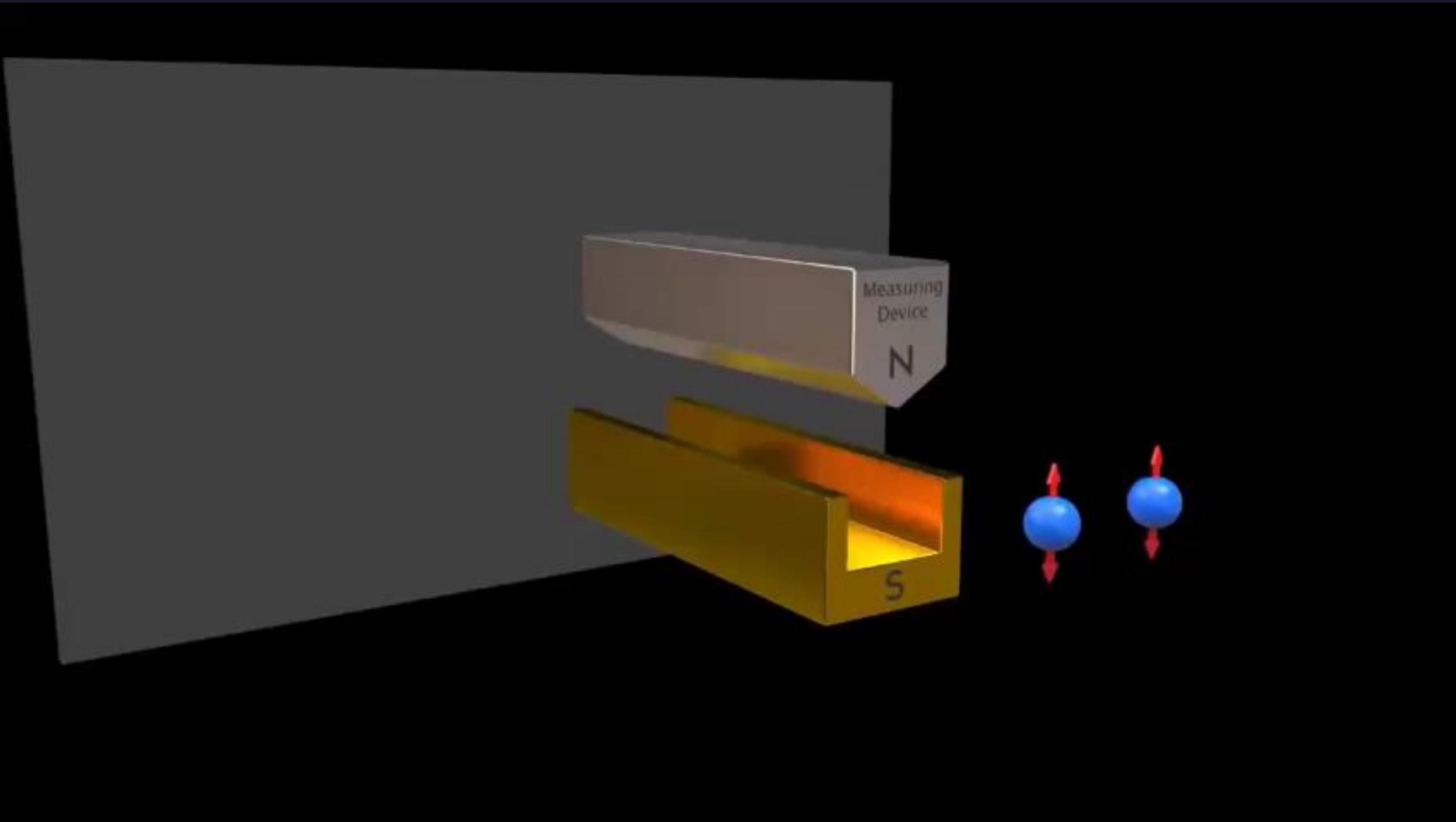




Conservazione - Correlazione



- si possono creare due elettroni in modo che la somma dei loro spin faccia esattamente zero
- non ci interessa sapere esattamente come facciamo questa cosa il punto veramente importante è che una volta che questi due elettroni sono stati creati o preparati in questo modo cioè con la somma dello spin complessivo uguale a zero sono costretti a rimanere in questo stato cioè sono **correlati** quindi
- se uno dei due spin è più un mezzo l'altro deve essere per forza meno un mezzo **la somma deve fare zero** qualunque cosa accada

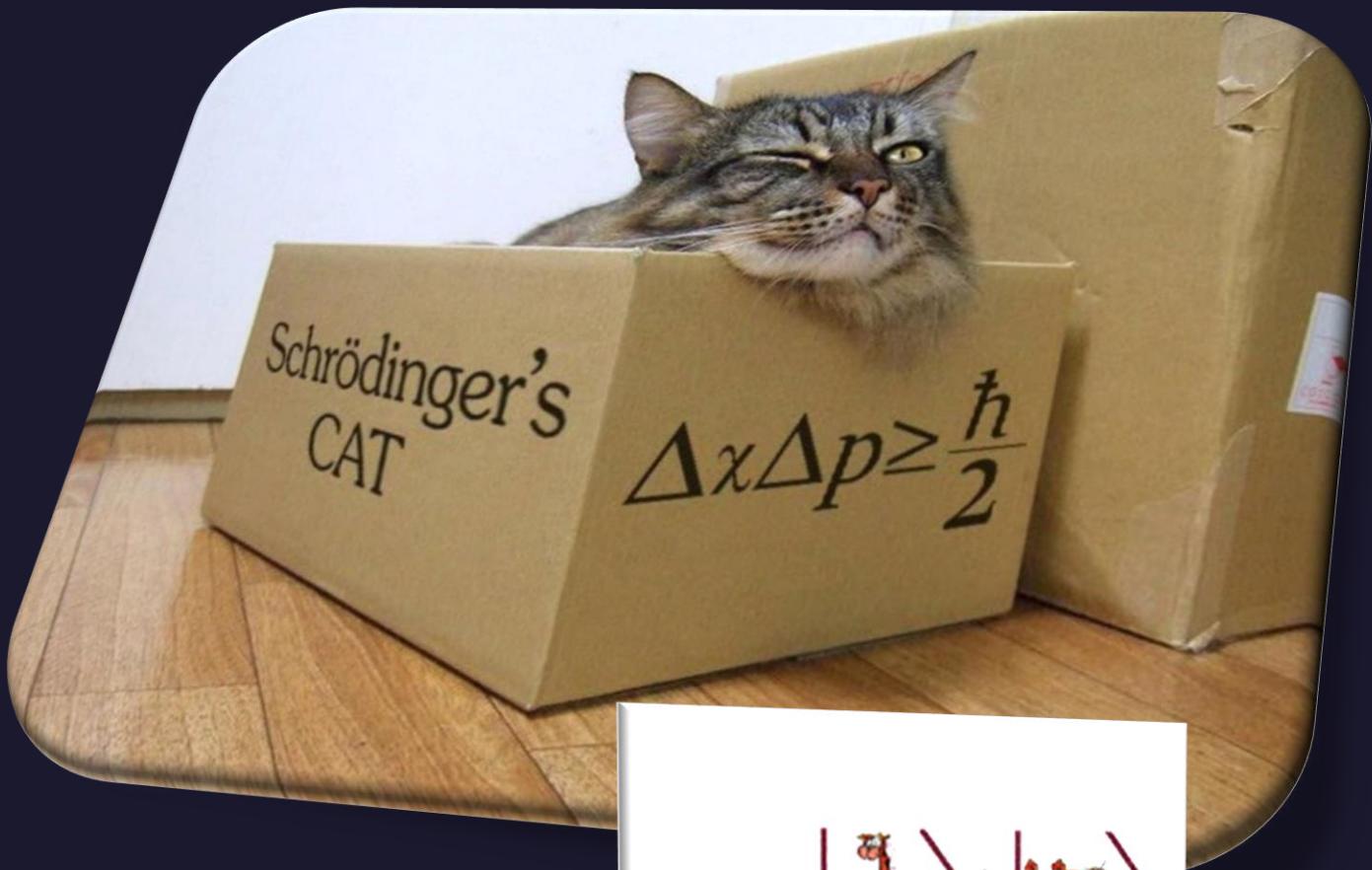


Sovrapposizione



Sovrapposizione

In meccanica quantistica però la cosa è in effetti un po' più strana perché le particelle quantistiche non hanno proprietà definite fino a quando non andiamo a misurarle quindi lo spin di un elettrone per esempio non è $+1/2$ o $-1/2$ un mezzo prima della misura ma in realtà è quello che meccanica quantistica viene chiamato una **sovraposizione**



$$|\Psi\rangle = \frac{|\text{alive}\rangle + |\text{dead}\rangle}{\sqrt{2}}$$

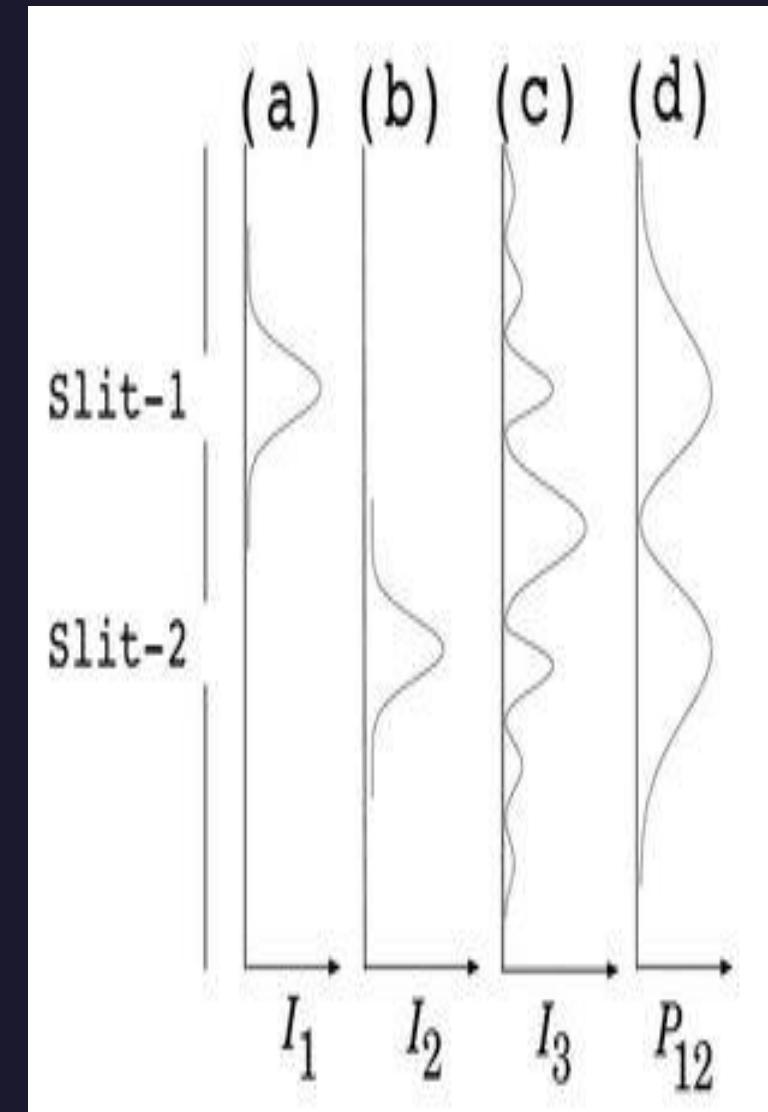
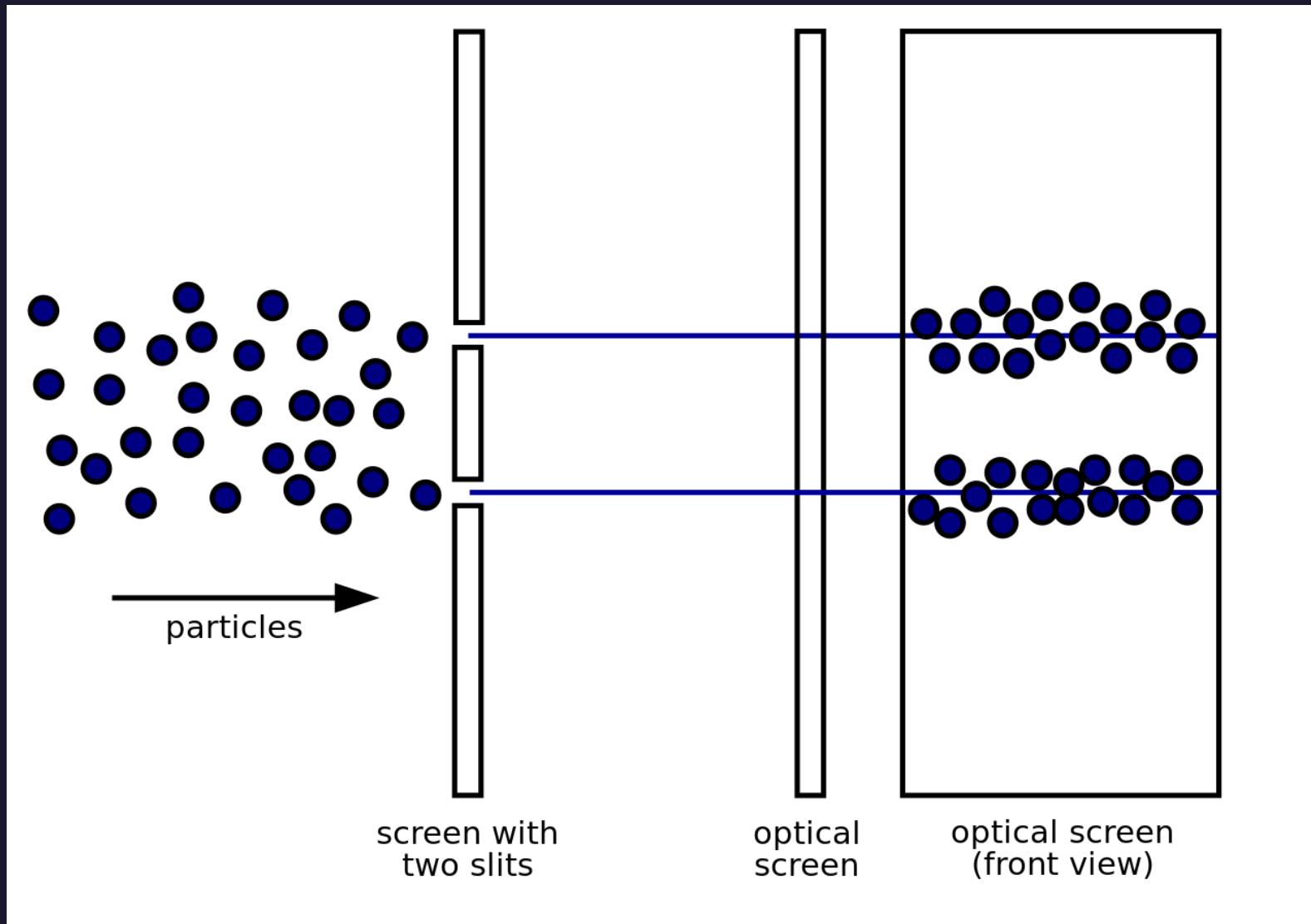
Sovrapposizione



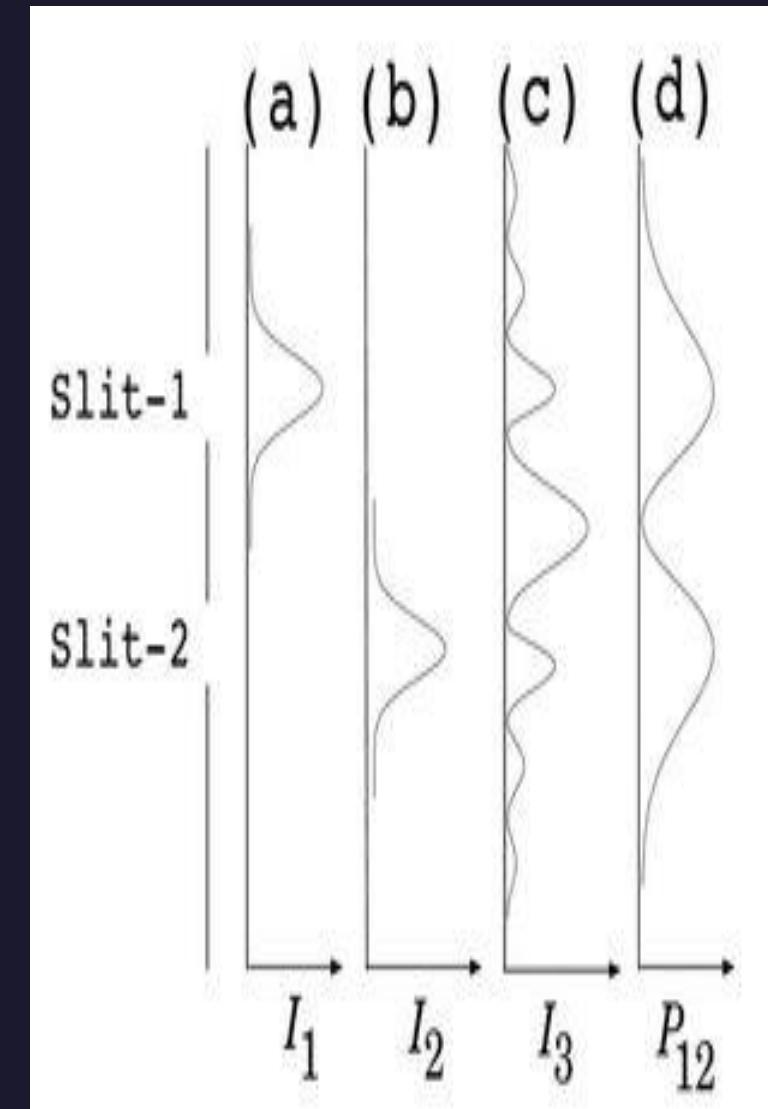
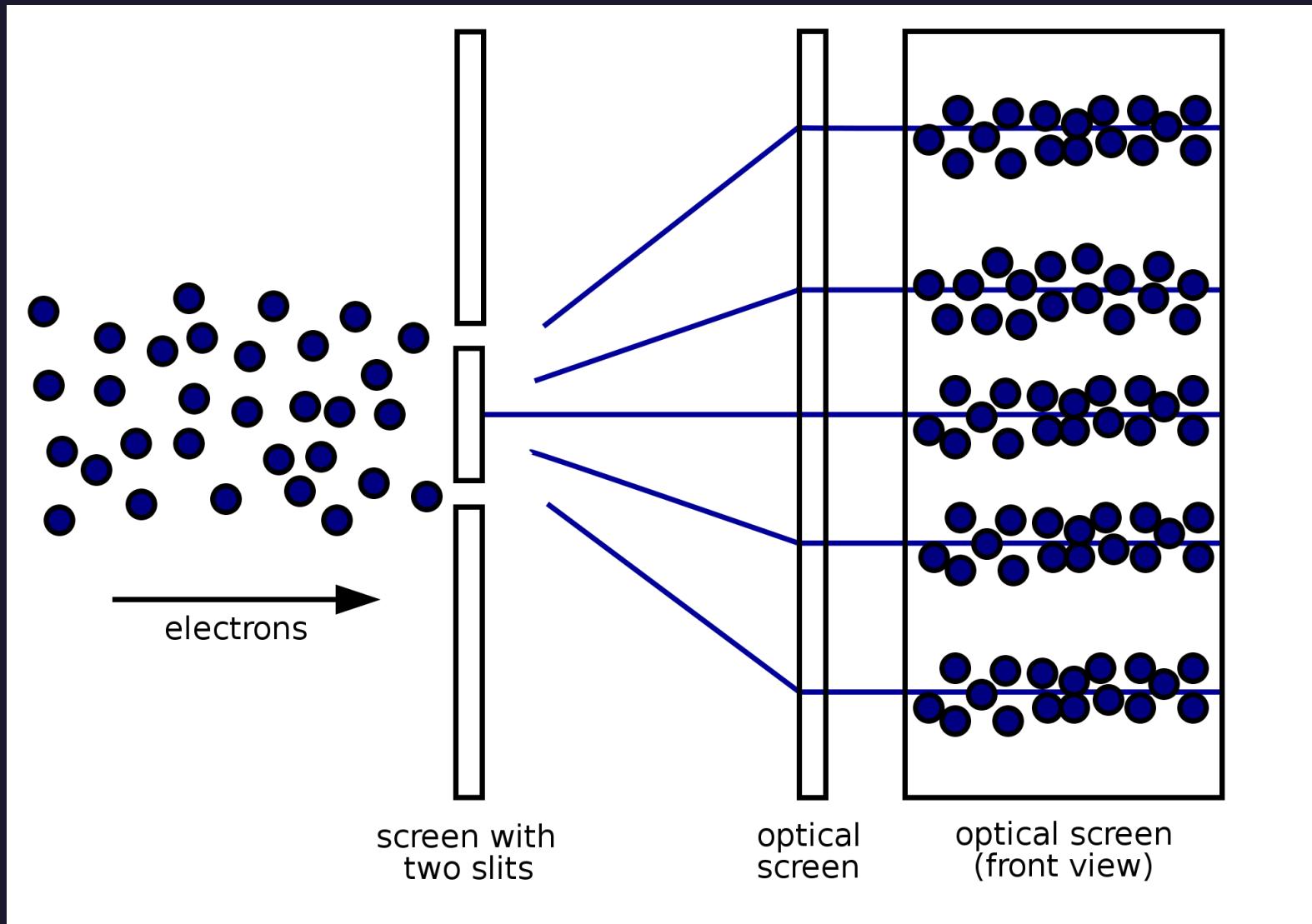
$$|\Psi\rangle = \frac{|\text{Up}\rangle + |\text{Down}\rangle}{\sqrt{2}}$$

- Anche su questo c'è un po' di confusione perché spesso si legge che fino a quando non facciamo una misura dello spin dell'elettrone sappiamo solo che c'è 50 per cento di probabilità che sia sue 50 per cento probabilità che sia giù!
- Ma questo è vero anche in un sistema classico. Non c'è niente di strano! Se ho una moneta dentro una scatola non so se è testa o croce fino a quando non avrò aperto la scatola, quindi c'è una probabilità del 50 per cento di aprire e trovare che la moneta con la faccia in su indica testa o il 50 per cento di aprire e vedere croce.
- In meccanica quantistica la faccenda è diversa!

Sovrapposizione



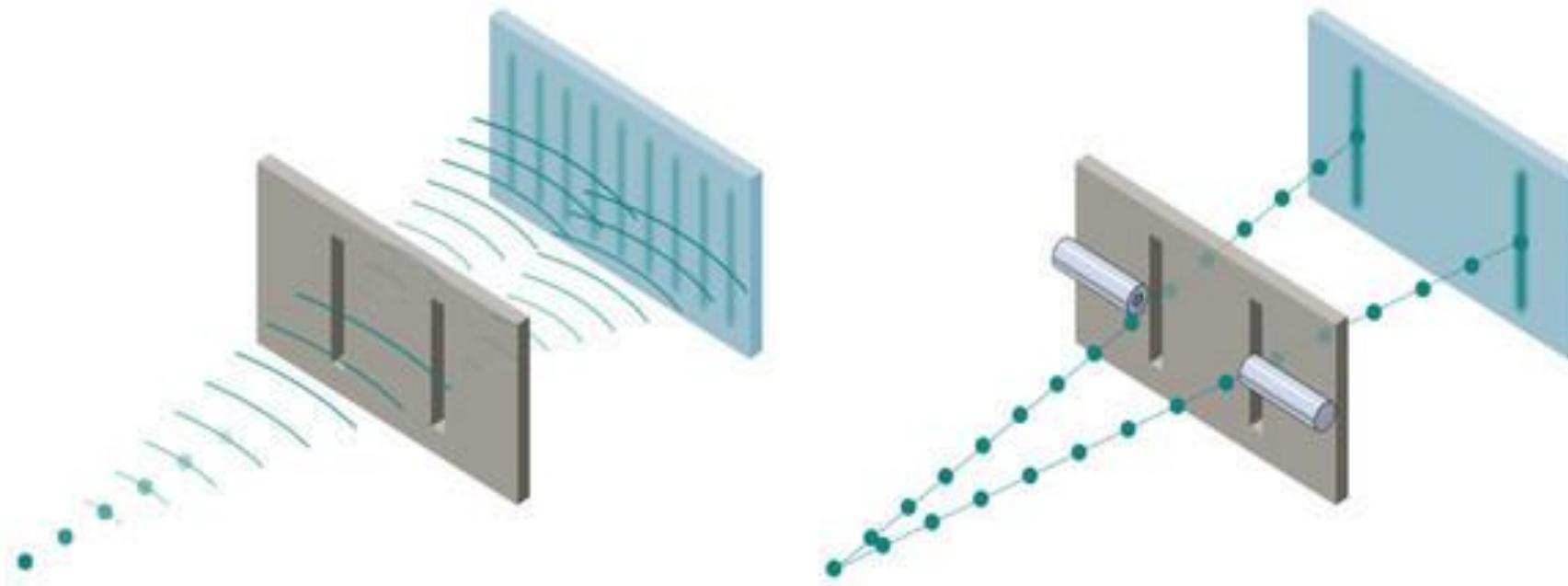
Sovrapposizione



Sovrapposizione

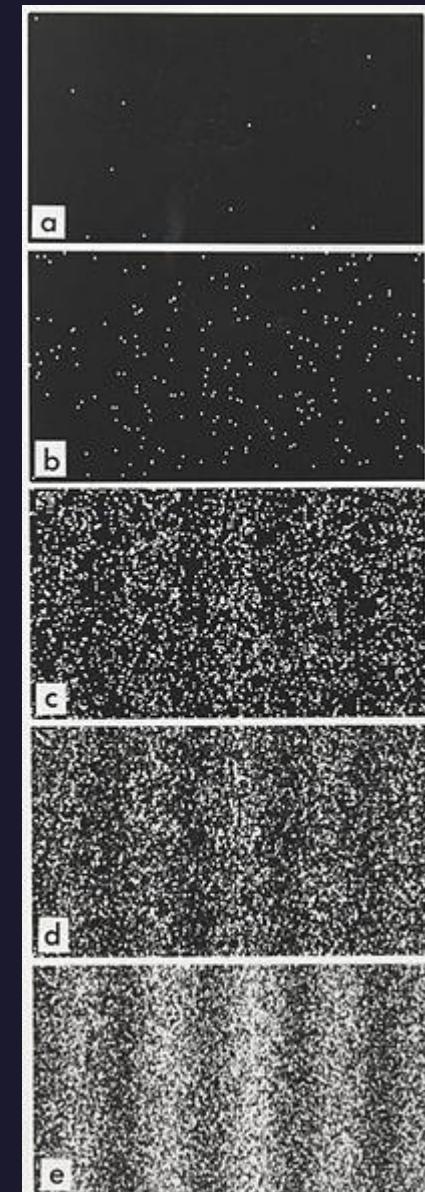
A central mystery

The classic double slit experiment seems to suggest quantum objects such as electrons are sometimes **particles**, sometimes **waves** – and we decide which guise they take



A stream of single electrons is fired at two slits and measured on a screen behind. An interference pattern forms, as if each electron were a wave that passed through both slits at once

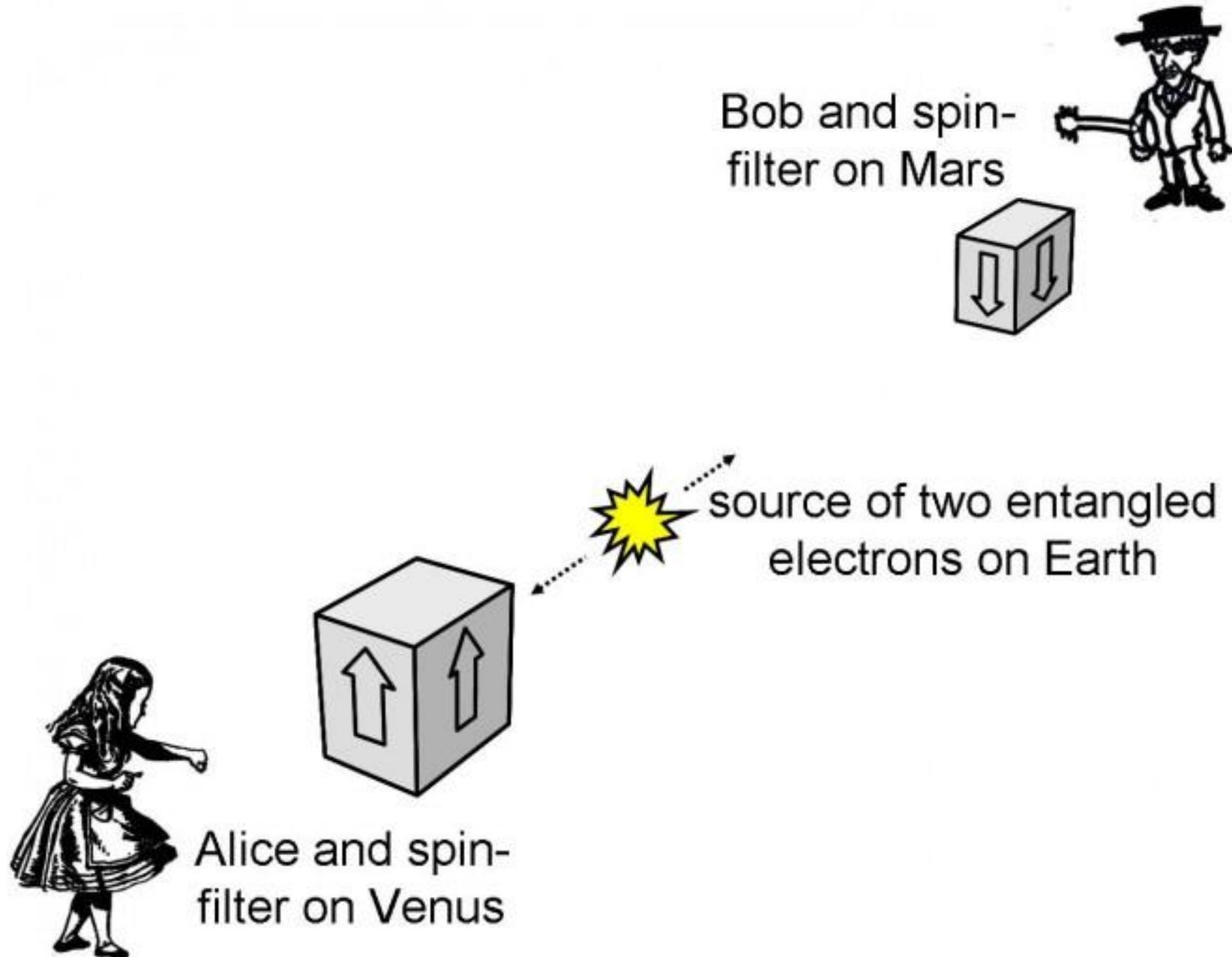
Measure the electrons first at the slits, however, and you see individual **particles** passing through one slit or the other – and the interference pattern on the screen disappears



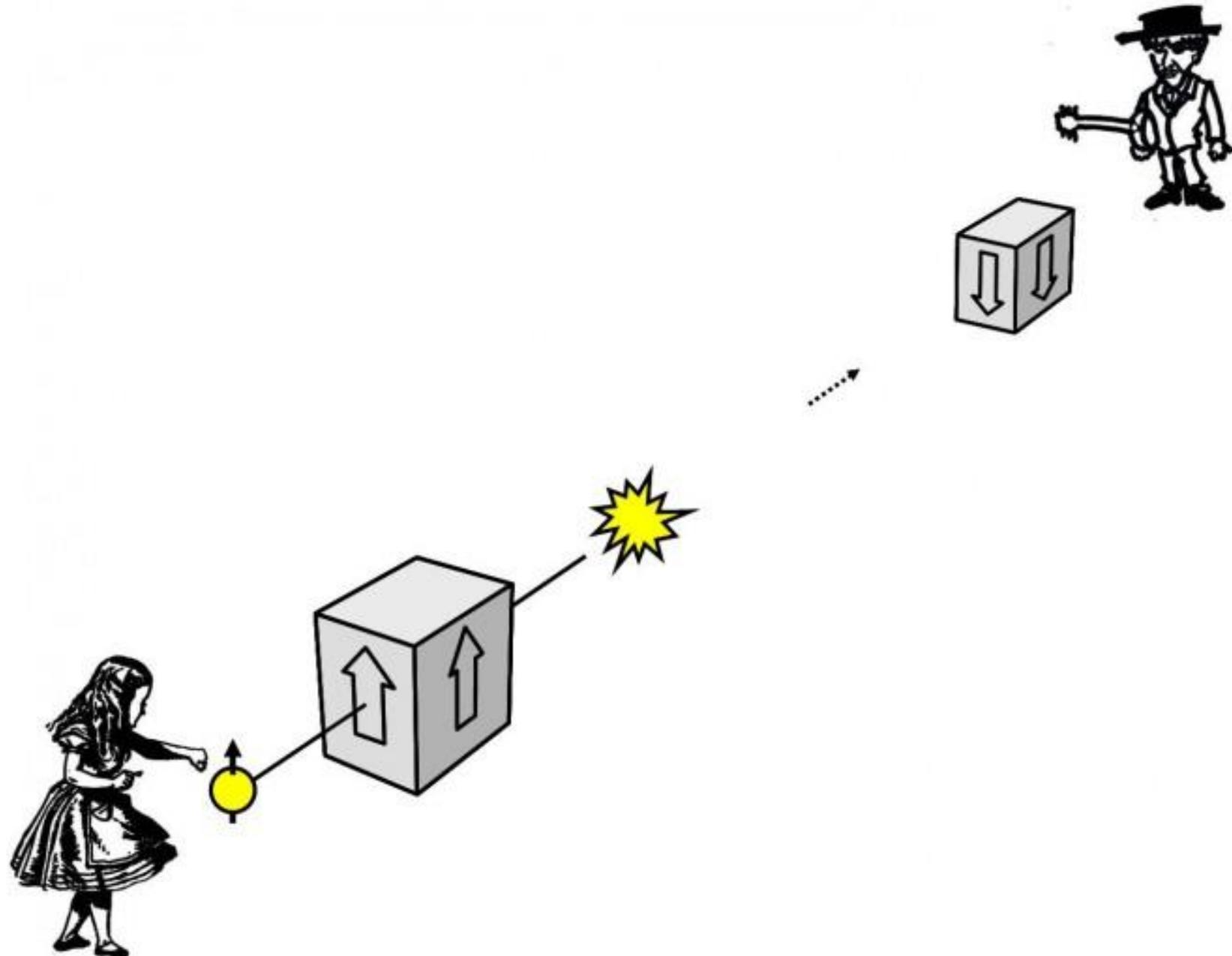
Entanglement



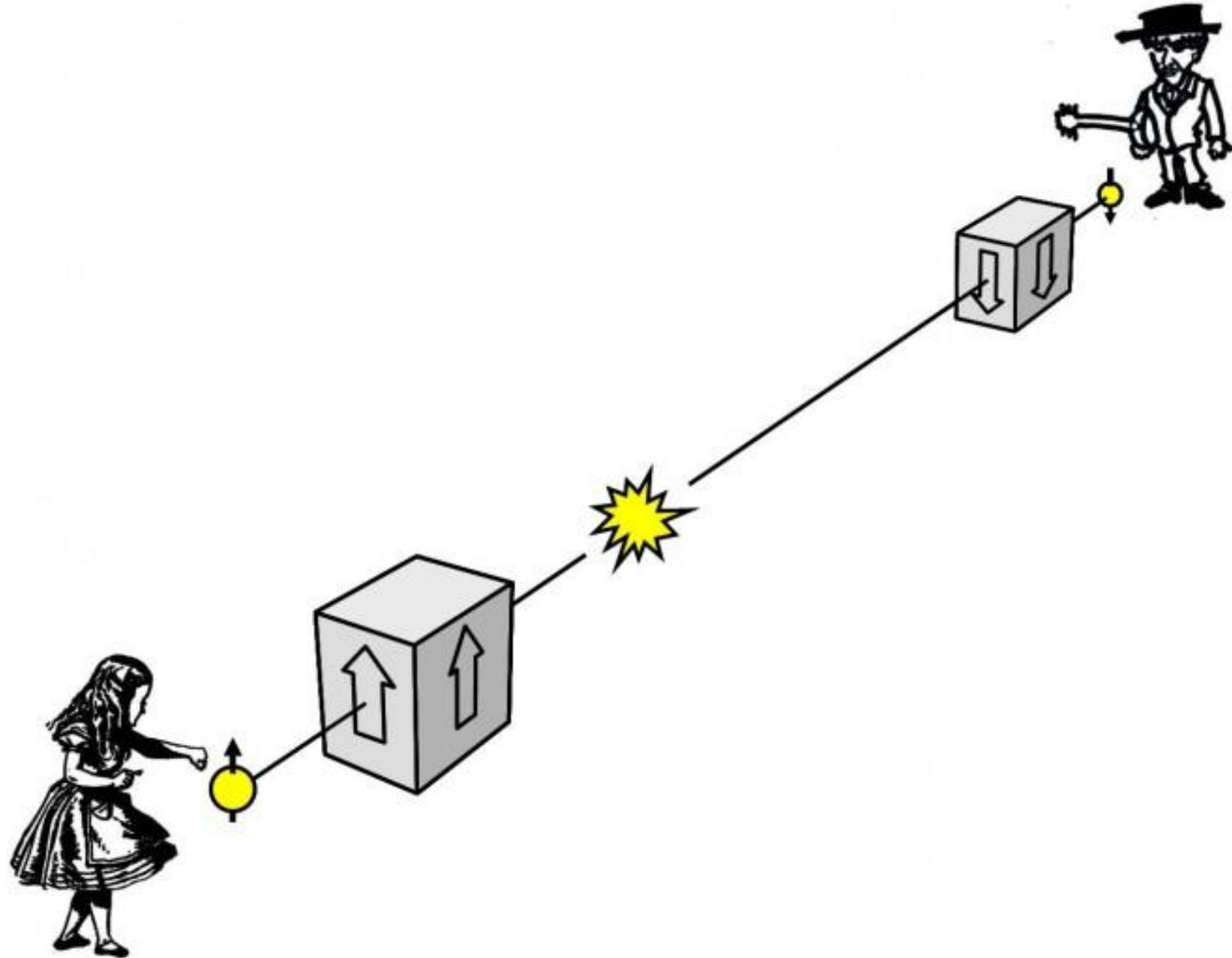
Entanglement



Entanglement



Entanglement



Entanglement: Può la Meccanica Quantistica Ritenersi Completa?

300

SCIENCE NEWS LETTER for May 11, 1935

PHYSICS

Einstein Attacks Quantum Mechanics

Calls One of Science's Most Important Theories
"Incomplete" and Anticipates More Satisfactory One

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 "correct" it is not "complete."

With two colleagues at the Institute for Advanced Study at Princeton, N. J., the great relativist is about to report to

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 explor-

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, an atom, a molecule, a "wave function," etc., completely describes the physical sys-

1935

The New York Times.

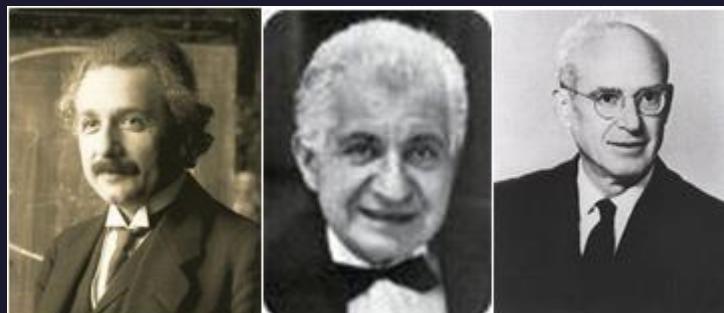
Copyright, 1935, by The New York Times Company.

NEW YORK, SATURDAY, MAY 4, 1935.

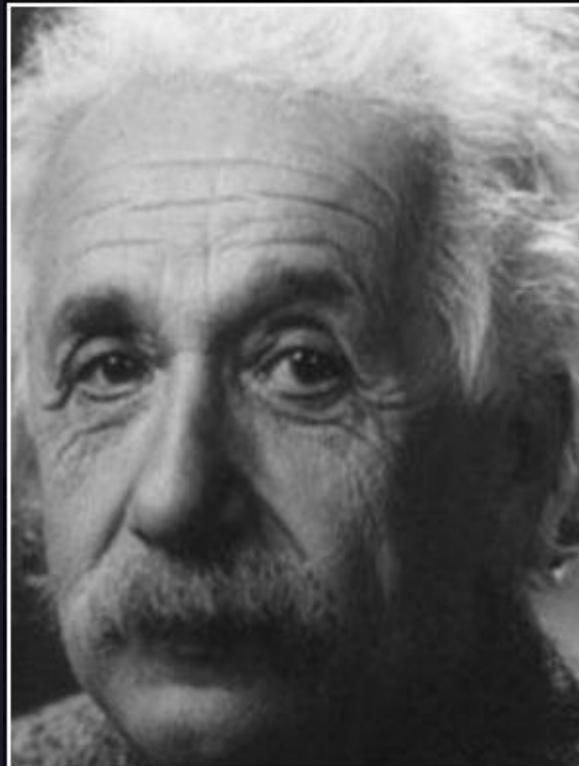
P TWO CEN

EINSTEIN ATTACKS QUANTUM THEORY

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



Entanglement: Può la Meccanica Quantistica Ritenersi Completa?

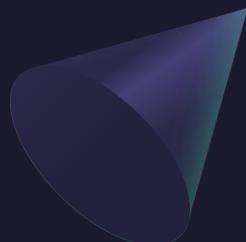


I cannot seriously believe in it [quantum theory] because the theory cannot be reconciled with the idea that physics should represent a reality in time and space, free from spooky actions at a distance [spukhafte Fernwirkungen].

— *Albert Einstein* —

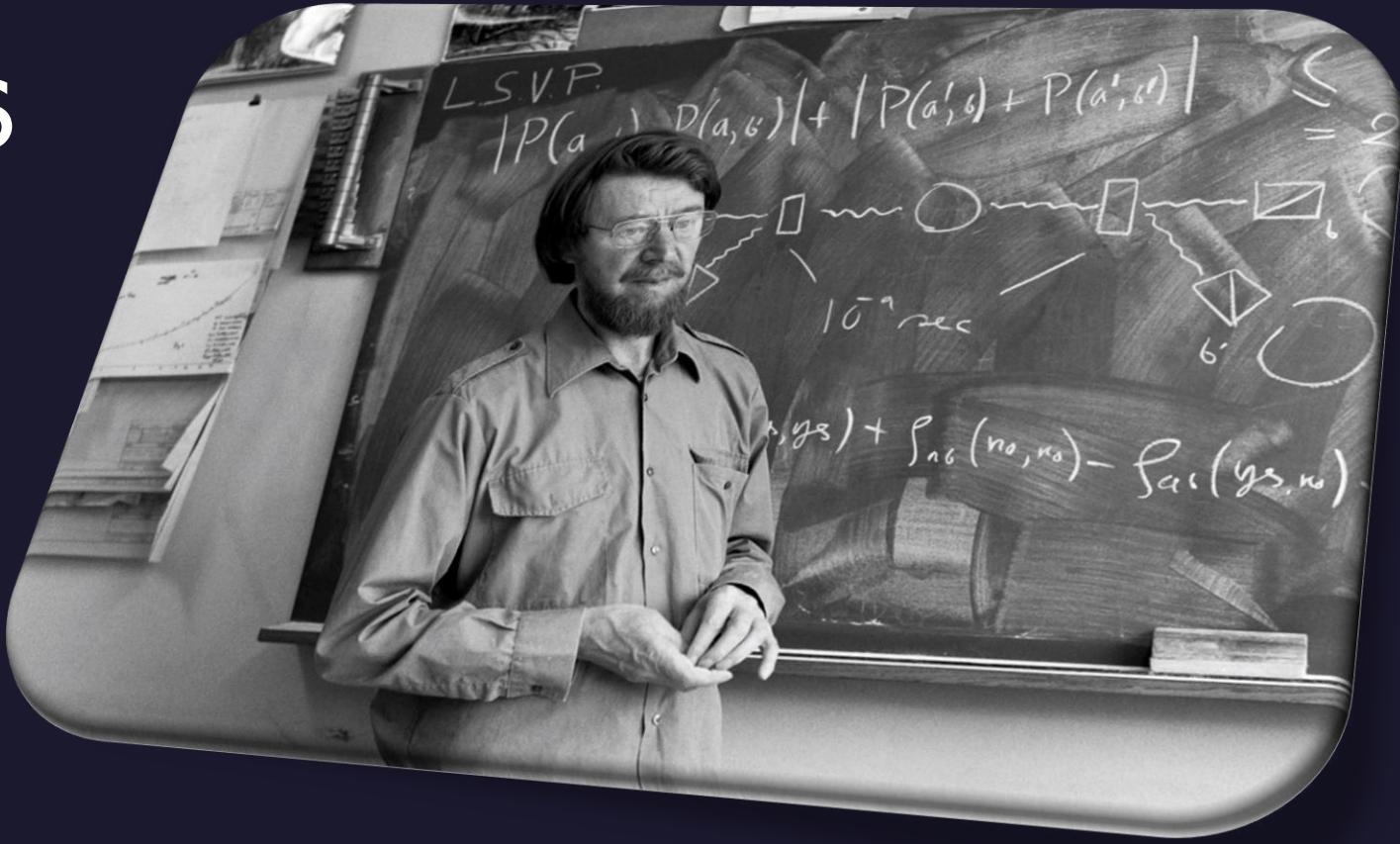
AZ QUOTES

1935



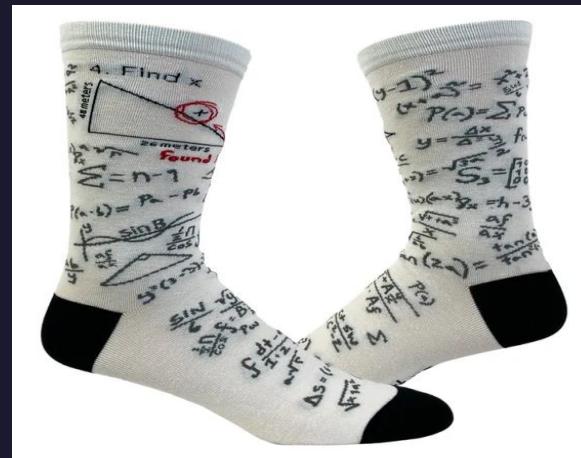
Il Teorema di Bell 1966

- J. Bell riesce a stabilire la possibilità di ciò che nella filosofia della scienza viene chiamato «**Esperimento Cruciale**»: una nuova situazione sperimentale per la quale la previsione teoria della meccanica quantistica è discrepante con ciò che necessariamente fa **qualsiasi teoria che presuppone l'esistenza di elementi di realtà locali**;
- L'esperimento ipotizza la misura di 3 proprietà binarie



John Stewart Bell (1928-1990)

Il Teorema di Bell



Proprietà 1 : Indossare il Cappello

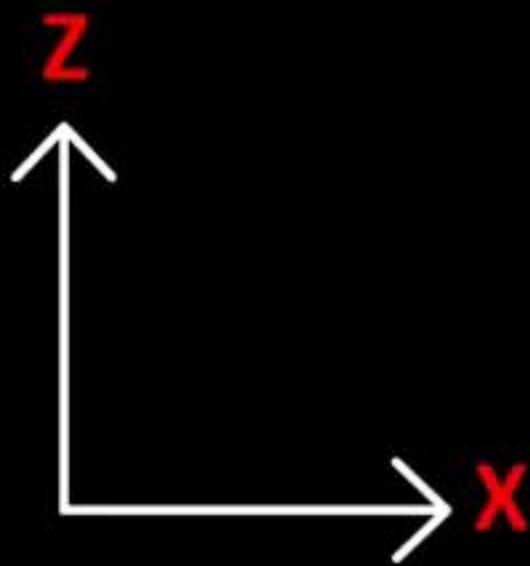


Proprietà 2 : Indossare gli Occhiali



Proprietà 3 : Indossare i Calzini



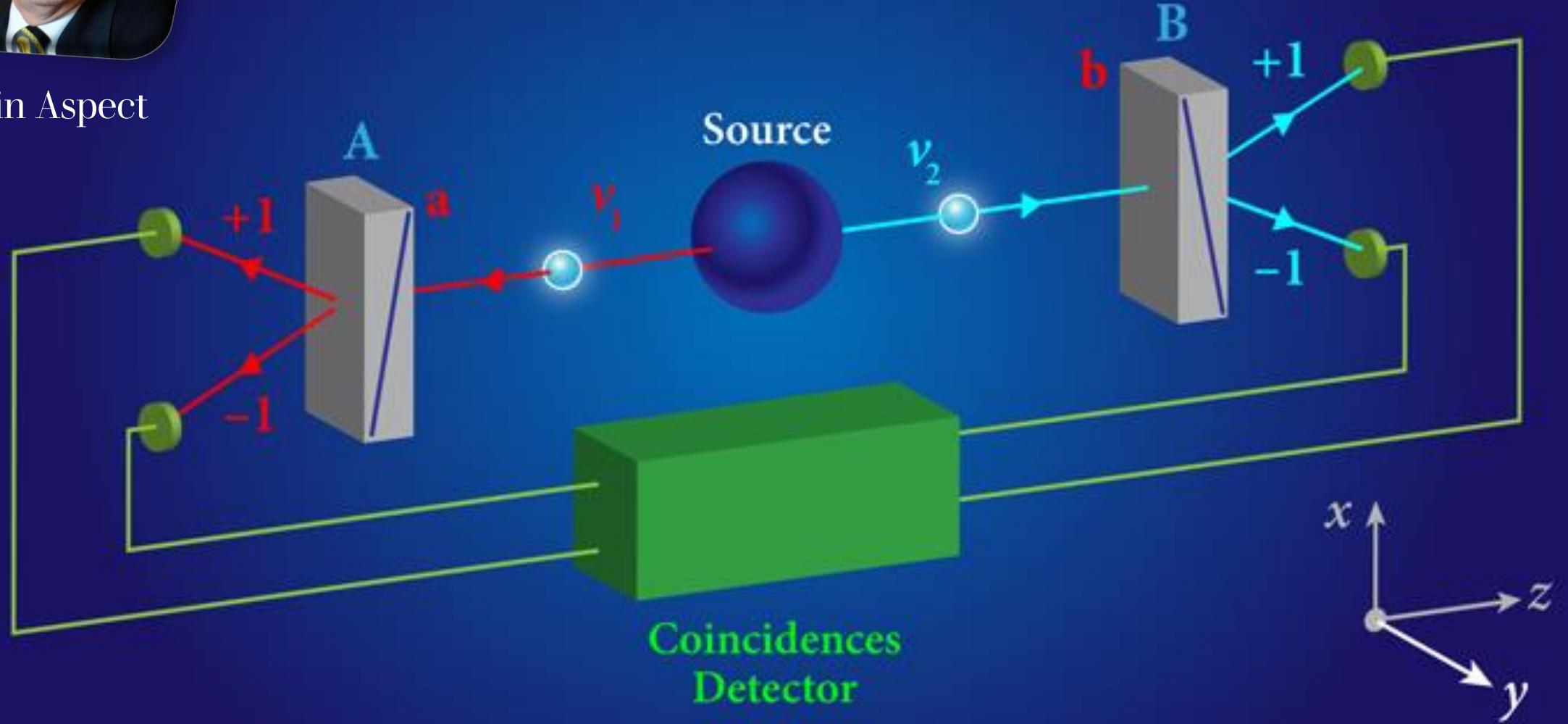




Alain Aspect

$$|\Psi(\nu_1, \nu_2)\rangle = \frac{1}{\sqrt{2}} \{ |x, x\rangle + |y, y\rangle \}$$

1982



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

VOLUME 49, NUMBER 2

PHYSICAL REVIEW LETTERS

12 JULY 1982

Experimental Realization of Einstein-Podolsky-Rosen-Bohm Gedankenexperiment: A New Violation of Bell's Inequalities

Alain Aspect, Philippe Grangier, and Gérard Roger
Institut d'Optique Théorique et Appliquée, Laboratoire associé au Centre National de la Recherche Scientifique,
Université Paris-Sud, F-91406 Orsay, France
(Received 30 December 1981)

The linear-polarization correlation of pairs of photons emitted in a radiative cascade of calcium has been measured. The new experimental scheme, using two-channel polarizers (i.e., optical analogs of Stern-Gerlach filters), is a straightforward transposition of Einstein-Podolsky-Rosen-Bohm gedankenexperiment. The present results agree with the quantum mechanical predictions. The present results realized Bell's inequalities ever achieved.

PACS numbers: 03.65.Bz, 35.80.+s

In the well-known Einstein-Podolsky-Rosen-Bohm gedankenexperiment¹ (Fig. 1), a source emits pairs of spin- $\frac{1}{2}$ particles, in a singlet state (or pairs of photons in a similar nonfactorizing state). After the particles have separated, one performs correlated measurements of their spin components along arbitrary directions \hat{a} and \hat{b} . Each measurement can yield two results, denoted

± 1 ; for photons, a $+1$ if the result $+1$ if the direction \hat{a} , and -1 if the direction \hat{b} is particular. For a singlet state, one predicts some correlations between the measurements on the two particles $P_{\hat{a}\hat{b}}(\hat{a}, \hat{b})$ (the probability of finding ± 1 along \hat{a} (particle 1) and ± 1 along \hat{b} (particle 2)). The quantity

<http://arxiv.org/abs/1508.05949>

Experimental loophole-free violation of a Bell inequality using entangled electron spins separated by 1.3 km

B. Hensen, H. Bernien, A.E. Dréau, A. Reiserer, N. Kalb, M.S. Blok, J. Ruitenberg, R.F.L. Vermeulen, R.N. Schouten, C. Abellán, W. Amaya, V. Pruneri, M.W. Mitchell, M. Markham, D.J. Twitchen, D. Elkouss, S. Wehner, T.H. Taminiau, R. Hanson (Submitted on 24 Aug 2015)

For more than 80 years, the counterintuitive predictions of quantum theory have stimulated debate about the nature of reality. In his seminal work, John Bell proved that no theory of nature that obeys locality and realism can reproduce all the predictions of quantum theory. Bell showed that in any local realist theory the correlations between distant measurements satisfy an inequality and, moreover, that this inequality can be violated according to quantum theory.

80 Anni di Studio!

Entanglement e Informazione





Teletrasporto

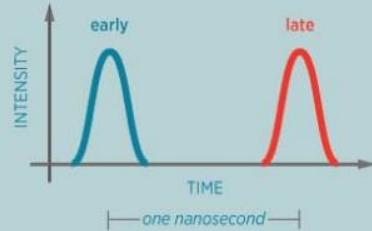
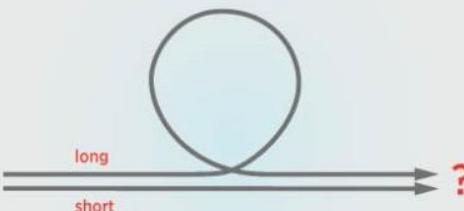
Teletrasporto



CREATING THE QUANTUM STATES

The NIST experiment adds quantum information to a photon in its position in a very small slice of time.

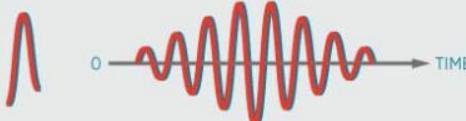
The photon can take a short path, or a long path, with a 50/50 chance ...



So it can be either "early" or "late" in the time bin.

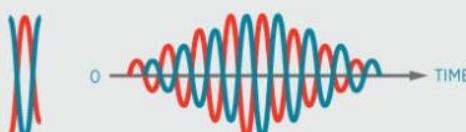
If we don't know which, then it's both—a quantum "superposition" in time.

If the photon is in a superposition of two states, they can be "in phase"—the peaks of their waves lining up with each other ...



OR

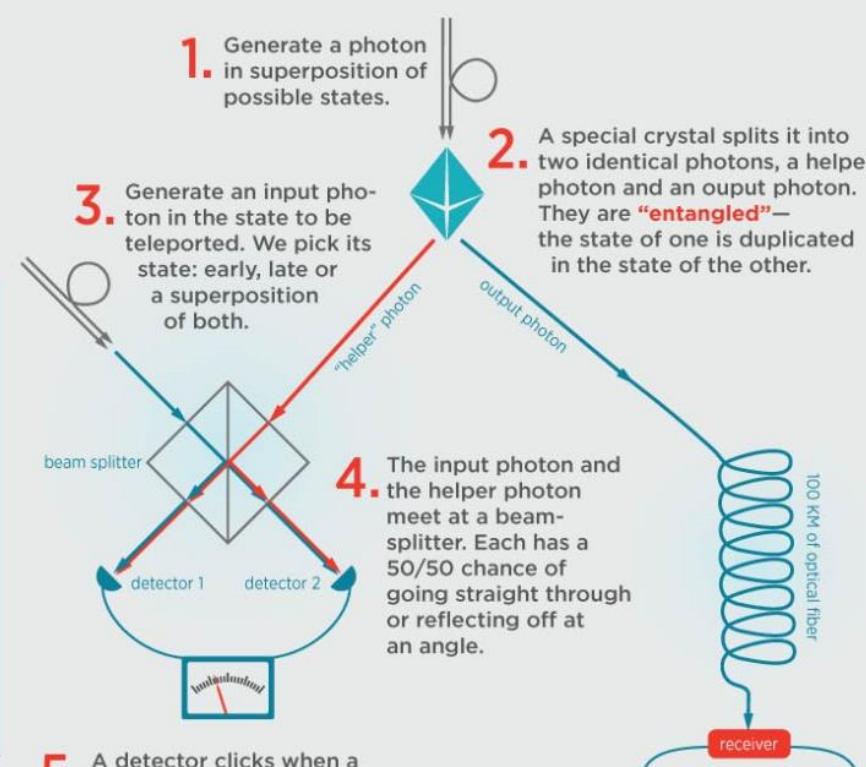
"out of phase", with their waves cancelling each other out.



Simultaneous out-of-phase photons cancel out.

THE EXPERIMENT

1. Generate a photon in superposition of possible states.



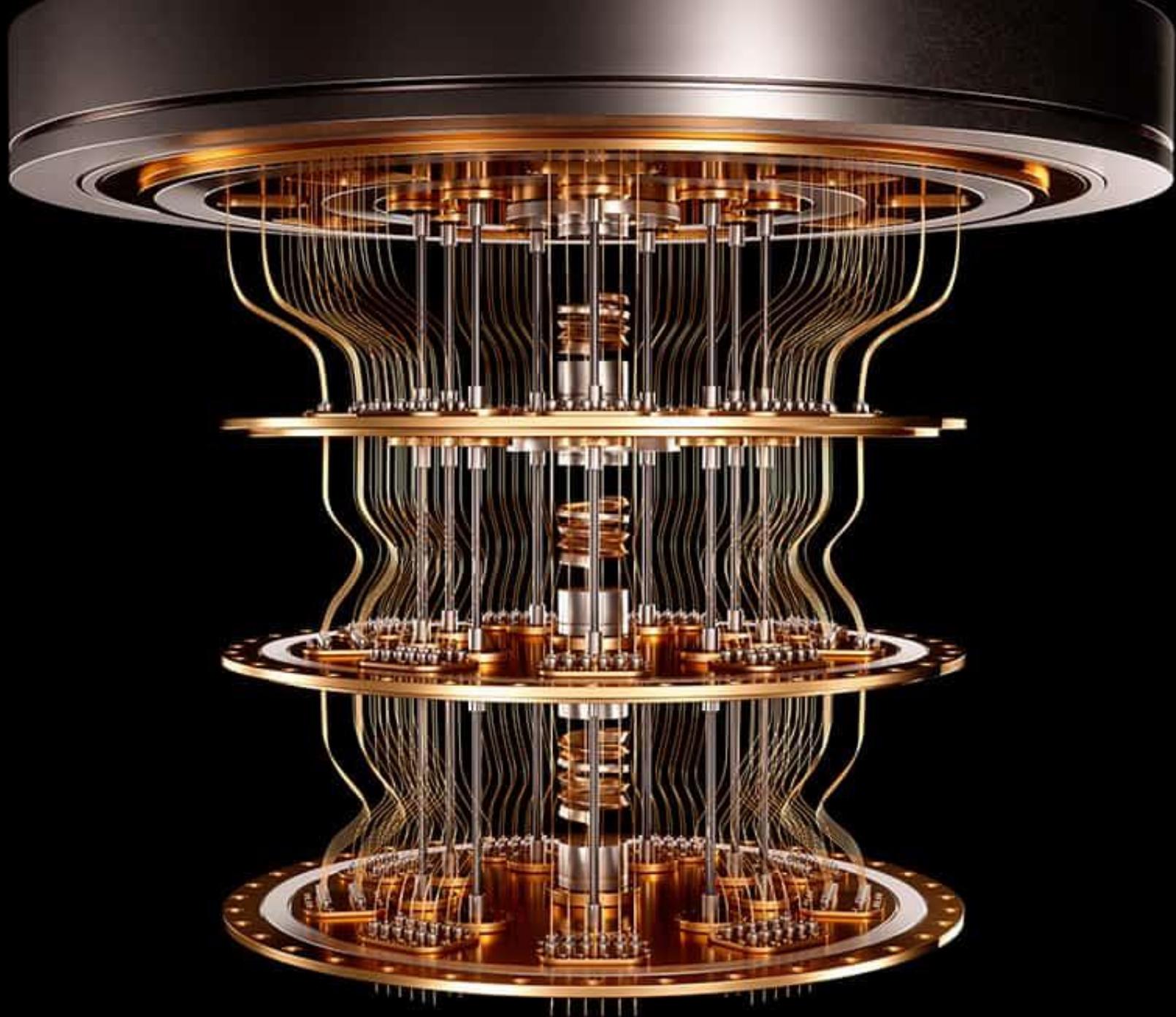
6. Because the output photon is entangled with the helper photon, we know it is in the same state—which is also (from Step 5) the opposite state of the input photon. In effect we've "teleported" the evil twin of the input photon. Detectors 3 and 4 measure the state of output photons to confirm.

EXAMPLE:

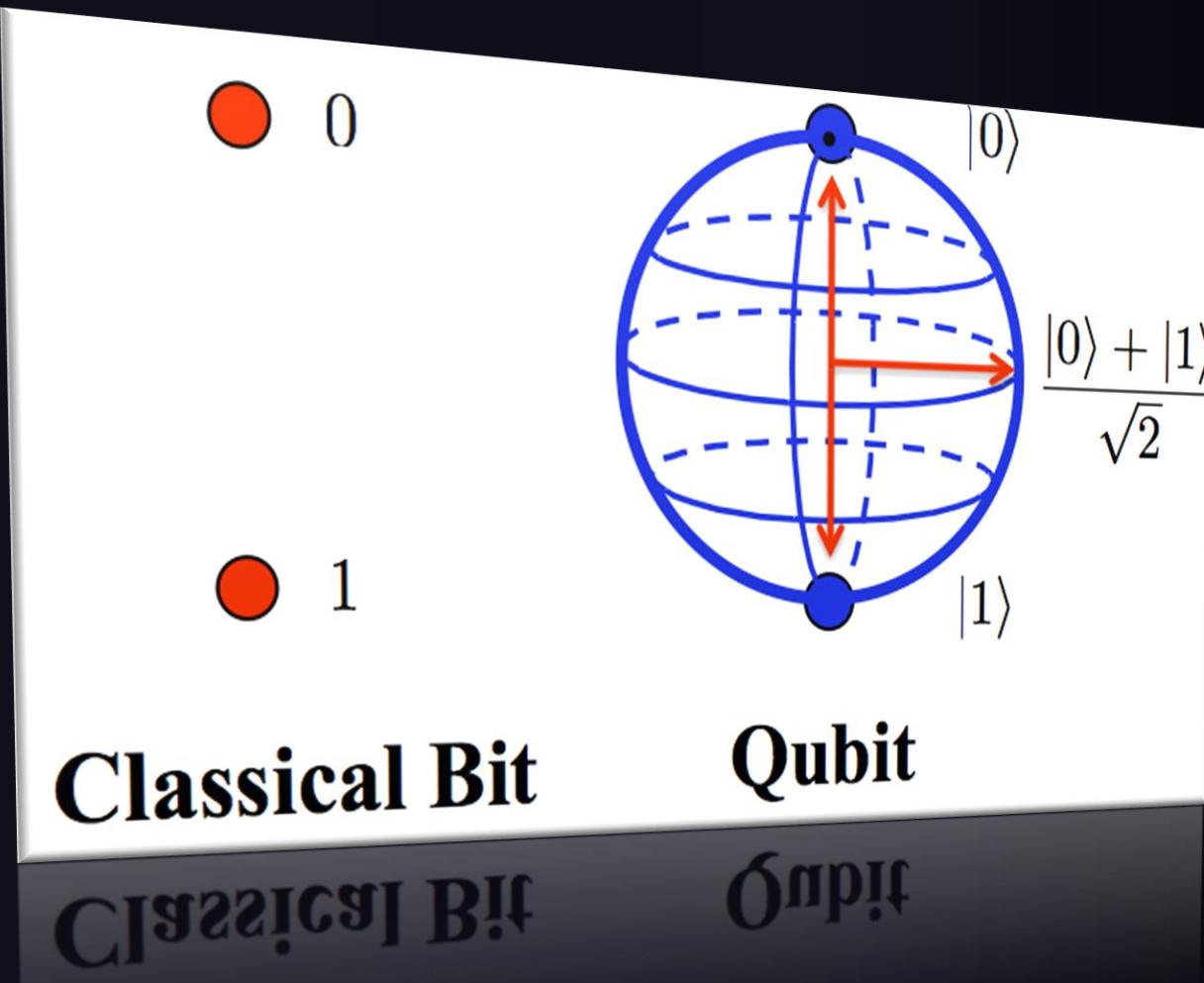
Input	Output
early	late
in-phase superposition	out-of-phase superposition

Teletrasporto

QBit

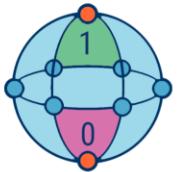


QBit

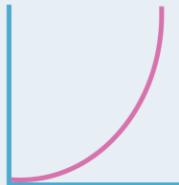


- Rispetto al bit, nella teoria quantistica l'unità di informazione è il Qbit che, in base alla sua natura quantistica, anche se è anch'esso dicotomico per quanto riguarda i valori possibili di una misurazione, può tuttavia occupare stati di sovrapposizione...

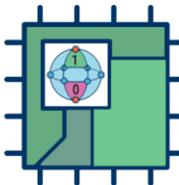
Quantum Computing Vs. Classical Computing



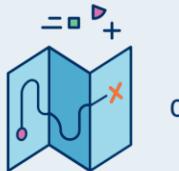
Calculates with qubits, which can represent 0 and 1 at the same time



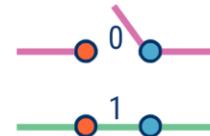
Power increases exponentially in proportion to the number of qubits



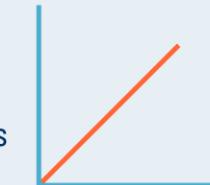
Quantum computers have high error rates and need to be kept ultracold



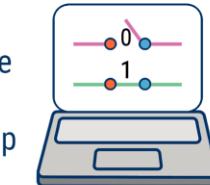
Well suited for tasks like optimization problems, data analysis, and simulations



Calculates with transistors, which can represent either 0 or 1



Power increases in a 1:1 relationship with the number of transistors



Classical computers have low error rates and can operate at room temp



Most everyday processing is best handled by classical computers

QBit

$$\frac{1}{\sqrt{Q}} \sum_{x=0}^{Q-1} |x\rangle = \left(\frac{1}{\sqrt{2}} \sum_{x_1=0}^1 |x_1\rangle \right) \otimes \cdots \otimes \left(\frac{1}{\sqrt{2}} \sum_{x_q=0}^1 |x_q\rangle \right).$$

$$= \frac{1}{Q^2} \left| \sum_{b=0}^{m-1} \omega^{bqy} \right|^2 = \frac{1}{Q^2} \left| \frac{\omega^{mqy} - 1}{\omega^{qy} - 1} \right|^2 = \frac{1}{Q^2} \sin^2$$

$$\left| \frac{d}{s} \right| < \frac{1}{2Q}$$

$$f: \mathbb{Z}_p \times \mathbb{Z}_p \rightarrow G; f(a,b) =$$

$$\sqrt[k]{N}$$

$$2^q = Q$$

$$\overline{\overline{Q}} \quad \frac{1}{Q} \sum_{x=0}^{Q-1} \sum_{y=0}^{Q-1} \omega^{xy} |y, x\rangle$$

$$U_f |x, 0^q\rangle = |x, f(x)\rangle$$

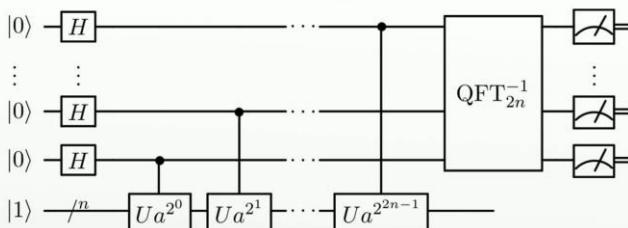
$$\omega^{xy} = \sum_{b=0}^{m-1} \omega^{(x_0+rb)y} = \omega^{x_0y} \sum_{b=0}^{m-1} \omega^{rb y}.$$

$$\frac{Q}{r} \quad d = \gcd(b -$$

$$(b^2 - 1)u + N(b + 1)v = b + 1.$$

$$1 = \left\lfloor \frac{Q - x_0 - 1}{r} \right\rfloor$$

Shor's algorithm

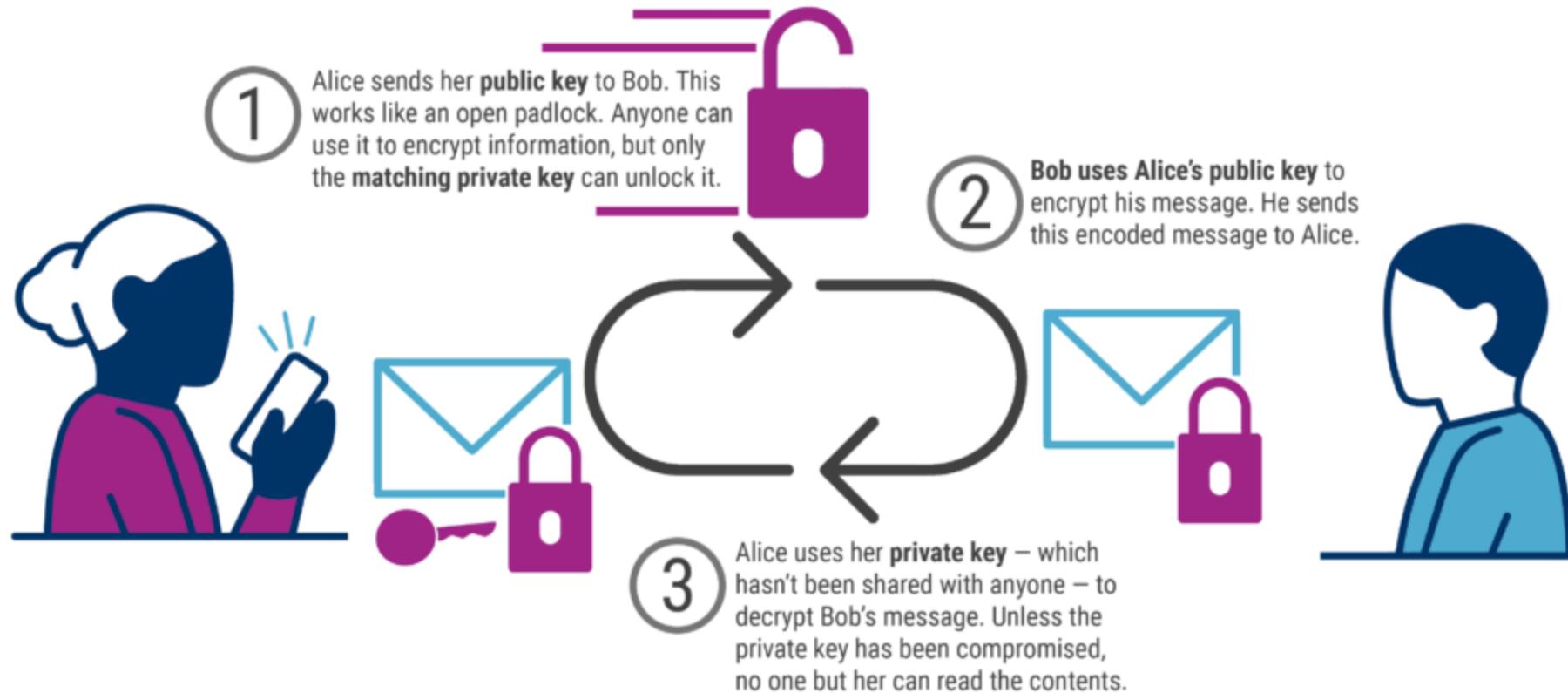


https://en.wikipedia.org/wiki/File:Shor's_algorithm.svg



Crittografia

How public-key cryptography works



Why quantum computers threaten today's public-key cryptography

Public-key cryptography is commonly used to communicate online

Bob wants to send a message to Alice. To do this privately, **Alice generates a public key and a private key**. Bob uses the public key to encrypt a message that can only be decoded using Alice's matching private key.

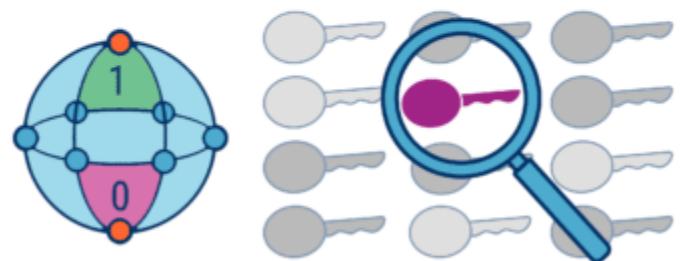


Classical computers find identifying a private key extremely difficult

Only Alice has the private key, but **her public key is accessible to anyone**. Classical computers find the current mathematical problems linking private keys to public keys very challenging – minimizing the risk they pose.

But quantum computers can figure out a private key quickly

Quantum computers process information in a different way to conventional computers, allowing new types of calculation. This includes an algorithm that can **quickly figure out a private key purely from a public key** for encryption methods commonly used online.



Quantum cryptography system

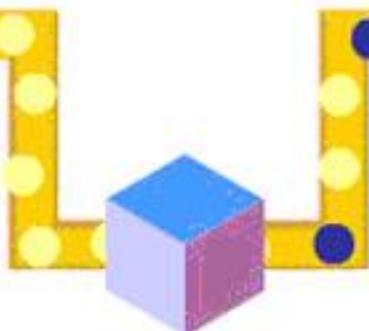
Sender



Recipient



A single photon works as a private key



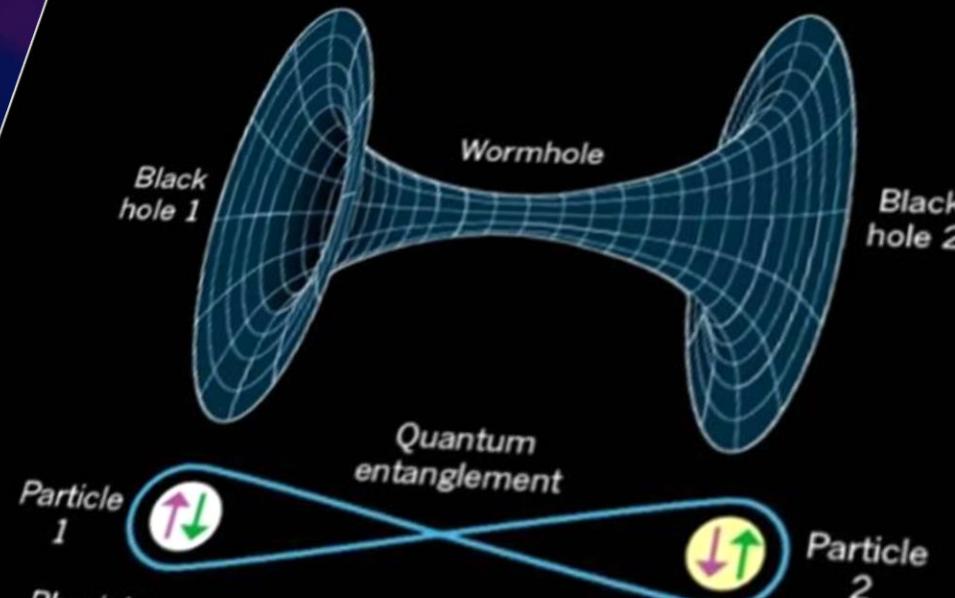
Eavesdropper



Recipients can discern the presence of eavesdroppers because the quantum state has changed due to observation.

$H = EPR$

Also in 1935, Einstein and Rosen (ER) showed that widely separated black holes can be connected by a tunnel through space-time now often known as a wormhole.



Physicists suspect that the connection in a wormhole
and the connection in quantum entanglement
are the same thing, just on a vastly different scale.
Aside from their size there is no fundamental difference.

© nature

NIK SCHEMEL

Quantum Gravity e oltre ...

Grazie

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<https://github.com/polyhedron-gdl>

