TELEPORTATION PROTOCOL

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I SEE

It's your time to imagine the futures

Goals:

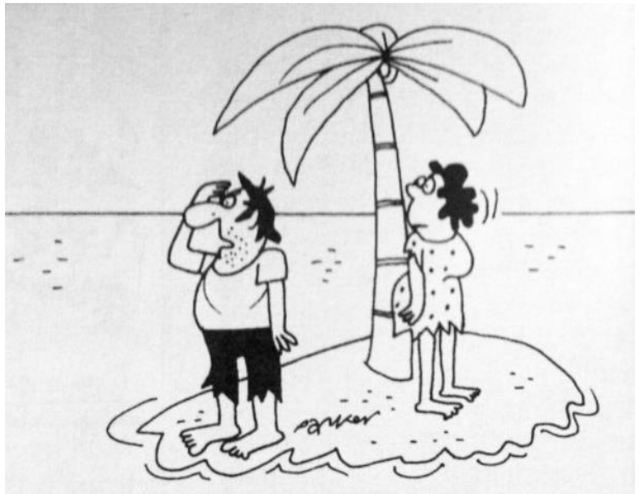
1. Application of the entanglement: teleportation experiment
2. Rereading of the experiment in terms of circuit

Three levels:

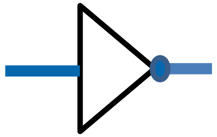
NARRATIVE

LOGICAL

Of MECHANISM

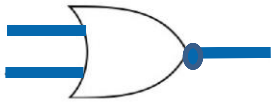


NOT



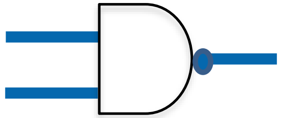
A	NOT (A)
1	0
0	1

OR

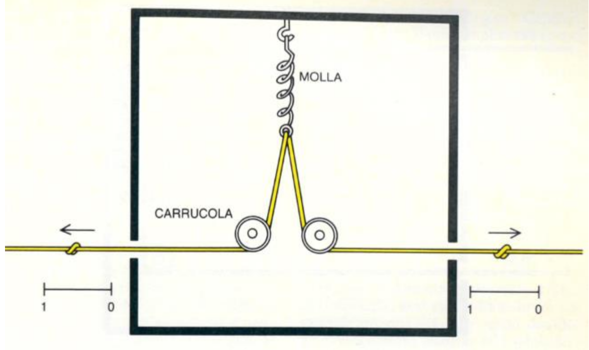


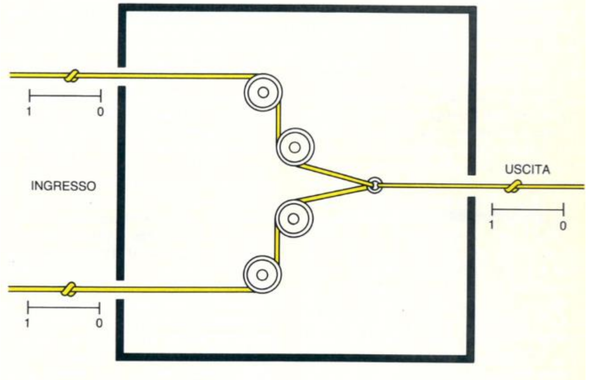
A	B	A OR B
1	1	1
1	0	1
0	1	1
0	0	0

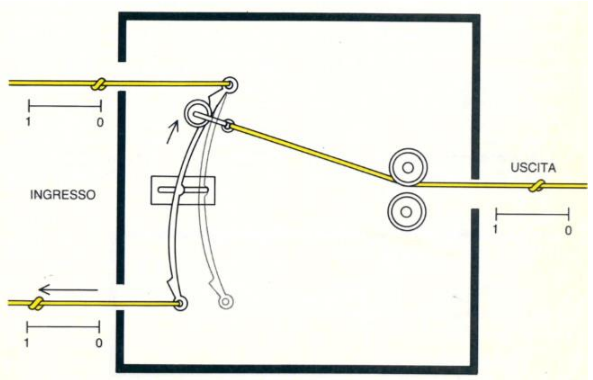
AND

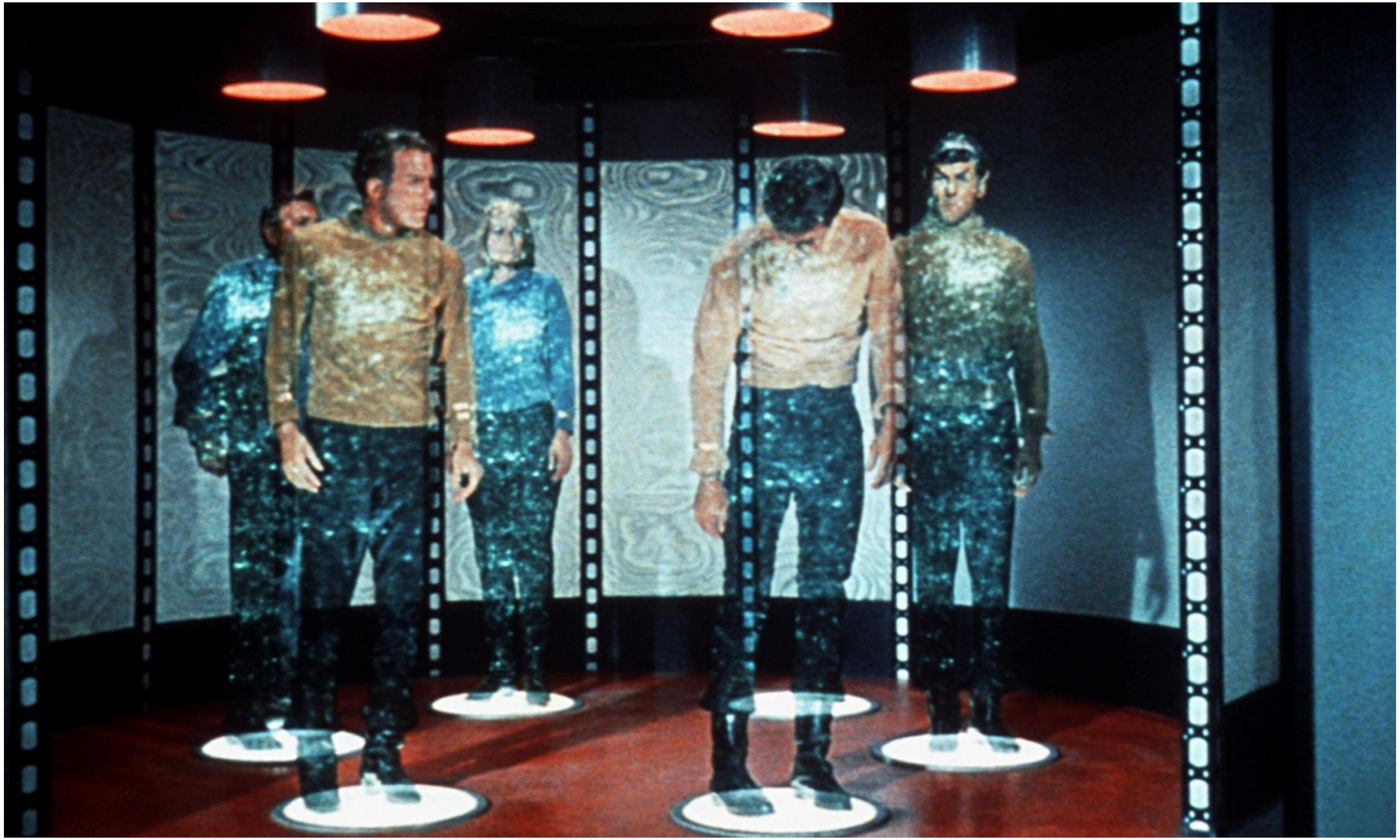


A	B	A AND B
1	1	1
1	0	0
0	1	0
0	0	0









Alice and Bob met during a robbery, after which they had to separate. Before doing it, they exchanged a pair of entangled photons. After several years Alice without having had any news of her Bob decides to get in touch with him and to share the status of another photon that she has procured. How does she?

Bell states

Bell states describe

maximally

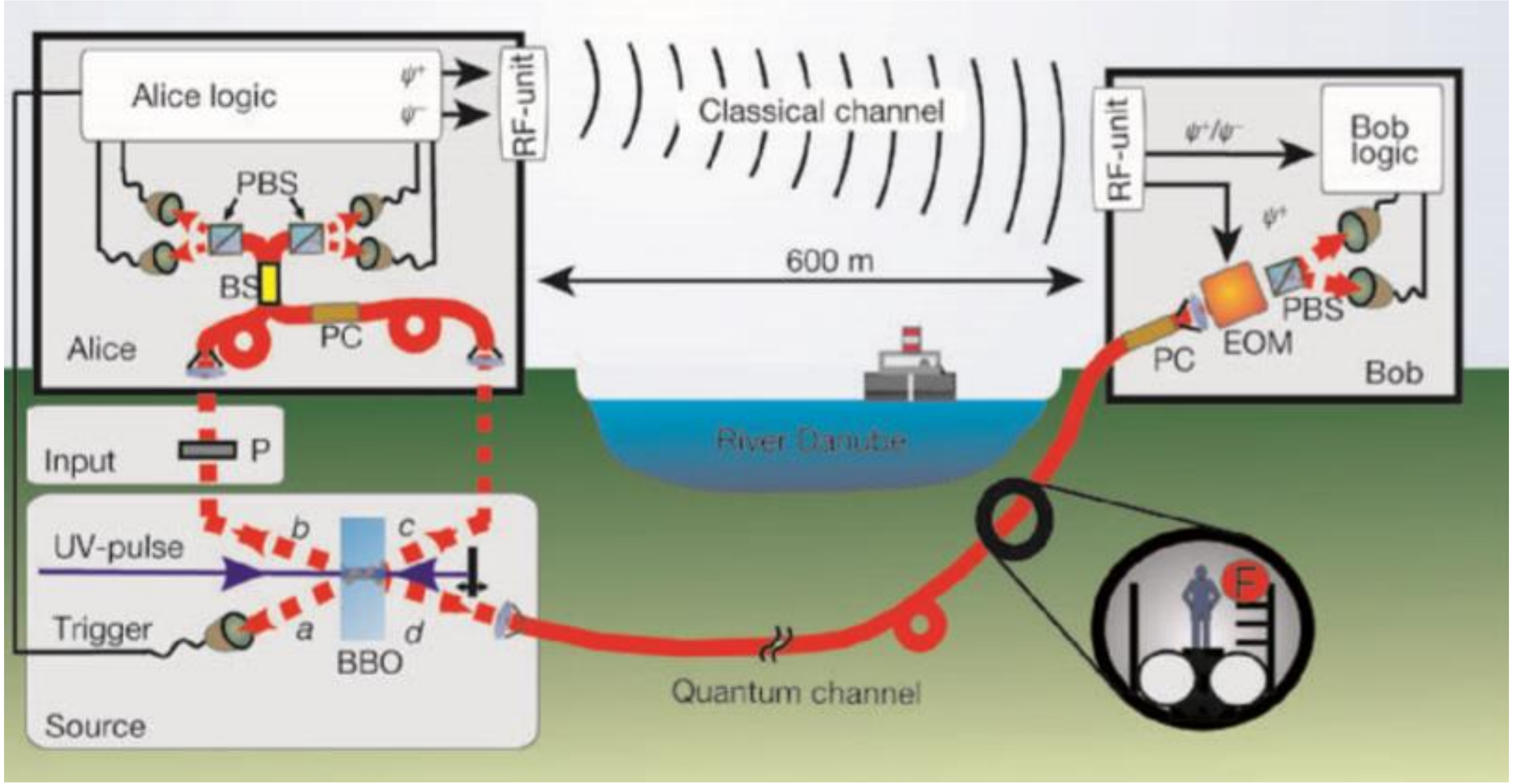
entangled states

$$|\beta_{00}\rangle = \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

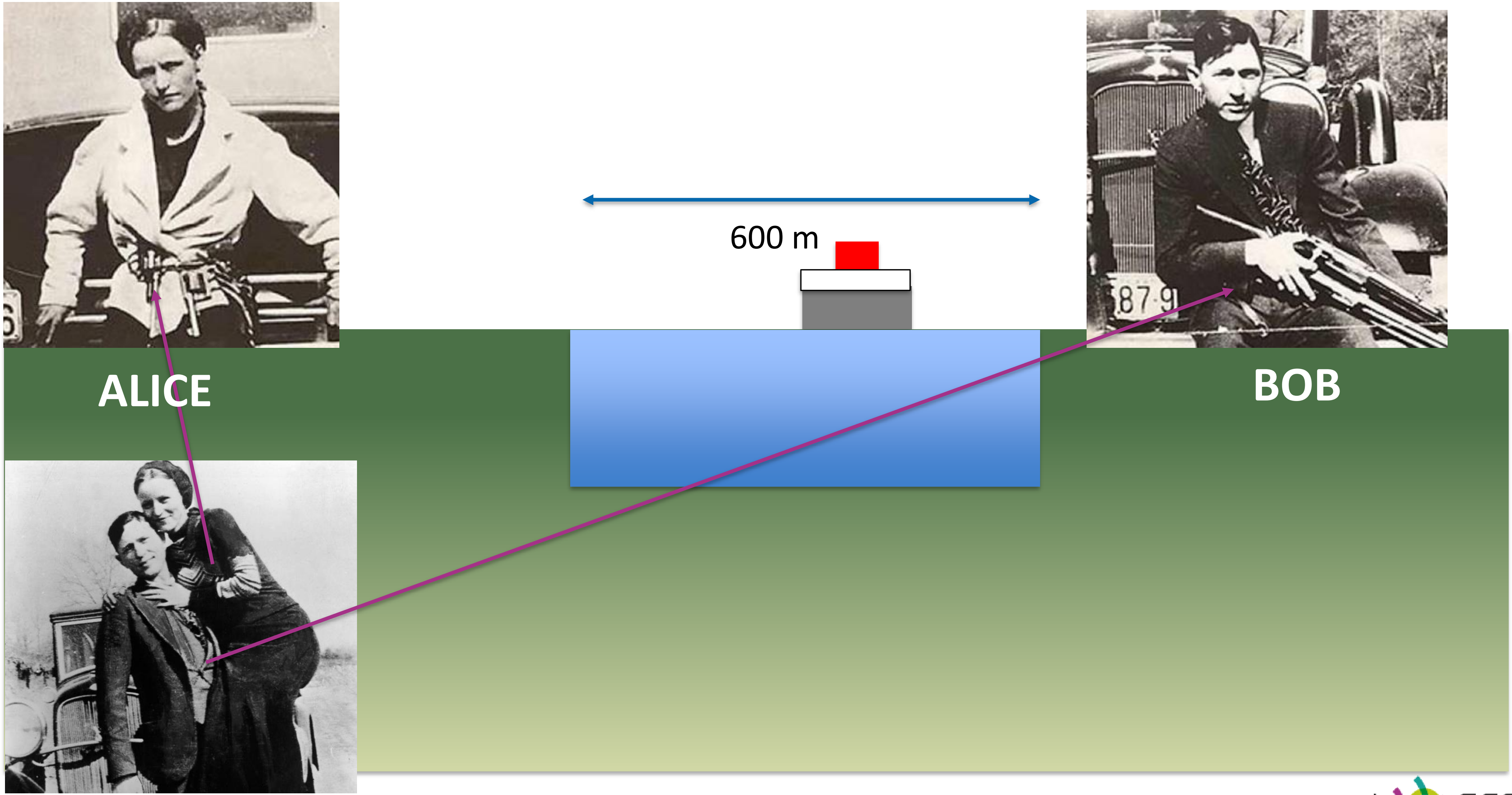
$$|\beta_{01}\rangle = \frac{|01\rangle + |10\rangle}{\sqrt{2}}$$

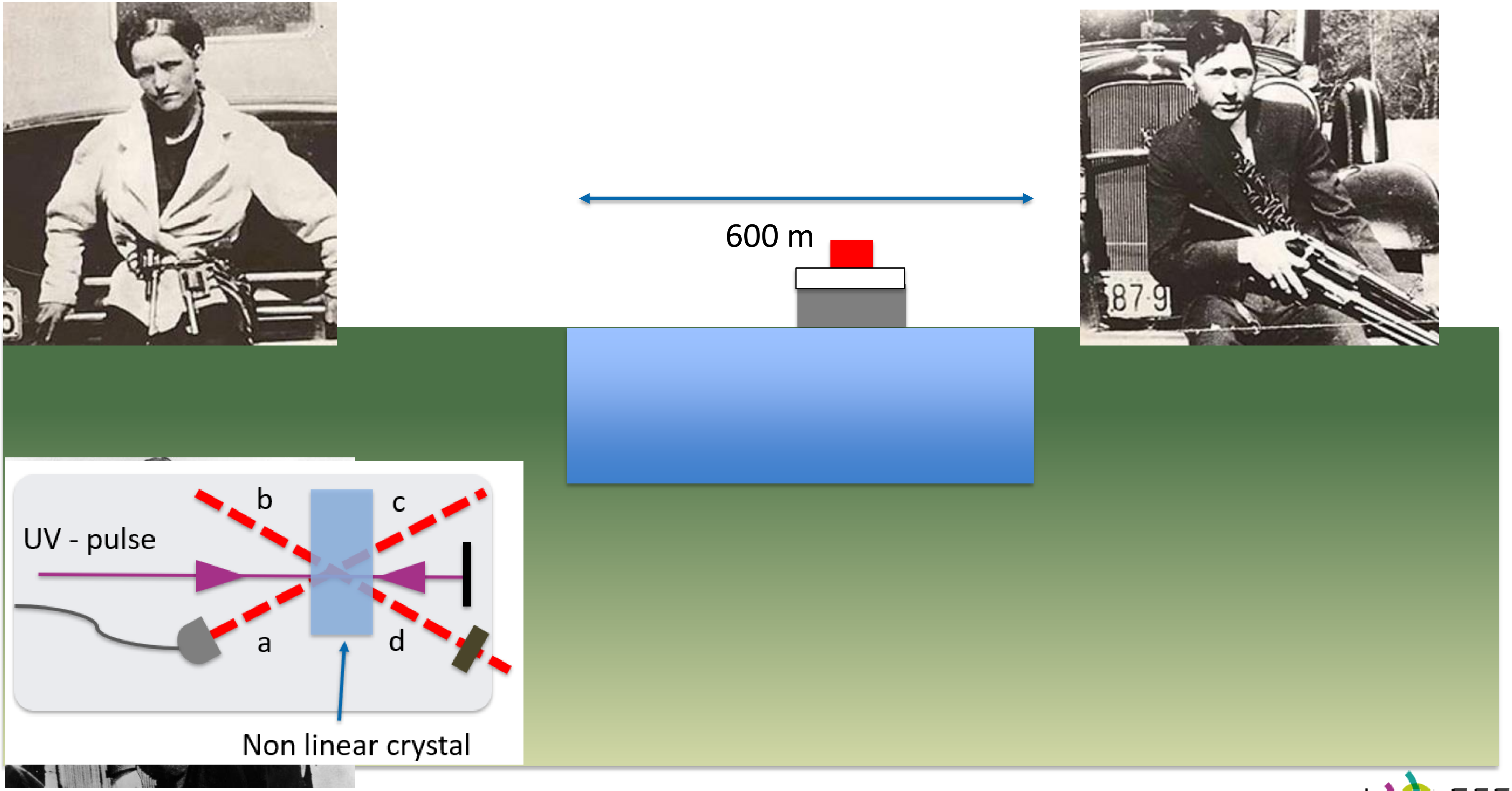
$$|\beta_{10}\rangle = \frac{|00\rangle - |11\rangle}{\sqrt{2}}$$

$$|\beta_{11}\rangle = \frac{|01\rangle - |10\rangle}{\sqrt{2}}$$



Alice logic
RF-unit
Classical channel
RF-unit
Bob logic
PBS
BS
PC
Alice
600 m
PC
EOM
PBS
Bob
Input
P
River Danube
UV-pulse
Trigger
BBO
Quantum channel
Source


600 m
ALICE
BOB


600 m
UV - pulse
b
c
a
d
Non linear crystal

PRODUCTION OF TWO PAIRS OF ENTANGLED PHOTONS:

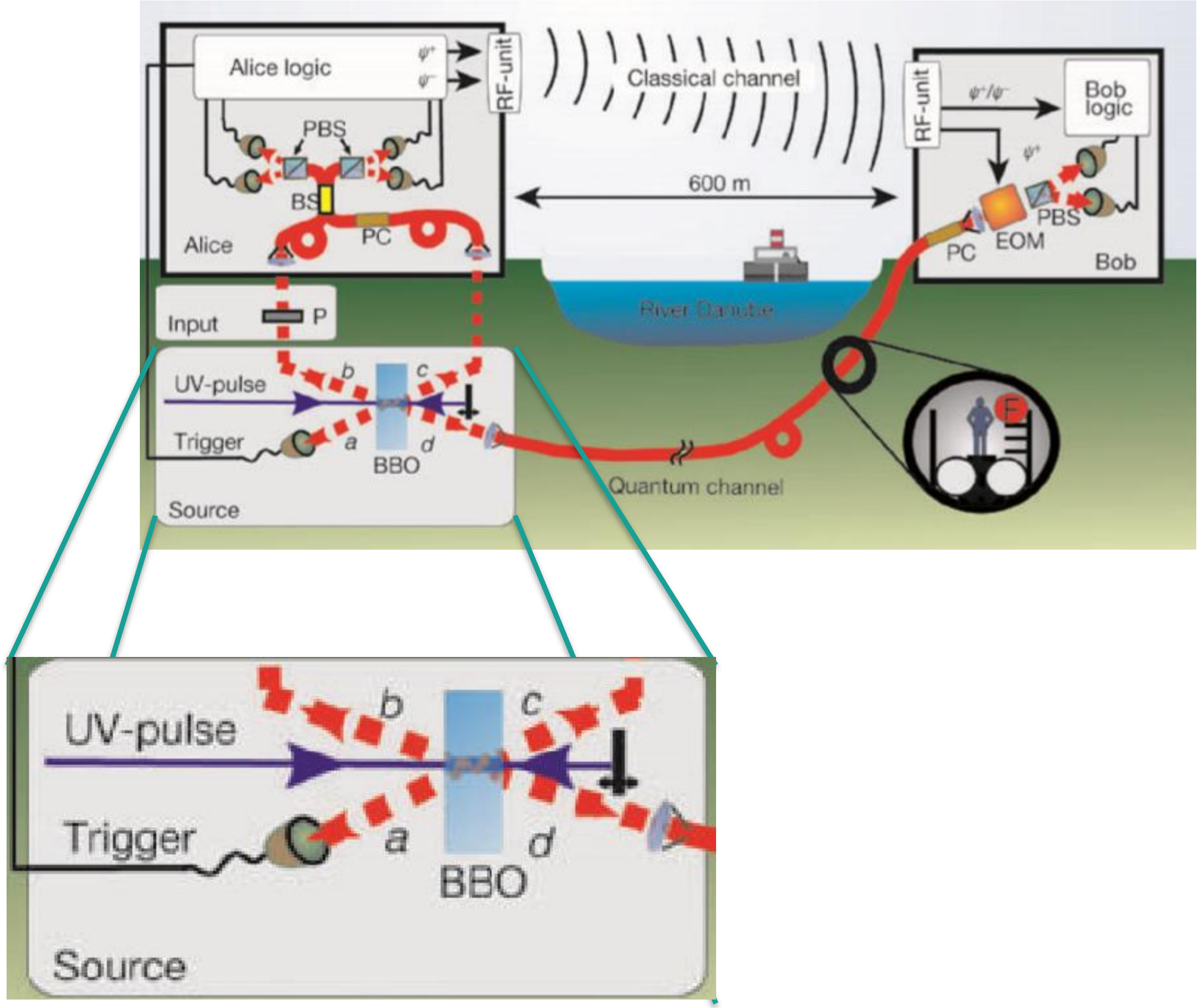
c and d

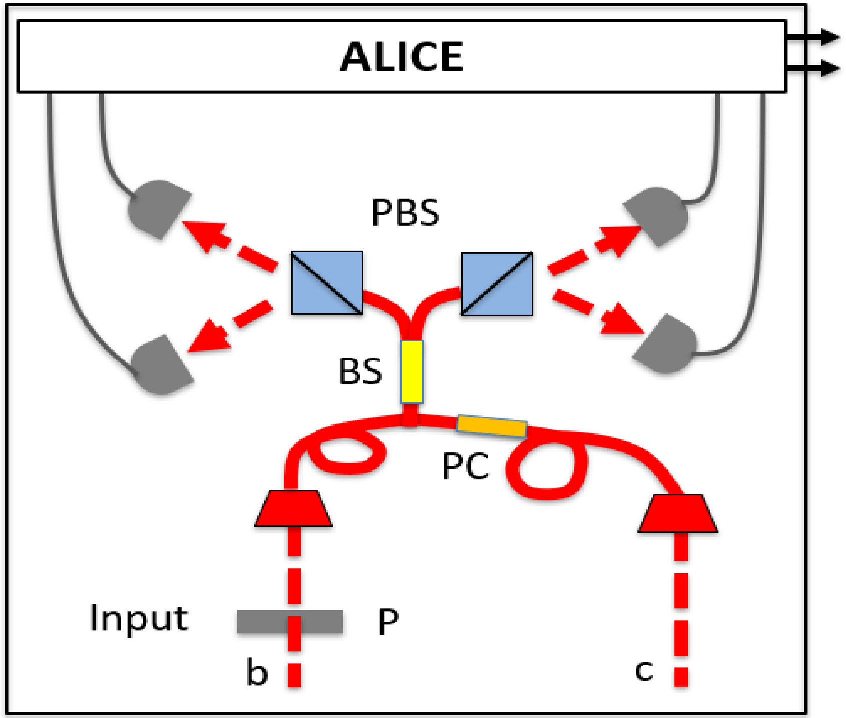
a and b

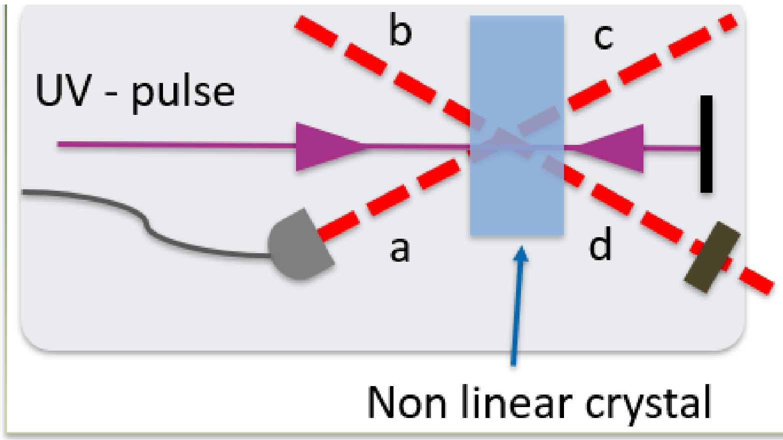
PULSED LIGHT BEAM

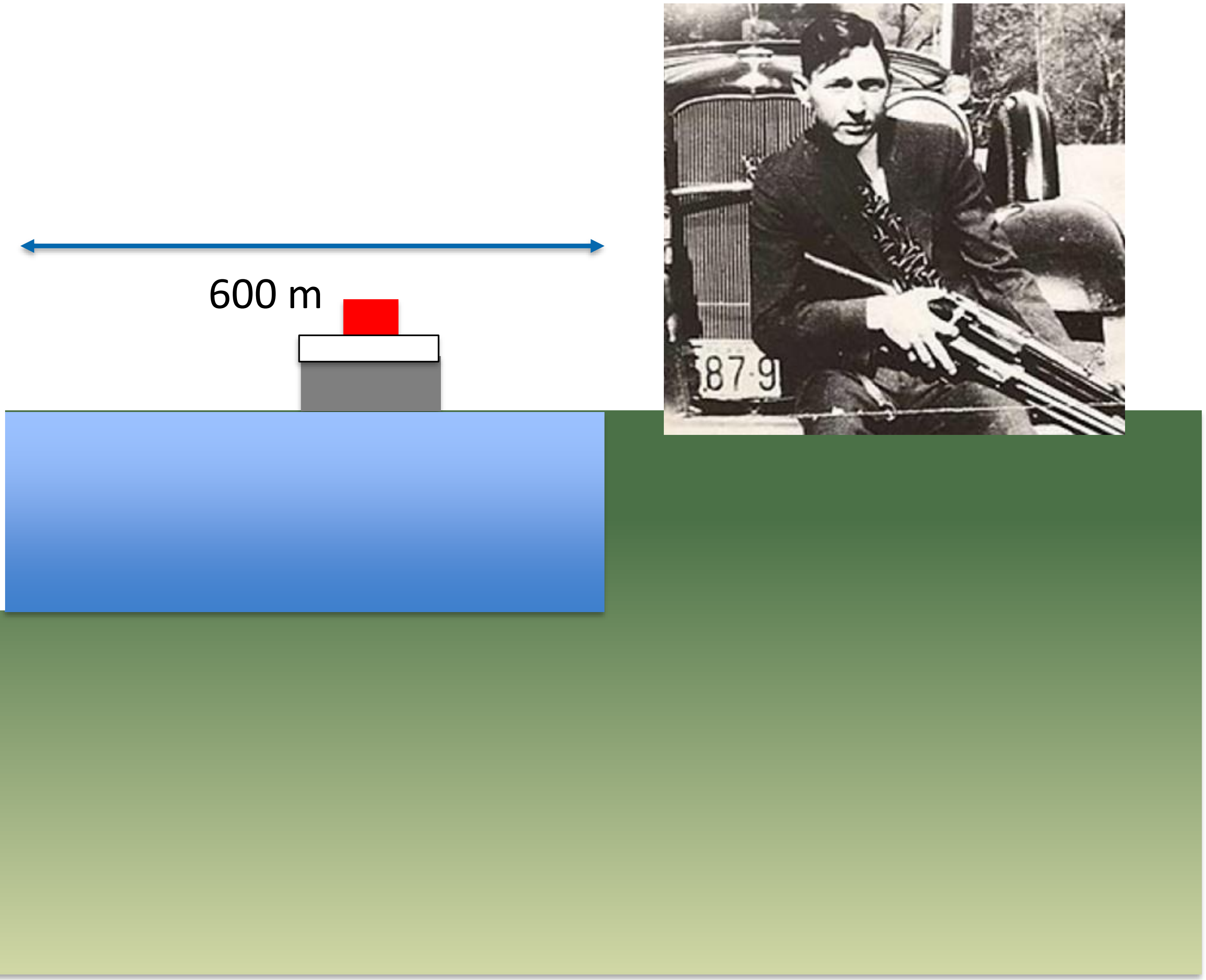
NON-LINEAT CRYSTAL

MIRROR

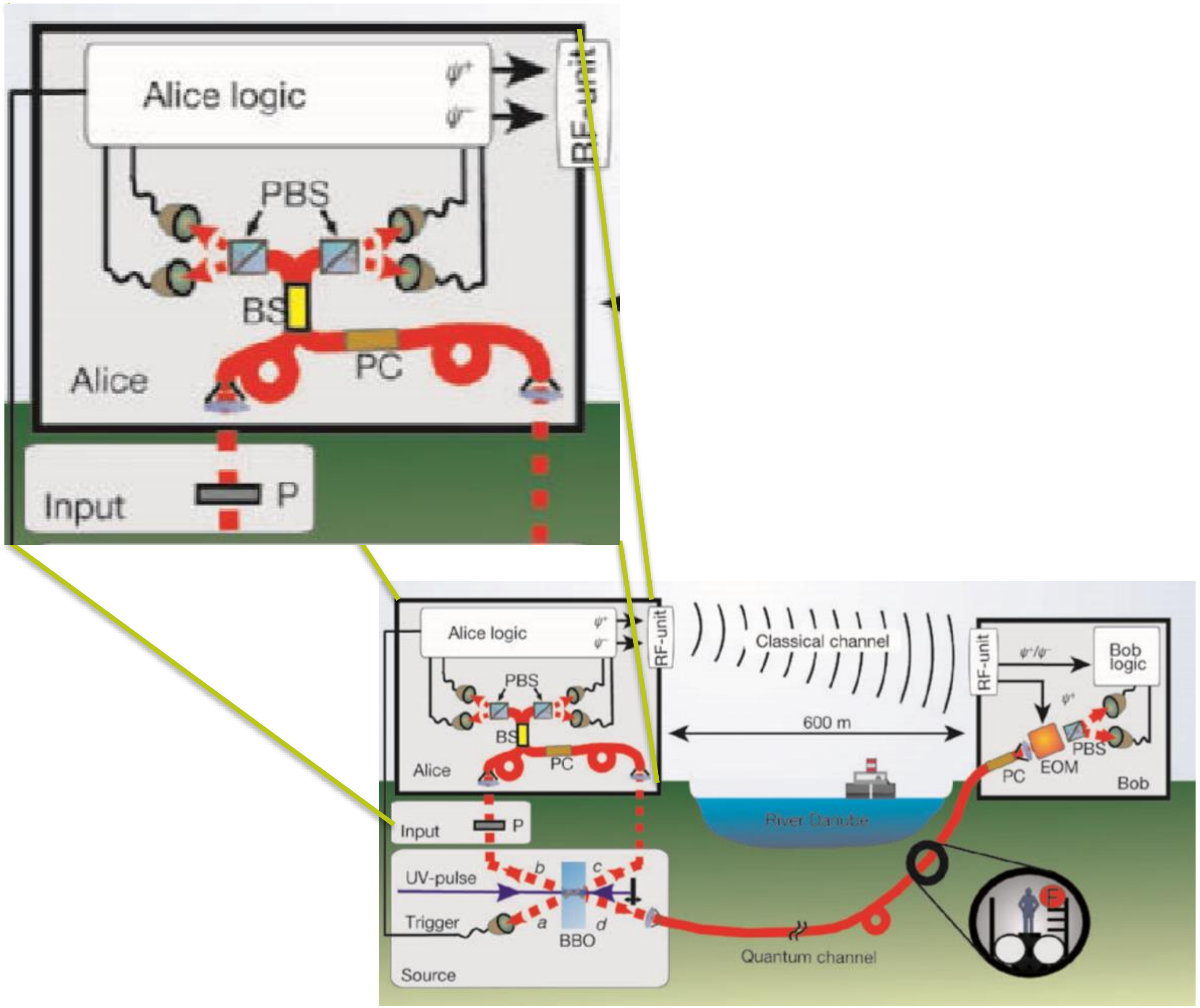


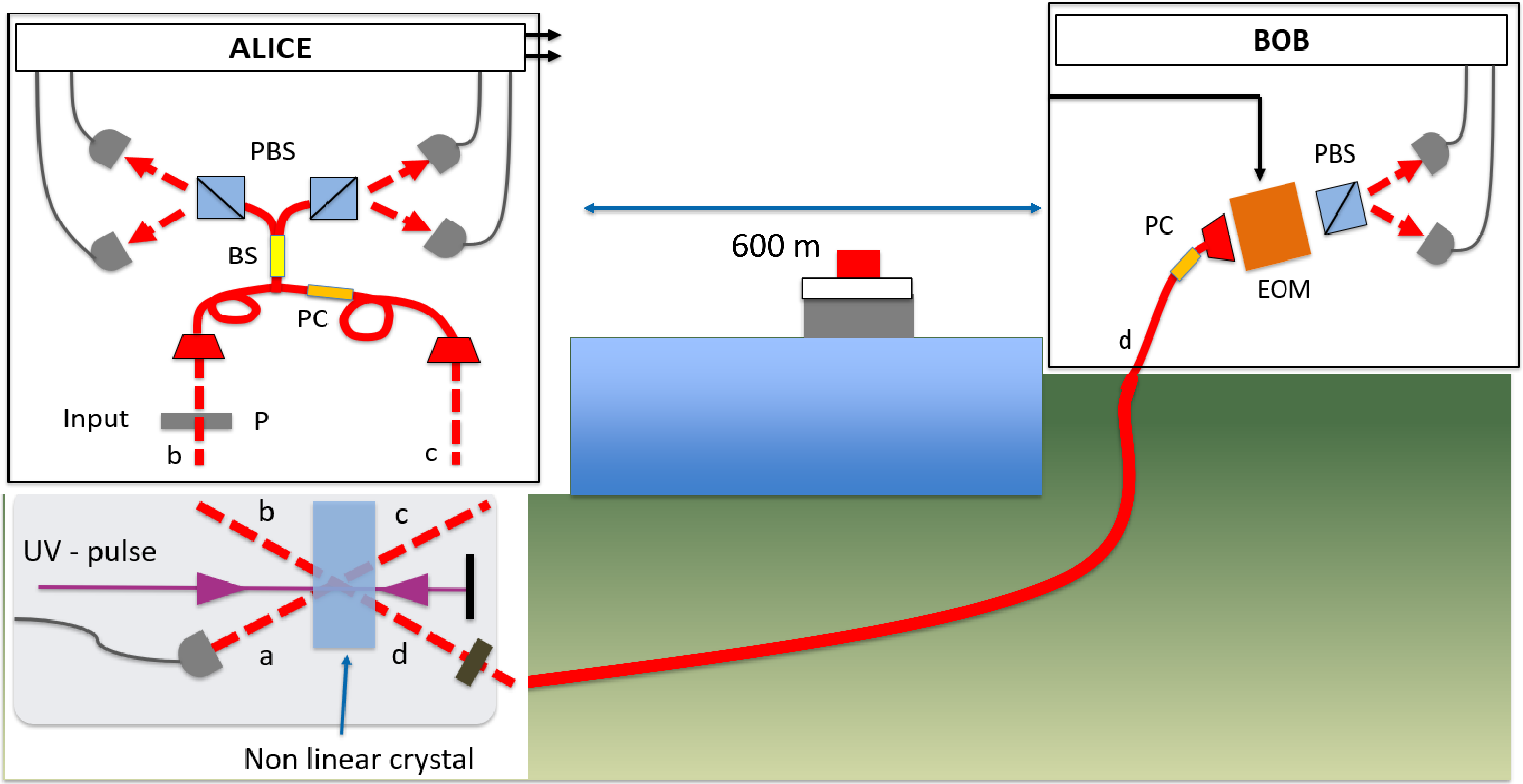

ALICE
PBS
BS
PC
Input
P
b
c


UV - pulse
b
c
a
d
Non linear crystal

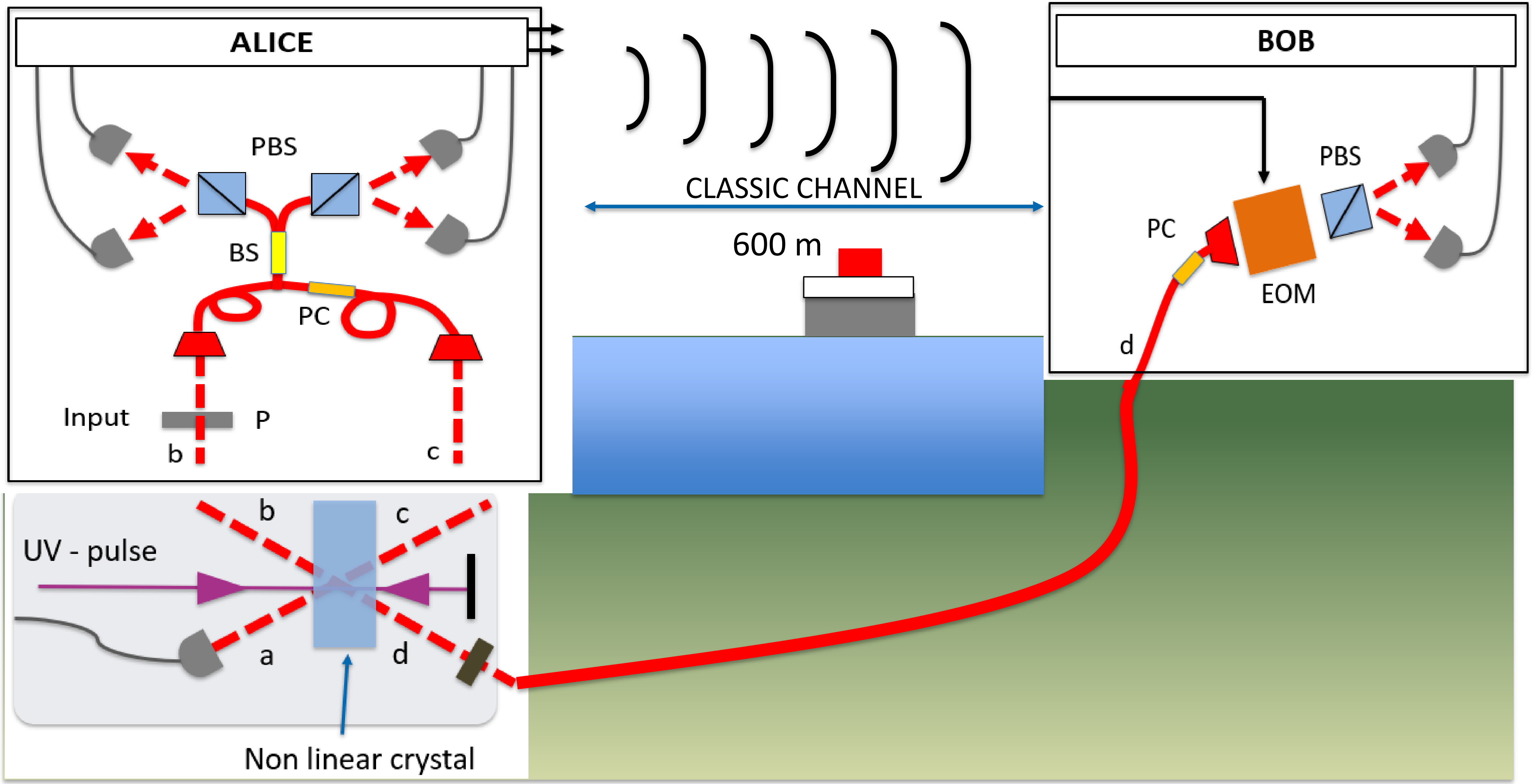

600 m

P (polarizator): preparation of teleportation input
SET UP: set of tools that allow us to make photons b and c entangled. We can say that they are entangled if the detectors measure a coincidence.

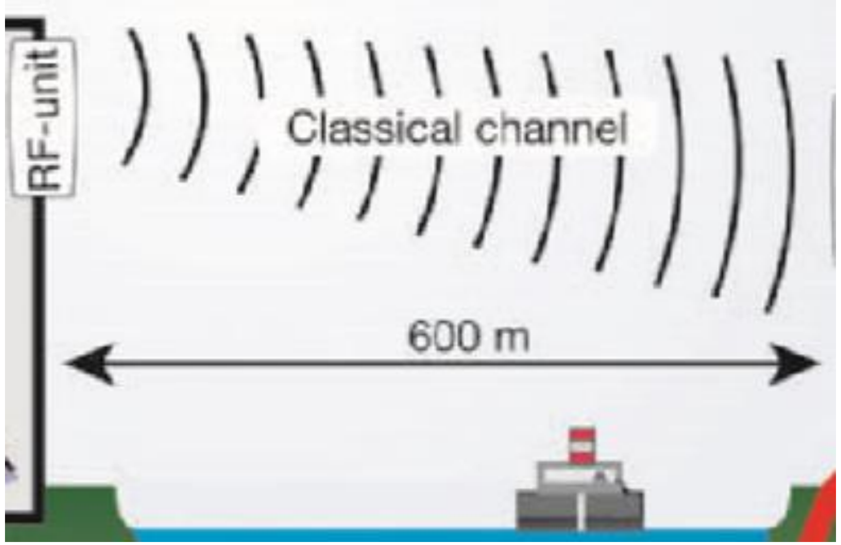


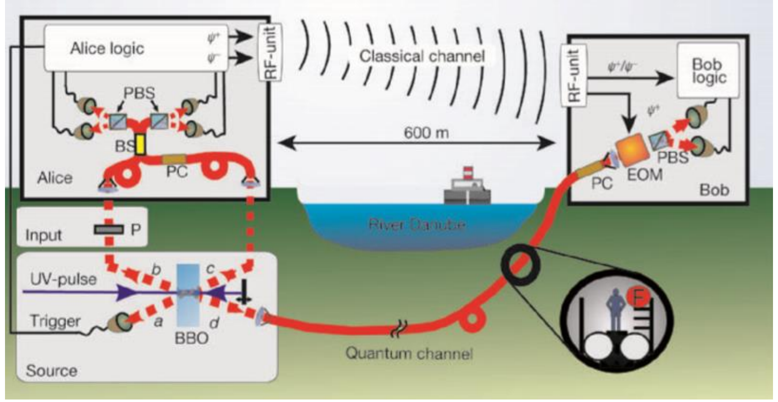


IDSEE
It's your time to imagine the futures

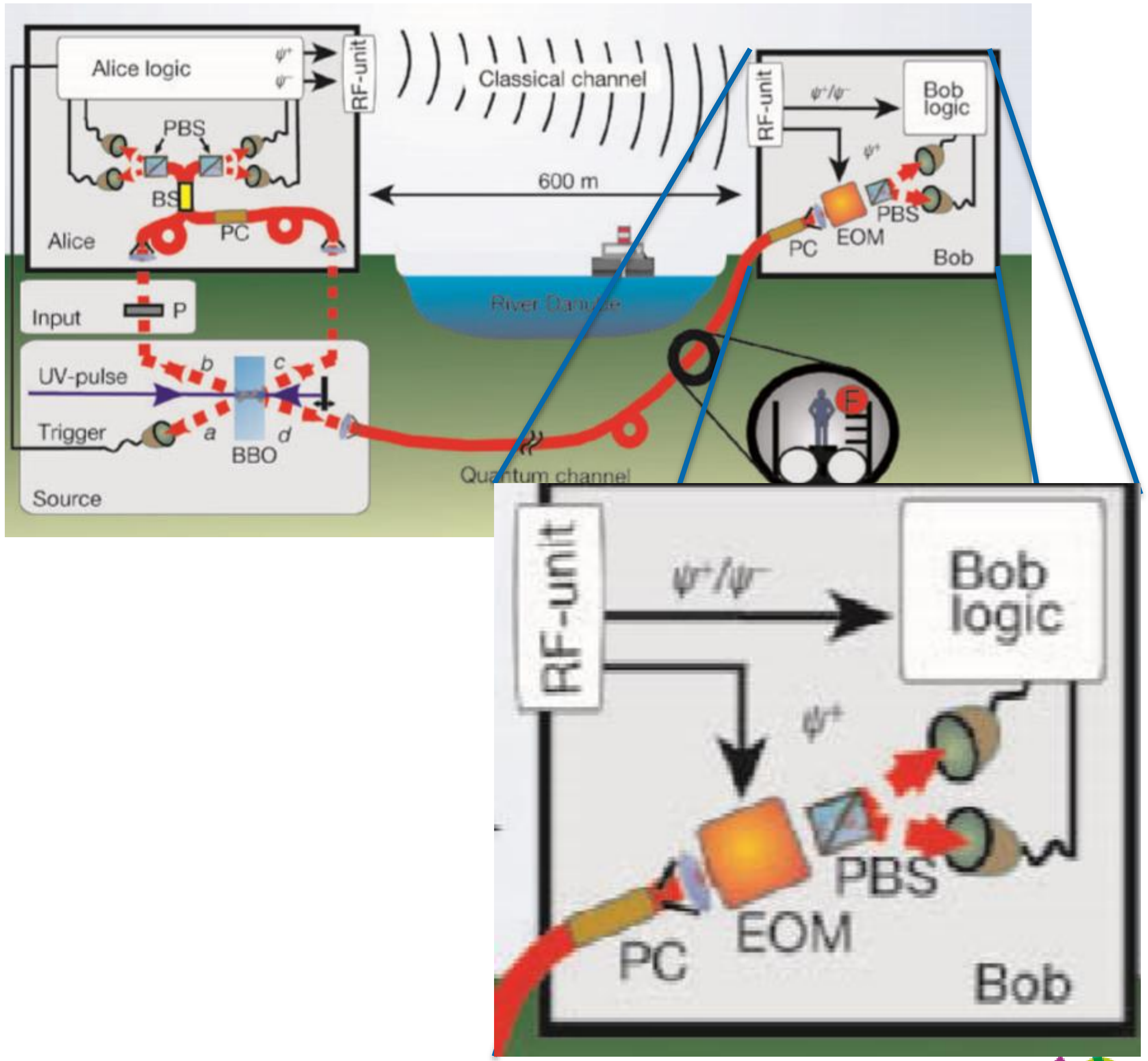

ALICE
PBS
BS
PC
Input
P
b
c
CLASSIC CHANNEL
600 m
BOB
PBS
PC
EOM
d
UV - pulse
b
c
a
d
Non linear crystal

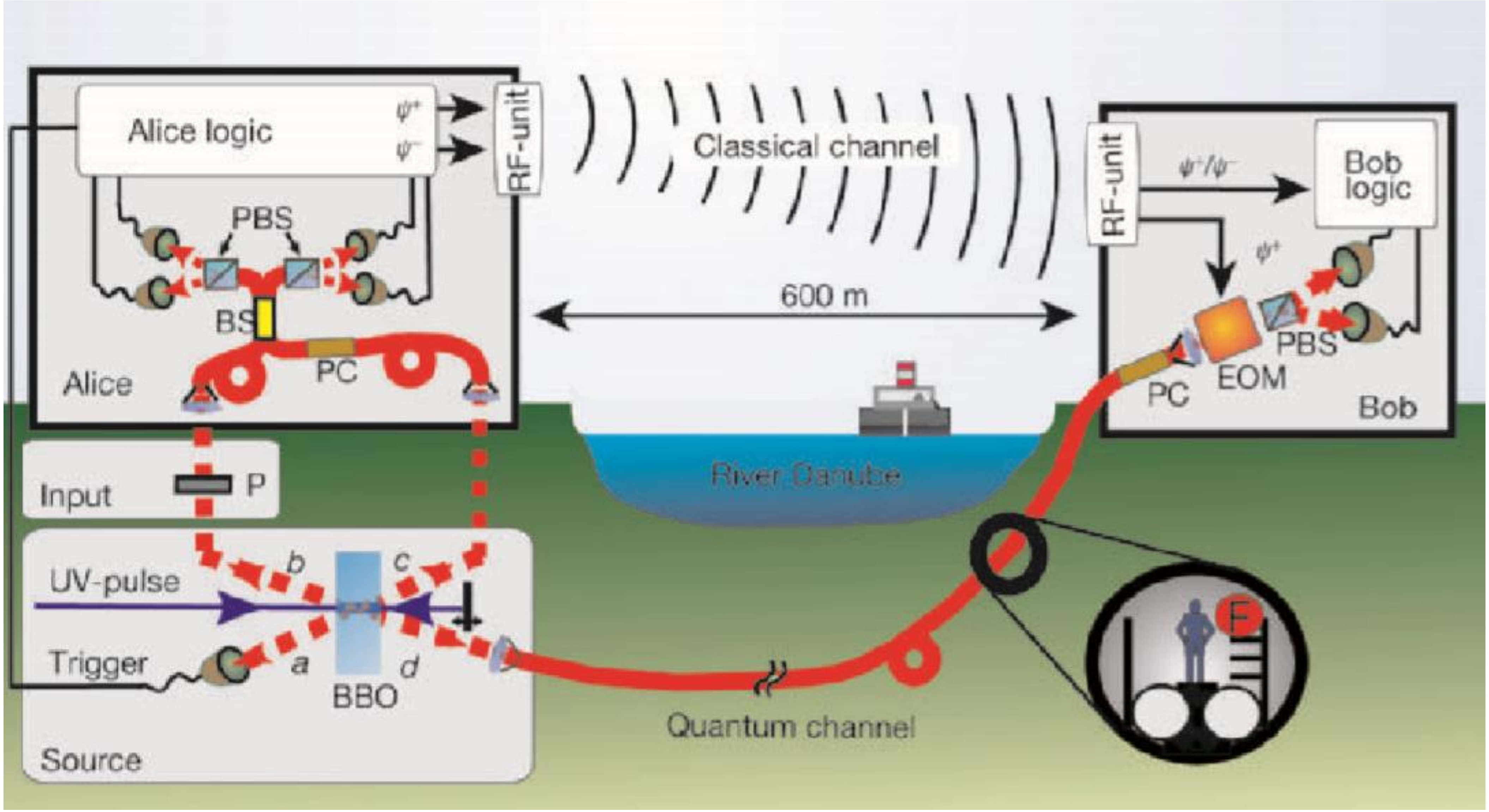
Through classic channel Alice relates to Bob the outcome of her measurements. Teleportation occurs because Bob receives the outcome of the measure of Alice 1.5 μs before the photon d reaches him.

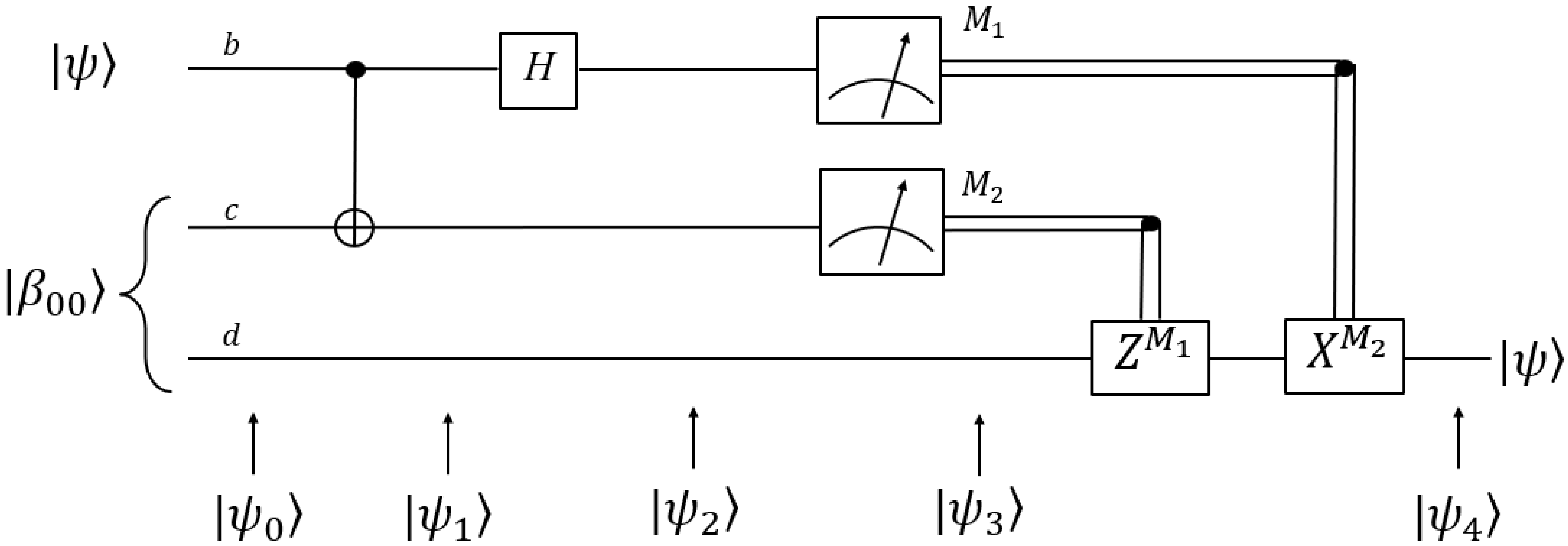


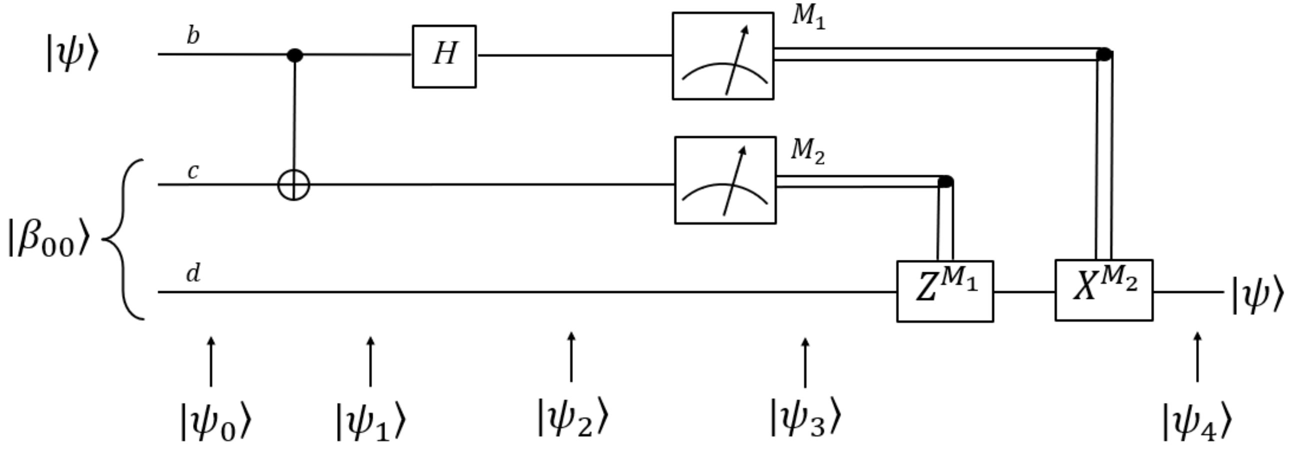


Based on the result communicated to him by Alice, Bob applies (or does not) a voltage via EOM in order to obtain the teleportation input.




Alice logic
ψ+
ψ−
RF-unit
Classical channel
RF-unit
ψ+/ψ−
Bob logic
PBS
BS
PC
Alice
ψ+
600 m
PBS
PC
EOM
Bob
Input
P
River Danube
UV-pulse
b
c
Trigger
a
d
BBO
Quantum channel
Source
E


$|\psi\rangle$
$|\beta_{00}\rangle$
b
c
d
H
M_1
M_2
Z^{M_1}
X^{M_2}
$|\psi\rangle$
$|\psi_0\rangle$
$|\psi_1\rangle$
$|\psi_2\rangle$
$|\psi_3\rangle$
$|\psi_4\rangle$



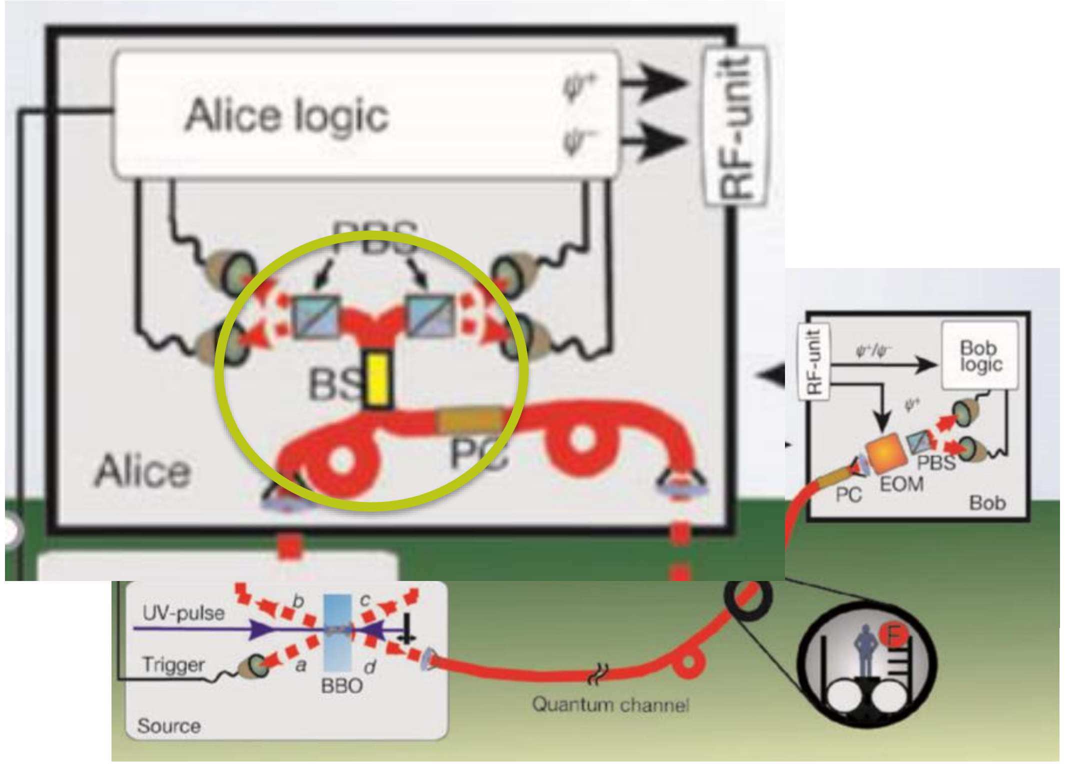
$$|\psi\rangle = \alpha|0\rangle_b + \beta|1\rangle_b$$

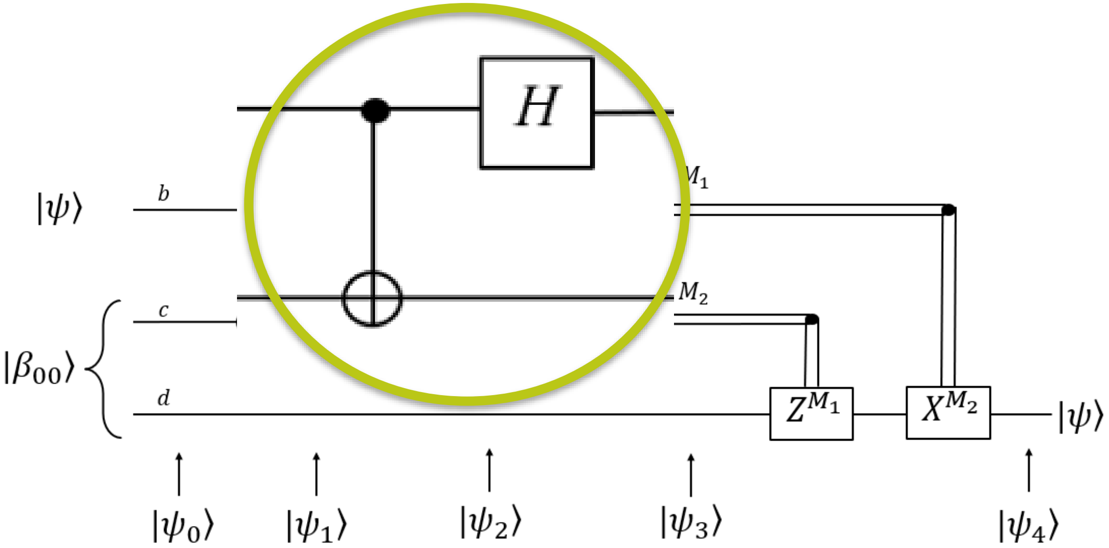
$$|\beta_{00}\rangle = \frac{|00\rangle_{cd} + |11\rangle_{cd}}{\sqrt{2}}$$

$$|\psi_0\rangle = |\psi\rangle|\beta_{00}\rangle = (\alpha|0\rangle_b + \beta|1\rangle_b)\,\frac{|00\rangle_{cd} + |11\rangle_{cd}}{\sqrt{2}}$$

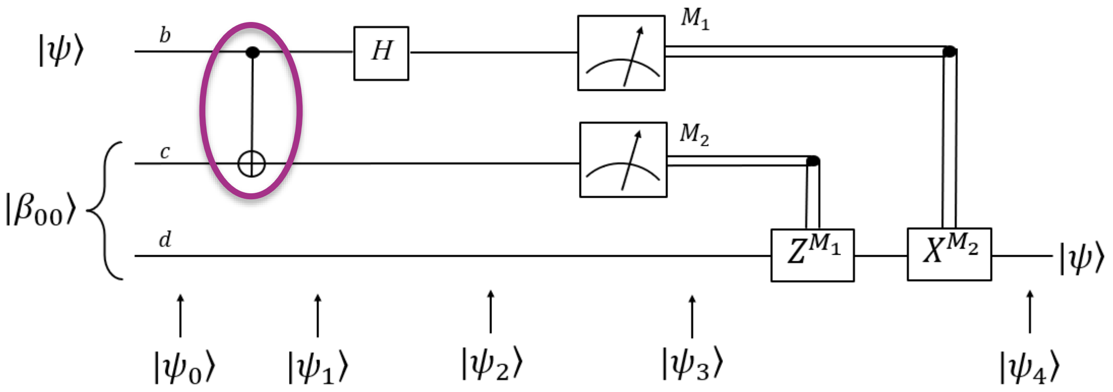
$$|\psi_0\rangle = (\alpha|0\rangle_b + \beta|1\rangle_b)\ \frac{|00\rangle_{cd} + |11\rangle_{cd}}{\sqrt{2}}$$

$$|\psi_0\rangle = \frac{1}{\sqrt{2}}[\alpha|0\rangle_b(|00\rangle_{cd} + |11\rangle_{cd}) + \beta|1\rangle_b(|00\rangle_{cd} + ||11\rangle_{cd})]$$

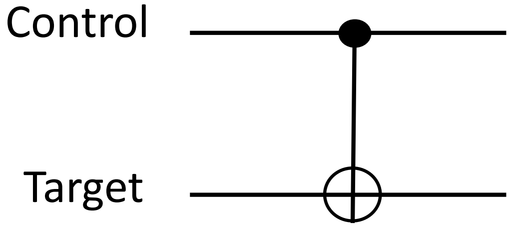

Alice logic
ψ+
ψ−
RF-unit
PBS
BS
PC
Alice
UV-pulse
Trigger
BBO
Source
a
b
c
d
Quantum channel
RF-unit
Bob logic
PBS
EOM
PC
Bob


|ψ⟩
b
c
d
|β00⟩
H
M1
M2
Z^M1
X^M2
|ψ⟩
|ψ0⟩
|ψ1⟩
|ψ2⟩
|ψ3⟩
|ψ4⟩

$$|\psi_0\rangle = |\psi\rangle|\beta_{00}\rangle = \frac{1}{\sqrt{2}}[\alpha|0\rangle_b(|00\rangle_{cd} + |11\rangle_{cd}) + \beta|1\rangle_b(|00\rangle_{cd} + ||11\rangle_{cd})]$$



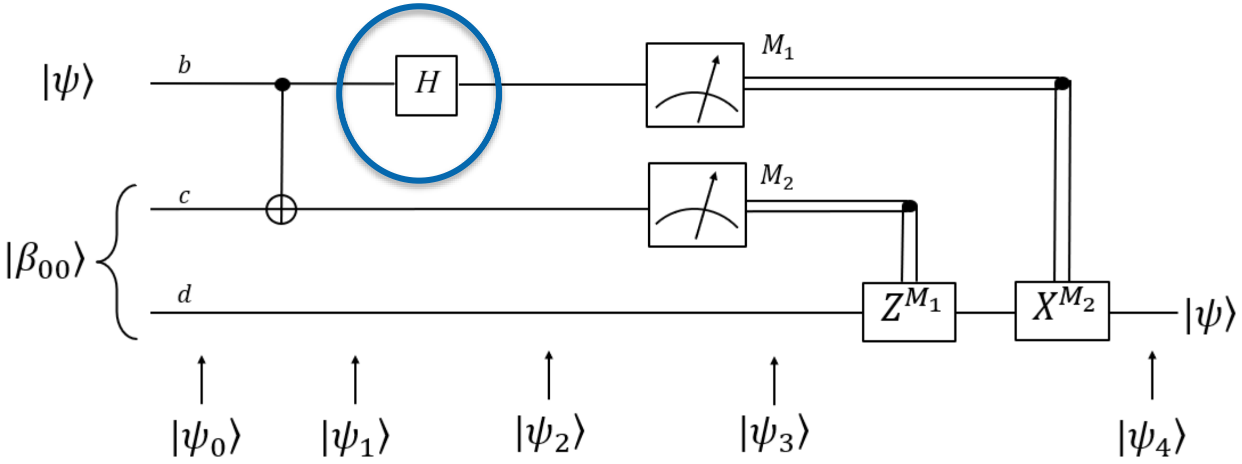
CNOT GATE



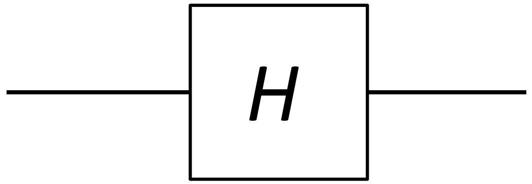
Prima		Dopo	
Control	Target	Control	Target
$\|0\rangle$	$\|0\rangle$	$\|0\rangle$	$\|0\rangle$
$\|0\rangle$	$\|1\rangle$	$\|0\rangle$	$\|1\rangle$
$\|1\rangle$	$\|0\rangle$	$\|1\rangle$	$\|1\rangle$
$\|1\rangle$	$\|1\rangle$	$\|1\rangle$	$\|0\rangle$

$$|\boldsymbol{\psi_1}\rangle = \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}[\boldsymbol{\alpha}|\mathbf{0}\rangle_{\boldsymbol{b}}(|\mathbf{00}\rangle_{\boldsymbol{cd}} + |\mathbf{11}\rangle_{\boldsymbol{cd}}) + \boldsymbol{\beta}|\mathbf{1}\rangle_{\boldsymbol{b}}(|\mathbf{10}\rangle_{\boldsymbol{cd}} + |\mathbf{01}\rangle_{\boldsymbol{cd}})]$$

$$|\psi_1\rangle = \frac{1}{\sqrt{2}}[\alpha|0\rangle_b(|00\rangle_{cd} + |11\rangle_{cd}) + \beta|1\rangle_b(|10\rangle_{cd} + |01\rangle_{cd})]$$



HADAMARD GATE



Prima	Dopo
$\|0\rangle$	$\frac{\|0\rangle + \|1\rangle}{\sqrt{2}}$
$\|1\rangle$	$\frac{\|0\rangle - \|1\rangle}{\sqrt{2}}$

$$|\psi_2\rangle = \frac{1}{2}[\alpha(|0\rangle_b + |1\rangle_b)\,(|00\rangle_{cd} + |11\rangle_{cd}) +$$

$$+\,\beta(|0\rangle_b - |1\rangle_b)(|10\rangle_{cd} + |01\rangle_{cd}]$$

$$|\psi_2\rangle = \frac{1}{2}[\alpha|00\rangle_{bc}|0\rangle_d + \alpha|10\rangle_{bc}|0\rangle_d + \alpha|01\rangle_{bc}|1\rangle_d + \alpha|11\rangle_{bc}|1\rangle_d +$$

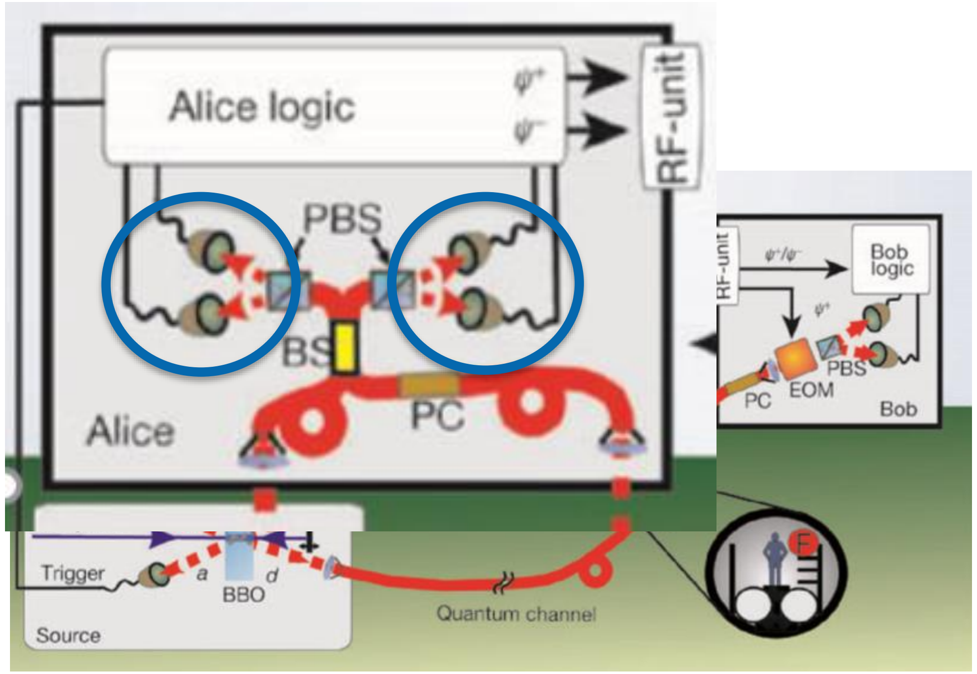
$$+ \beta|01\rangle_{bc}|0\rangle_d - \beta|11\rangle_{bc}|0\rangle_d + \beta|00\rangle_{bc}|1\rangle_d - \beta|10\rangle_{bc}|1\rangle_d]$$

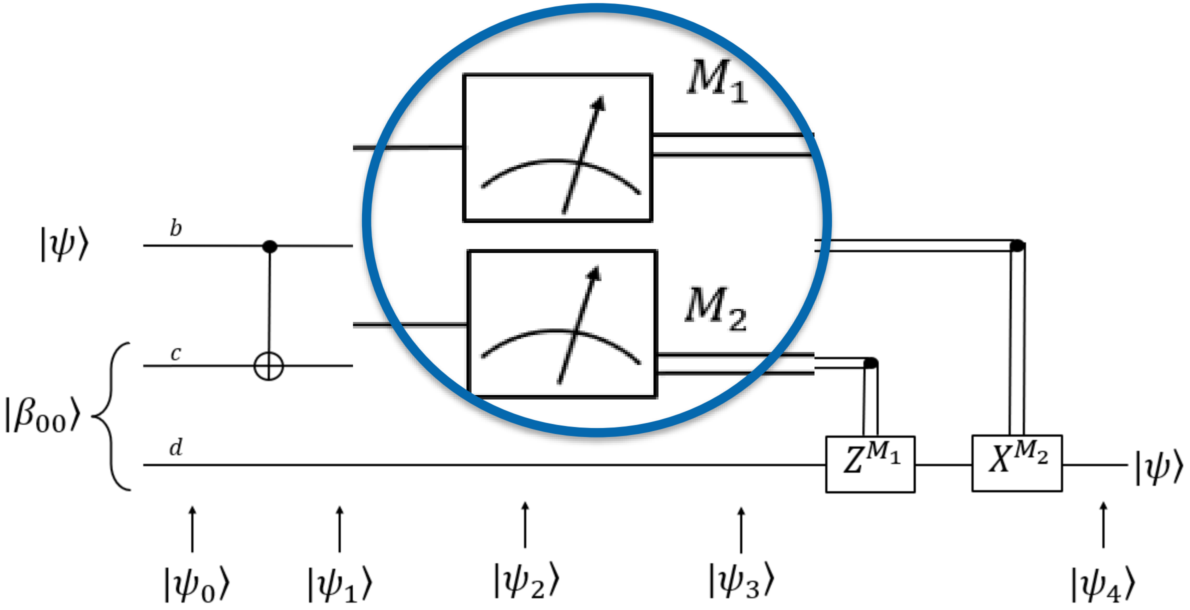
It's your time to imagine the futures

Riorganizzando i termini

$$|\psi_2\rangle = \frac{1}{2}[|00\rangle_{bc}(\alpha|0\rangle_d + \beta|1\rangle_d) + |01\rangle_{bc}(\alpha|1\rangle_d + \beta|0\rangle_d) +$$

$$+|10\rangle_{bc}(\alpha|0\rangle_d - \beta|1\rangle_d) + |11\rangle_{bc}(\alpha|1\rangle_d - \beta|0\rangle_d)]$$



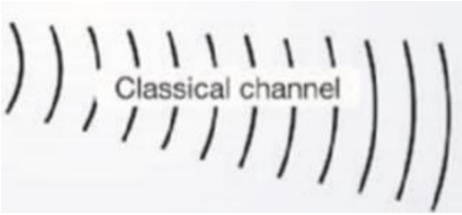


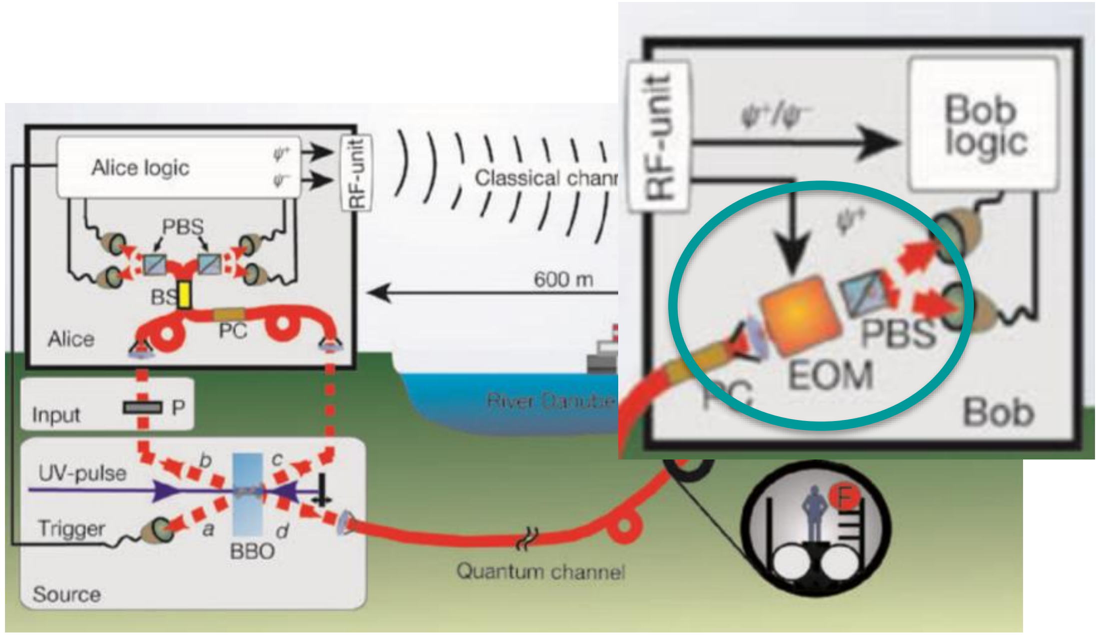
I)◊< SEE
It's your time to imagine the futures

$$|\psi_2\rangle = \frac{1}{2}[|00\rangle_{bc}(\alpha|0\rangle_d + \beta|1\rangle_d) + |01\rangle_{bc}(\alpha|1\rangle_d + \beta|0\rangle_d) +$$

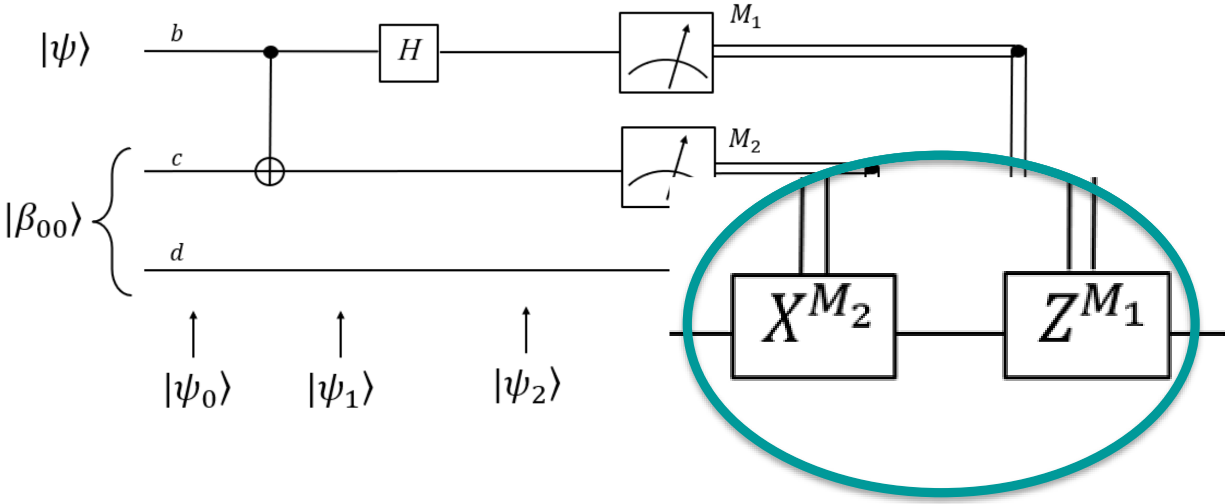
$$+|10\rangle_{bc}(\alpha|0\rangle_d - \beta|1\rangle_d) + |11\rangle_{bc}(\alpha|1\rangle_d - \beta|0\rangle_d)]$$

ALICE	BOB
00	$\lvert\psi_3(00)\rangle \equiv [\alpha\lvert 0\rangle + \beta\lvert 1\rangle]$
01	$\lvert\psi_3(01)\rangle \equiv [\alpha\lvert 1\rangle + \beta\lvert 0\rangle]$
10	$\lvert\psi_3(10)\rangle \equiv [\alpha\lvert 0\rangle - \beta\lvert 1\rangle]$
11	$\lvert\psi_3(11)\rangle \equiv [\alpha\lvert 1\rangle - \beta\lvert 0\rangle]$

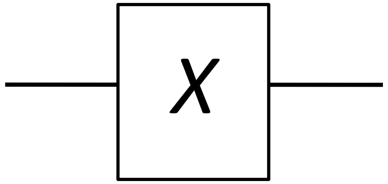




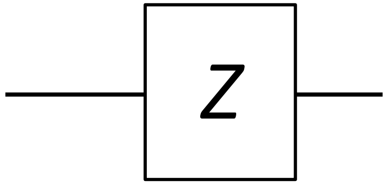
Alice logic
RF-unit
Classical chann
PBS
BS
PC
Alice
600 m
Input
P
UV-pulse
b
c
Trigger
a
d
BBO
Source
River Danube
Quantum channel
RF-unit
ψ^+/ψ^-
Bob logic
ψ^+
EOM
PBS
Bob



$|\psi\rangle$
b
c
d
$|\beta_{00}\rangle$
H
M_1
M_2
X^{M_2}
Z^{M_1}
$|\psi_0\rangle$
$|\psi_1\rangle$
$|\psi_2\rangle$



Prima	Dopo
$\|0\rangle$	$\|1\rangle$
$\|1\rangle$	$\|0\rangle$



Prima	Dopo
$\|0\rangle$	$\|0\rangle$
$\|1\rangle$	$-\|1\rangle$

ALICE	BOB		BOB
00	$[\alpha\|0\rangle + \beta\|1\rangle]$		$[\alpha\|0\rangle + \beta\|1\rangle]$
01	$[\alpha\|1\rangle + \beta\|0\rangle]$	X	$[\alpha\|0\rangle + \beta\|1\rangle]$
10	$[\alpha\|0\rangle - \beta\|1\rangle]$	Z	$[\alpha\|0\rangle + \beta\|1\rangle]$
11	$[\alpha\|1\rangle - \beta\|0\rangle]$	X Z	$[\alpha\|0\rangle + \beta\|1\rangle]$

What does it mean to teleport a state?

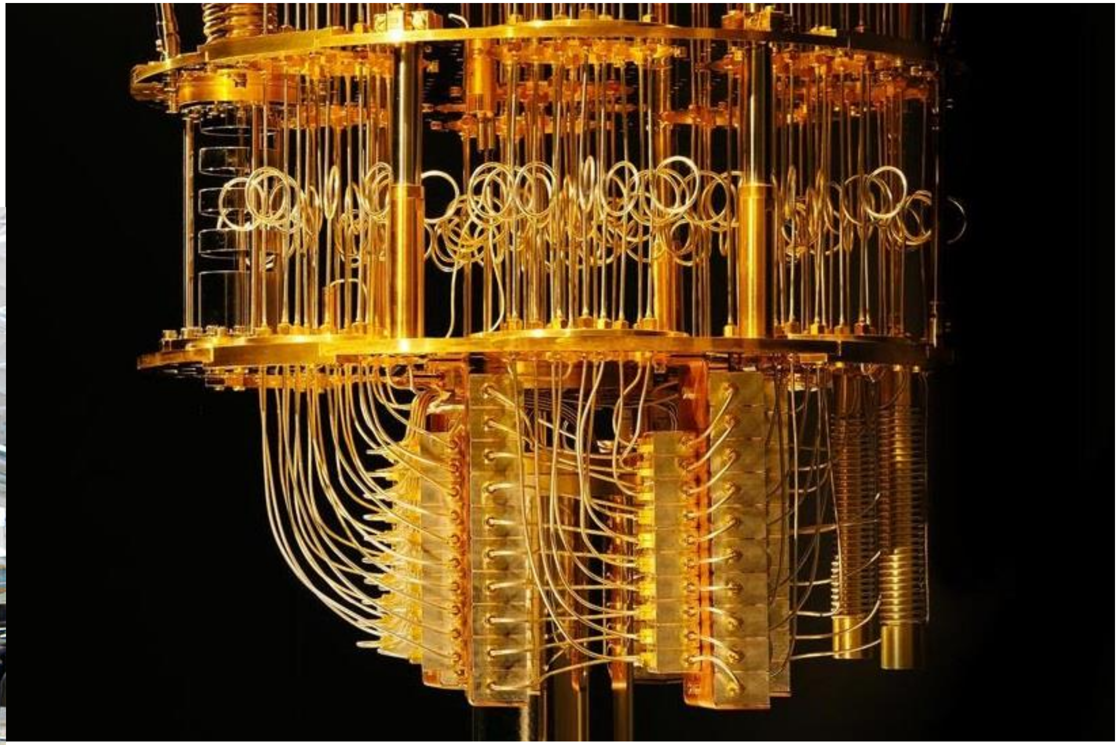
So:

ONLY the STATE of the photon is teleported and not the photon itself

THE PHOTON ALSO RAMAINS TO ALICE

But then, does the state go faster than light? Did the information pass instantly to Bob? What happens to the state of Alice?

And now, what is the teleportation for?




D:wave
D:wave
D:wave

The transition to miniaturization is not foreseen, we will have access, through the network, to a shared pool of computing resources (to a quantum computer) cloud computing

MEMORY → CRYSTAL/ATOMS

PROCESSOR → ACCESS TO PROCESSORS THROUGH CLOUD

LINK OF NETWORK → QUANTUM INTERNET AND QUANTUM REPEATERS

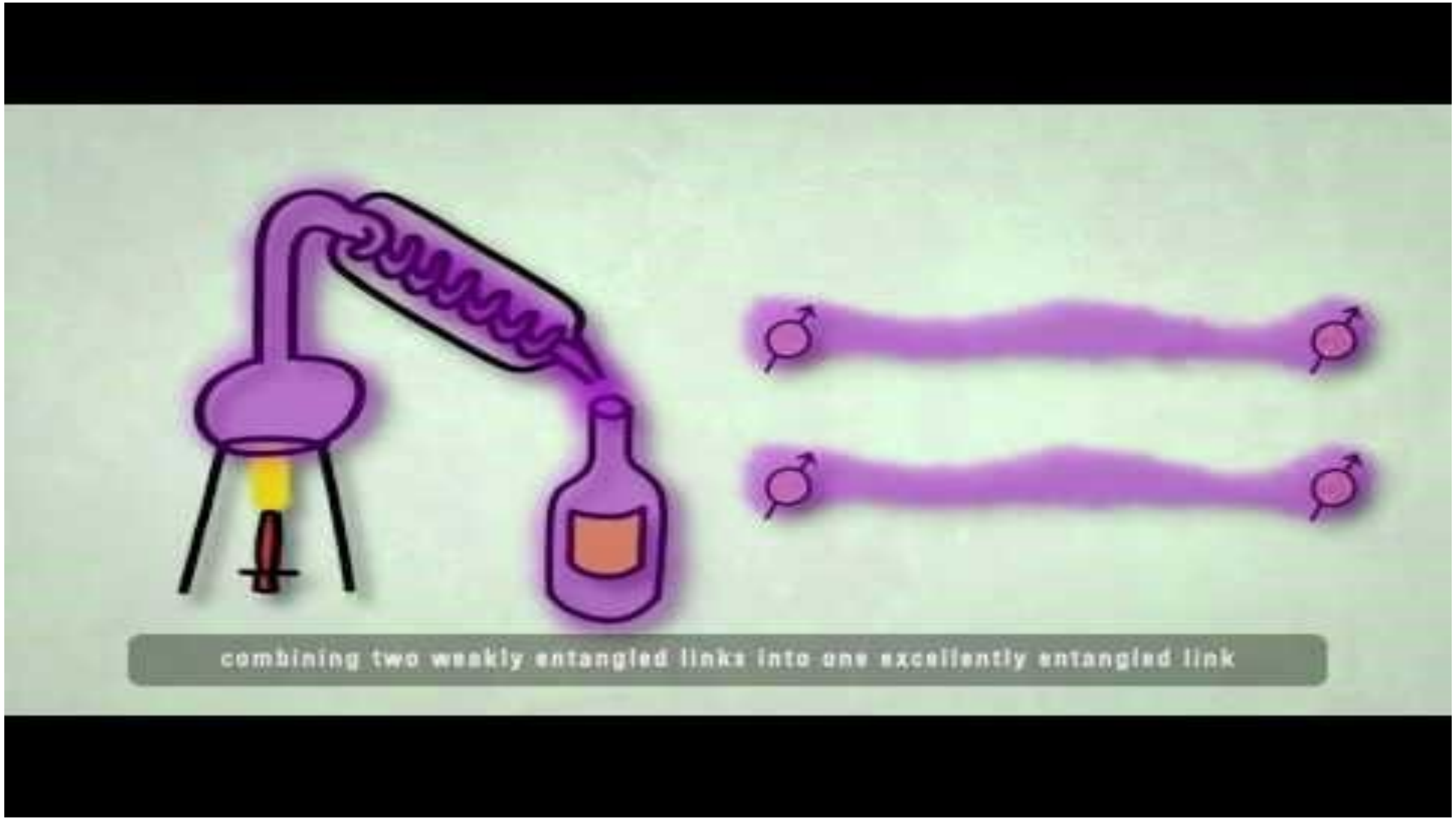
PROBLEM:
The entanglement is fragile

Decoherence due to the interaction of the quantum system with the environment

Quantum noise

The signal is affected by effects of change in the shape of the fiber, i.e. absorption, dispersion and non-linearity

Creation of a strongly entangled bond by combining weaker quantum bonds into one (distillation).



What do we need?

Quantum communication is limited to a range of about 100 km beyond which states can no longer be reliably measured.

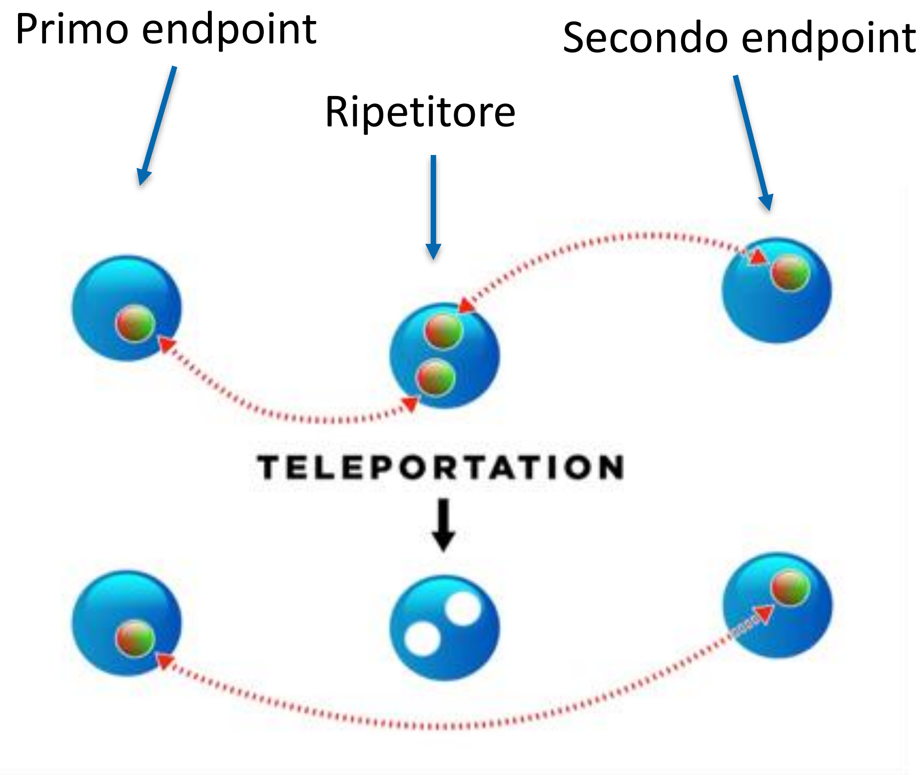
We need a **quantum repeater** that, similarly to the classical one, can extend the range of quantum communication between sender and receiver.

It's your time to imagine the futures

Quantum repeater

We want to transmit information between two nodes of the network 200 km away, but they are too far away because the transmission directly. How do we do it?

1. We create the first two entangled qubits between the first endpoint and the repeater (100km apart).
2. We create the two entangled qubits between the repeater and the second endpoint (100km apart). The repeater uses quantum teleportation to transfer the qubit that is entangled with the first endpoint to the second endpoint, forming an entangled link.



Who works at quantum internet?

QuTech (research and development in quantum techonology).
A Delft group has already started building the first true quantum network in the Netherlands. This project should be completed by 2020, it could be the quantum version of ARPANET, a communication network developed by the US military in the late 1960s that paved the way for today's Internet.
(https://qutech.nl/one-step-closer-to-the-quantum-internet-by-distillation/)

Partners

FONDAZIONE GOLINELLI

LANDVERND
ICELANDIC ENVIRONMENT ASSOCIATION

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

UNIVERSITY OF HELSINKI

Liceo Scientifico Einstein

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STOFNAÐUR 1966

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Promoting Excellence in Science Teaching and Learning