Wydział Fizyki

POLITECHNIKA WARSZAWSKA

Violation of Bell Inequalities on Quantum Computers

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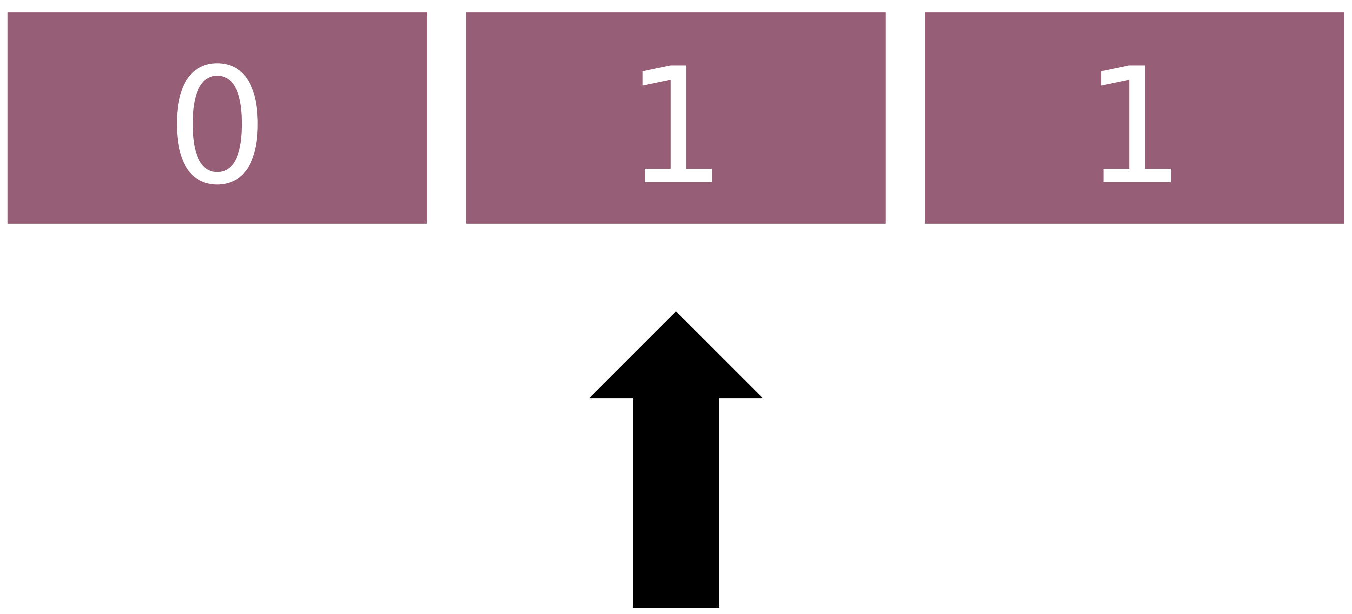
Quantum Computers

Bits in classical computers:



Classical value of a bit taken from the set:

B

Quantum Computers

Bits in classical computers:

0	1	1

Classical value of a bit taken from the set:

B

Qubits in quantum computers:

$|0\rangle + |1\rangle$

$|0\rangle |1\rangle$

$1|0\rangle$

Quantum value of a qubit:

where and

Quantum Computers

Quantum measurement:

Any quantum system **that does not interact with the environment** evolves unitarily:

But if you measure the system, its unitary evolution is destructed.

The outcome of the measurement is truly random.

Entanglement

Separable states:

Consider a system of 2 particles, whose states are denoted and .

Suppose:

If the system can be described strictly as , then it is called a **separable** state.

Entanglement

Separable states:

May the subsystems A and B be given as:

Thus,

Entanglement

There are also states that cannot be decomposed onto the tensor product of 2 subsystems:

Example:

Entanglement

Entangled states:

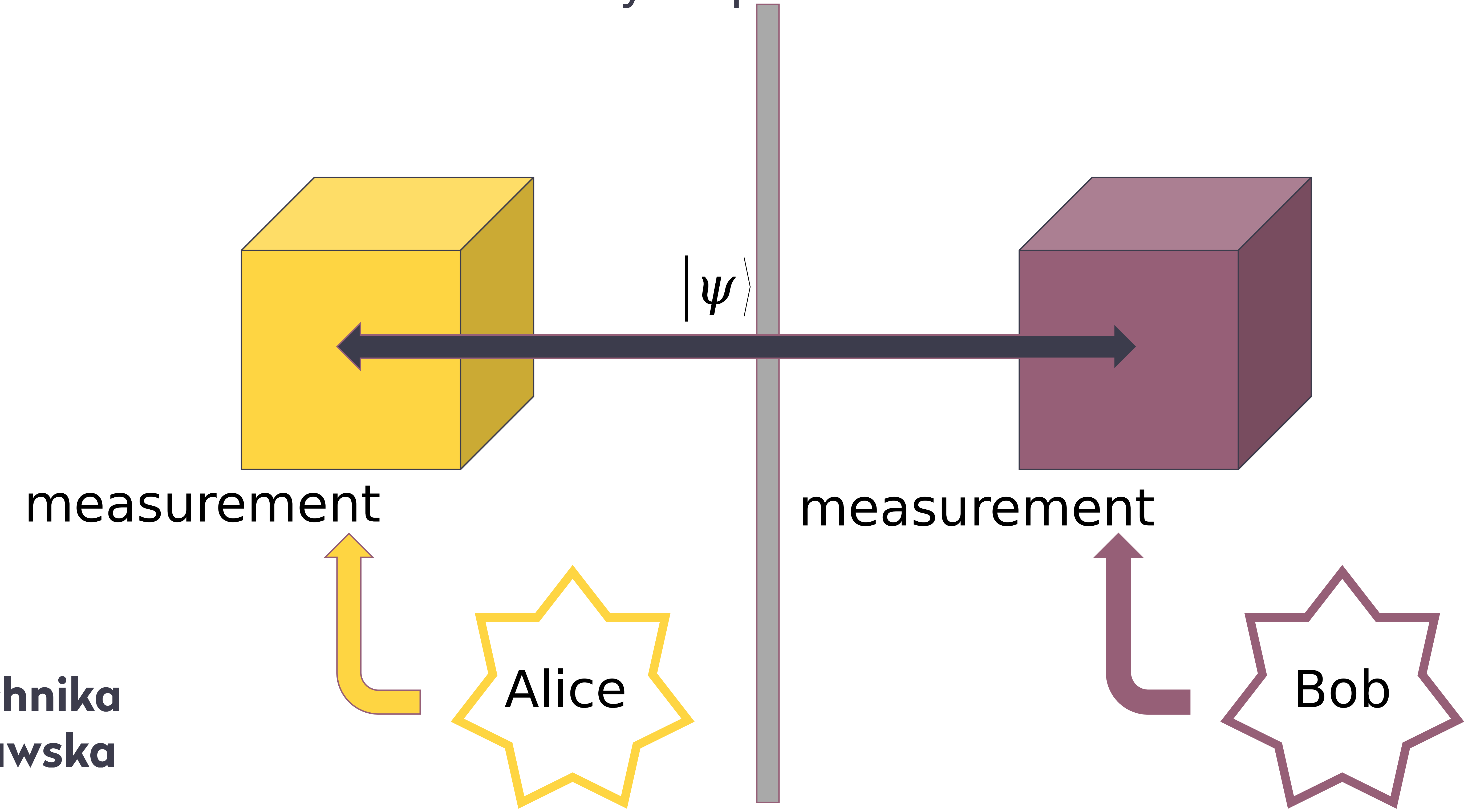
Physical interpretation of **entangled** states:

- We know a lot about the whole system ;
- We cannot describe any of the subsystems separately.

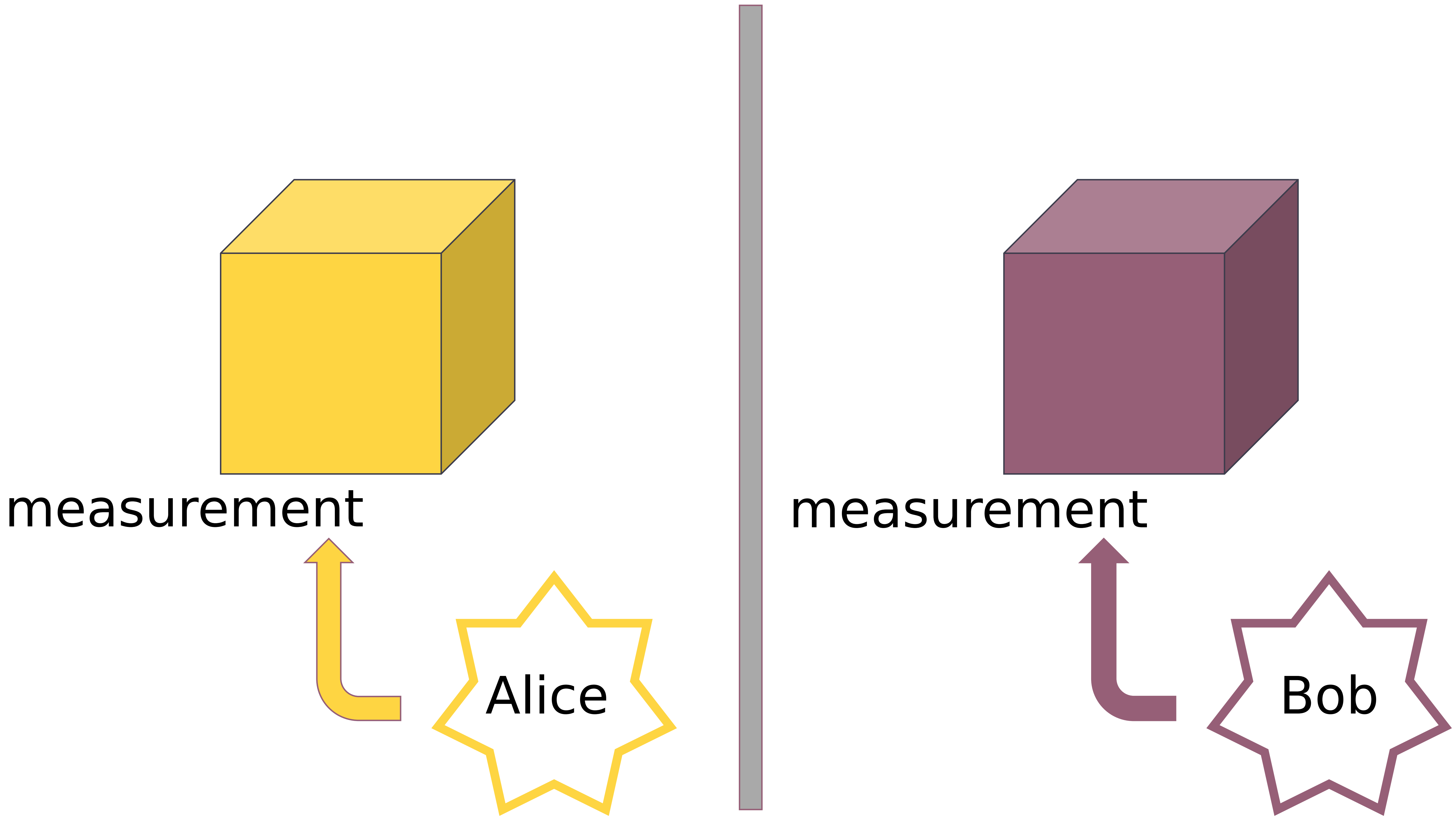
Bell Scenario

Consider the following system:

- 2 **entangled** qubits that cannot communicate with each other;
- 2 observables are measurable for each qubit;
- 2 scientists, Alice and Bob, are performing the experiment. Each of them has only 1 qubit.



Bell Scenario



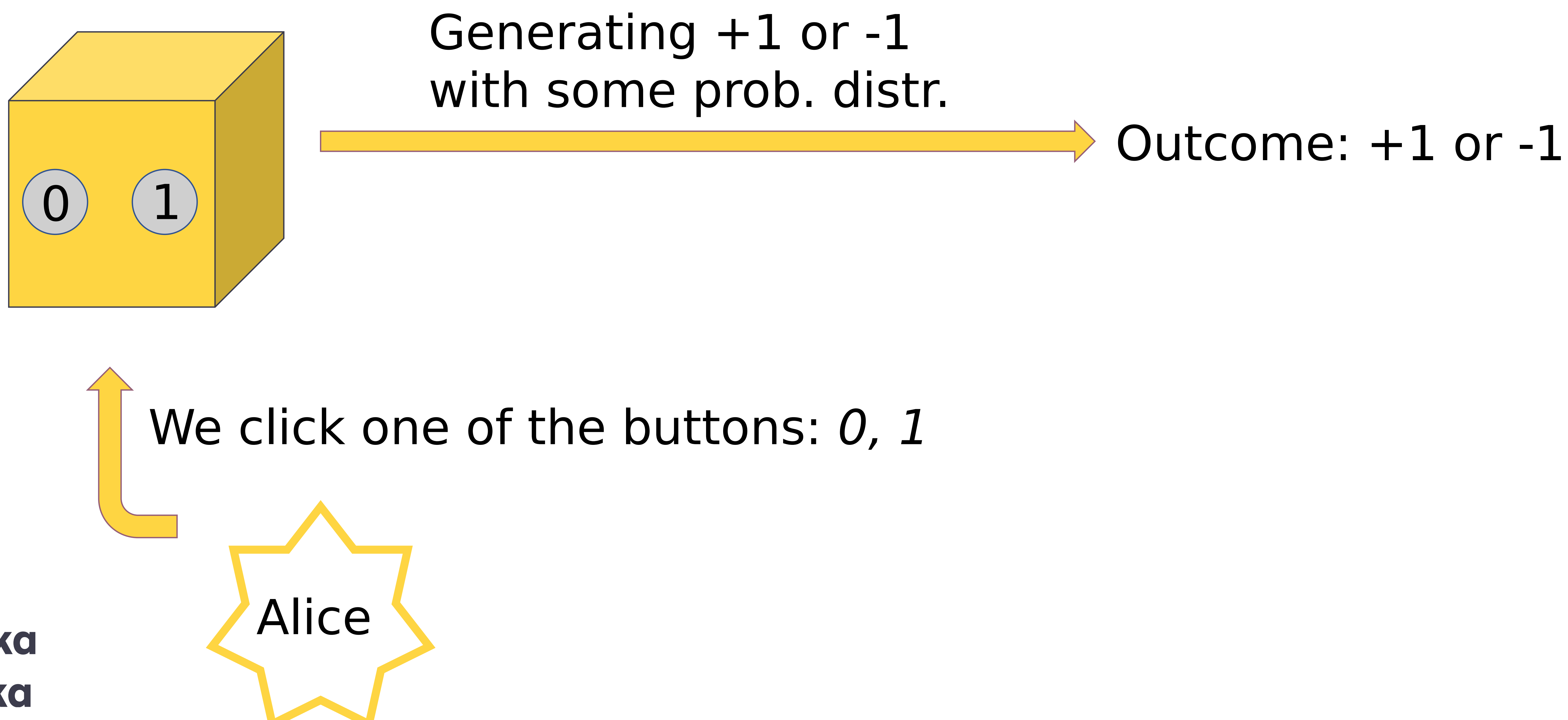
Alice and Bob measure their qubits simultaneously.

They do that many times, collecting the statistics

Bell Scenario

How the system would behave in classical physics?

Classically, the whole experiment could be understood as an RNG:



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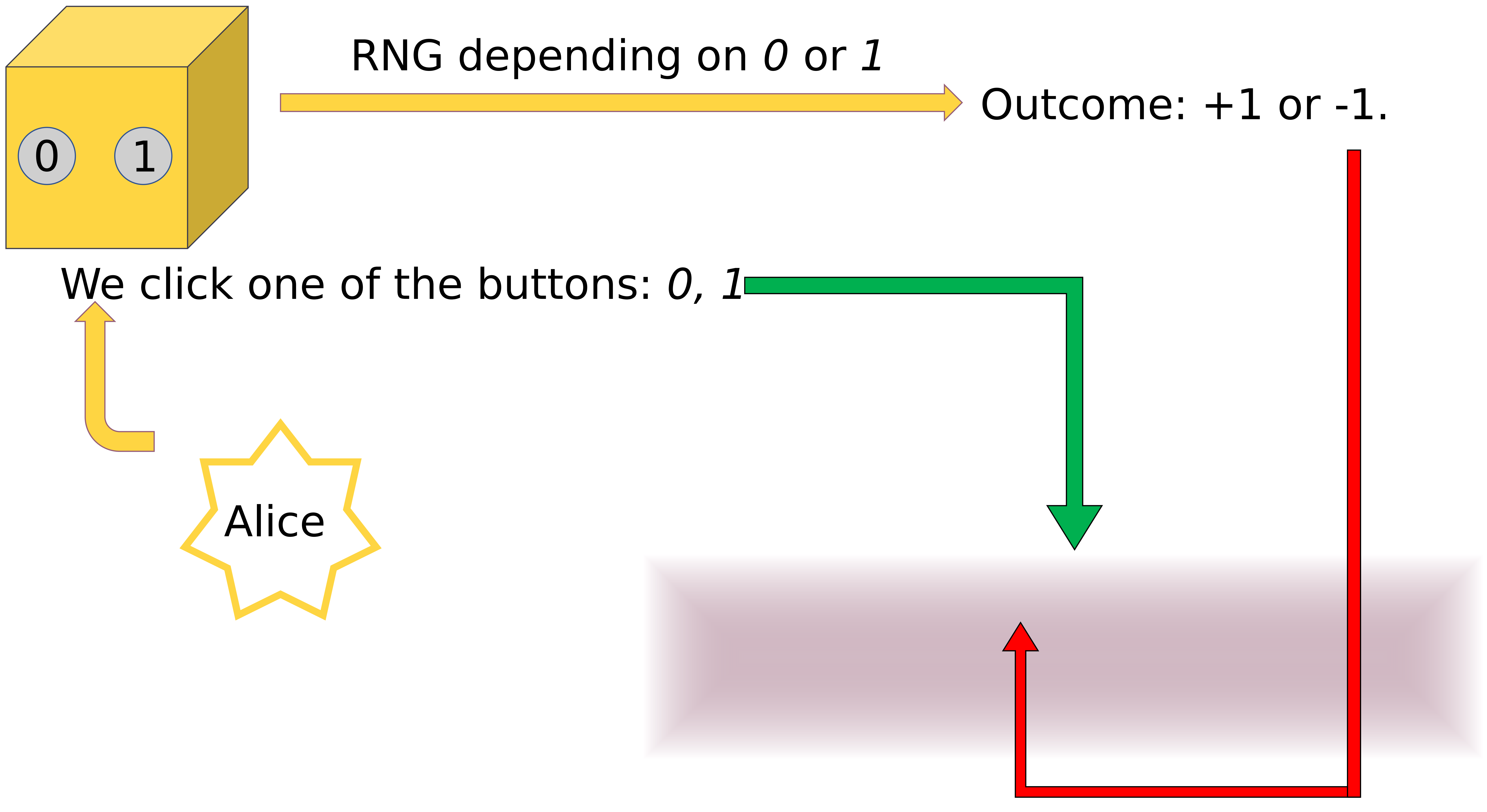
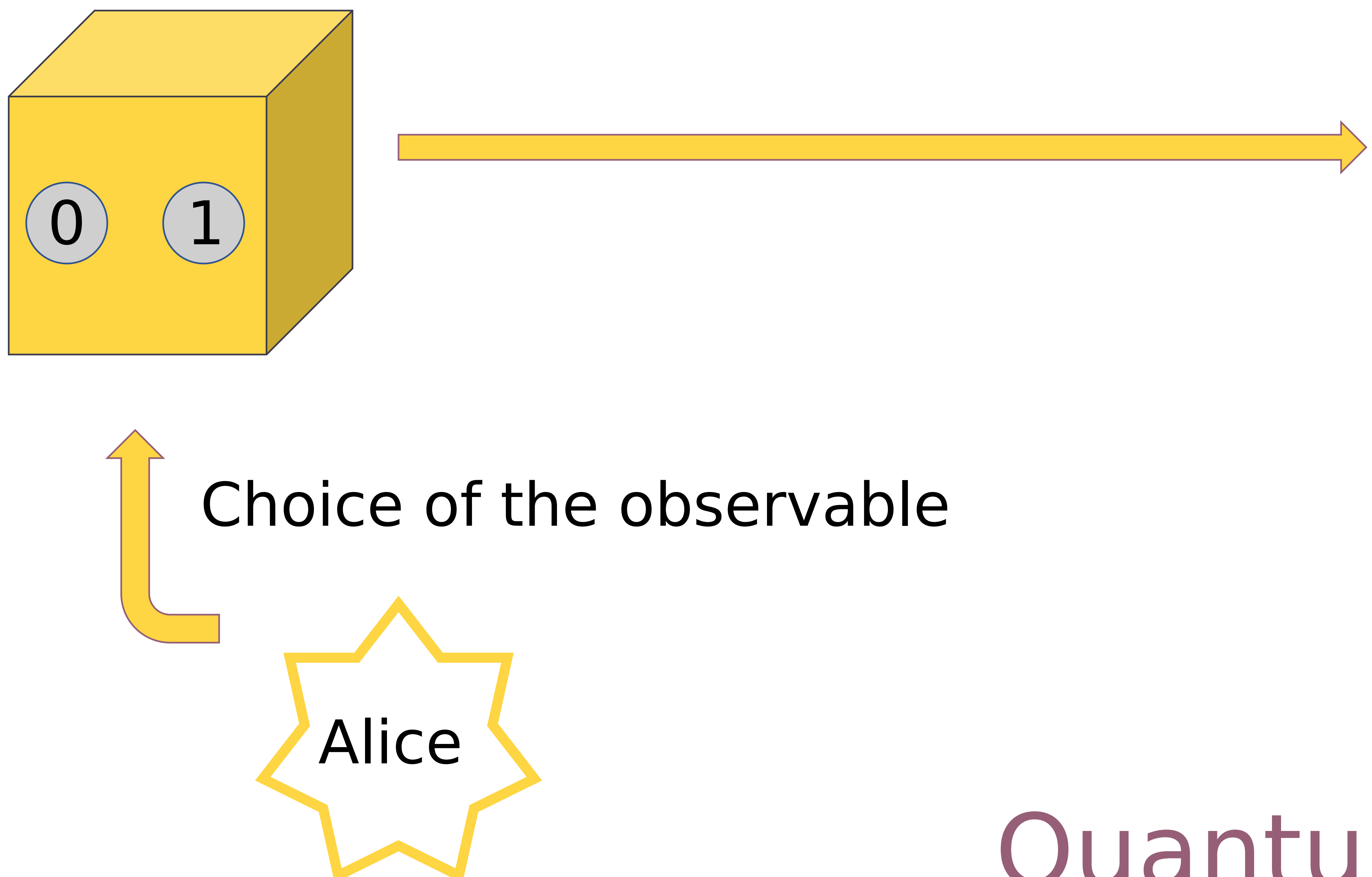
Bell Scenario



Bell Scenario



Outcome:
(or other pairs of states)

Quantum scenario

, but not only.

Bell Scenario

Locality:

A probability distribution is named **local** if:

so when there exist a phenomenon that explains the behaviour of the system in classical physics.

Otherwise the system is **non-local**.

Bell Inequalities

Expectation value of a joint measurement:

Locally:

In quantum mechanics (both local and non-local cases):

Bell Inequalities

Example:

In any local case:

There exist some entangled quantum states that violate such an inequality.

Bell Inequalities

Example:

The following operators construct a non-local experiment:

We will take this state:

Bell Inequalities

Example:

In such experiment:

The behaviour of the system is non-local, because .

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Thank you

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