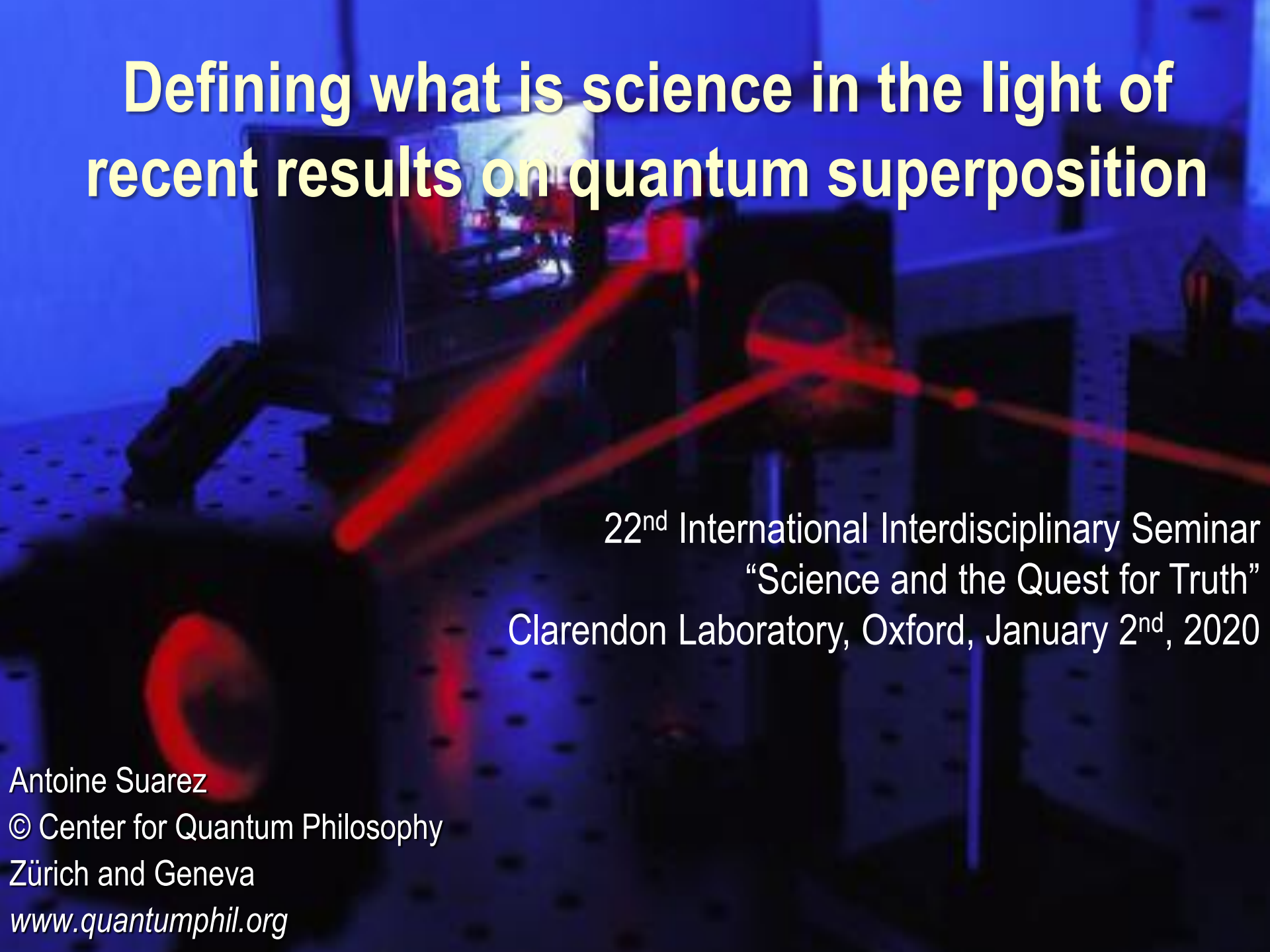


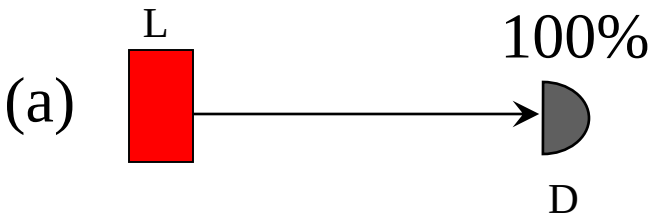
Defining what is science in the light of recent results on quantum superposition

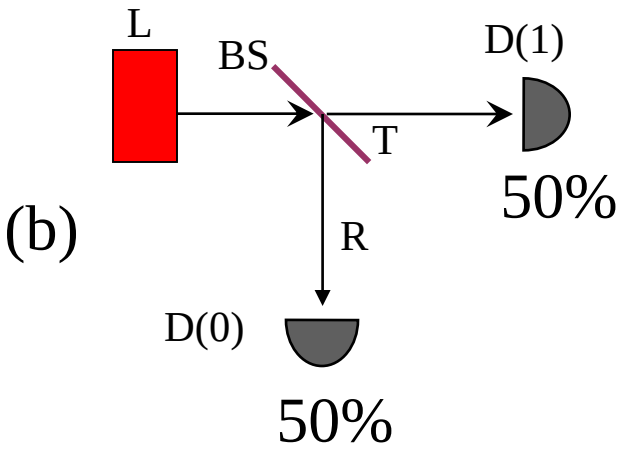
22nd International Interdisciplinary Seminar
"Science and the Quest for Truth"
Clarendon Laboratory, Oxford, January 2nd, 2020

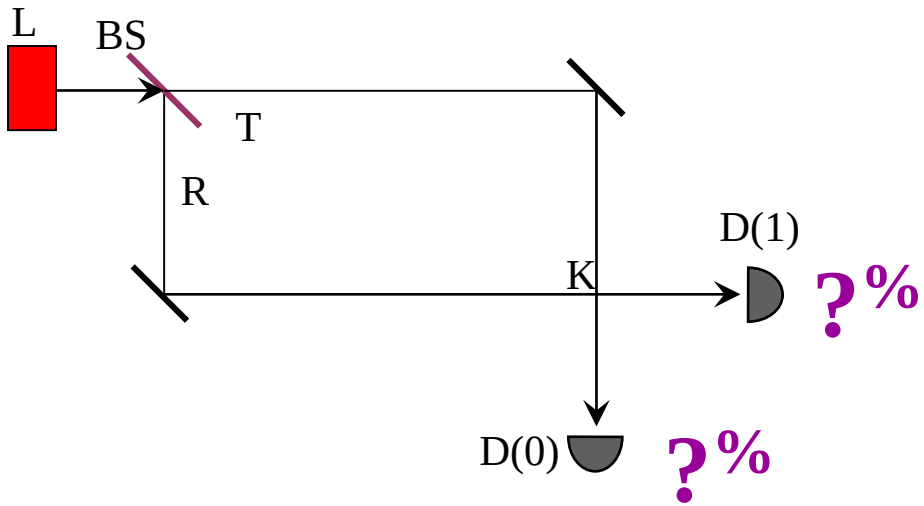
Antoine Suarez

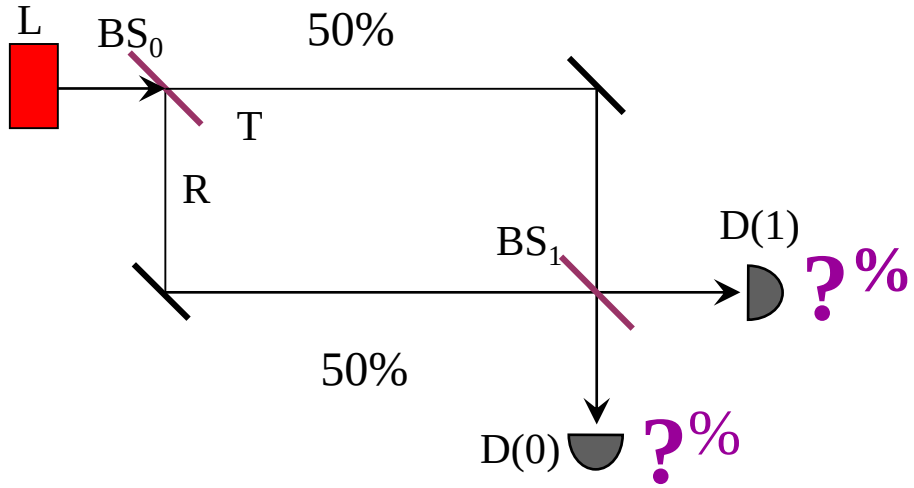
Zürich and Geneva
www.quantumphil.org

Newton: Light is made of particles



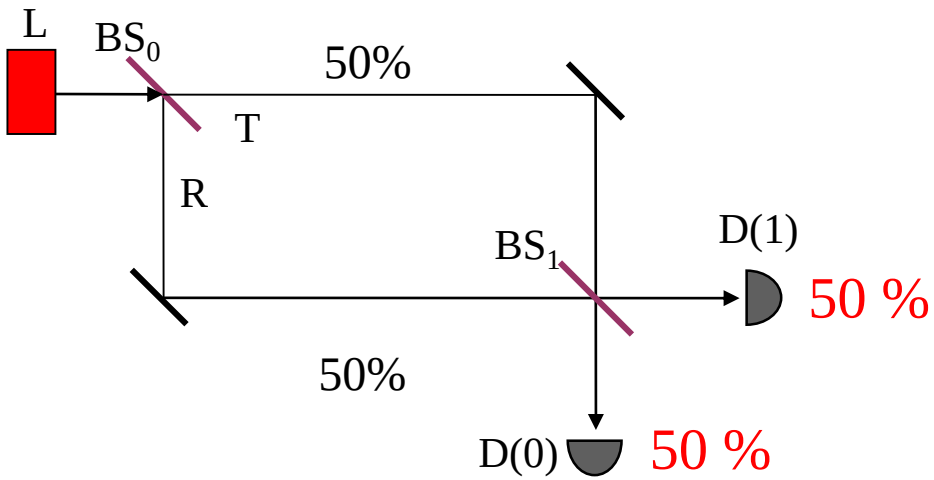




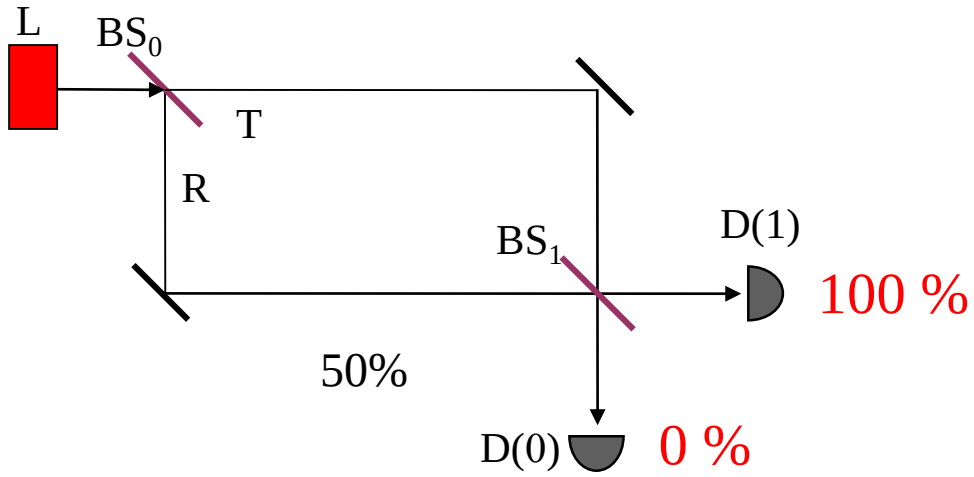


Newton's particle-model cannot explain interference

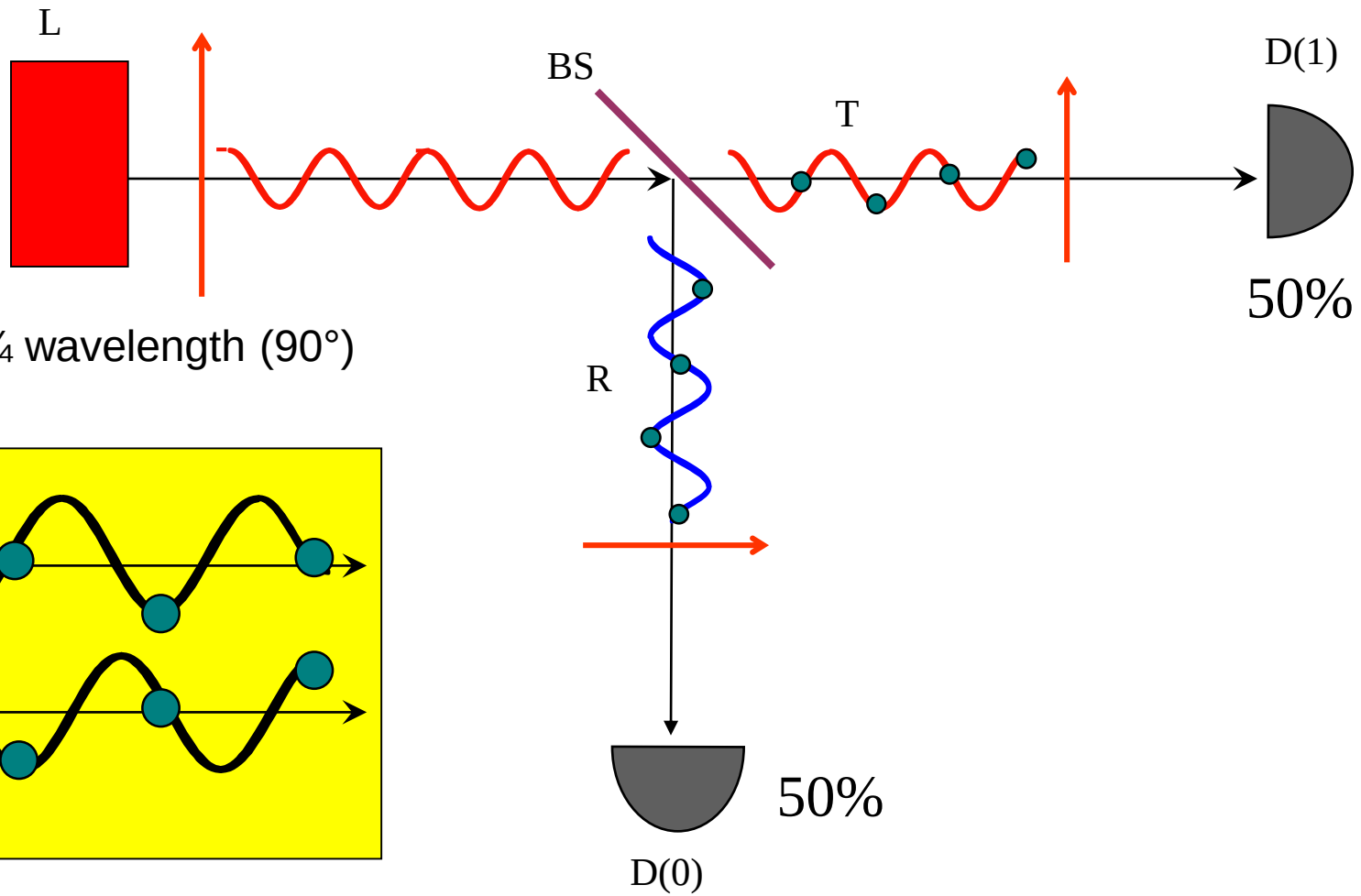
Prediction according to Newton's model



Experiment



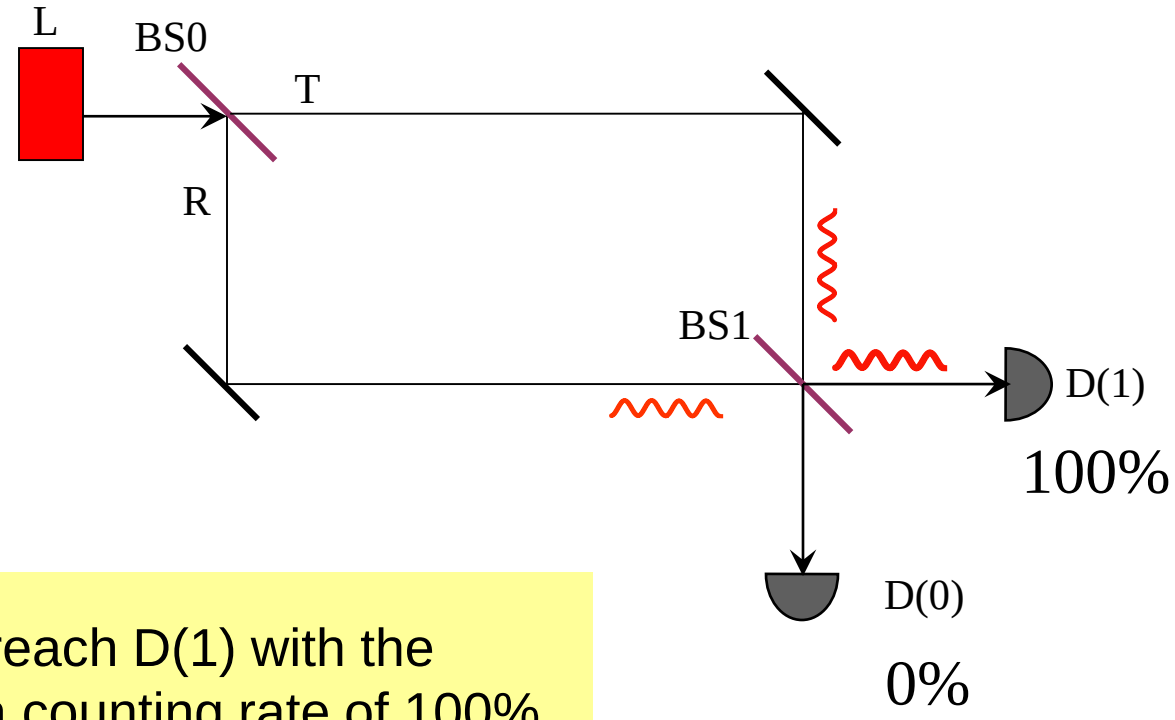
C. Huygens, T. Young und A. Fresnel
Wave-model explains well interference



Phase-shift of ¼ wavelength (90°)
at reflection

Interference

With 2 equal paths



The T and the R wave reach D(1) with the same phase and bear a counting rate of 100% (constructive interference).

The T and the R wave reach D(0) with a phase-shift of 1/2 wavelength (180°) and bear a counting rate of 0% (destructive interference).

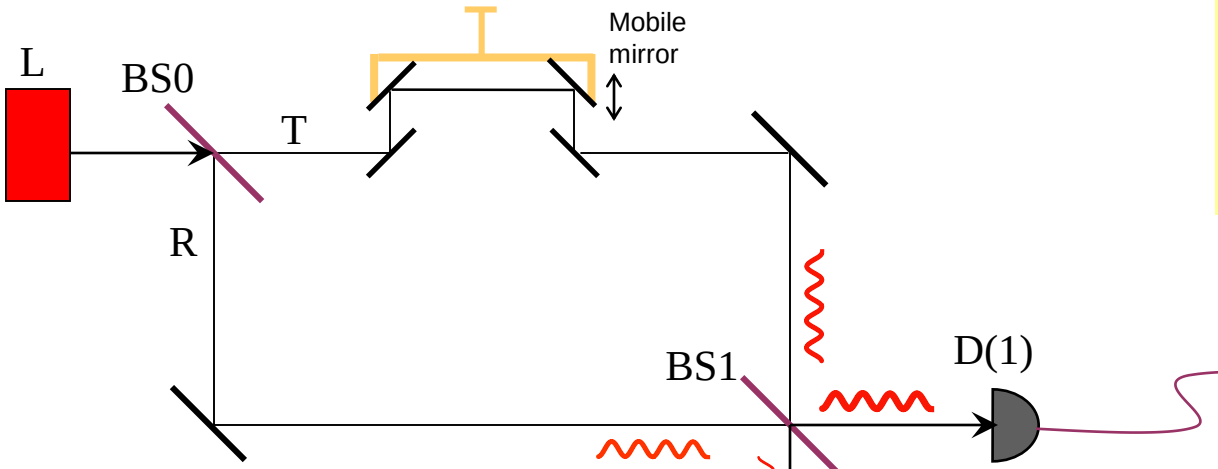
Interference The counting rate depends on the path-length-difference

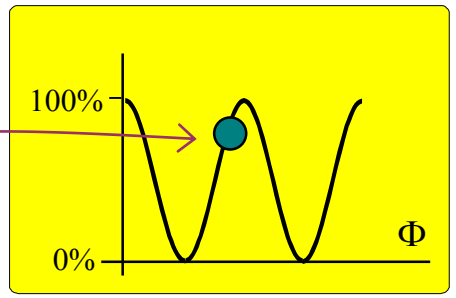
Phase-shift at D(1):

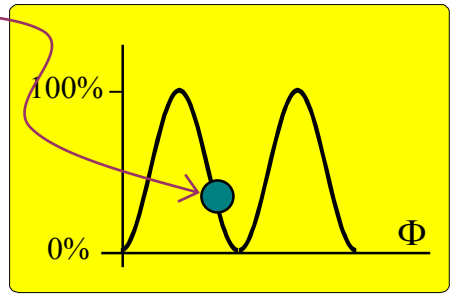
$$\theta = \omega\frac{l}{c} + \frac{\pi}{2} - \frac{\pi}{2} - \omega\frac{s}{c} = \Phi$$

Counting rate in D(1):

$$\Pr(1) = \frac{1}{2}(1+\cos\Phi)$$







l : length of the long path

s : length of the short path

ν : frequency of the laser pump

ω : angular frequency = $2\pi\nu$

c : speed of licht

Φ: Phase-shift due to the Path-length difference

$$\Phi = \omega\frac{l-s}{c}$$

Phase-shift at D(0):

$$\theta = \omega\frac{l}{c} - \frac{\pi}{2} - \frac{s}{c} - \frac{\pi}{2} = \Phi - \pi$$

Counting rate in D(0):

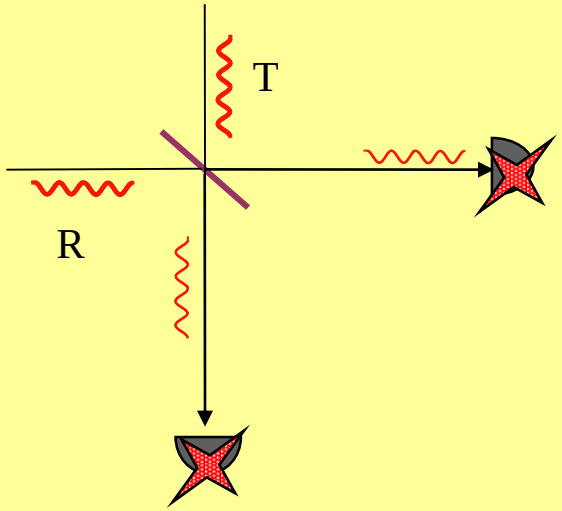
$$\Pr(0) = \frac{1}{2}(1-\cos\Phi)$$

Photoelectric effect

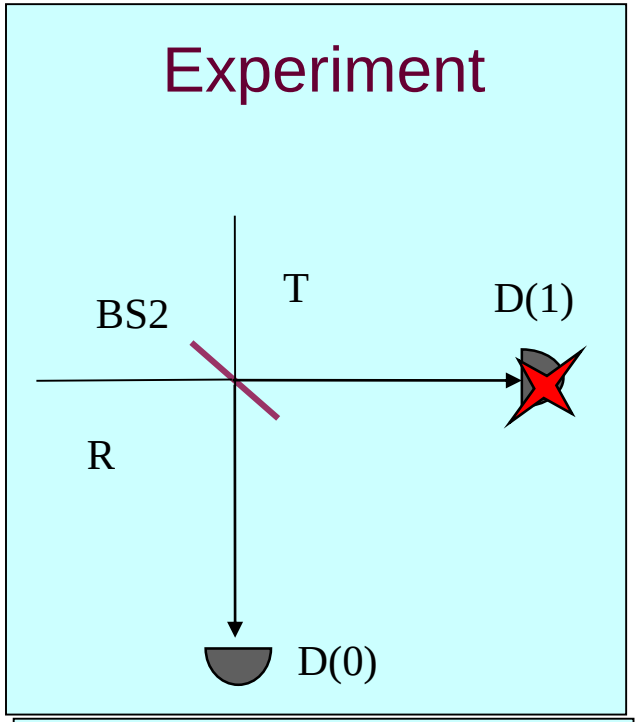
Light behaves according to the particle model

Prediction according to the wave model:

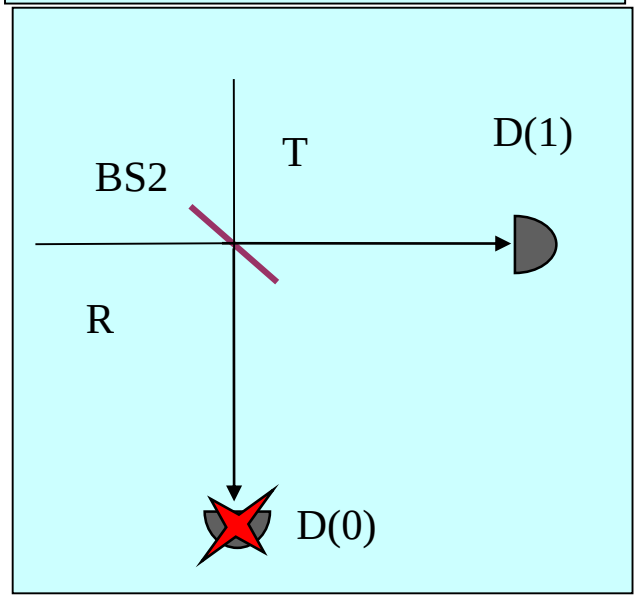
when the intensity of the light grows down, D(0) and D(1) should click weaker but together.



either D(1) clicks



or D(0) clicks

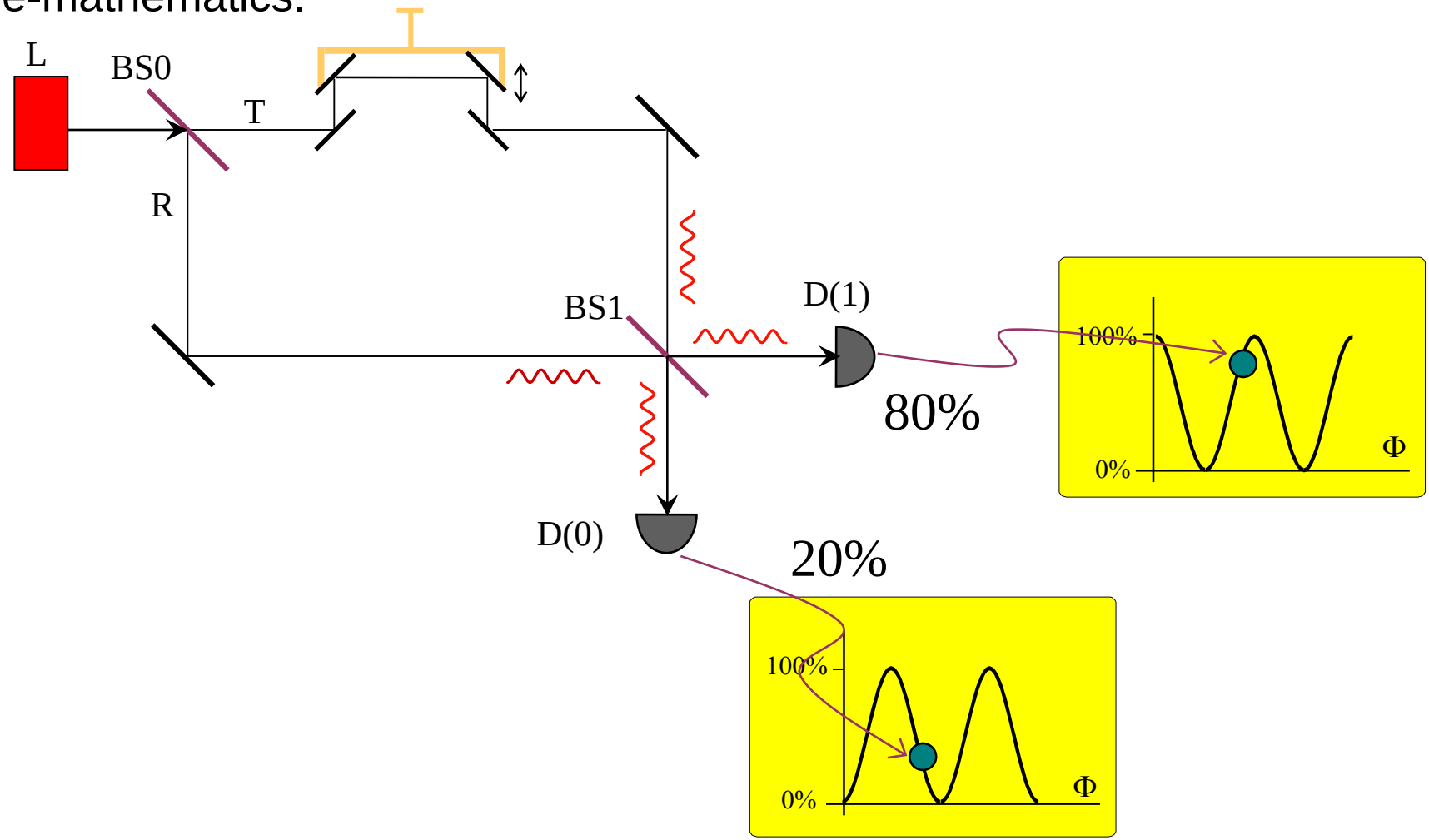


Entrance to quantum-world

Interference experiments:
Light behave according to the wave-mathematics.

+

Photoelectric experiments:
One count at a time



Platform 9 ¾ to the Quantum World

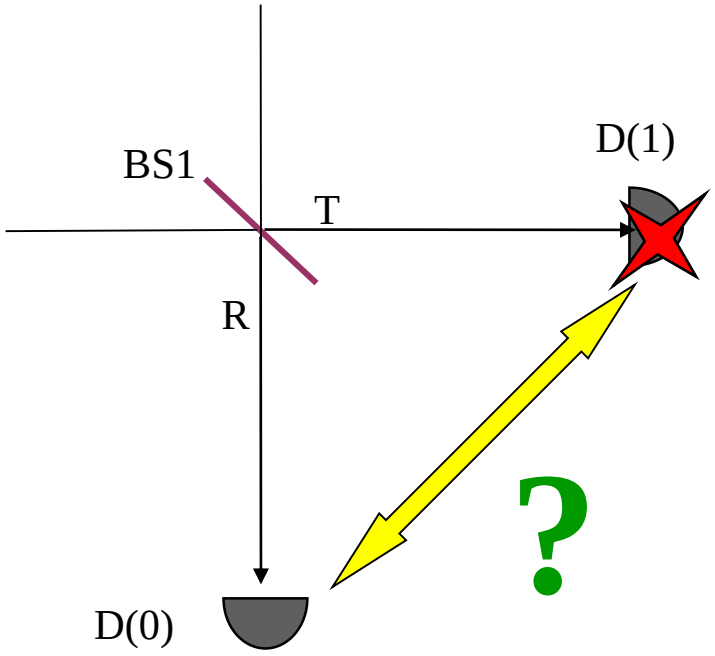
Photoelectric effect + Interferences

Copenhagen (Bohr, Heisenberg, Born):

„Agreement“ between Detectors

+

Statistical distribution
according to quantum mathematics
(i.e. mathematics of waves)



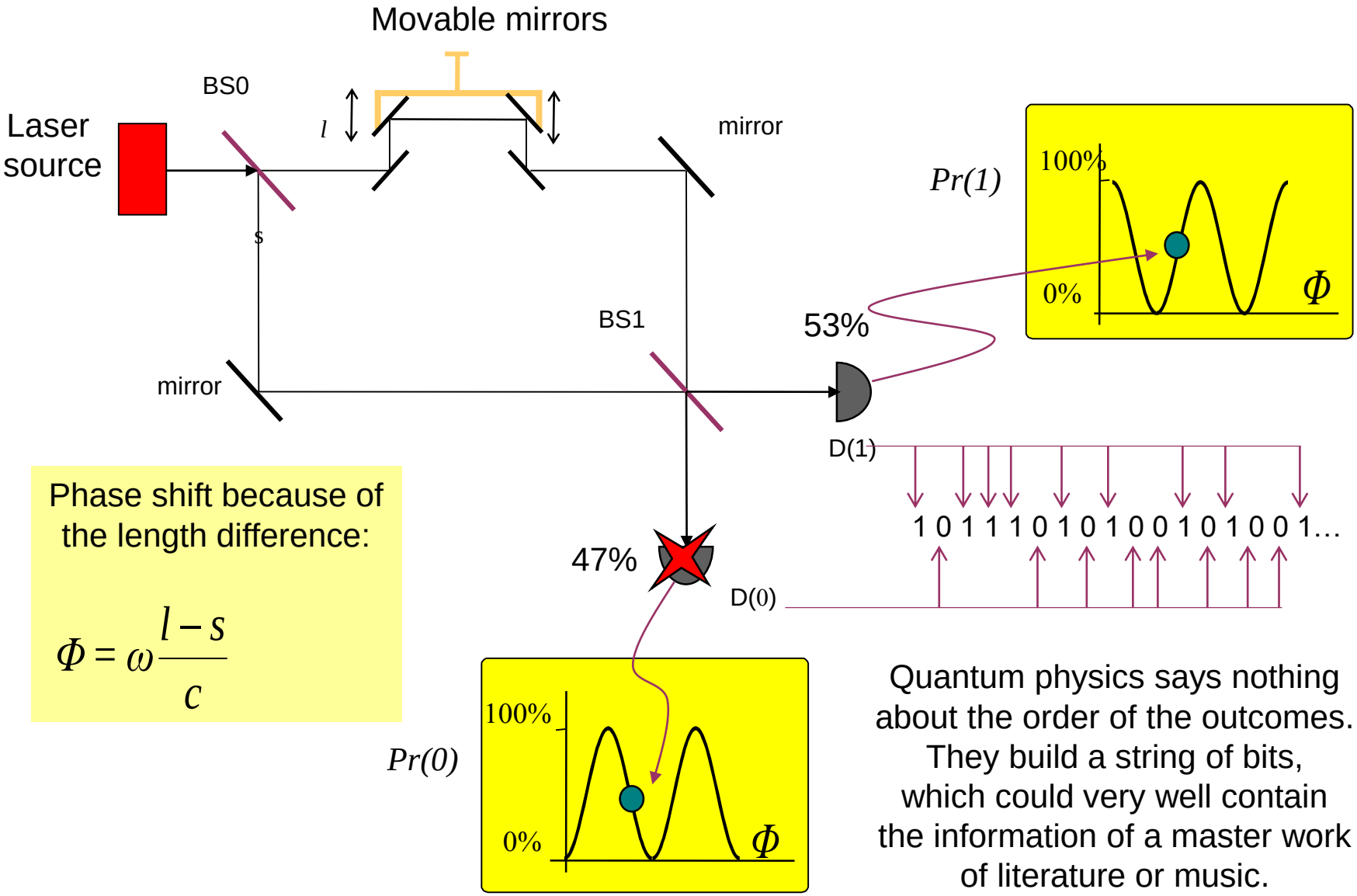
Copenhagen expressions like:

"Collapse of the wavefunction"

actually mean:

Nonlocal coordination
of
decisions at detectors

Interference The counting rate depends on the path-length-difference

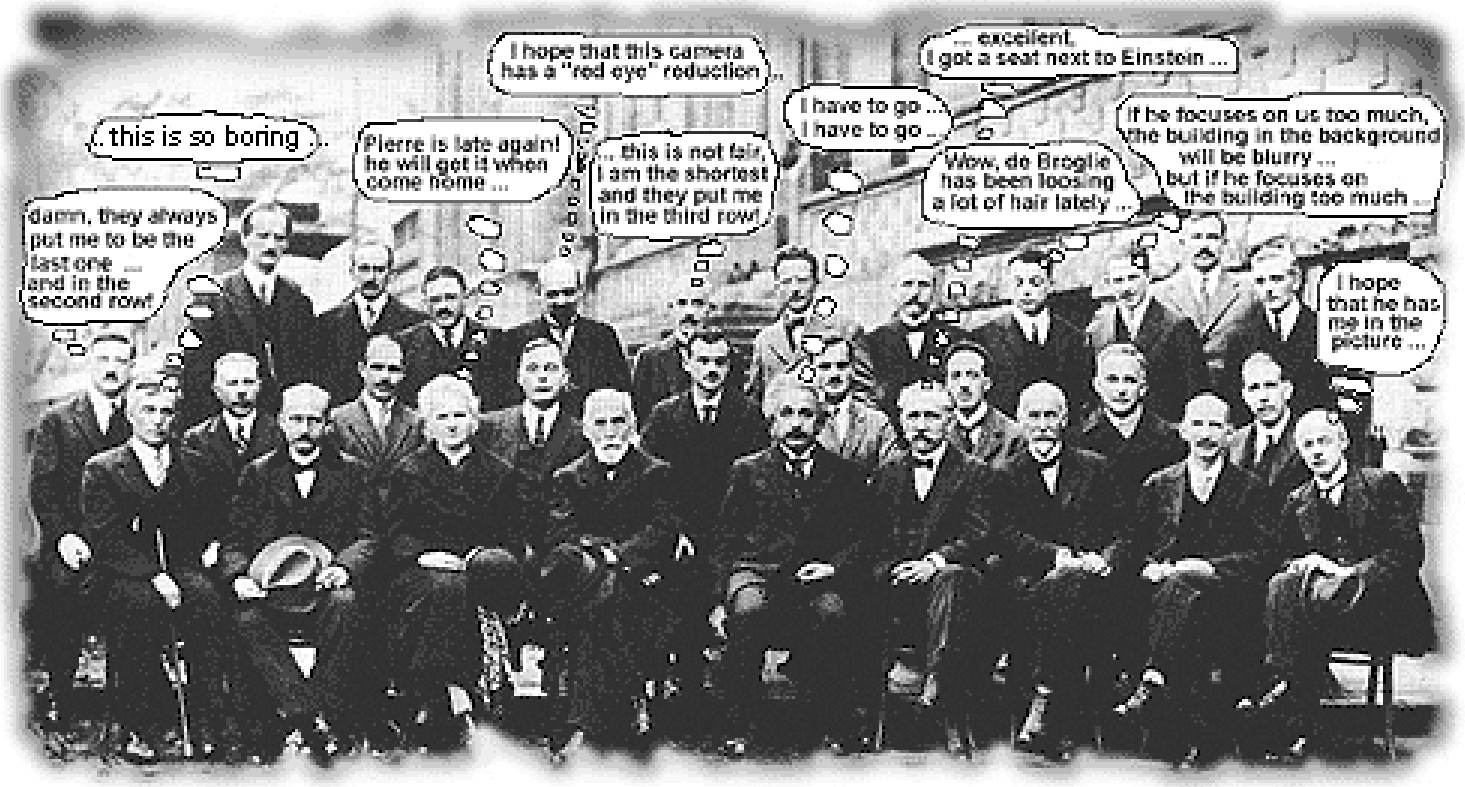


Phase shift because of the length difference:

$$\Phi = \omega \frac{l - s}{c}$$

Quantum physics says nothing about the order of the outcomes. They build a string of bits, which could very well contain the information of a master work of literature or music.

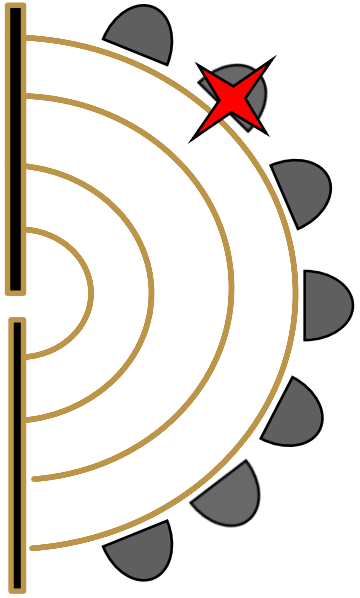
The Solvay Congress: Brussels 23-27.10.1927



[first row] (1) I. Langmuir, (2) M. Planck, (3) M. Curie, (4) H.A. Lorentz, (5) A. Einstein, (6) P. Langevin, (7) C.E. Guye, (8) C.T.R. Wilson, (9) O.W. Richardson
[second row] (1) P. Debye, (2) M. Knudsen, (3) W.L. Bragg, (4) H.A. Kramers, (5) P.A.M. Dirac, (6) A.H. Compton, (7) L.V. de Broglie, (8) M. Born, (9) N. Bohr
[third row] (1) A. Piccard, (2) E. Henriot, (3) P. Ehrenfest, (4) E. Herzen, (5) Th. de Donder, (6) E. Schroedinger, (7) E. Verschaffelt, (8) W. Pauli, (9) W. Heisenberg, (10) R.H. Fowler, (11) L. Brillouin.

This version of the classic photo has been "embellished" by PhysLINK's creator: Anton Skorucak.

Nonlocality at detection provoked Einstein in the Solvay Congress 1927, and led thereafter to the EPR controversy 1935.



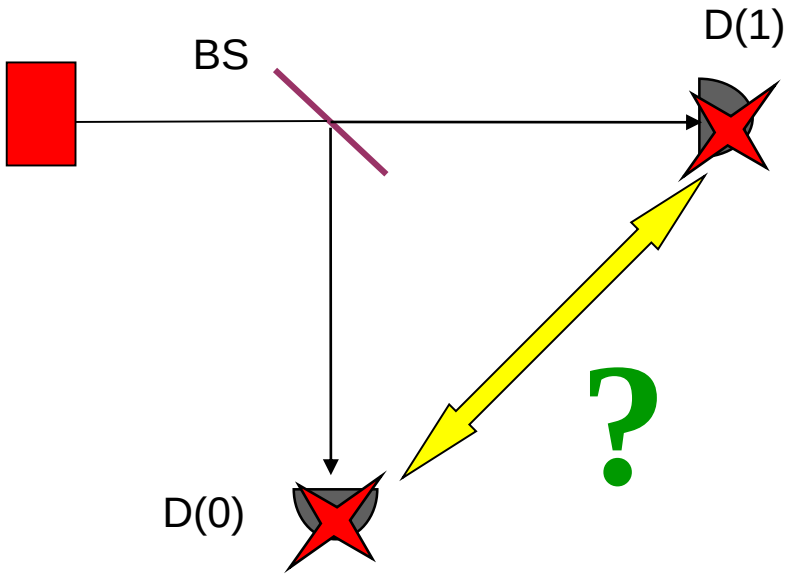
Light going trough a slit reaches a screen.
Deciding at which point the detection happens requires nonlocal coordination between all the detection units.

Decision at detection

(Collapse of the wave function)

implies

coordination at a distance between detectors



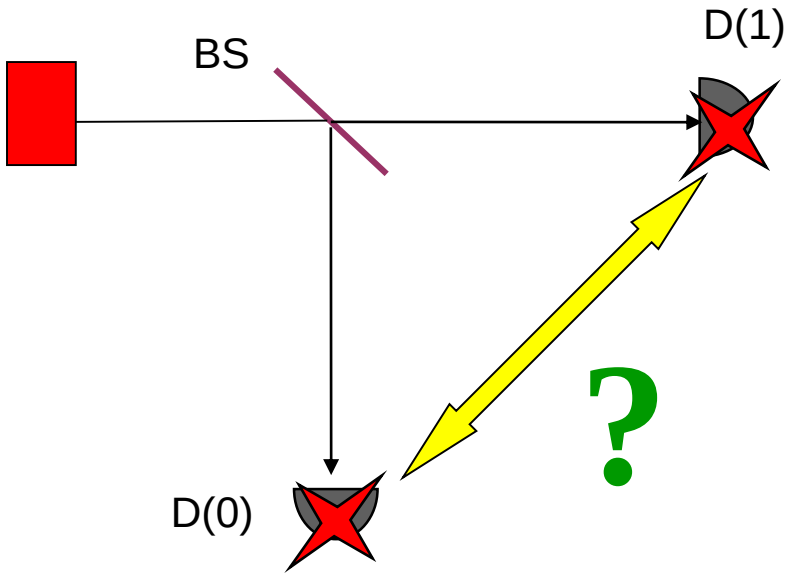
D(1)	D(0)
1	-
-	1

1	1
-	-

Before detection the system is in a state of **quantum superposition**

$$|\psi\rangle_S = \frac{1}{\sqrt{2}}(|1\rangle_S + |0\rangle_S)$$

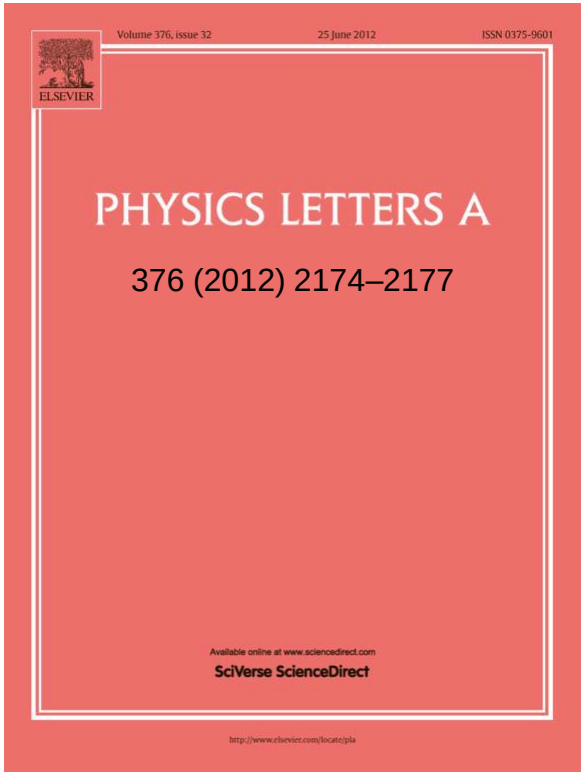
At detection we will observe either outcome ‘0’ with probability 50%, or outcome ‘1’ with probability 50%



D(1)	D(0)
1	-
-	1

Welcome the Qubit!

Quantum nonlocality at detection, or the standard quantum «collapse»



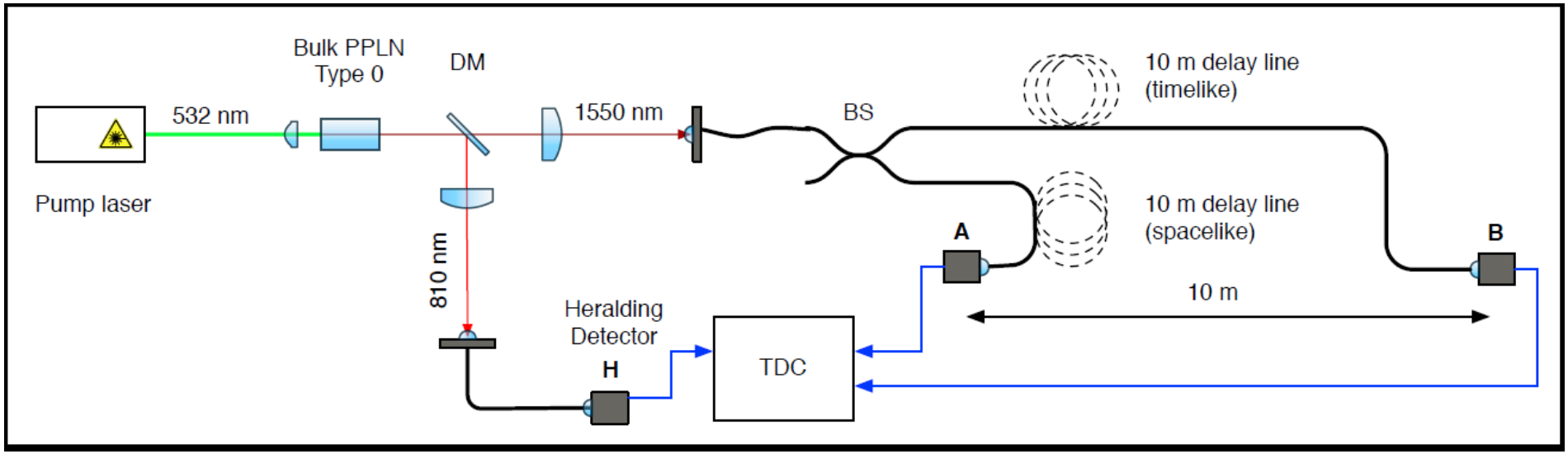
Single-photon space-like antibunching

Thiago Guerreiro a, Bruno Sanguinetti a, Hugo Zbinden a, Nicolas Gisin a, Antoine Suarez b,*
a *Group of Applied Physics, University of Geneva, 1211 Geneva 4, Switzerland*
b *Center for Quantum Philosophy, P.O. Box 304, 8044 Zurich, Switzerland*

Nonlocality at detection

Single-photon space-like antibunching

T. Guerreiro, B. Sanguinetti, H. Zbinden, N.Gisin and A. Suarez (2012)



$P^{TL}(1,1)=P^{TL}(0,0)=0$

$P^{TL}(1,0)=P^{TL}(0,1)=0.5$

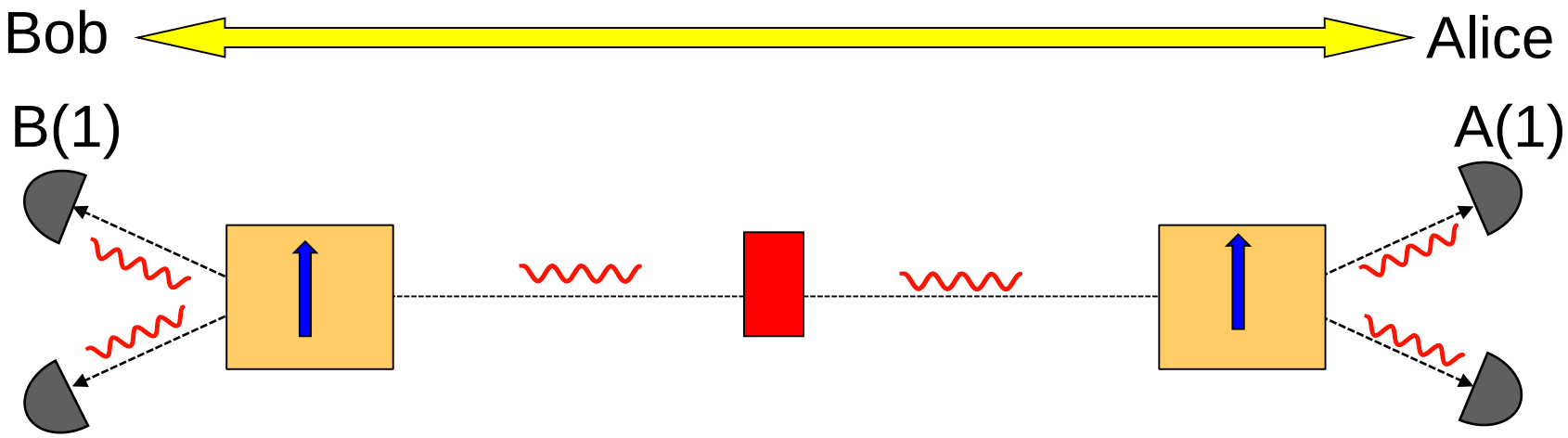
$P_A{}^{TL}=P_B{}^{TL}=0.5$

$P^{SL}(1,1)=P^{SL}(0,0)=P^{SL}(1,0)=P^{SL}(0,1)=0.25$

$P_A{}^{SL}=P_B{}^{SL}=0.5$

$$\boldsymbol{P^{SL}(1,1)=P_A{}^{SL}\cdot P_B{}^{SL}=0.25}$$

Einstein-Podolsky-Rosen (EPR),1935; Bohm, 1952



B(1)	B(0)	A(1)	A(0)
1	-	1	-
1	0	0	1
0	1	1	0
-	1	-	1

John Bell:
Strengthening quantum nonlocality

https://wn.com/john_bell

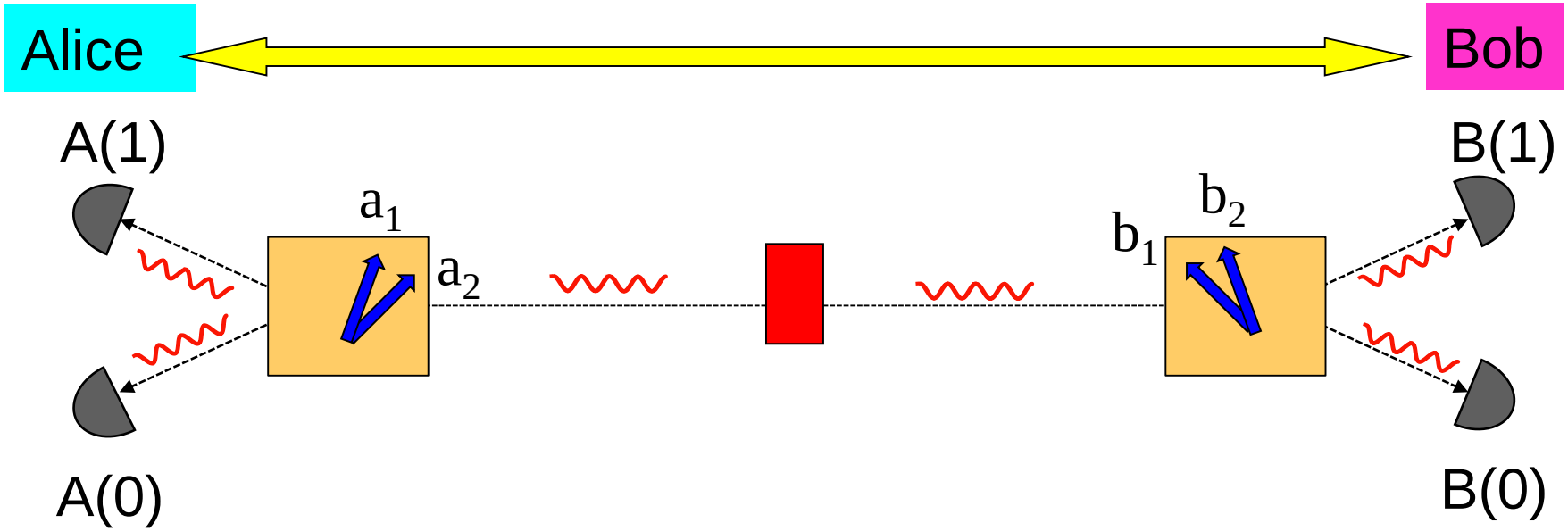
I am speaking to you today because during the years 1988-1990 I could promote with John Bell discussions on Quantum Philosophy like this at CERN:

Indeterminism and nonlocality

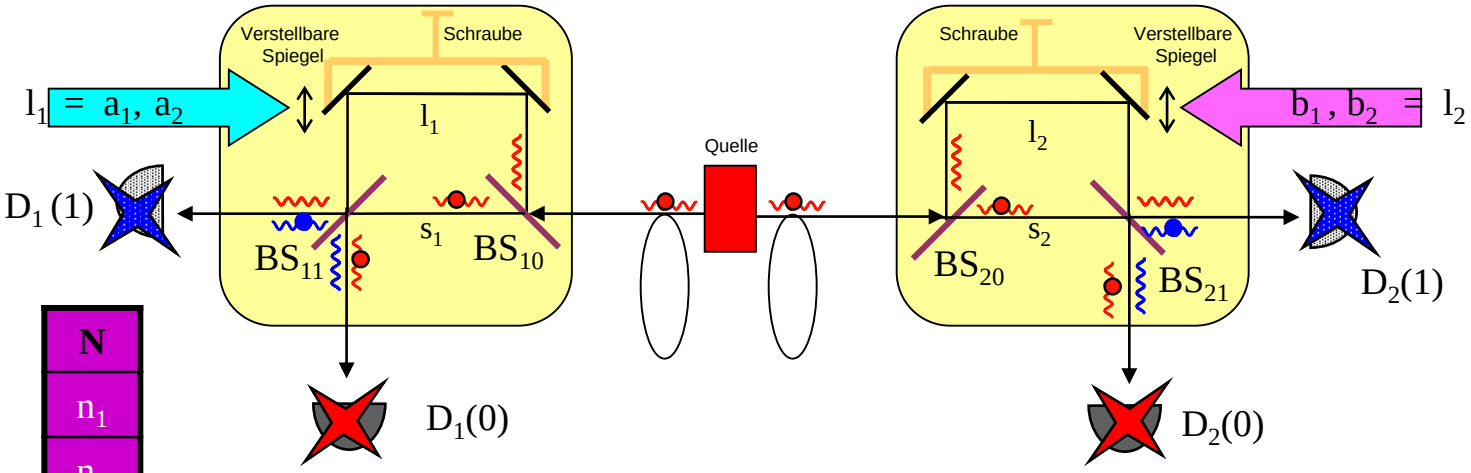
22 January 1990

© 1990 Center for Quantum Philosophy of Geneva

Bell's theorem



Bell inequality



a_1	a_2	b_1	b_2	N
1	1	1	1	n_1
1	1	1	0	n_2
1	1	0	1	n_3
1	1	0	0	n_4
1	0	1	1	n_5
1	0	1	0	n_6
1	0	0	1	n_7
1	0	0	0	n_8
0	1	1	1	n_9
0	1	1	0	n_{10}
0	1	0	1	n_{11}
0	1	0	0	n_{12}
0	0	1	1	n_{13}
0	0	1	0	n_{14}
0	0	0	1	n_{15}
0	0	0	0	n_{16}

Quantity S:

$$S = \frac{1}{N}\sum_{i=1}^{i=16} n_i \cdot a_1 \cdot b_1 + \frac{1}{N}\sum_{i=1}^{i=16} n_i \cdot a_1 \cdot b_2 + \frac{1}{N}\sum_{i=1}^{i=16} n_i \cdot a_2 \cdot b_1 - \frac{1}{N}\sum_{i=1}^{i=16} n_i \cdot a_2 \cdot b_2$$

$$S = \frac{1}{N}\sum_{i=1}^{i=16} n_i S_i$$

If all pairs were of the samy type:

$$\text{Either } S_i = +2, \text{ or } S_i = -2$$

From this follows the Bells inequality:

$$-2 \le S \le +2$$

Indeterminism and nonlocality

CERN, Geneva, 22 January 1990

~~"Shut up and calculate"~~

Correlations cry out for explanation!

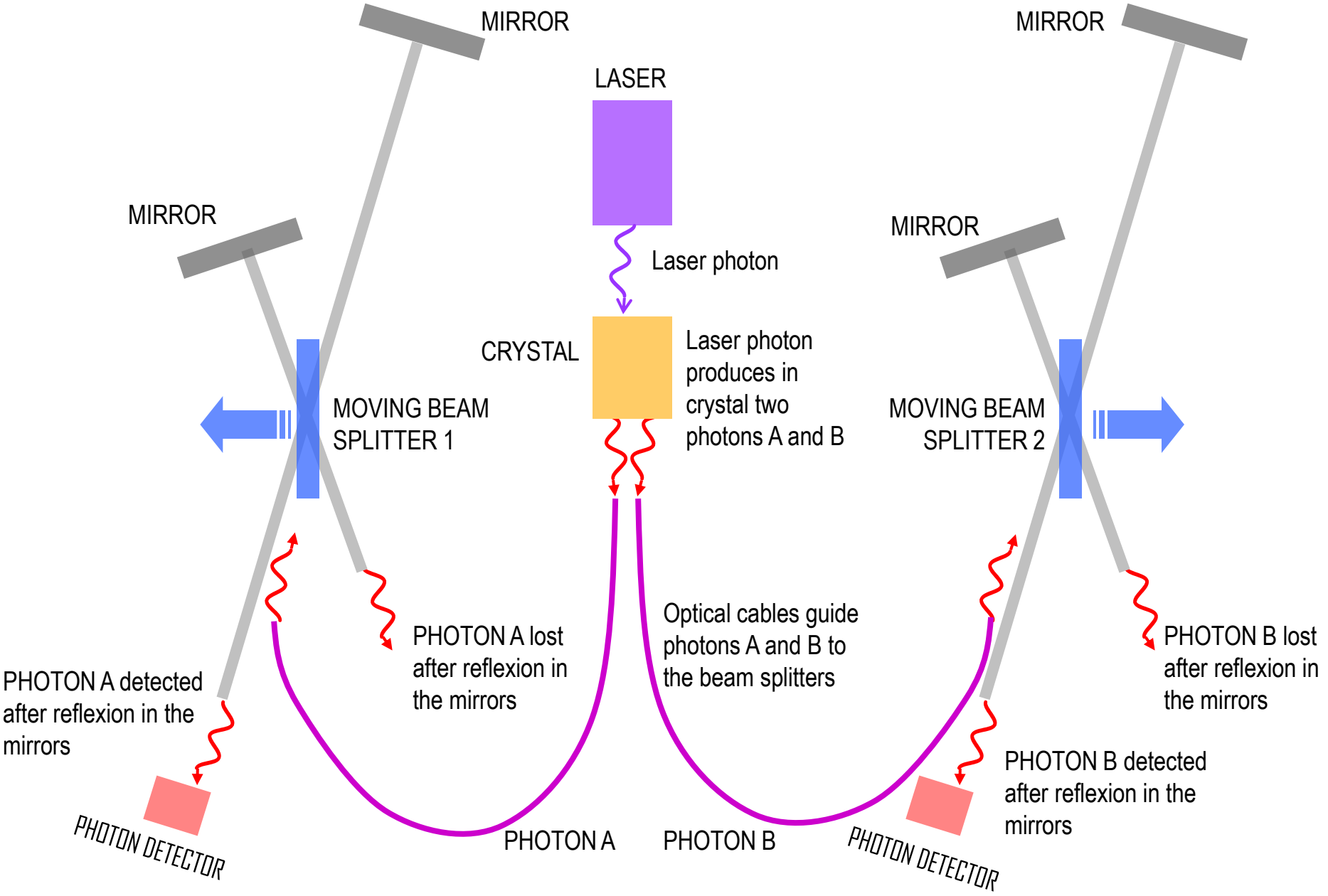
Indeterminism and nonlocality

CERN, Geneva, 22 January 1990

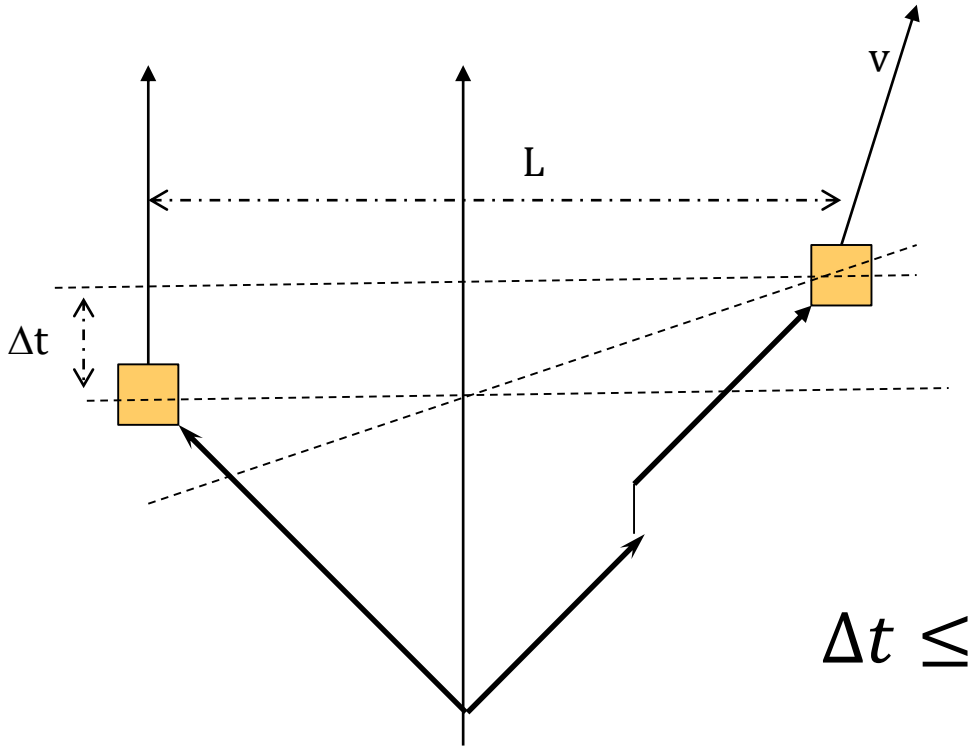
In this colloquium John Bell was asked whether he thought that relativity and quantum mechanics could be incompatible.
He answered:

"No, I can't say that, because I think someone will find one day a way to demonstrate that they are compatible. But I haven't seen it yet. To me, it's very hard to put them together, but I think somebody will put them together, and we'll just see that my imagination was too limited."

Testing Multisimultaneity: The Before-Before Experiment



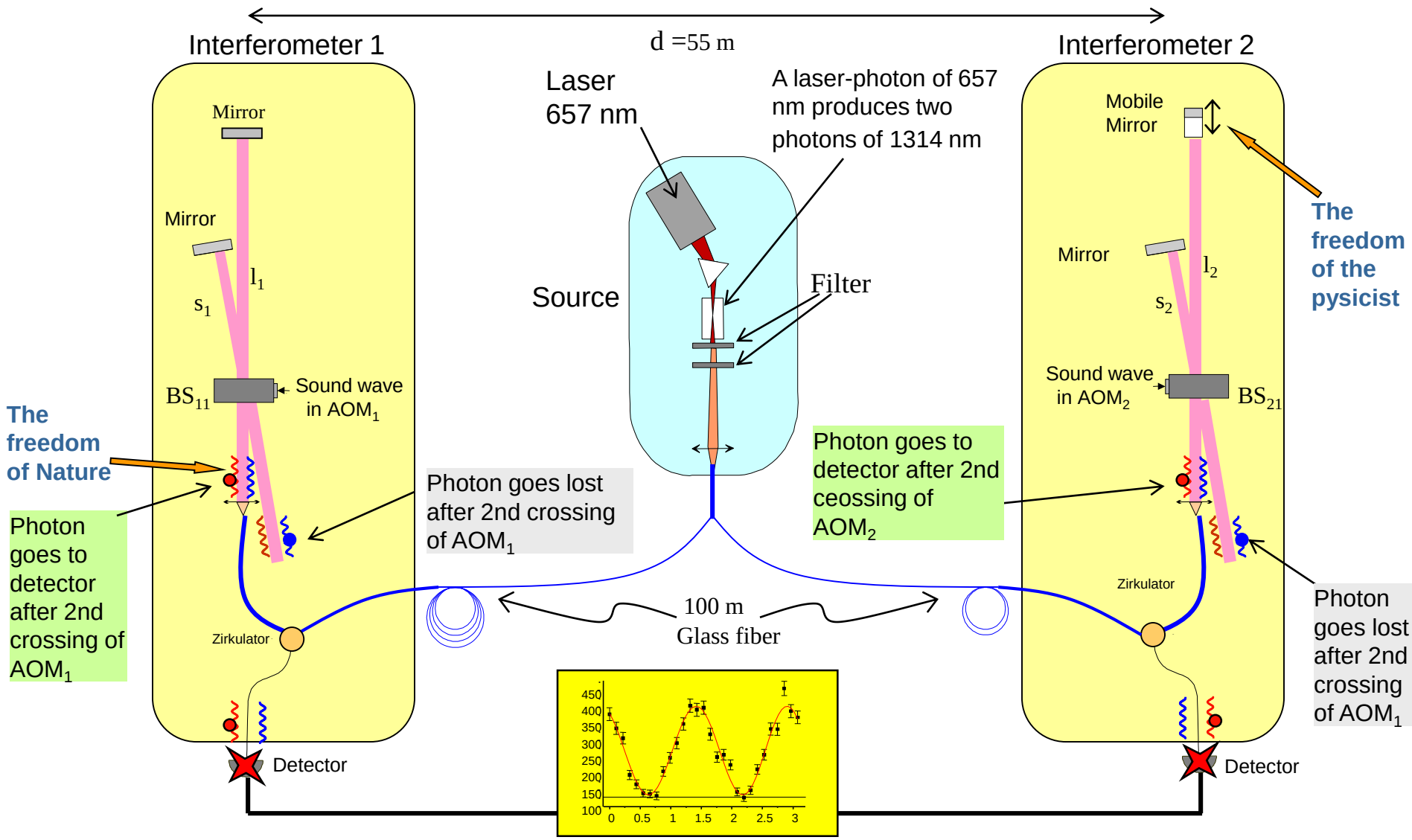
Multisimultaneity
Condition for before-before timing



$$\Delta t \leq \frac{v\,L}{c^2}$$

The Before-Before Experiment

A. Stefanov, H. Zbinden, N.Gisin and A. Suarez (2001)



“Before-Before”

- Sponsored by a private banker of Geneva

- Realized by Nicolas Gisin’s group (Geneva)

Strong Motivation:
To beat Quantum Mechanics!

Story of the „before-before“ experiment

A. Suarez & V. Scarani (1997)

A. Stefanov, H. Zbinden, N. Gisin, A. Suarez (2001)

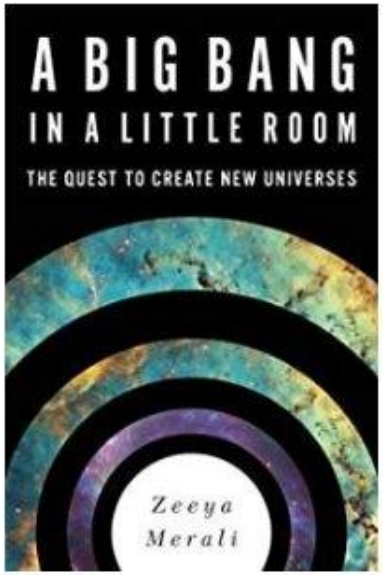
Wolfgang Tittel, Hugo Zbinden, Nicolas Gisin,

Valerio Scarani, Antoine Suarez, André Stefanov

“Before-Before” experiment:

On Friday 22 june 2001, at 9:30, when André Stefanov presented the results, I had the impression that I was assisting to my burial!

On Tuesday 26 june, at 19:15,
I suddenly realized that we had buried « time ».



Best Seller

A Big Bang in a Little Room: The Quest to Create New Universes

by Zeeya Merali

Hardcover

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Chapter 2
Beyond Space and Time: The Quantum Realm

Beyond Space and Time

"Each chapter focuses on one key subtopic, and features scientists who work in it. We learn about the foundations of quantum physics through the reflections of Antoine Suarez on his distinguished career creating ever more powerful laboratory tests of quantum theory."

Andreas Albrecht, Nature 542 (2017) 164

QUANTUM PHYSICS

Spooky Twins Survive Einsteinian Torture

SCIENCE VOL 294 9 NOVEMBER 2001

–CHARLES SEIFE

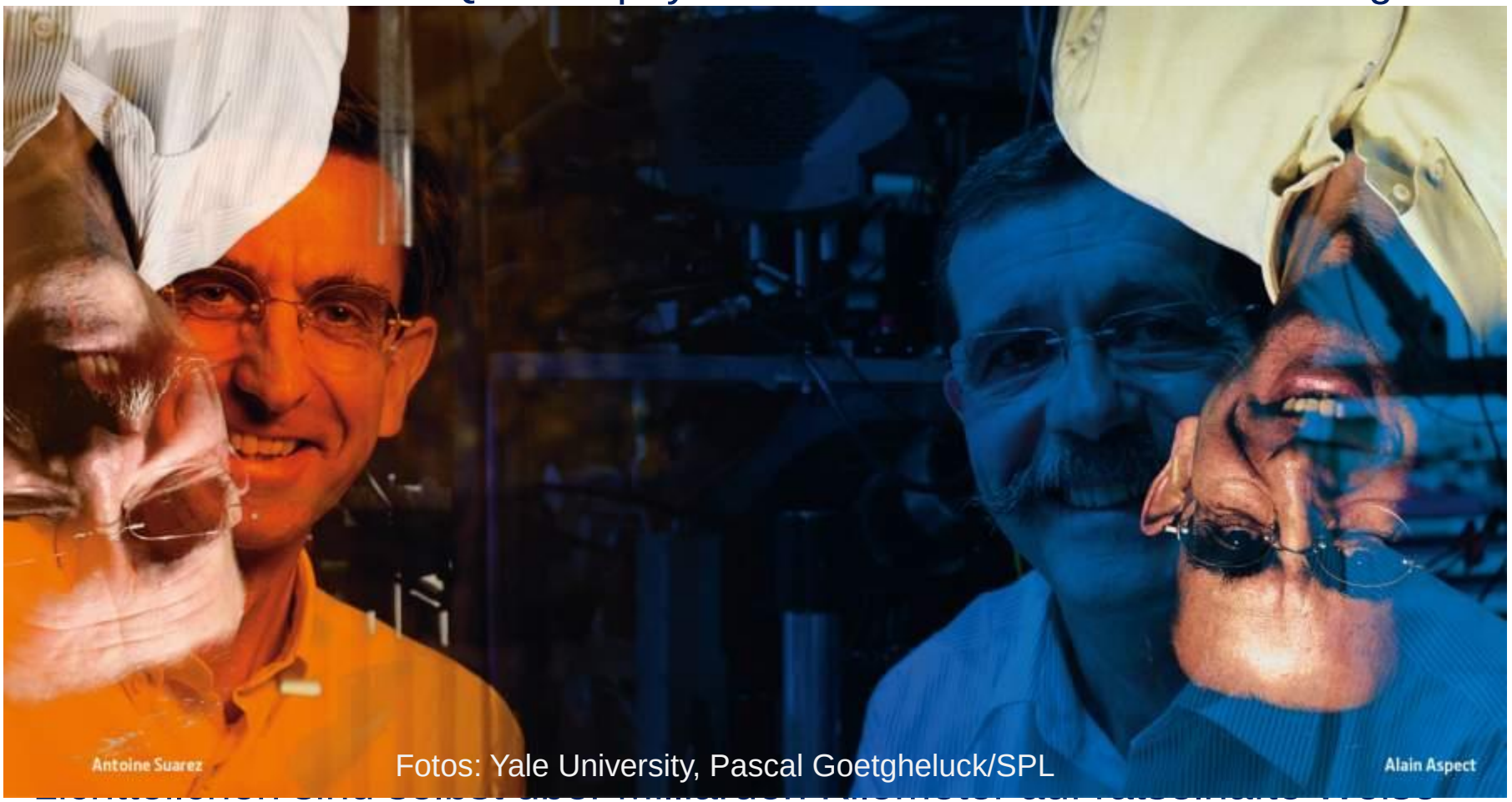
Bernard d'Espagnat:
Candide et le physicien.

Jean Staune:
Notre existence a-t-elle un sens ?

Technology Review 6/2019, S. 44

Religion und Ratio

Eine Geschichte über Quantenphysik und die Grenzen der Vorstellungskraft.

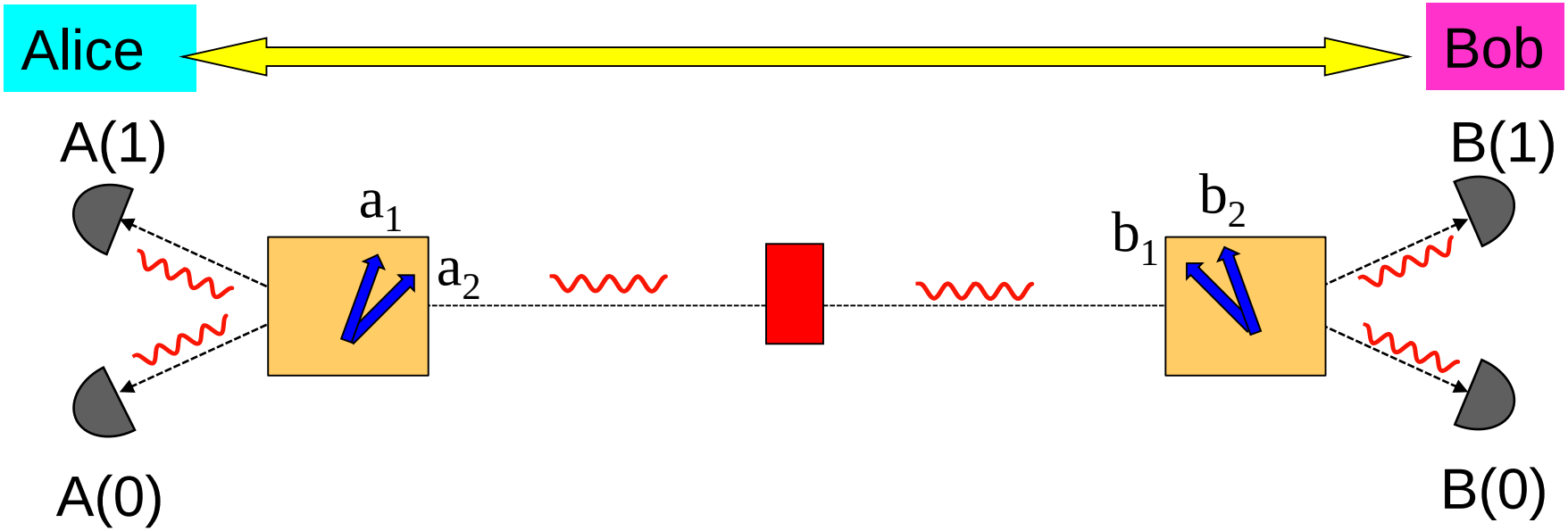


Fotos: Yale University, Pascal Goetgheluck/SPL

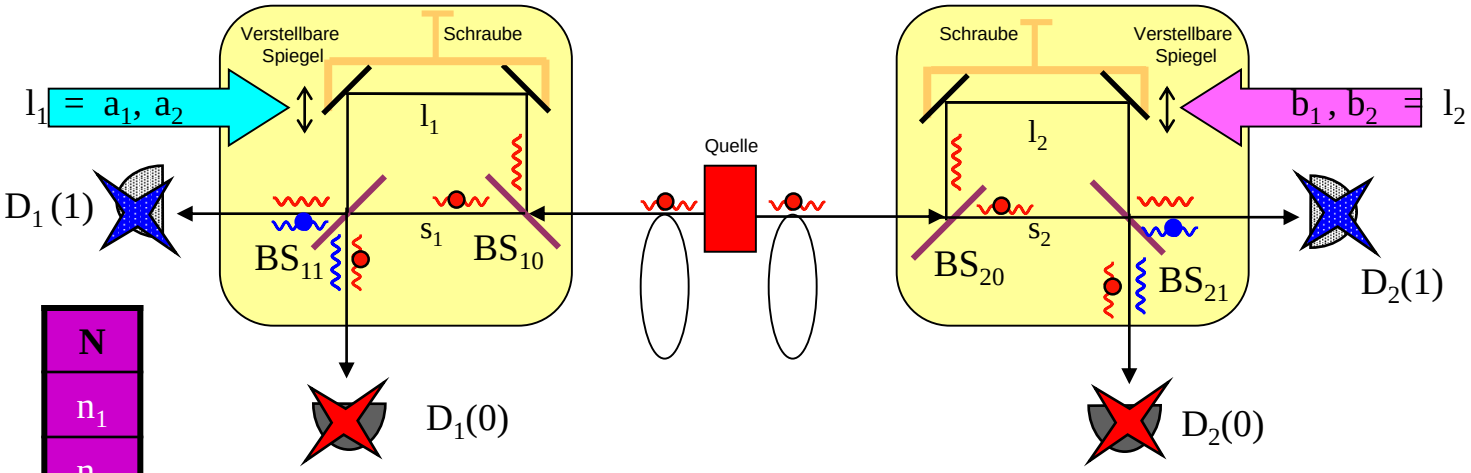
miteinander verbunden. **Zwei Forscher arbeiteten sich an dem Beweis ab.** Einer fand die Erklärung in Gott, der andere blieb bei der Physik.

https://www.heise.de/select/tr/2019/6/1559554364390298

Bell's theorem



Bell inequality



a_1	a_2	b_1	b_2	N
1	1	1	1	n_1
1	1	1	0	n_2
1	1	0	1	n_3
1	1	0	0	n_4
1	0	1	1	n_5
1	0	1	0	n_6
1	0	0	1	n_7
1	0	0	0	n_8
0	1	1	1	n_9
0	1	1	0	n_{10}
0	1	0	1	n_{11}
0	1	0	0	n_{12}
0	0	1	1	n_{13}
0	0	1	0	n_{14}
0	0	0	1	n_{15}
0	0	0	0	n_{16}

Quantity S:

$$S = \frac{1}{N}\sum_{i=1}^{i=16} n_i \cdot a_1 \cdot b_1 + \frac{1}{N}\sum_{i=1}^{i=16} n_i \cdot a_1 \cdot b_2 + \frac{1}{N}\sum_{i=1}^{i=16} n_i \cdot a_2 \cdot b_1 - \frac{1}{N}\sum_{i=1}^{i=16} n_i \cdot a_2 \cdot b_2$$

$$S = \frac{1}{N}\sum_{i=1}^{i=16} n_i S_i$$

If all pairs were of the samy type:

$$\text{Either } S_i = +2, \text{ or } S_i = -2$$

From this follows the Bells inequality:

$$-2 \le S \le +2$$

Many-Worlds

Hugh Everett III
(1930-1982)

At any choice (for instance a1, b2) the world and the agent split in 4 parallell worlds, so that all possible outcomes become realised although in different parallel worlds, which are **experimentally inaccessible** to each other.

a1, b2	a1, b2	a1, b2	a1, b2
Agent [1] 10	Agent [2] 01	Agent [3] 11	Agent [4] 00

And similarly for choices:
[a1, b1]
[a2, b1]
[a2, b2]

Many-Worlds completed

MW (consistently) requires that at any choice (for instance [a1, b2]) the other possible choices [a1, b1], [a2, b1], [a2, b2]) happen as well in 3 other parallell worlds

Manyworlds completed

a1, b2	a1, b1	a2, b1	a2, b2
Agent 10	Agent 01	Agent 10	Agent 10

And additionnally for each outcome the world and the agent splits in 3 other paralell worlds:
In total 16 paralell worlds!

Many-Worlds razored !

MW (consistently) requires that at any choice (for instance [a1, b2]) the other possible choices [a1, b1], [a2, b1], [a2, b2]) happen as well in 3 other parallell worlds

Manyworlds completed

a1, b2	a1, b1	a2, b1	a2, b2
Agent 10	Agent 01	Agent 10	Agent 10

And additionnally for each outcome the world and the agent splits in other paralell worlds:
In total 16 paralell worlds!

All-Possible-Worlds

Many-Worlds & Quantum (nonlocal) Contextuality

The «omniscient mind» assigns an outcome to each of the four possible choices an agent can do.

Agent	a1, b2	a1, b1	a2, b1	a2, b2
Choice 1	10	10	10	01
Choice 2	10	10	01	01
Choice 3	10	01	10	01
Choice 4	10	01	01	10
Choice 5	01	10	10	01
Choice 6	01	10	01	10
Choice 7	01	01	10	01
Choice 8	01	01	01	10

The agent is free to make the choice he wishes!

3 Principles

Principle A (Accessibility): All that is in space-time is accessible to observation.

Principle Q: (Quantum): Not all what matters for physical phenomena is contained in space-time.

Principle D (Detection): Detection outcomes (like death) are *ordinarily* irreversible and observer-independent.

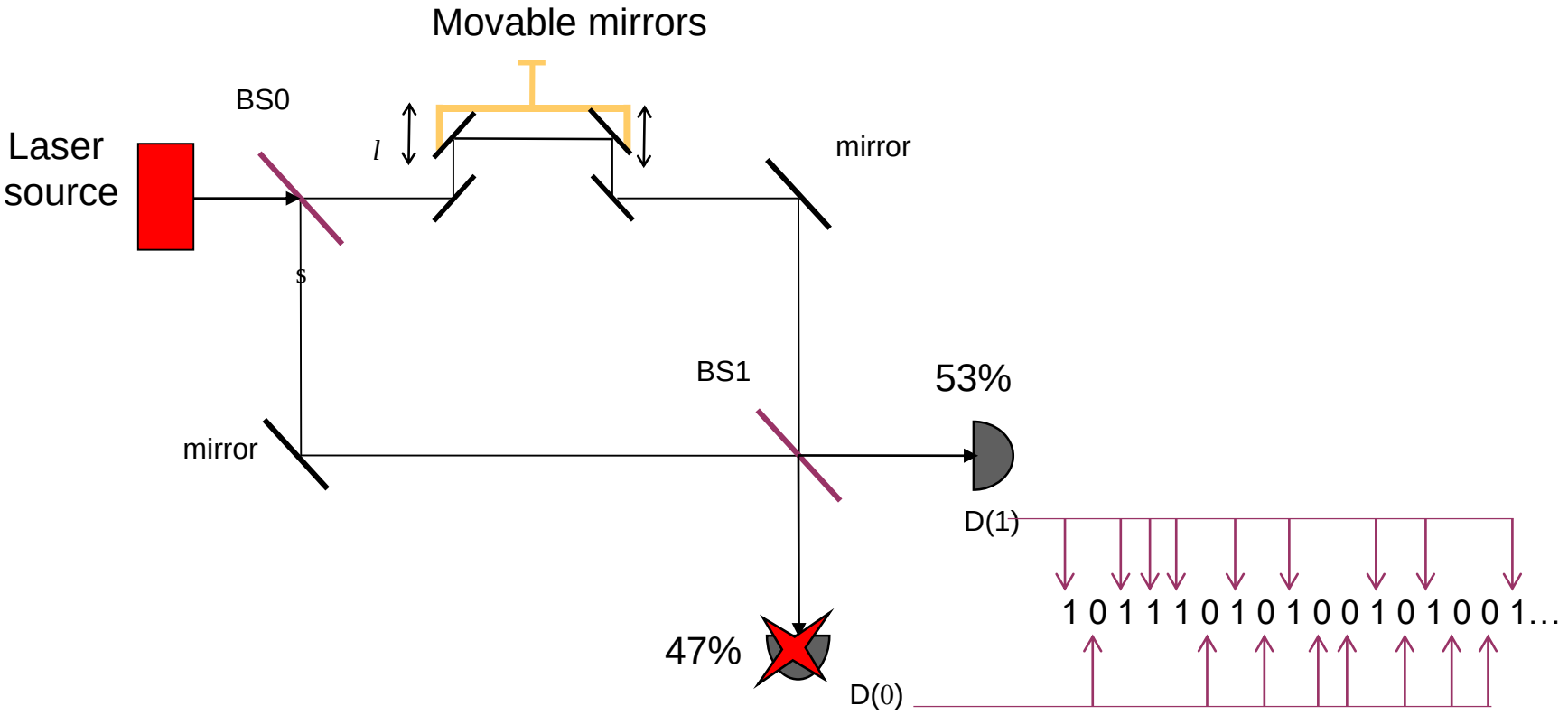
Principle Q: (Quantum): Not all what matters for physical phenomena is contained in space-time.

Space-time itself comes from outside space-time.

Space-time is pixelated.

Both, quantum nonlocal correlations and local relativistic ones, happen without continuous connection in space-time.

Implications for the intereaction between spirit and matter



Quantum physics says nothing about the order of the outcomes. They build a string of bits, which could very well contain the information of a master work of literature or music.

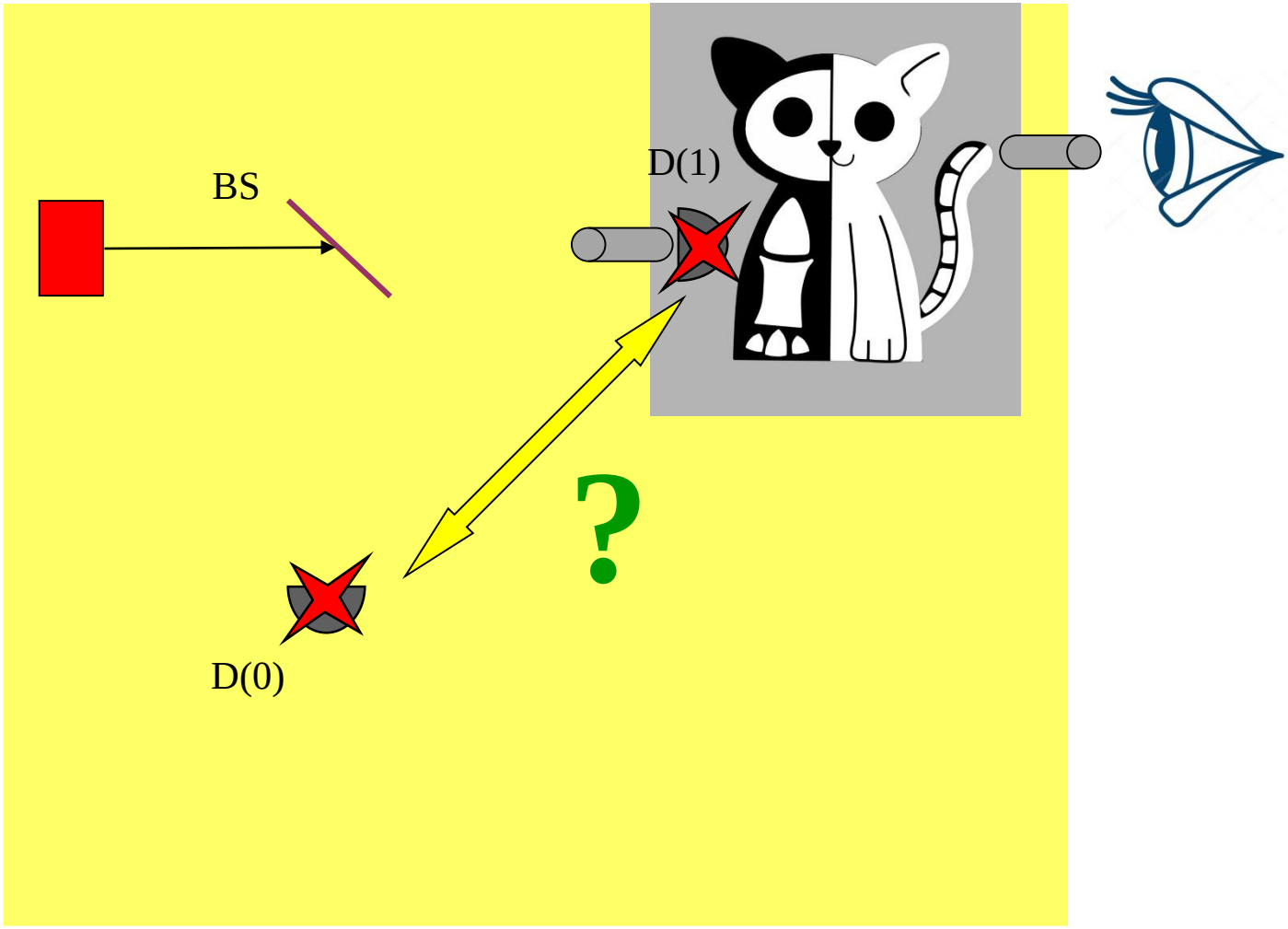
3 Principles

Principle A (Accessibility): All that is in space-time is accessible to observation (except in case of space-like separation).

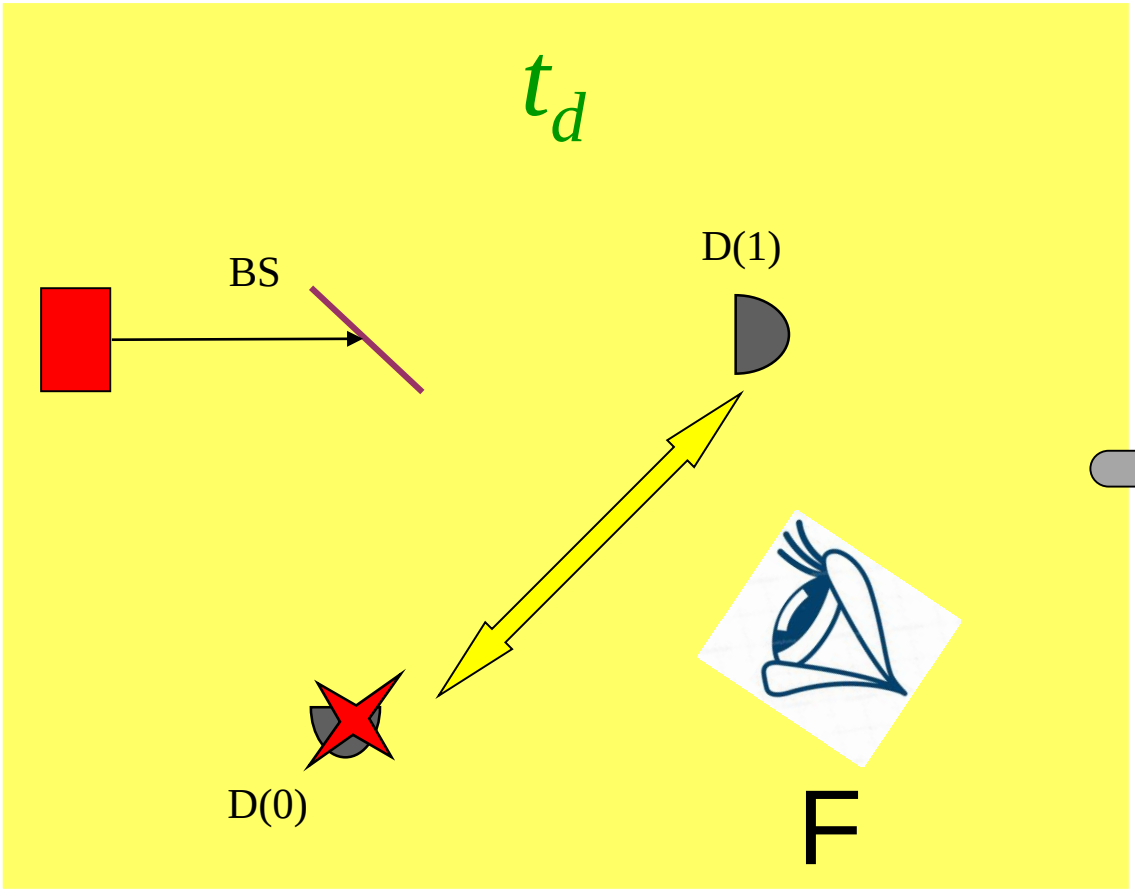
Principle Q: (Quantum): Not all what matters for physical phenomena is contained in space-time.

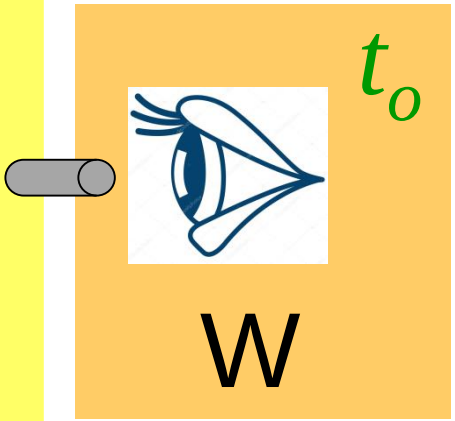
Principle D (Detection): Detection outcomes (like death) are *ordinarily* irreversible and observer-independent.

Schrödinger's Cat



Wigner's friend





F [W] (at time $t < t_d$): $|\psi\rangle_S = \frac{1}{\sqrt{2}}(|1\rangle_S + |0\rangle_S)$

F (at time t_d): $|\psi\rangle_S = |0\rangle_S$

W (at time t_d): either $|\psi\rangle_S = |1\rangle_S$ or $|\psi\rangle_S = |0\rangle_S$

At time t_d I [F] will observe either outcome 0 or 1

At time t_d I observe 0

At time t_d F observes either 0 or 1

W (at $t < t_o$): $|\psi\rangle_{S\otimes F} = \frac{1}{\sqrt{2}}(|1\rangle_S \otimes |1\rangle_F + |0\rangle_S \otimes |0\rangle_F)$ At time $t_d < t_o$ F observes neither 0 nor 1

W (at t_o): $|\psi\rangle_{S\otimes F} = |0\rangle_S \otimes |0\rangle_F$ At time t_o W observes that F observes 0

Wigner's friend

If one applies quantum superposition to experimenters one is led to infer that outcomes of experiments depend on the observer.

Violation of Principle D ("irreversibility" of detection and death).

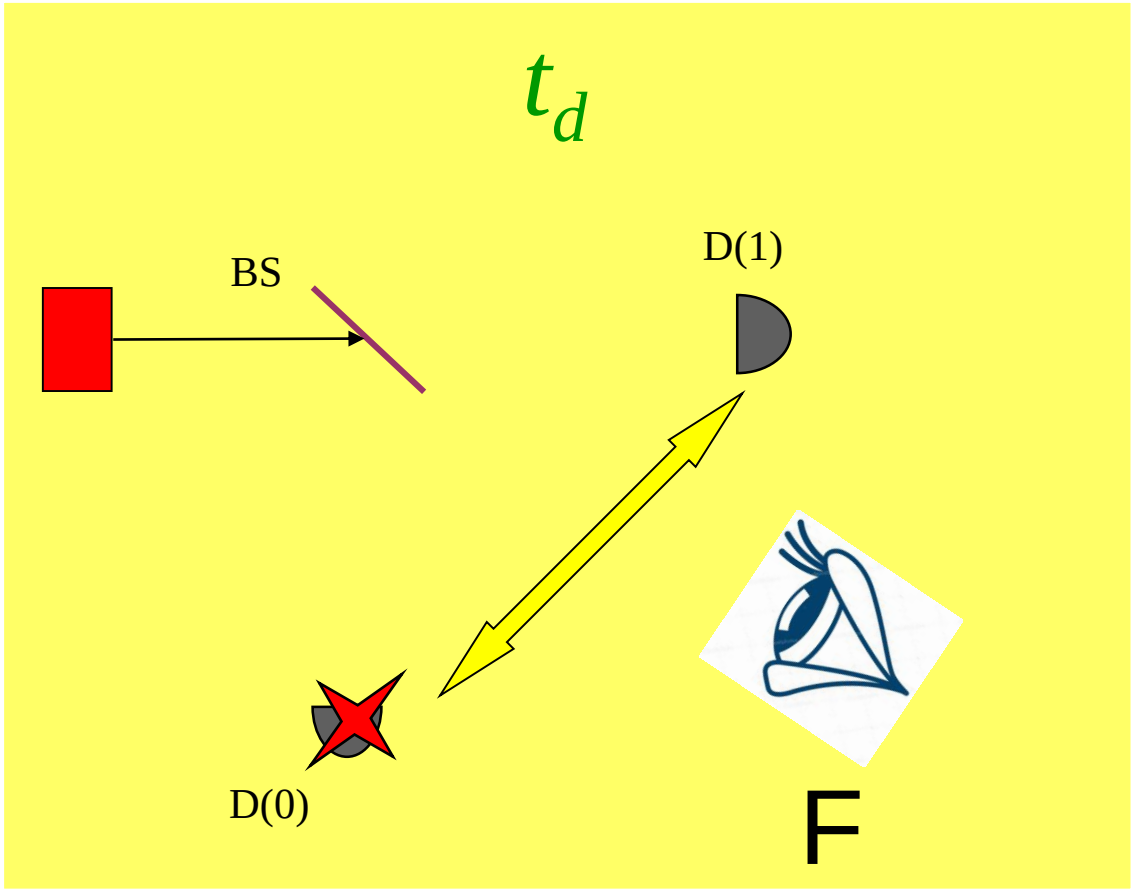
Wigner's friend paradox, a recent elaboration

Quantum theory cannot consistently describe the use of itself

Daniela Frauchiger & Renato Renner

Nature Communications **volume 9**, Article number: 3711 (2018)

Wigner's friend's recent elaboration: Frauchiger-Renner no-go theorem (2018)



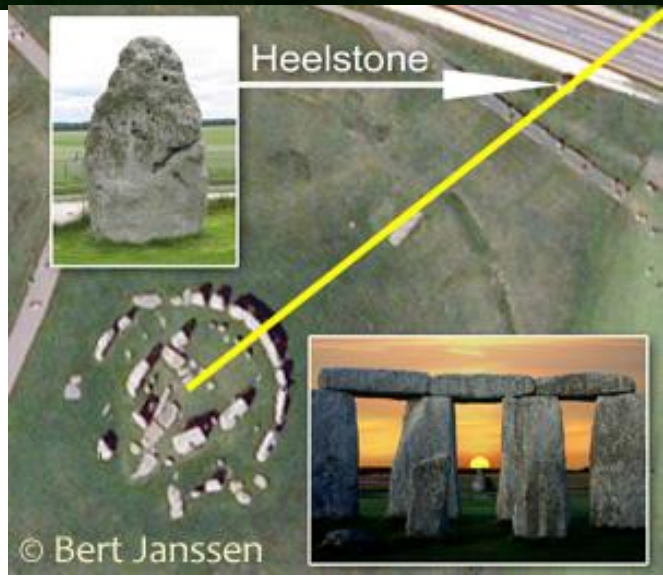
F: $|\psi\rangle_S = |0\rangle_S$ At time t_d I (F) observe 0

W: $|\psi\rangle_{S\otimes F} = |1\rangle_S \otimes |1\rangle_F$ At time t_d F observes 1

Classical Determinism

"Some 100 yards away from the centre of Stonehenge stands the so called Heelstone. It is a single large block of Sarsen stone. On the day of the summer solstice, usually 21 June, you can, while standing in Stonehenge, see the sun rise exactly above the Heelstone. It is a truly magical moment."

http://www.cropcirclesandmore.com/geometries/201101lss.html

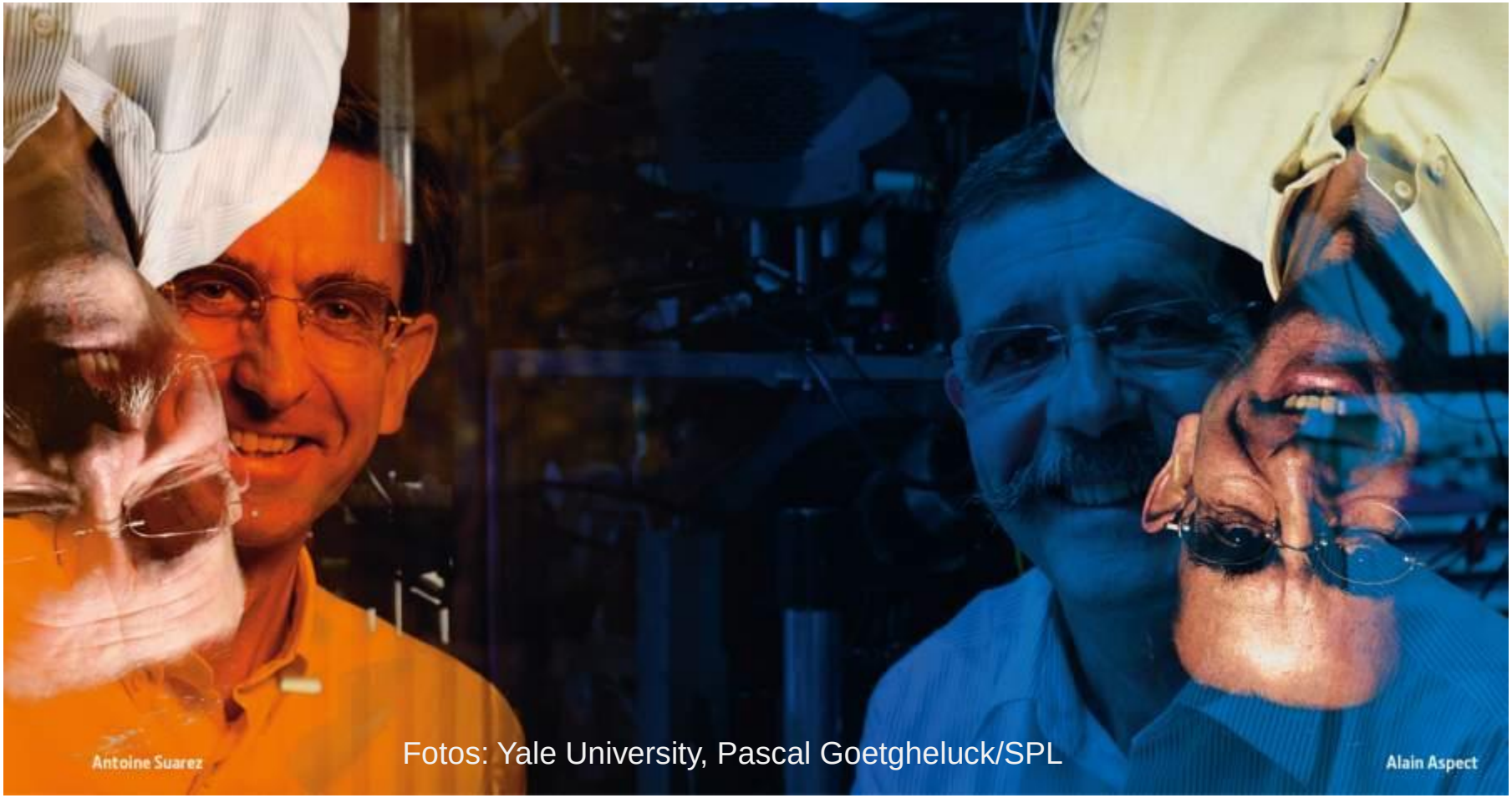


Crowds gather at the ancient stone circles of Stonehenge and Avebury in Wiltshire to celebrate sunrise on the longest day of the year and the beginning of summer.

Schrödinger's Sun?

To my knowledge there are no bookmakers accepting bets on whether the sun appears at the left, middle, or right arc!

Ordinarily observers are not in quantum superposition



Fotos: Yale University, Pascal Goetgheluck/SPL

https://www.heise.de/select/tr/2019/6/1559554364390298

Principle D:

Ordinarily
outcomes of experiments do
NOT
depend on the observer.

Principle D is an assumption!

It requires to limit quantum superposition.

However, nothing in principle speaks
against the existence of
extraordinary phenomena,
where observers are in quantum superposition
and Principle D does not hold.

The limits of quantum superposition: Should "Schrödinger's cat" and "Wigner's friend" be considered "miracle" narratives?

Antoine Suarez

https://arxiv.org/abs/1906.10524

(23 Jun 2019)

“Fatima's miracle of the Sun”

On October 13, 2017, about 70,000 pilgrims gathered in Cova da Iria (Fatima, Portugal) perceived the Sun dancing at 2 pm. By contrast 2 billion people in the rest of the world perceived the Sun following its usual trajectory

So during about 10 minutes two different groups of observers had different evidence of the “same” physical event depending on their location.
Since the physical reality is defined by the observations, one must conclude that what watched the 70,000 in Cova da Iria was as real (or as virtual) as what watched the two billion in the rest of the world.

``Fatima's miracle of the Sun“

October 13, 1917

Principle D:

Ordinarily outcomes of experiments do NOT depend on the observer

It defines the ordinary world where we live and move,
the world we can calculate and predict,
the world where science applies.

Von: **Renato Renner** <renner@phys.ethz.ch>
Date: Sa., 6. Juli 2019 um 10:06 Uhr
Subject: Re: New paper defining what is Quantum
To: Antoine Suarez <suarez.antoine@gmail.com>

Dear Antoine
Thanks for the link to your arXiv paper, which I read with interest. Your interpretation of our no-go theorem sounds fine to me.
[…]
Best wishes
Renato

Science is an important and highly useful part of knowledge.

But

it is not the only

Grammar of Assent

Defining what is science in the light of recent results on quantum superposition

22nd International Interdisciplinary Seminar
"Science and the Quest for Truth"
Clarendon Laboratory, Oxford, January 2nd, 2020

Antoine Suarez

Zürich and Geneva
www.quantumphil.org

The End