Photonics quantum information

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Photonics quantum information

- Introduction :
  - ”Bits” of classical information
  - The quantum bits : ”Qbits”
- Quantum communication :
  - Source of Qbits
  - Sources of entangled Qbits
  - Quantum interference between independent Qbits
- Guided-wave quantum communication in Nice

Photonics quantum information

- **Introduction :**
  - **”Bits” of classical information**
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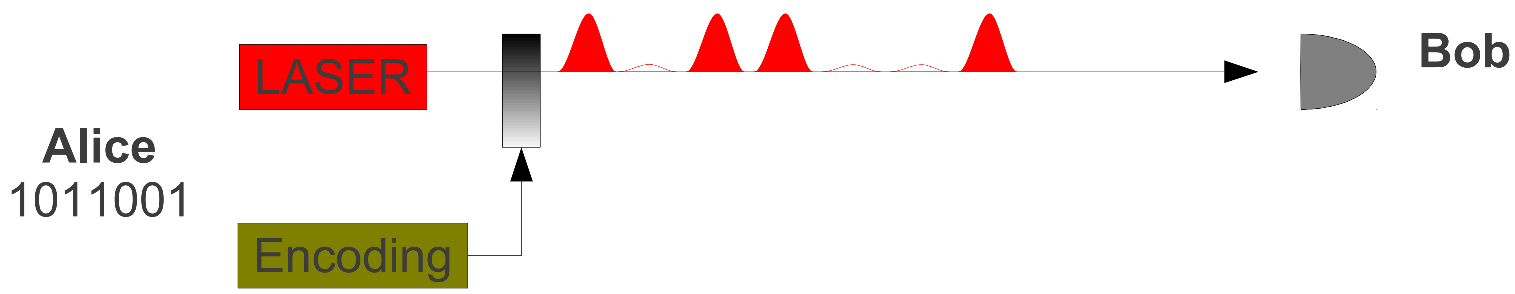
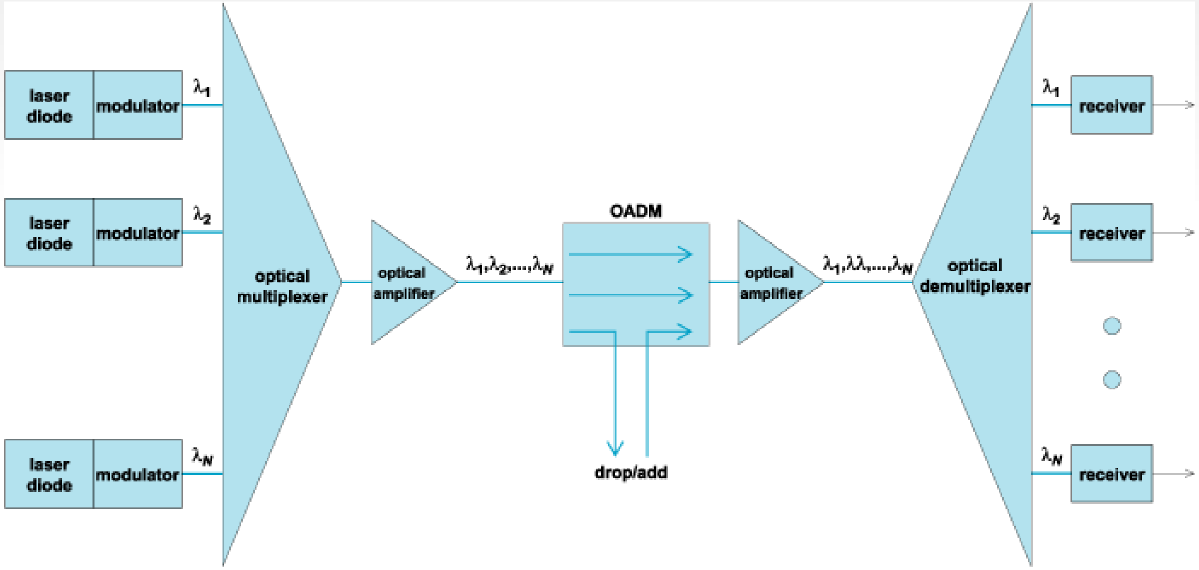
Bits of classical information

- Unit of information : **Bit**
- Carrier : **light pulse** with 0 or N photons
- Two possible states : **0** or **1**



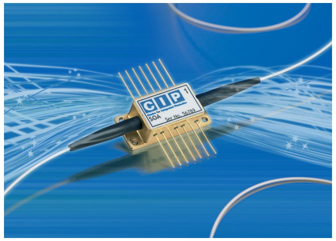
Bits of classical information

- **Optical communications:**
  - High communication rate : 40Gbit/s = 480000 phone call
  - High control :

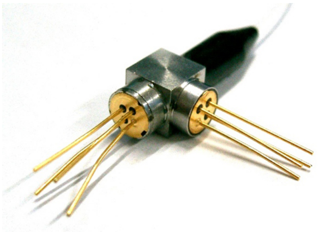


  - Highly compact technology

Source

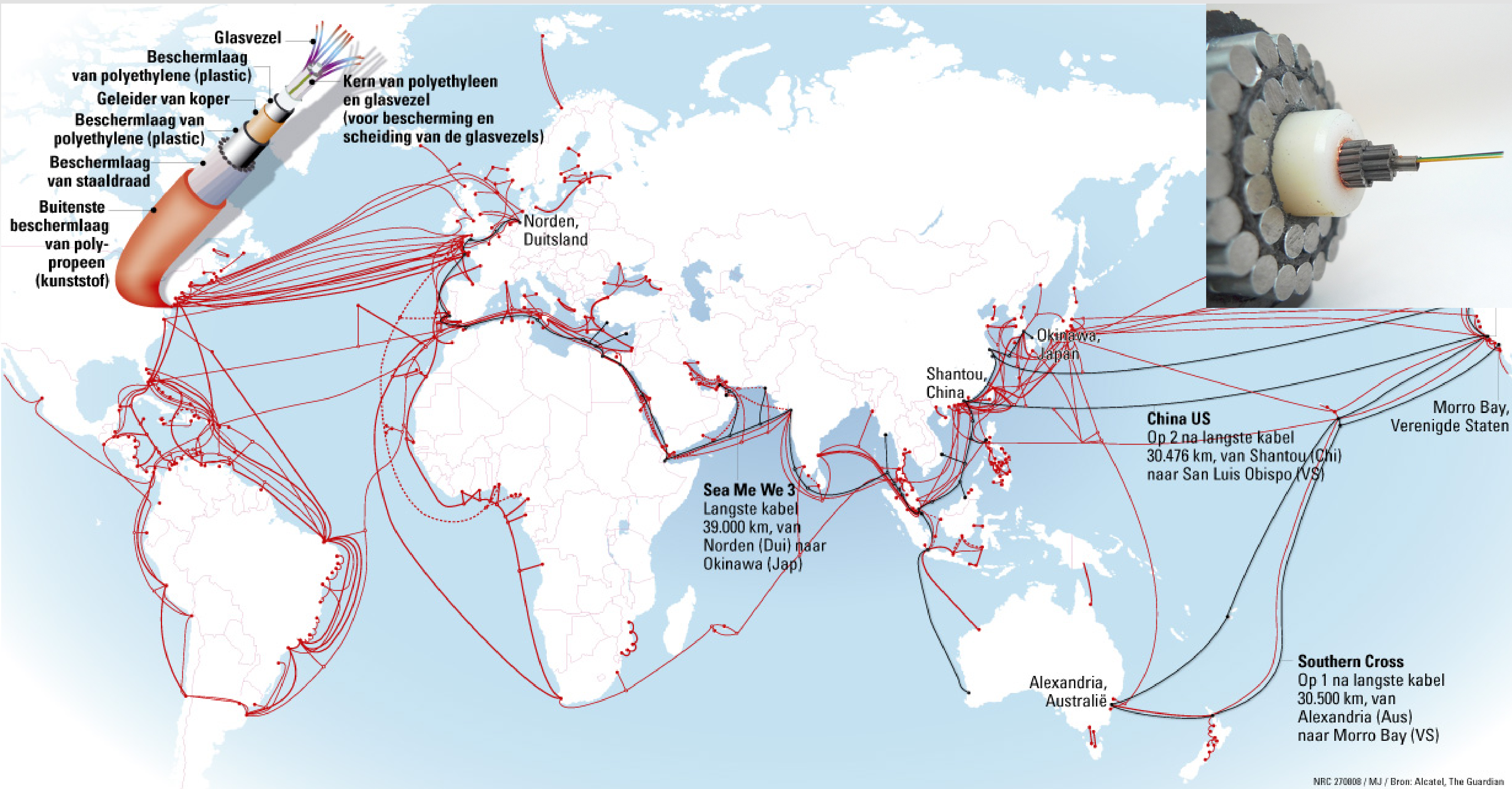


Amplifier

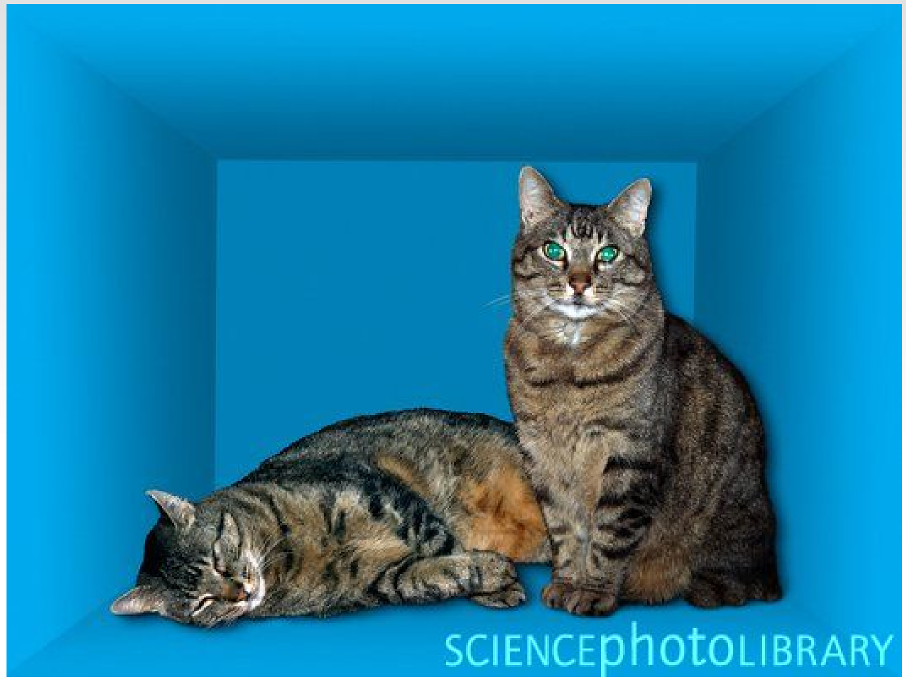


Detector

Bits of classical information



What does quantum physics add to the picture ?



What is quantum information ?
Bits vs Qbits

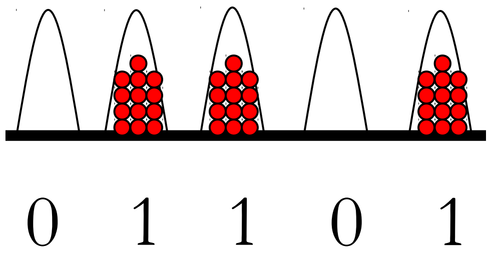
Classical Information

Elementary unit = **Bit**

2 possible states :

0 XOR 1

Light pulses



Quantum Information

Qubit

Coherent superposition of states

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

Single Q. systems (photons)

- 2 polar. states
- 2 times of emission

What is quantum information ?
Bits vs Qbits

Classical Information

Elementary unit = **Bit**

2 possible states :

0 XOR 1

Quantum Information

Qubit

Coherent superposition of states

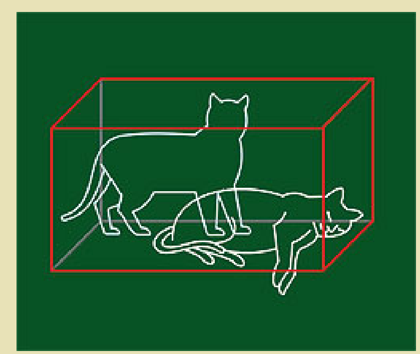
$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Copying is prohibited

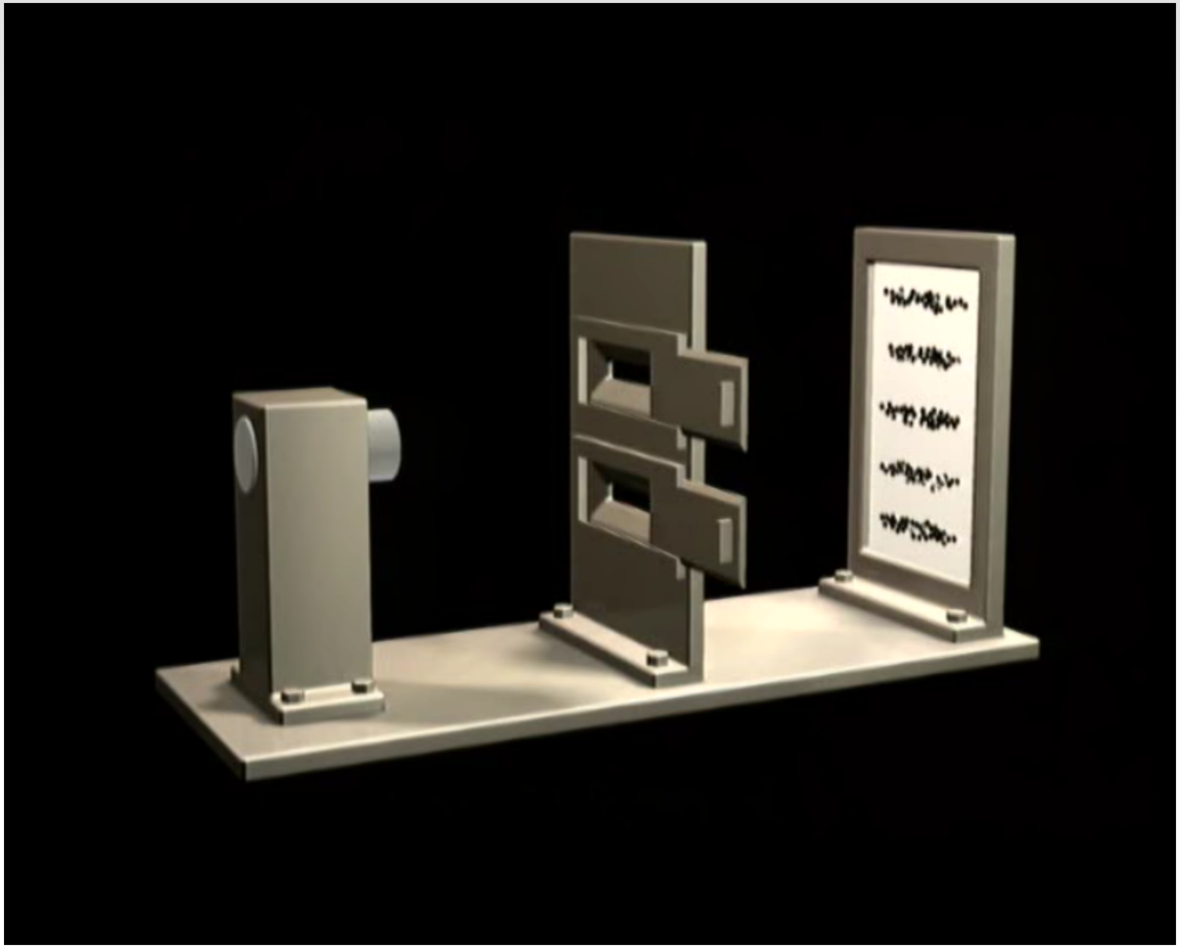
by Law !!

by Nature !!

$$|\Psi\rangle$$



Physical meaning of $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$



Only $|\psi\rangle = \frac{1}{\sqrt{2}}|top\rangle + \frac{1}{\sqrt{2}}|bot\rangle$ *can explain the interference pattern*

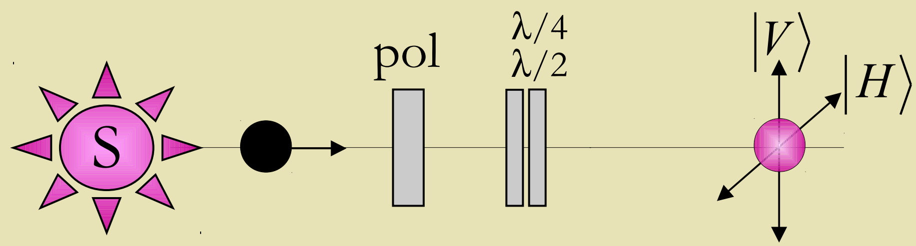
Photonic Qbit

Polarization Qbit

$$\Rightarrow |\psi\rangle = \alpha|H\rangle + \beta e^{i\phi}|V\rangle$$

Photonic Qbit

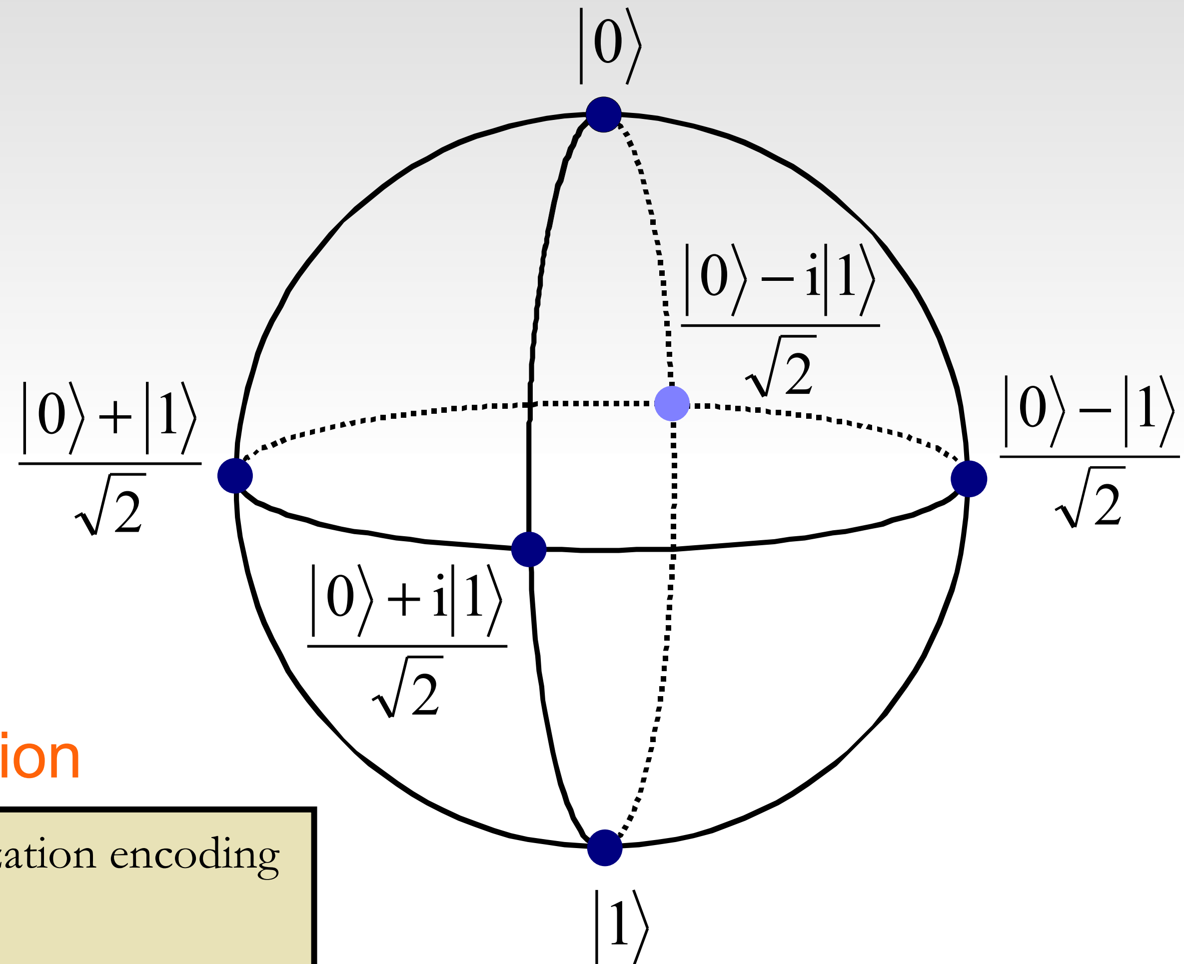
Polarization Qbit



$$\Rightarrow |\psi\rangle = \alpha|H\rangle + \beta e^{i\phi}|V\rangle$$

$$|\psi\rangle = \alpha|0\rangle + \beta e^{i\phi}|1\rangle$$

The Qbit Sphere

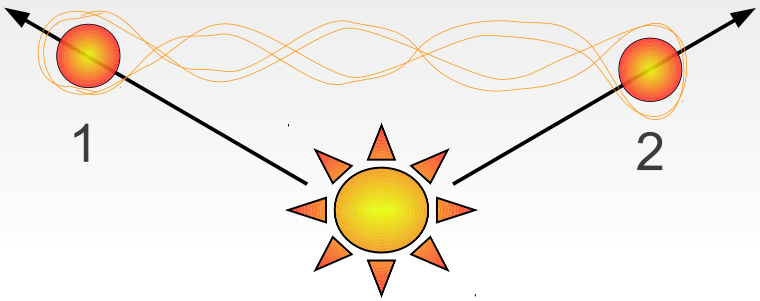


Equivalence Qbit / Polarisation

- $|0\rangle \; and \; |1\rangle$ $\Leftrightarrow$ H and V in the polarization encoding
- $\frac{|0\rangle \pm |1\rangle}{\sqrt{2}}$ $\Leftrightarrow$ diagonal polarizations
- $\frac{|0\rangle \pm i|1\rangle}{\sqrt{2}}$ $\Leftrightarrow$ left and right polarizations

The resources of Quantum information

Coherent superposition of correlated two photon states

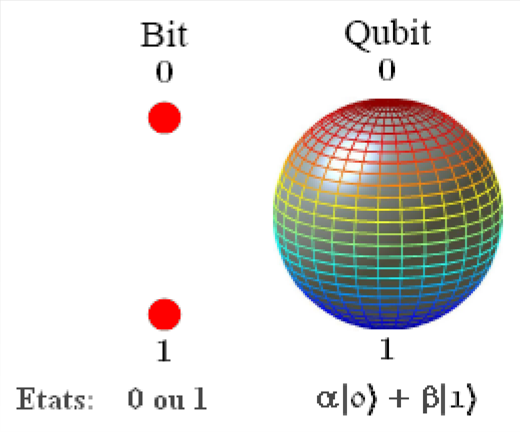


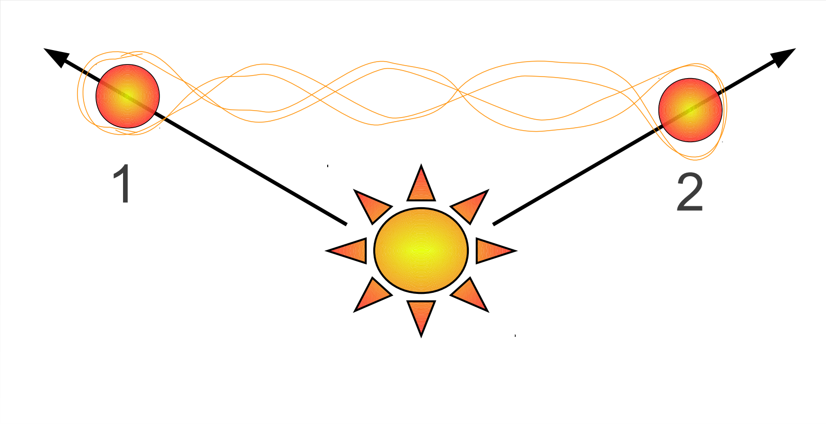
$$|\psi_{12}\rangle = \frac{|0\rangle_1|0\rangle_2 + |1\rangle_1|1\rangle_2}{\sqrt{2}} \neq |\Phi_1\rangle \otimes |\Phi_2\rangle$$

Entangled Qbits

Whatever the distance between the two photons : they behave as a single quantum object !!!

What can we do with quantum resources ?





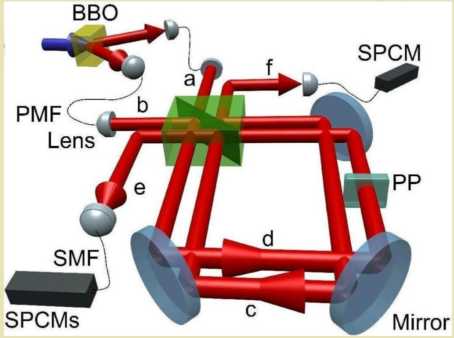
Quantum bits infinitely richer than classical bits

New range of operation impossible to realise with classical bits

Quantum communication

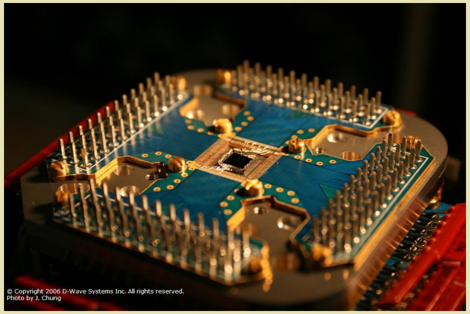
Quantum key distribution

Quantum metrology



Phase measurement

Quantum processing



Factoring large numbers

Photonics quantum information

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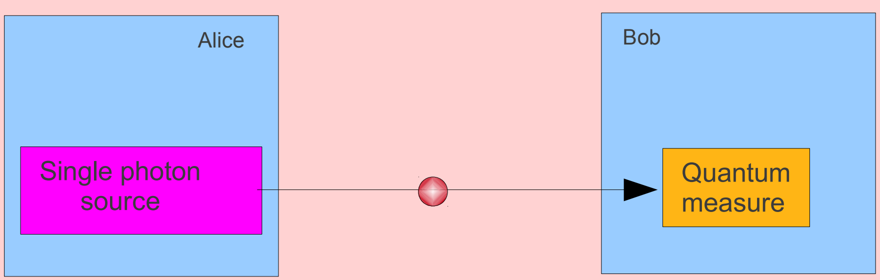
Quantum communication

⇨ Distribute Qubits between two or more partners

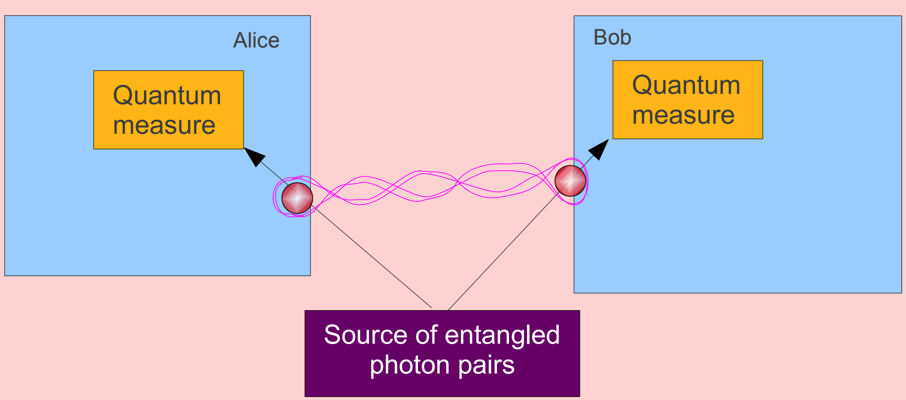
Quantum networking

Com. With single Qbits



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

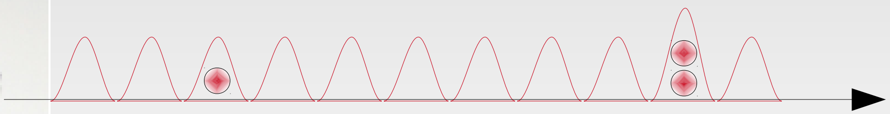
Com. with entangled Qbits



$$|\psi_{12}\rangle = \alpha|0\rangle_1|0\rangle_2 + \beta|1\rangle_1|1\rangle_2$$

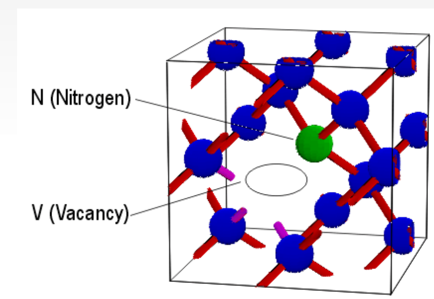
How to produce single Qbit ?

- Attenuated laser :



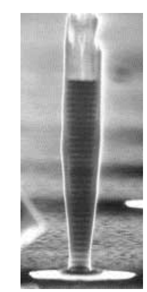
- Colored center in diamonds :

  Room temperature stable single-photon source.
  A. Beveratos, S. Kuhn, R. Brouri, T. Gacoin, J.-P. Poizat, and P. Grangier.
  Eur. Phys. J. D **18**, 191 (2002)



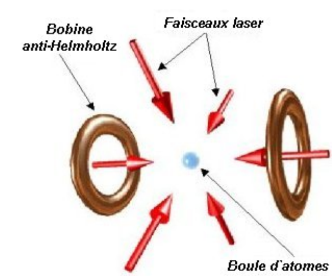
- Quantum dots in micro-pillars :

  Single-mode solid-state single photon source based on isolated quantum dots in pillar microcavities.
  E. Moreau, I. Robert, J. M. Gérard, I. Abram, L. Manin, and V. Thierry-Mieg.
  APL **79** (18), 2865 (2001)



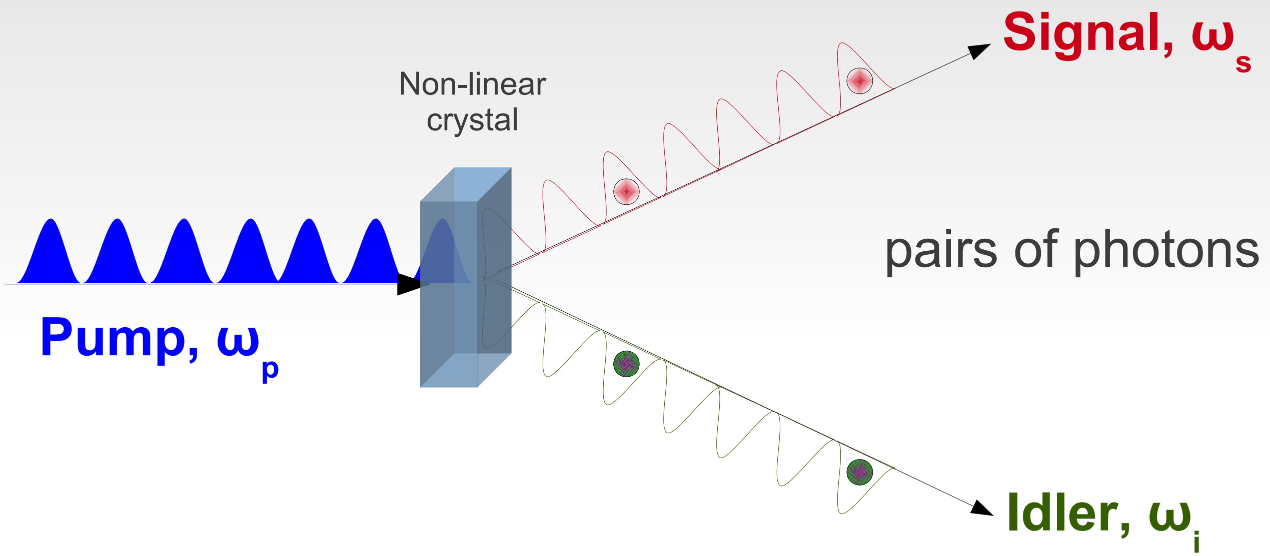
- Atoms (cold or in a cavity) :

  Generation of nonclassical photon pairs for scalable quantum communication with atomic ensembles
  A. Kuzmich, W. P. Bowen, A. D. Boozer, A. Boca, C. W. Chou, L.-M. Duan and H. J. Kimble
  Nature 423, 731-734 (2003)



Photon pairs for single Qbit

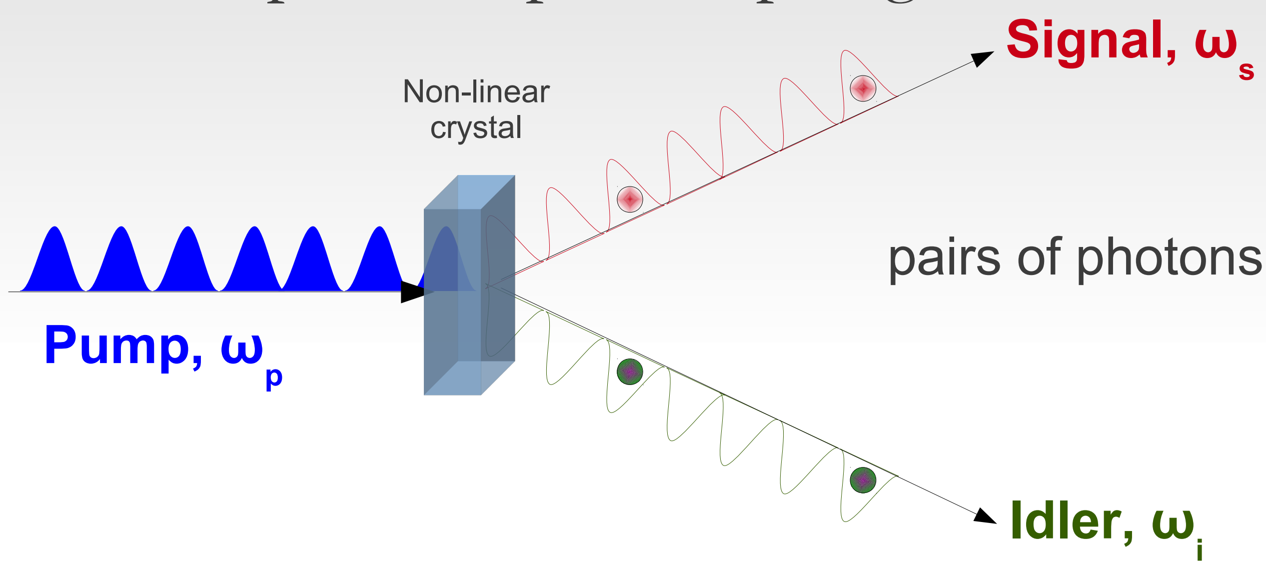
- Non-linear optics for photon pair generation



$$\omega_p = \omega_s + \omega_i$$
$$\vec{k}_p = \vec{k}_s + \vec{k}_i$$

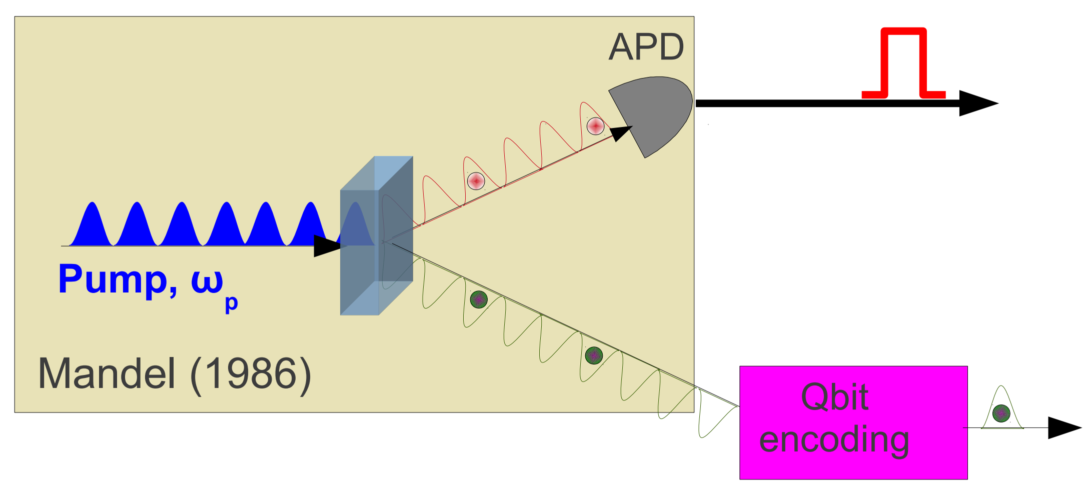
Photon pairs for single Qbit

- Non-linear optics for photon pair generation



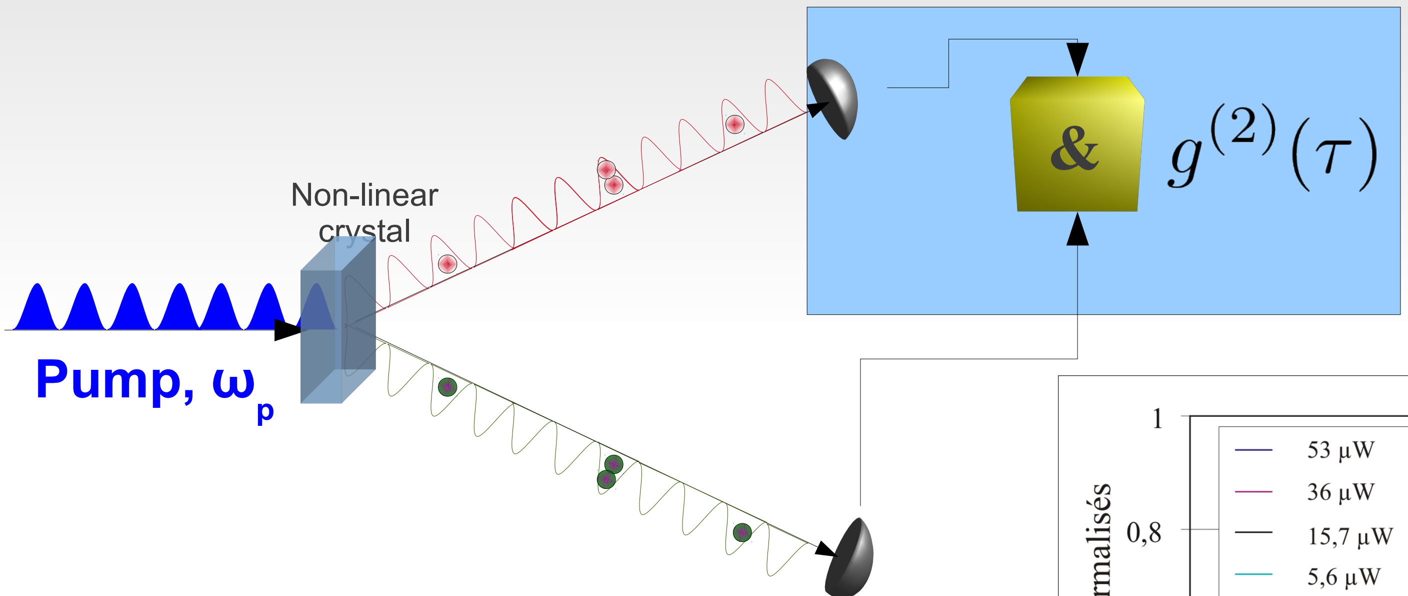
Simultaneous emission

Heralded single photon source

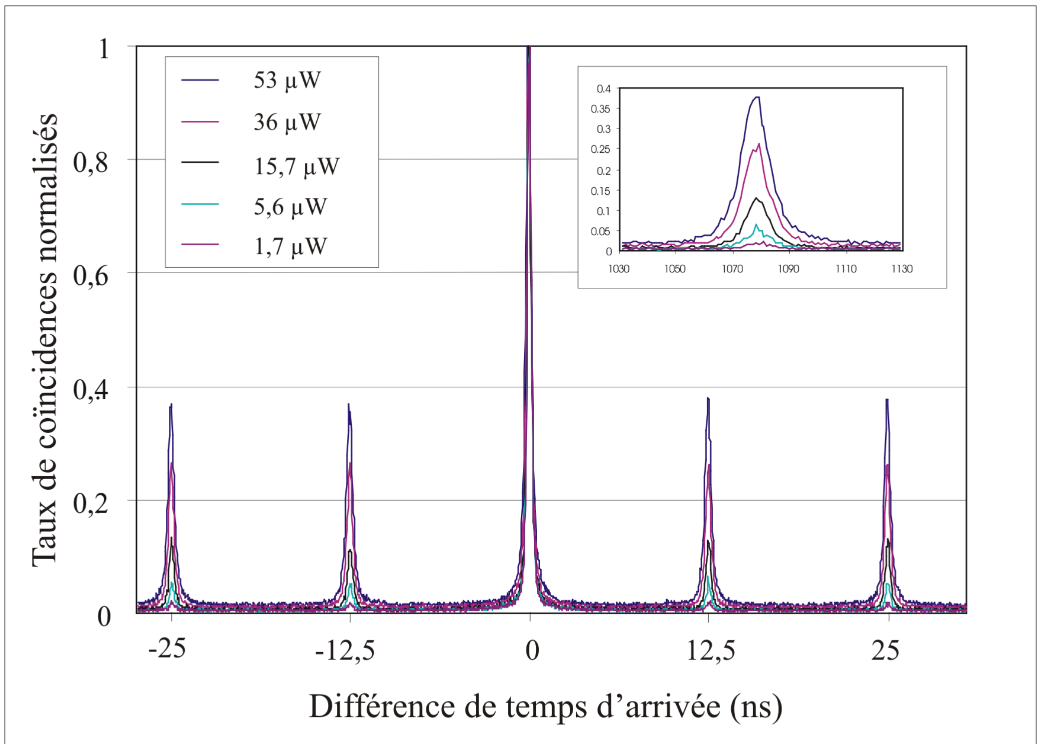


Photon pairs for single Qbit

- Performance measurement : *statistics and efficiency*



Access to:
- Mean number pair / pulse
- Heralding probability



Photon pairs for single Qbit

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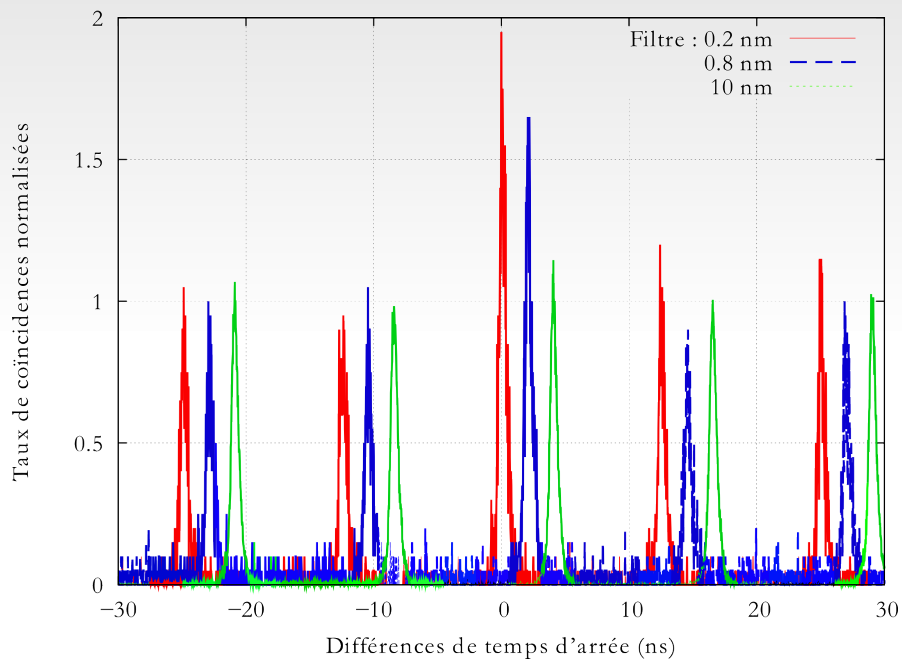
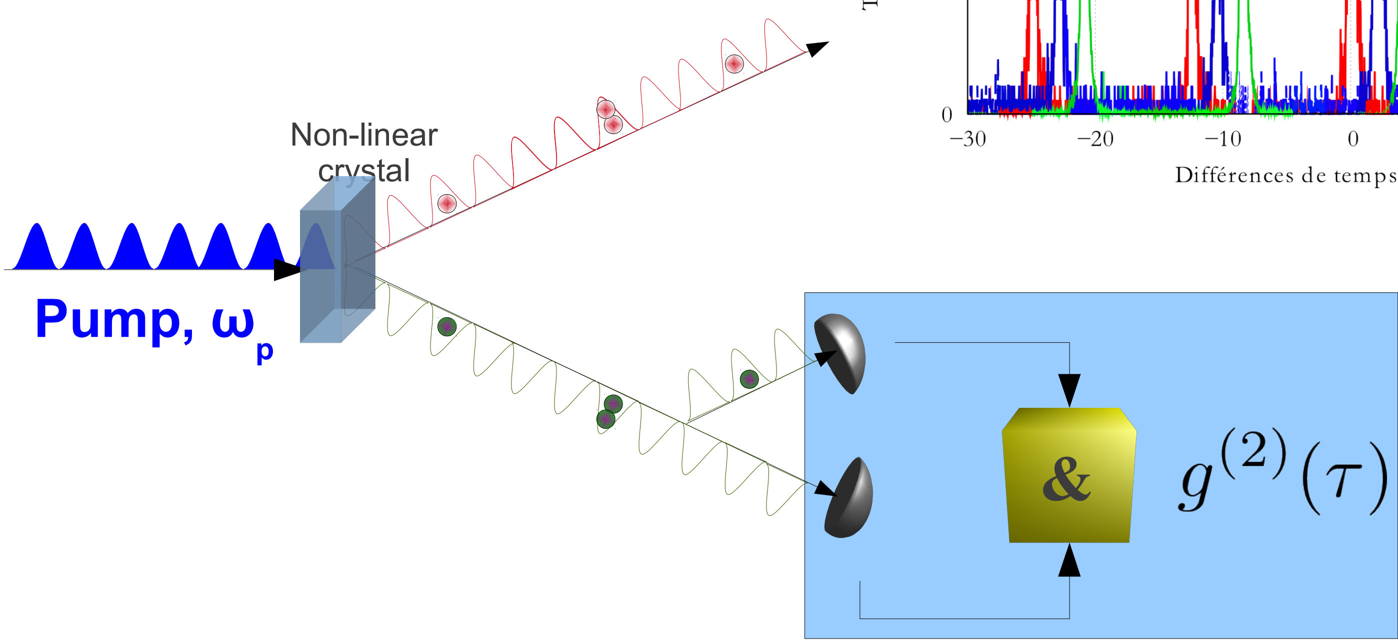
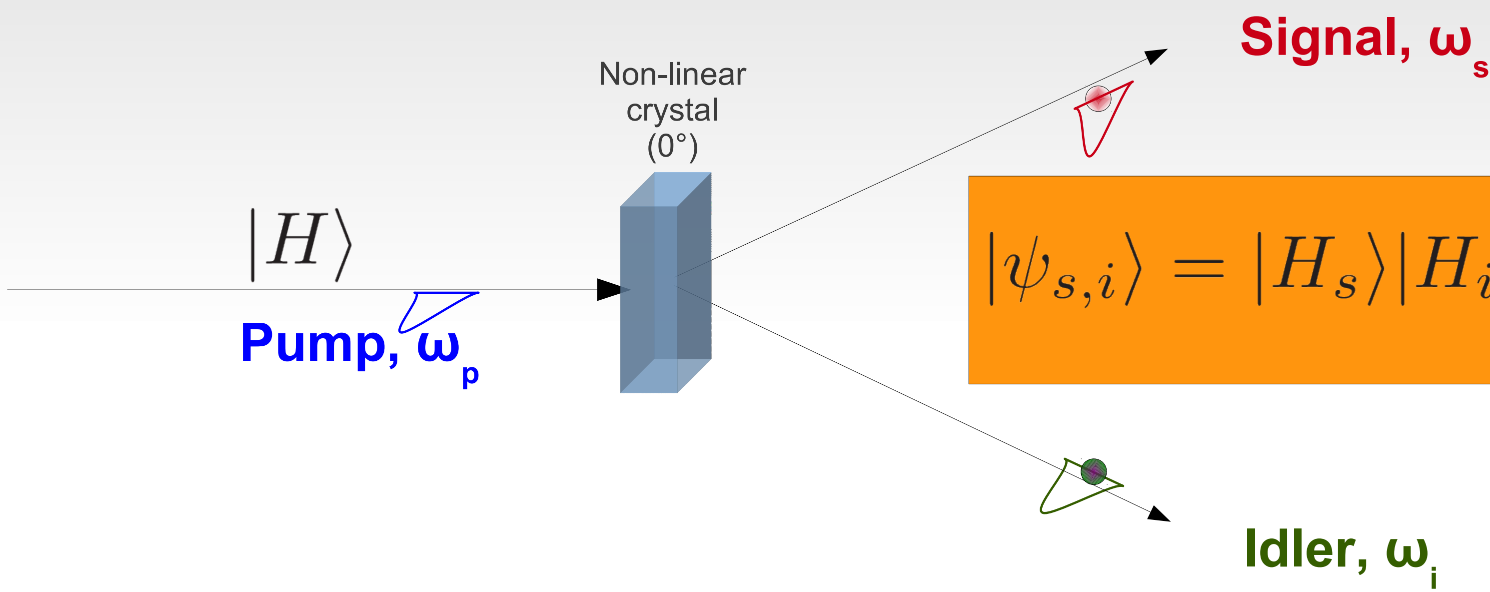


Access to:
- Photon pairs statistic
(Poissonnian / Thermal)



Photon pairs for entangled Qbits

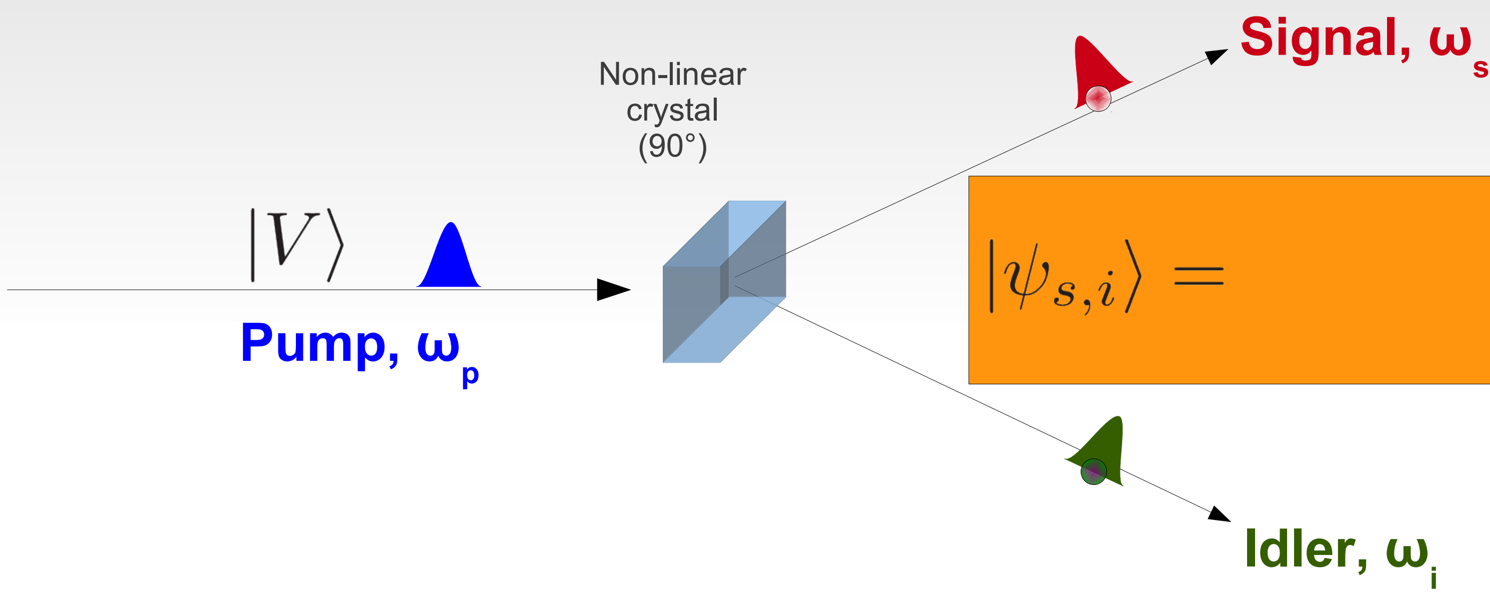


$$|\psi_{s,i}\rangle = |H_s\rangle|H_i\rangle$$

$$|H_p\rangle \rightarrow |H_s\rangle|H_i\rangle$$

Generation of co-polarized pair of photons

Photon pairs for entangled Qbits

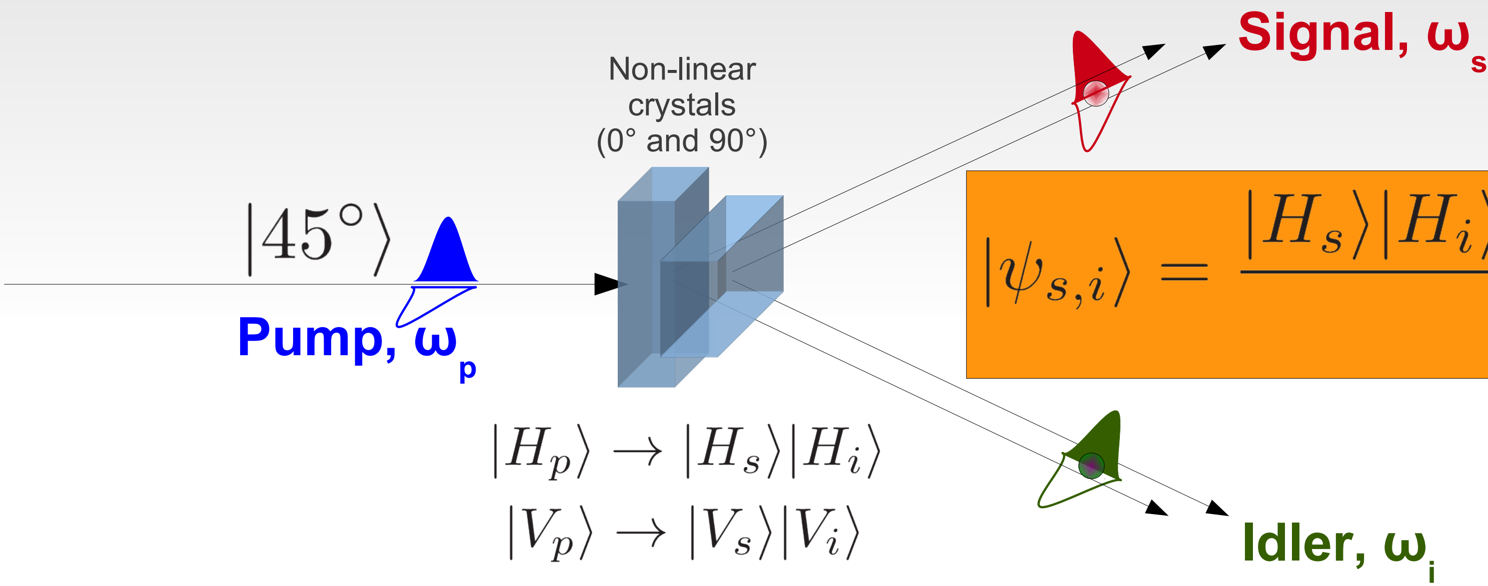


$$|\psi_{s,i}\rangle = |V_s\rangle|V_i\rangle$$

$$|V_p\rangle \rightarrow |V_s\rangle|V_i\rangle$$

Generation of co-polarized pair of photons

Photon pairs for entangled Qbits



$$|\psi_{s,i}\rangle = \frac{|H_s\rangle|H_i\rangle + |V_s\rangle|V_i\rangle}{\sqrt{2}}$$

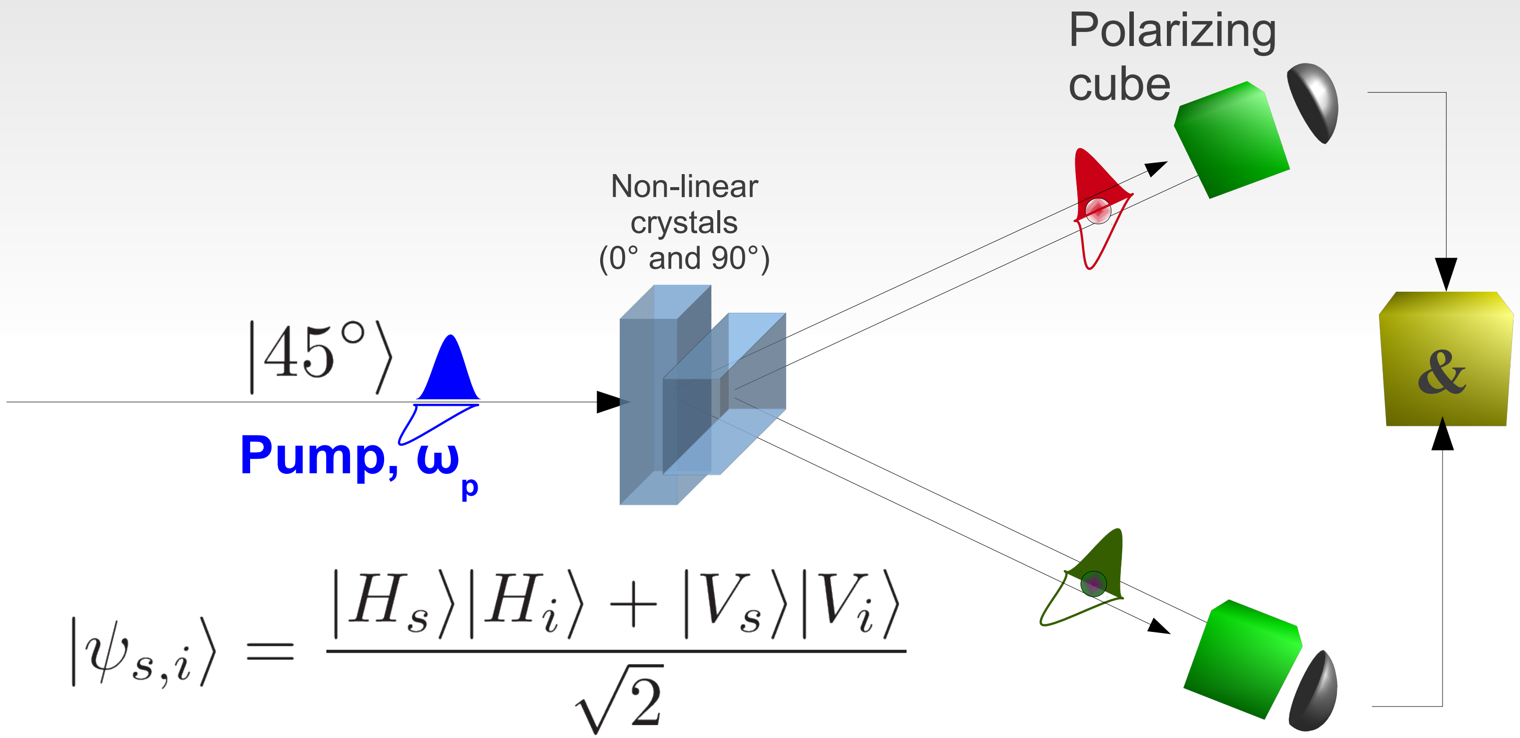
When impossible to know where the pair comes from

Quantum superposition of correlation

Source of entangled photon pairs

Photon pairs for entangled Qbits

- Performance measurement : *Quality of entanglement*

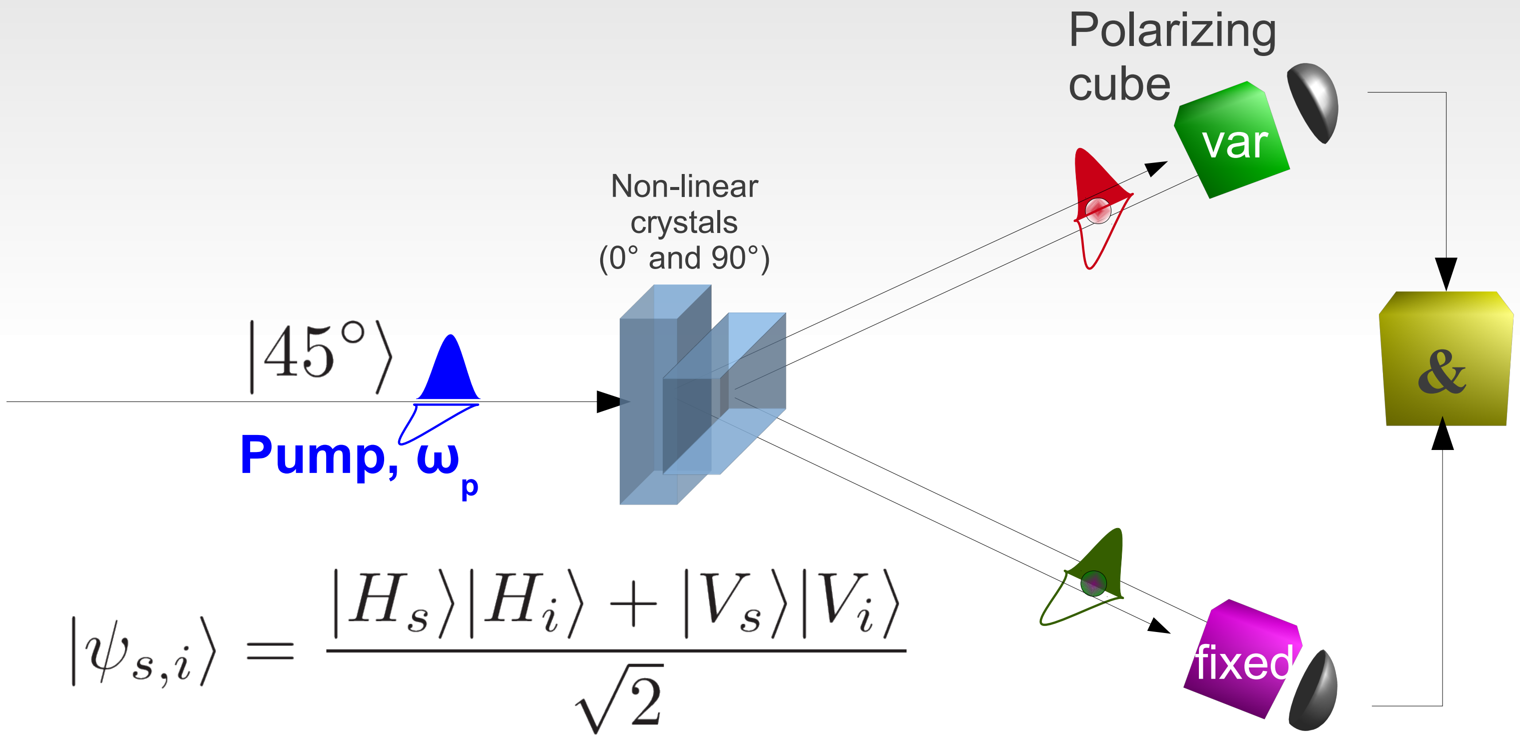


$$|\psi_{s,i}\rangle = \frac{|H_s\rangle|H_i\rangle + |V_s\rangle|V_i\rangle}{\sqrt{2}}$$

Test of entanglement by coincidence measurement while rotating the polarizing cubes

Photon pairs for entangled Qbits

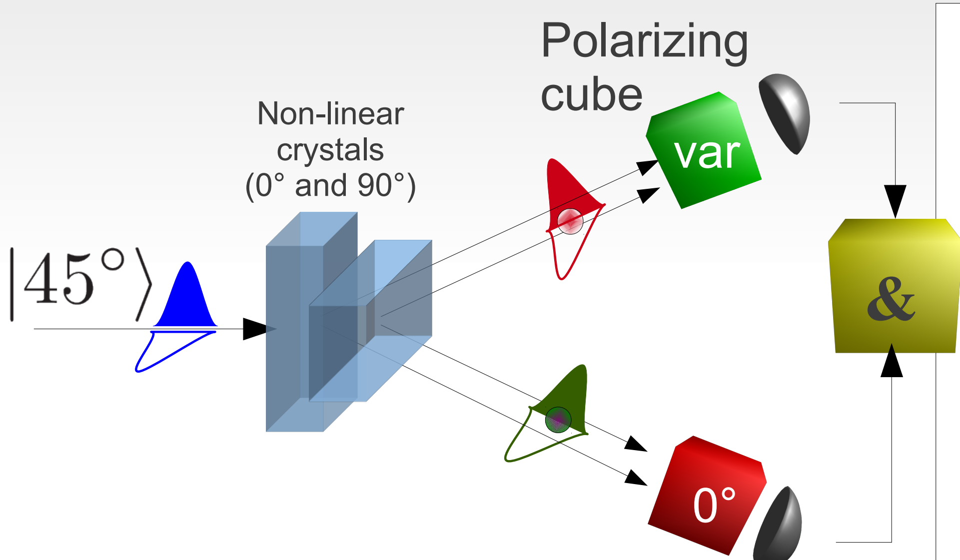
- Performance measurement : *Quality of entanglement*



Test of entanglement by coincidence measurement while rotating the polarizing cubes

Photon pairs for entangled Qbits

- Performance measurement : *Quality of entanglement*



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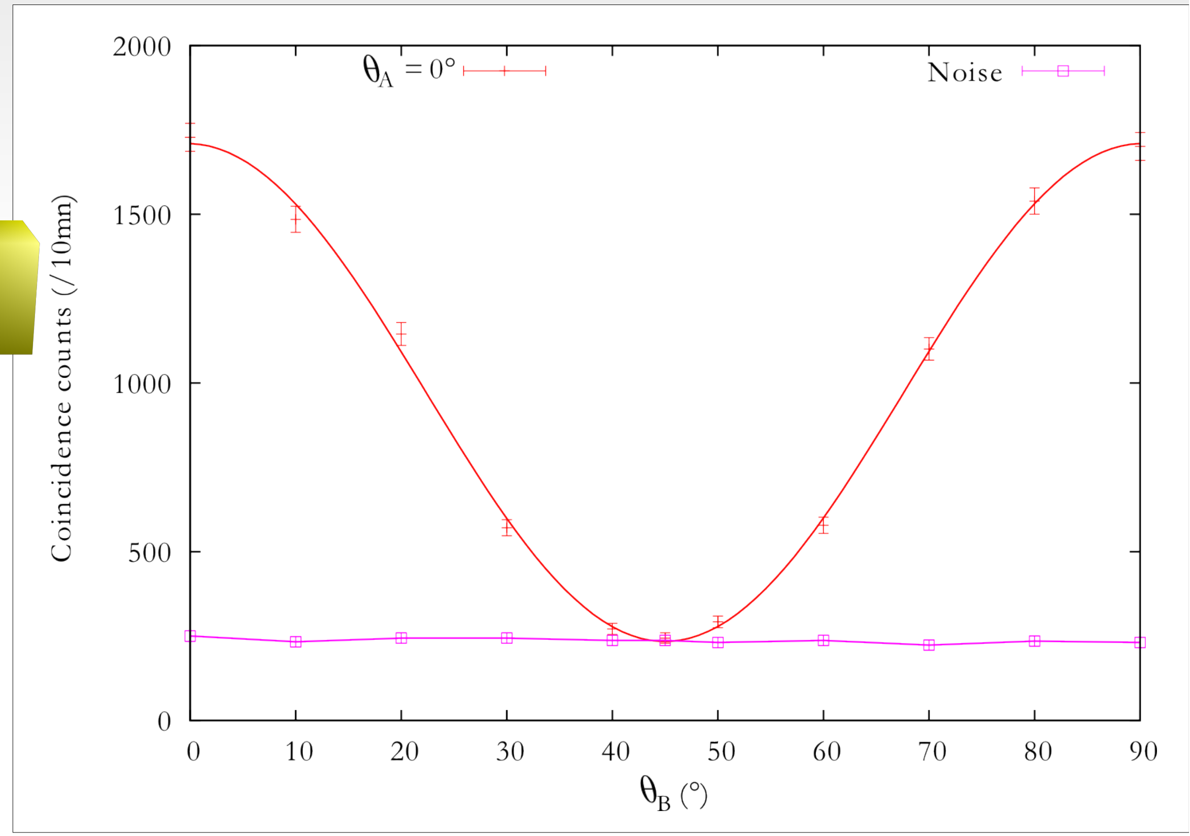

Photon pairs for entangled Qbits

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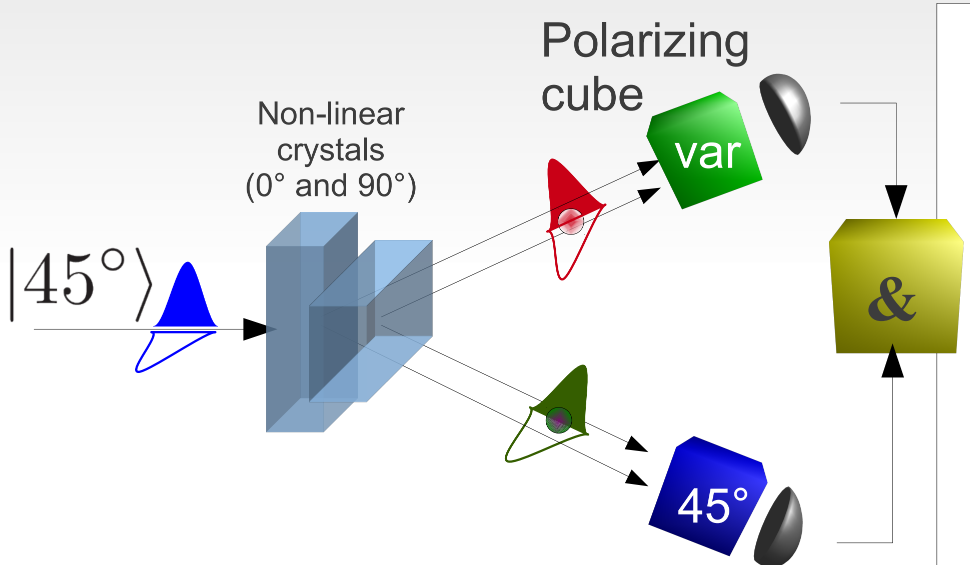

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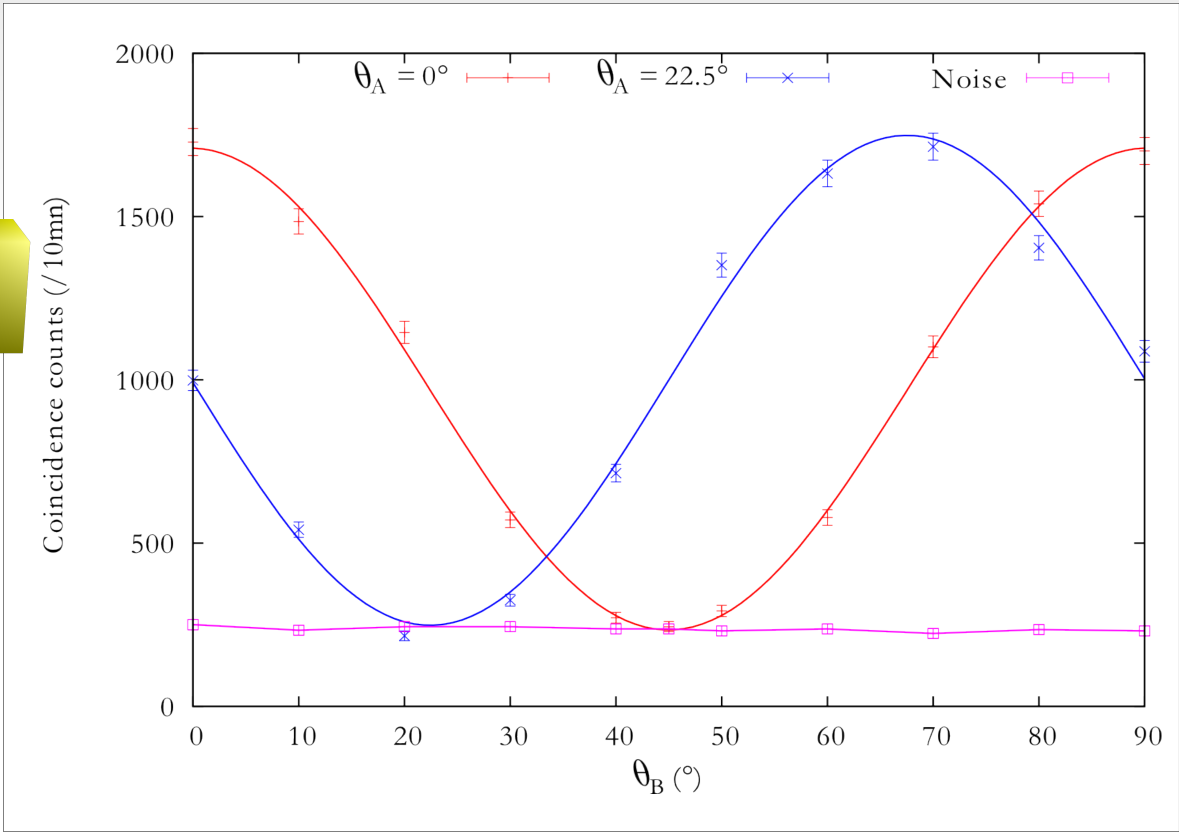
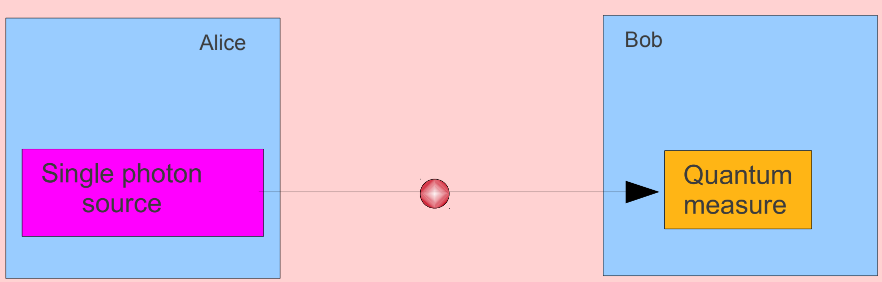


Quantum communication

For real quantum networking

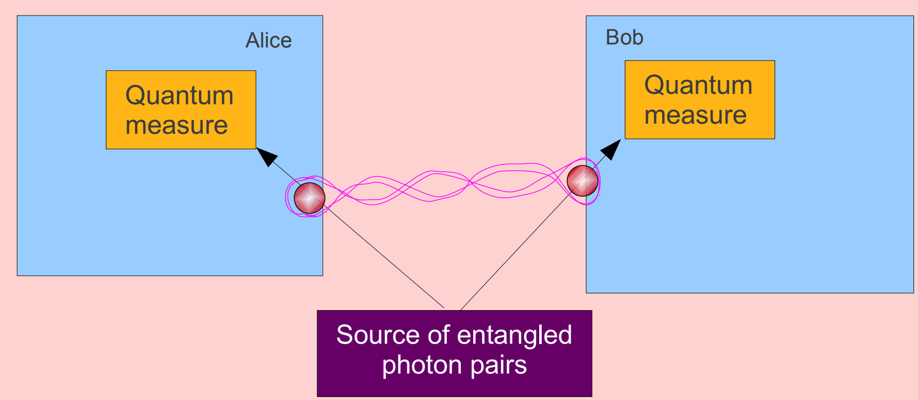
⇨ Need to link together independent photons

Com. With single Qbits



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

Com. with entangled Qbits



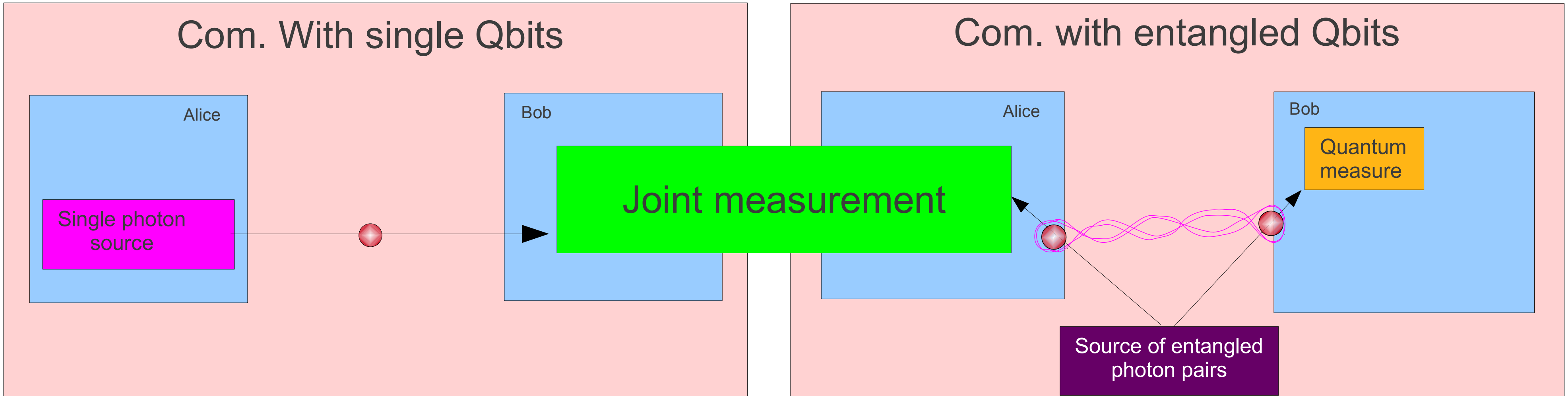
$$|\psi_{12}\rangle = \alpha|0\rangle_1|0\rangle_2 + \beta|1\rangle_1|1\rangle_2$$

Quantum communication

For real quantum networking

⇨ Need to link together independent photons

Two-photon interference



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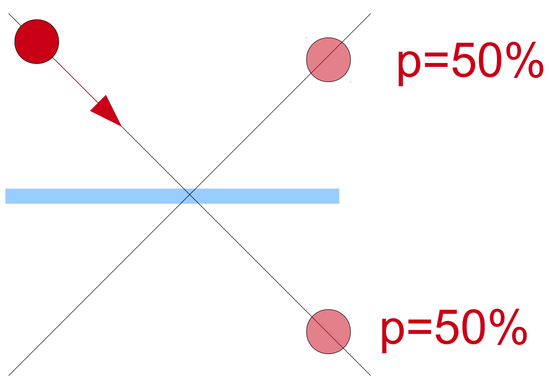
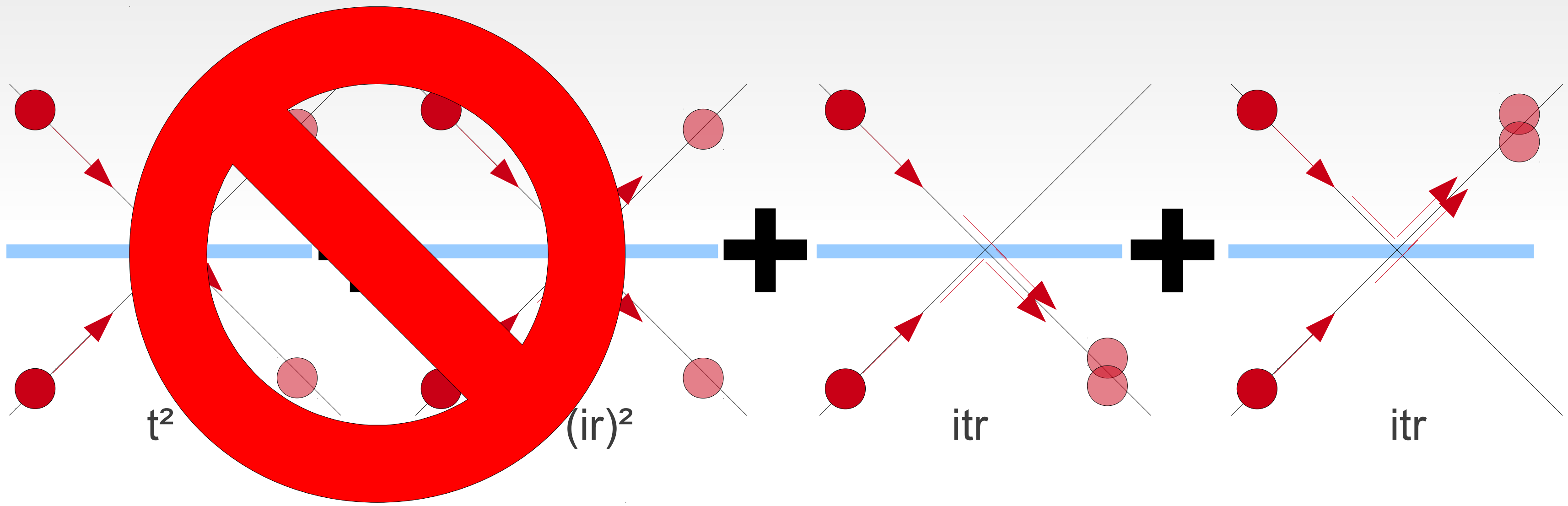
Quantum interference

- Two-photon interference on a beam-splitter



Quantum interference

- Two-photon inteference on a beam-splitter ($t^2=r^2=50\%$)



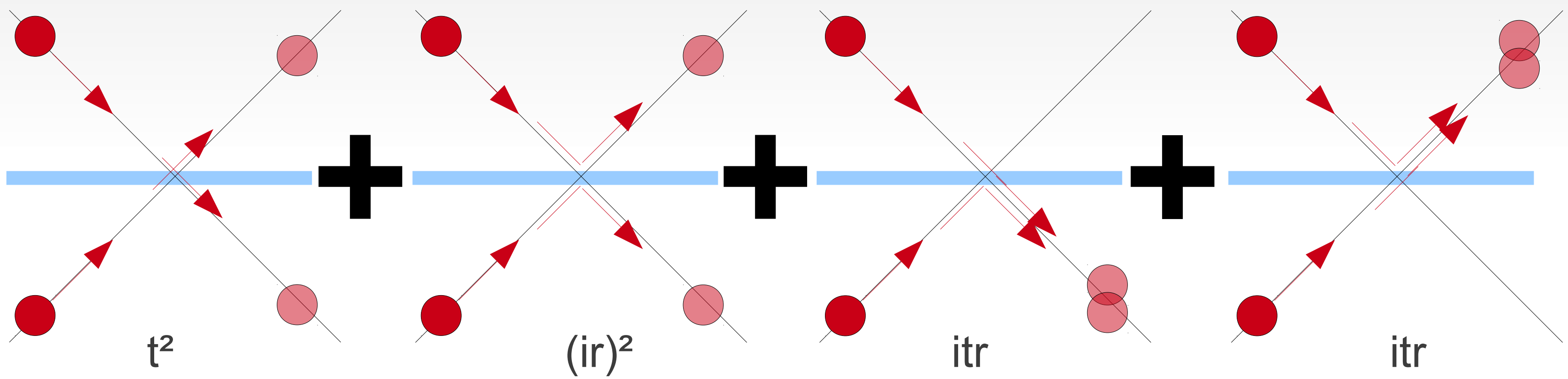
When photon are indistinguishable :

- λ
- Δλ
- Polarisation
- Spatial mode
- Arrival time

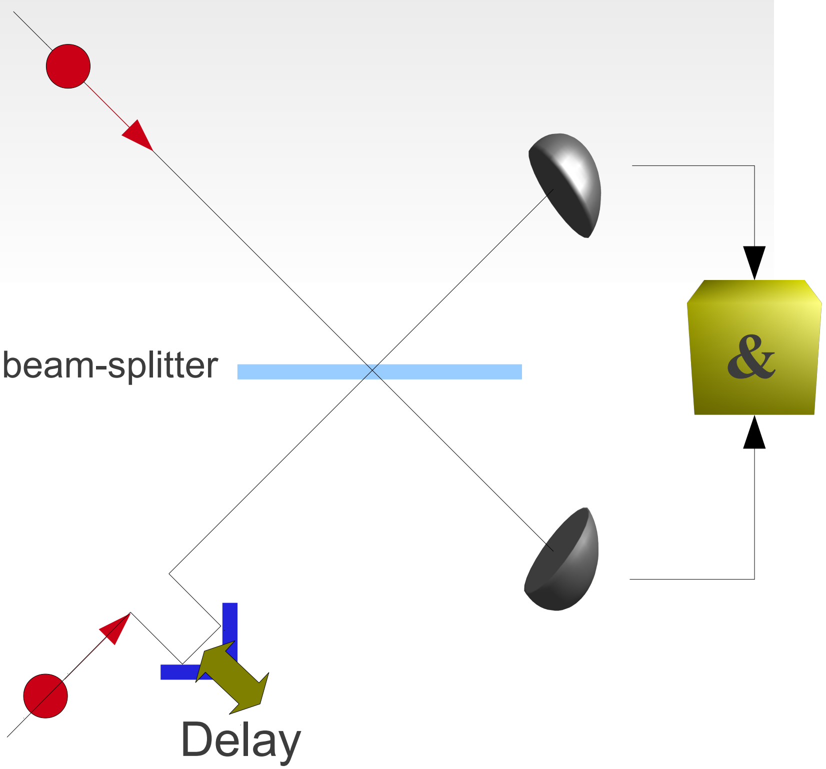
Photon bunching

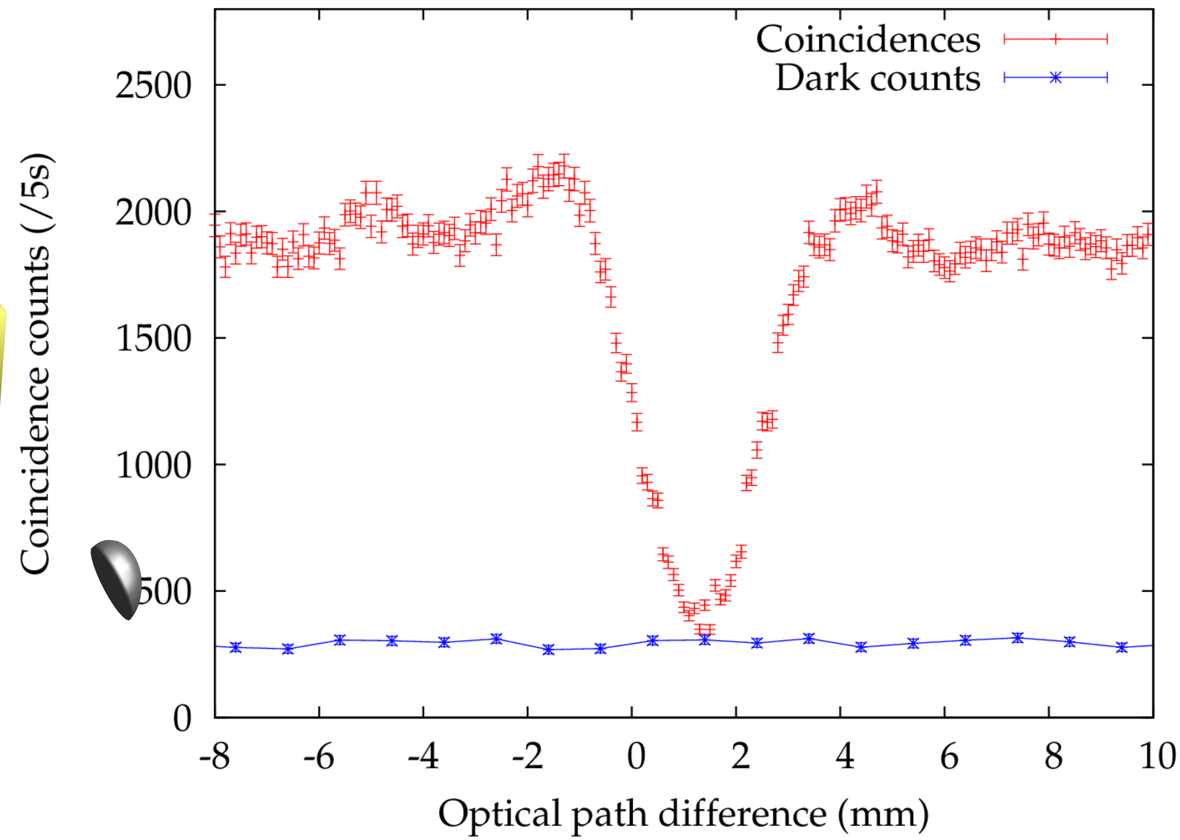
Quantum interference

- Two-photon inteference on a beam-splitter ($t^2 = r^2 = 50\%$)



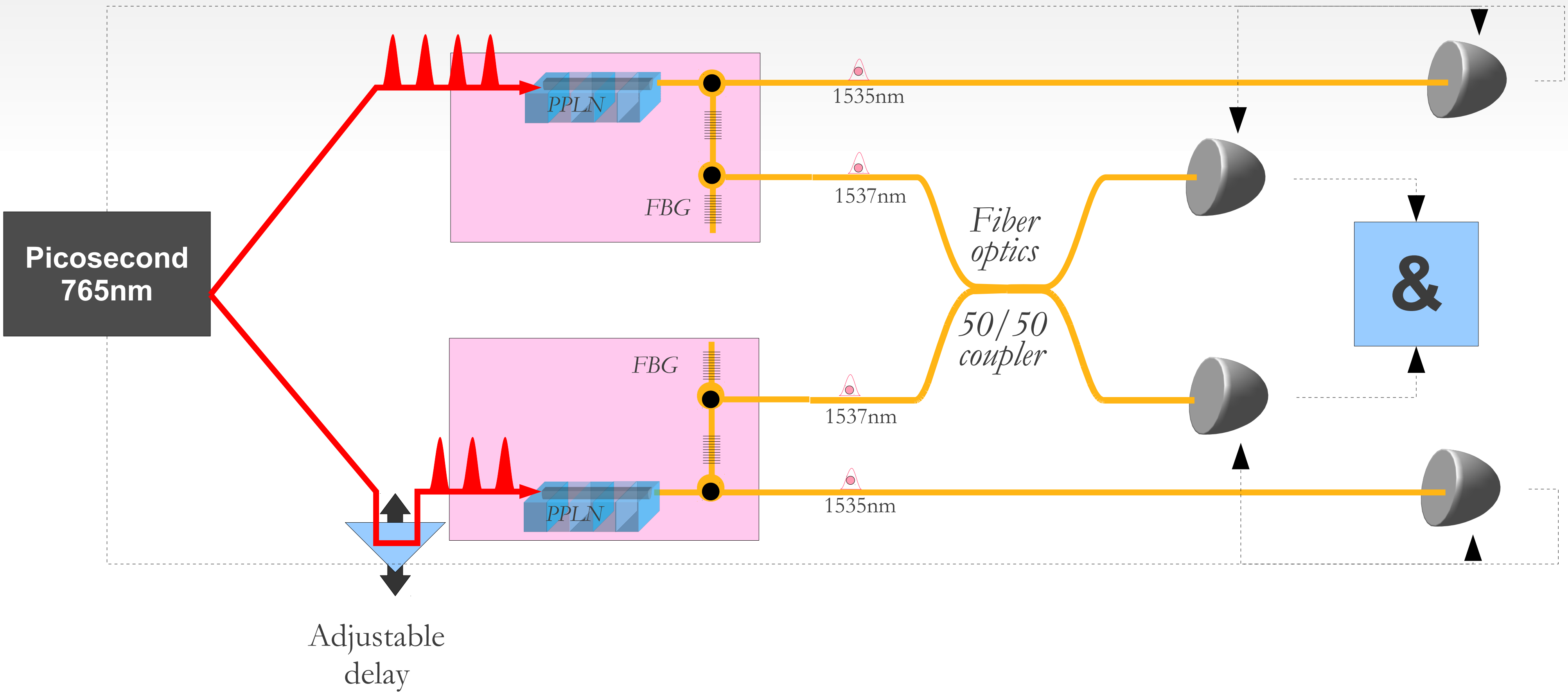
Quantum interference



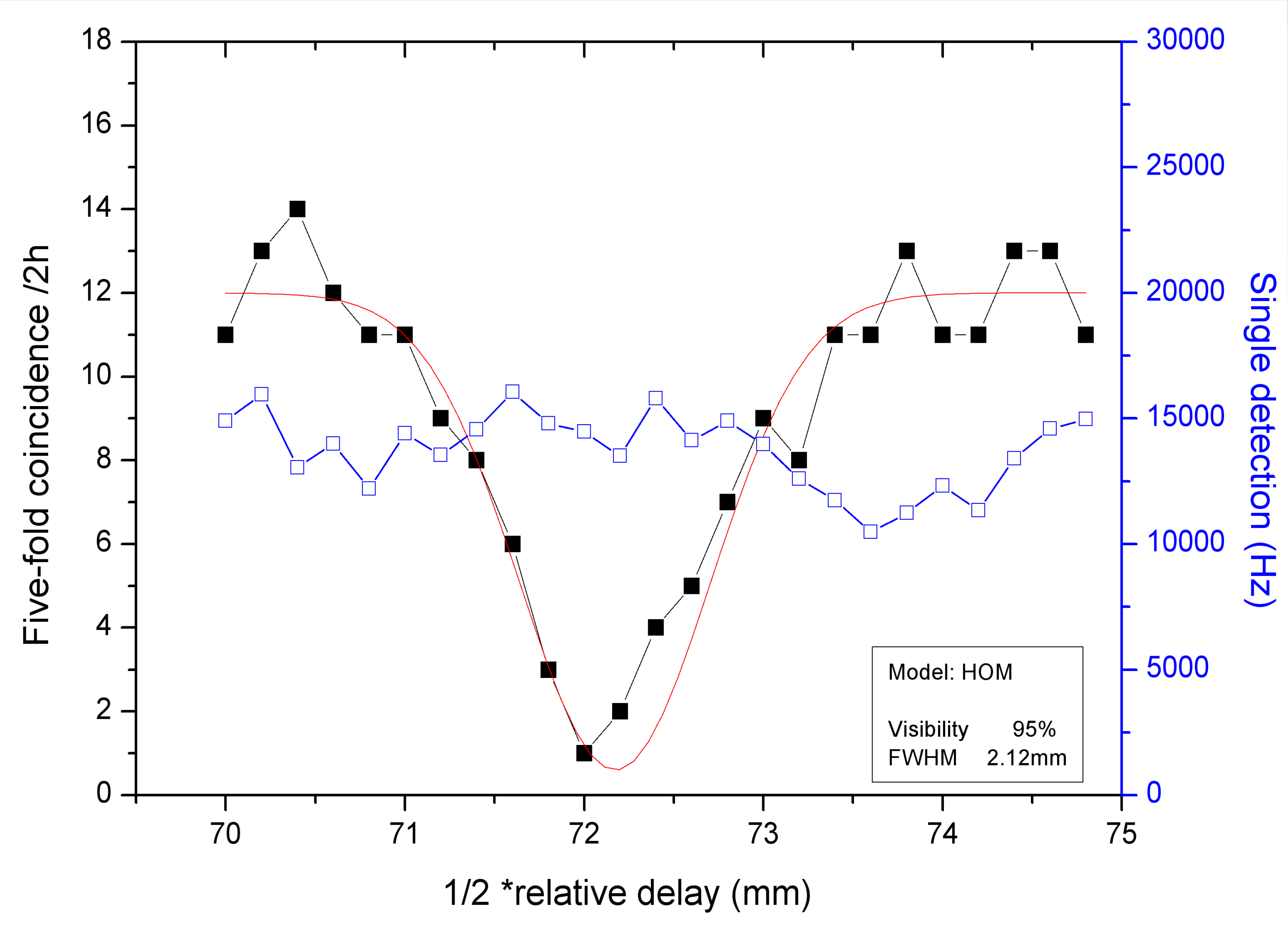


Two-photon interference $\Rightarrow$ $|\psi_{1,2}\rangle = \frac{1}{\sqrt{2}}|U_1, U_2\rangle - \frac{1}{\sqrt{2}}|B_1, B_2\rangle$

Quantum interference between 2 independent photons



Quantum interference between 2 independent photons



Photonics quantum information

- Introduction :
  - ”Bits” of classical information
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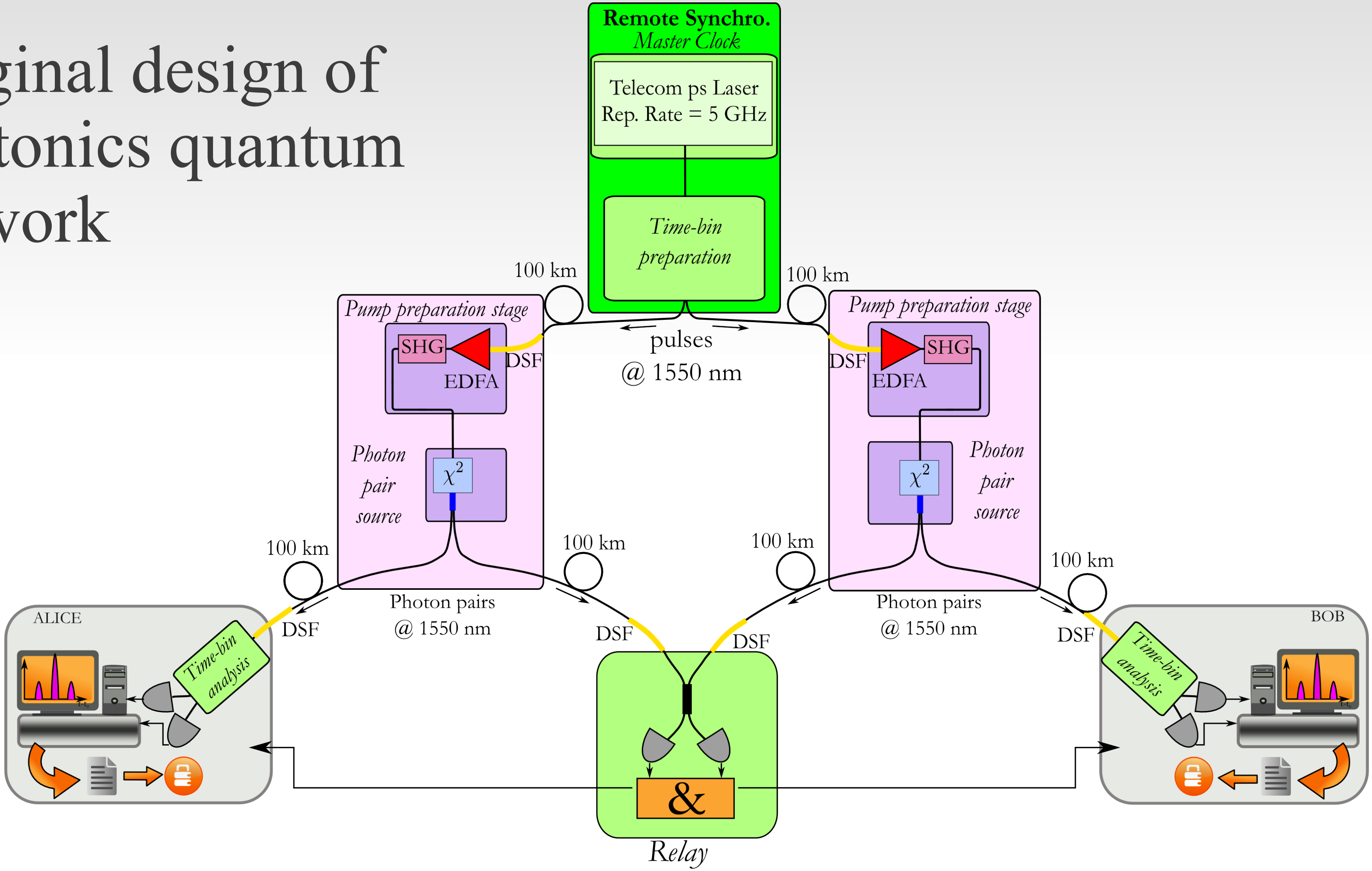
- Quantum communication :
  - The central role of photons pairs
  - Quantum interference
- **Guided-wave quantum communication in Nice**

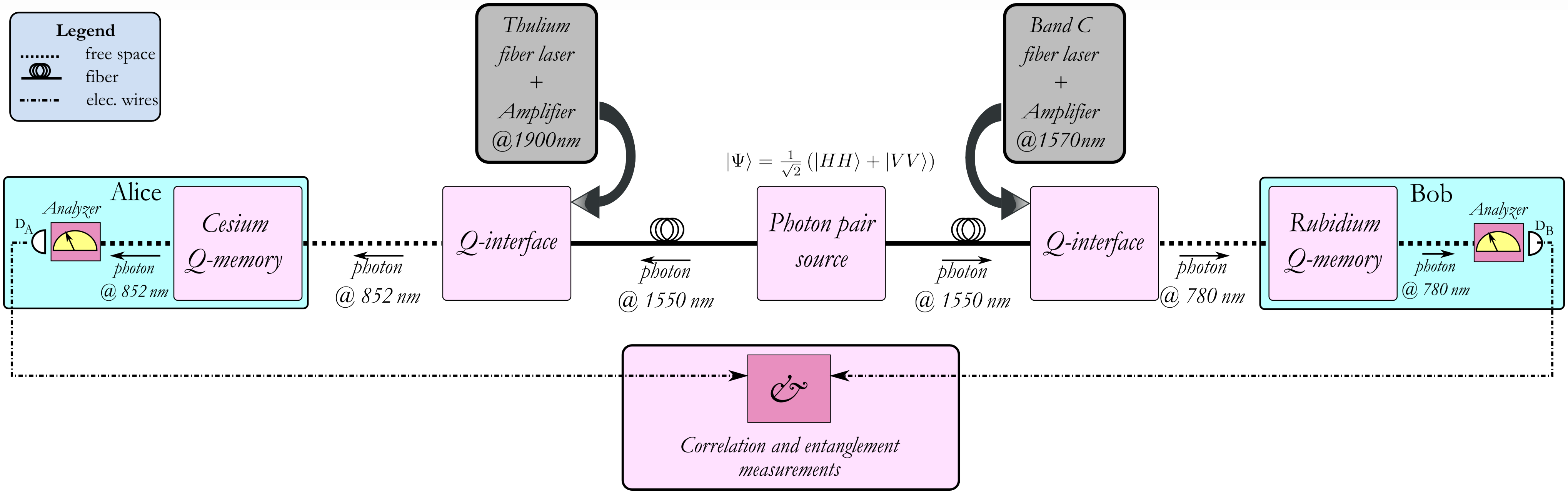
Photonics quantum information at LPMC

Original design of photonics quantum network



Photonics quantum information at LPMC

Original design of photonics quantum network



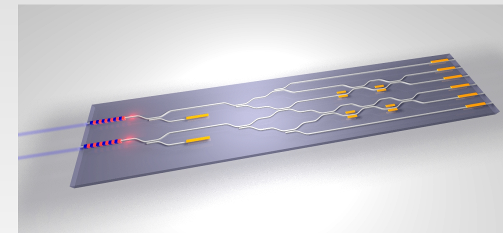
Photonics quantum information at LPMC

Knowledge in Quantum optics

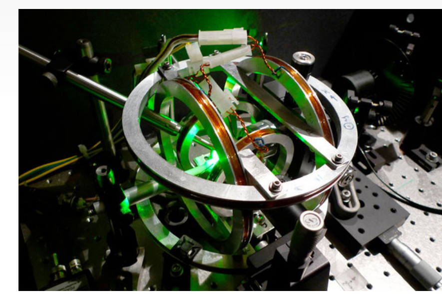
Design of photonic quantum network

Design of elementary components

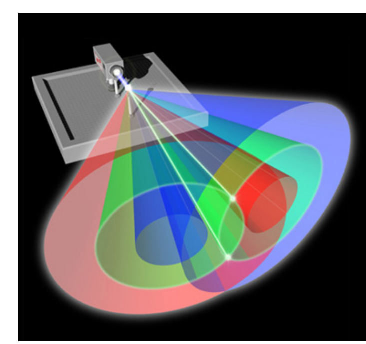
Quantum processing circuit



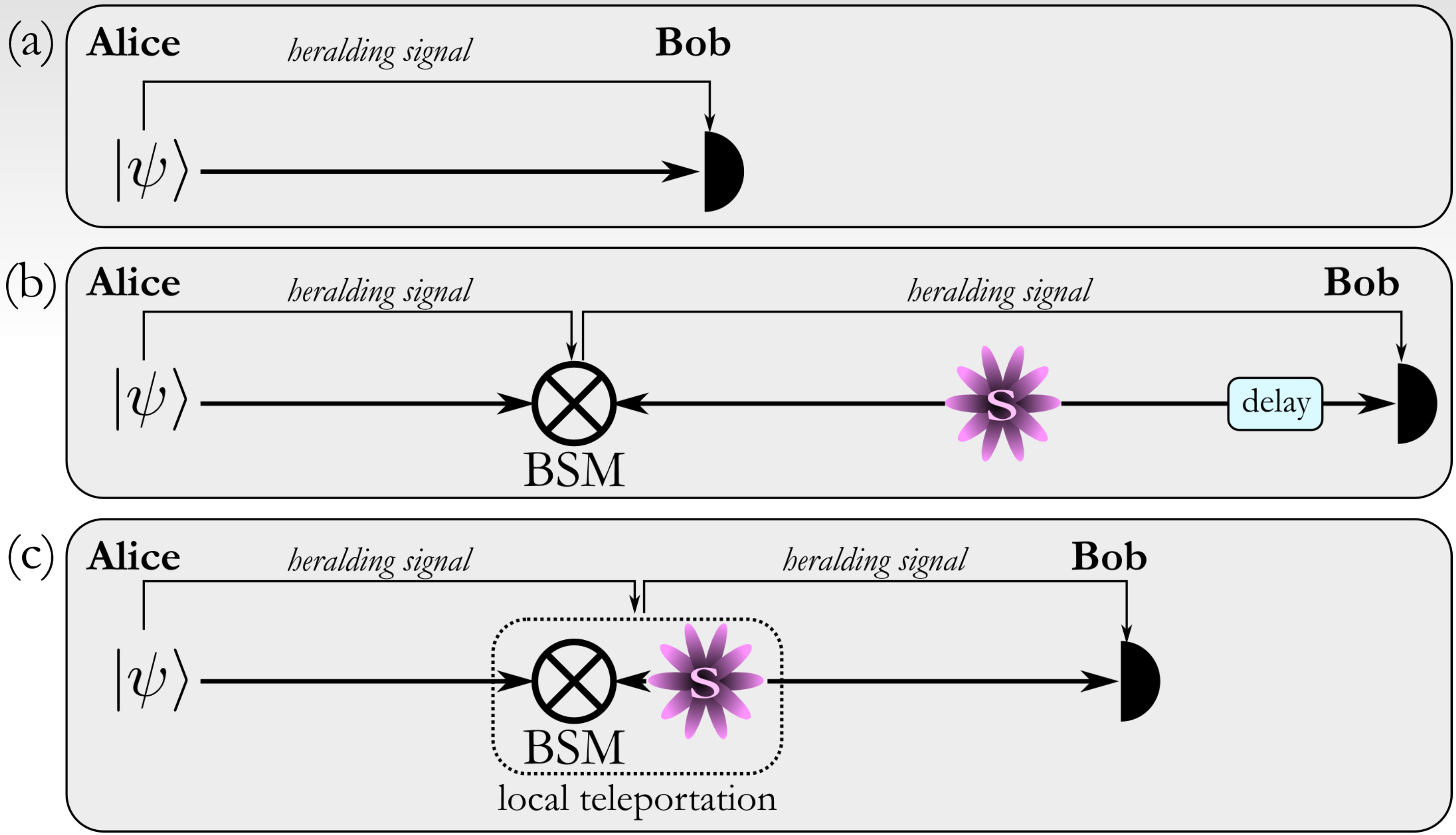
Quantum memory



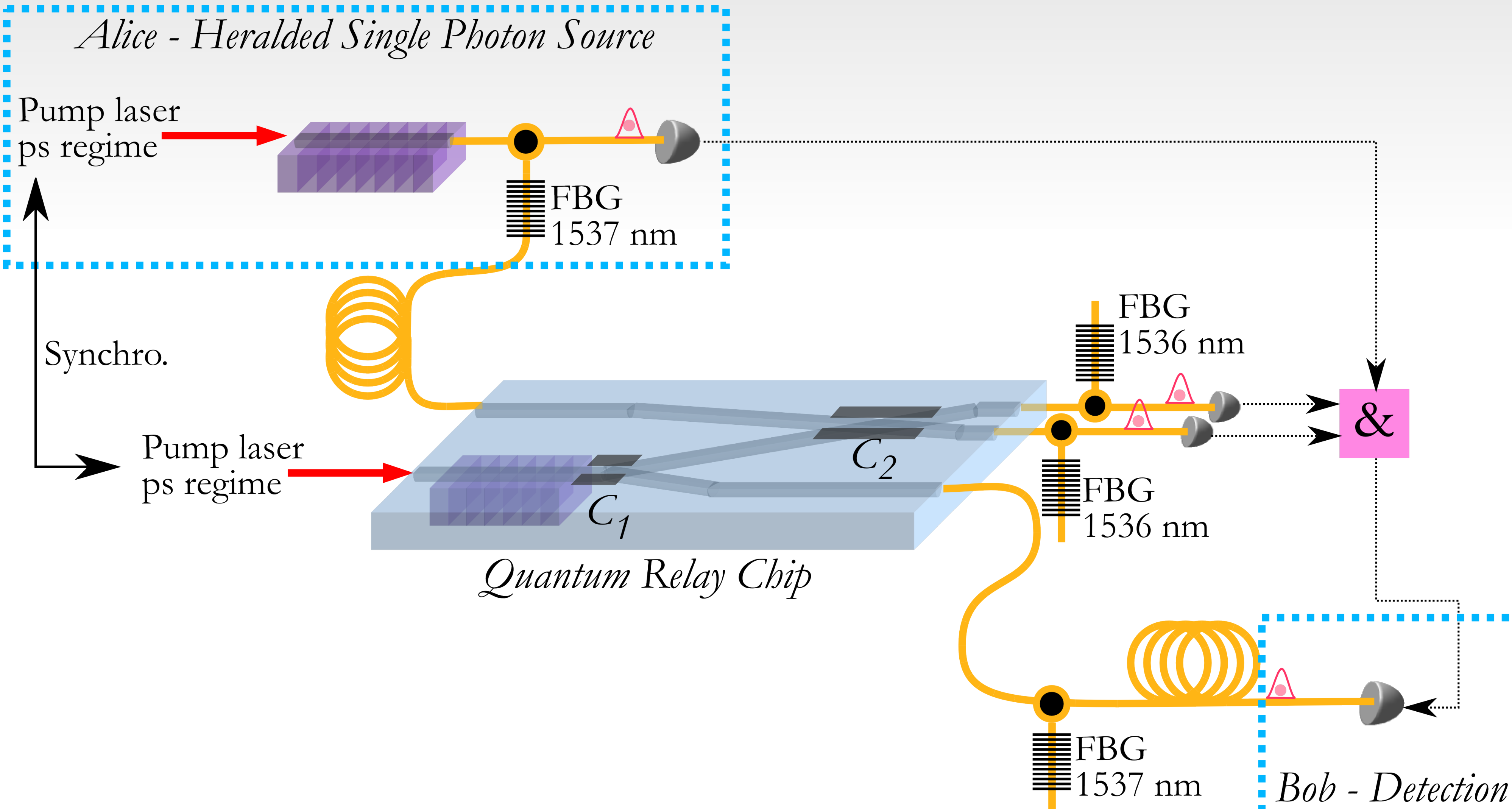
Quantum light source



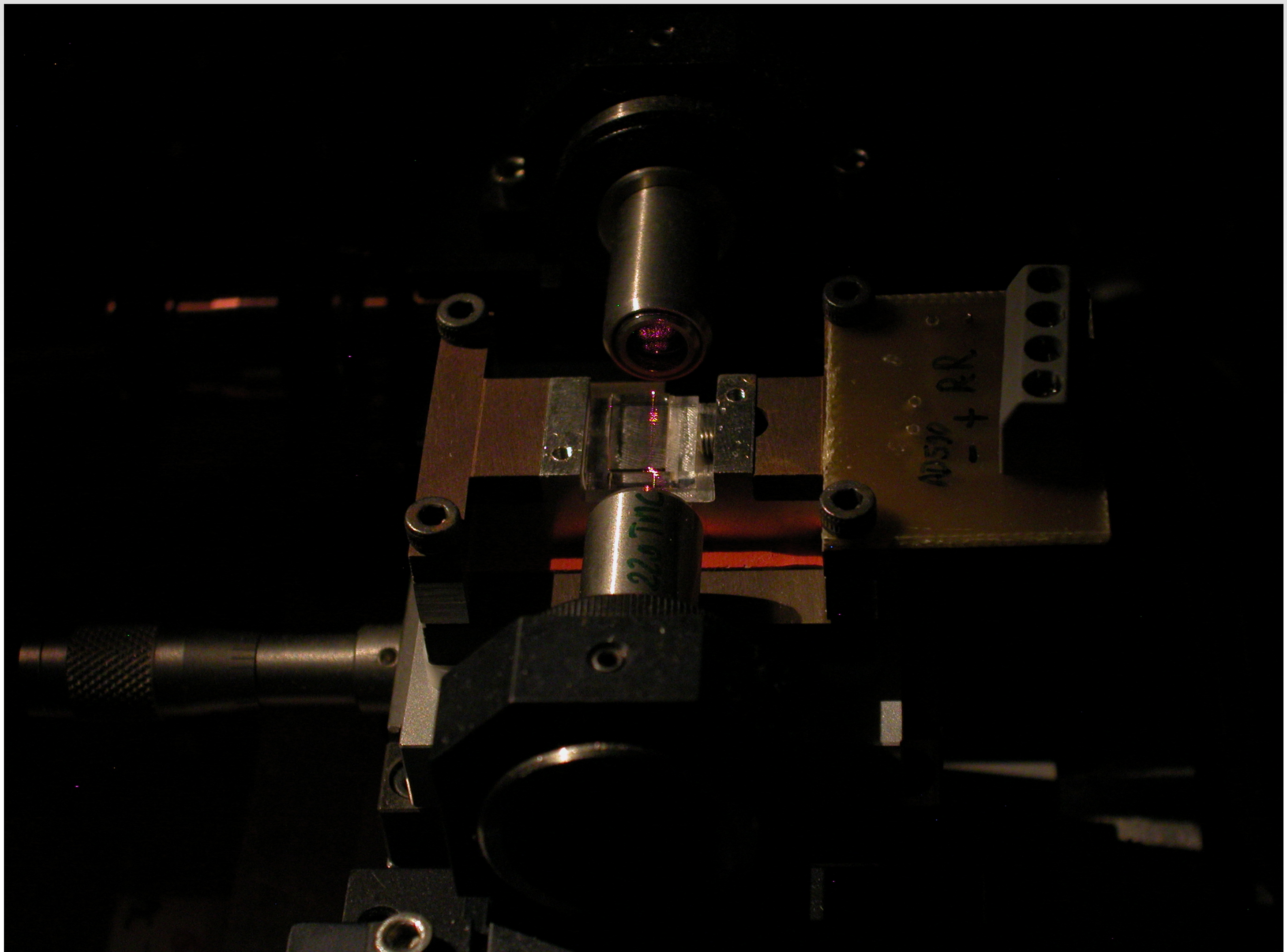
Quantum relay for long distance quantum communication



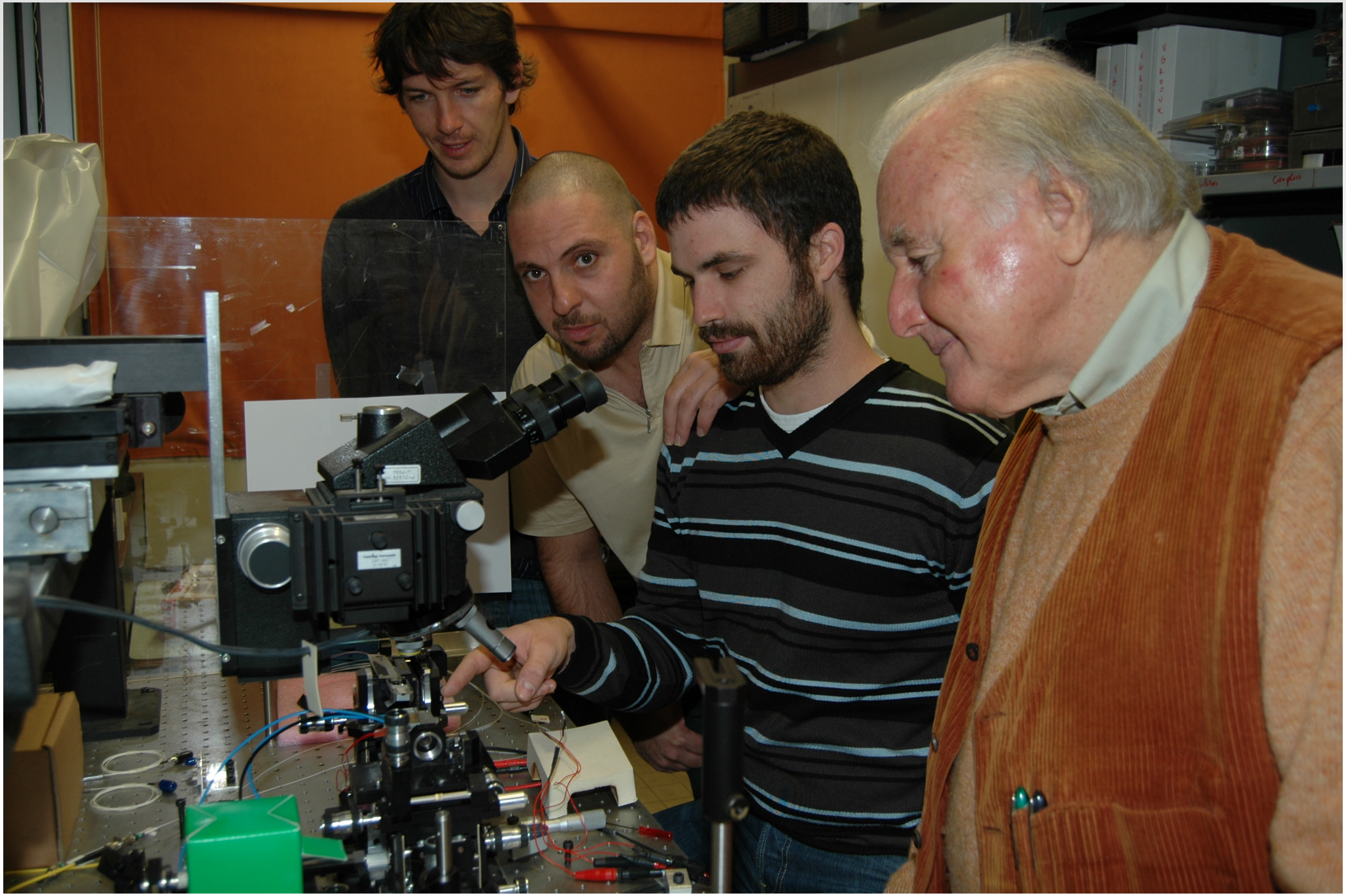
Integrated quantum relay at LPMC



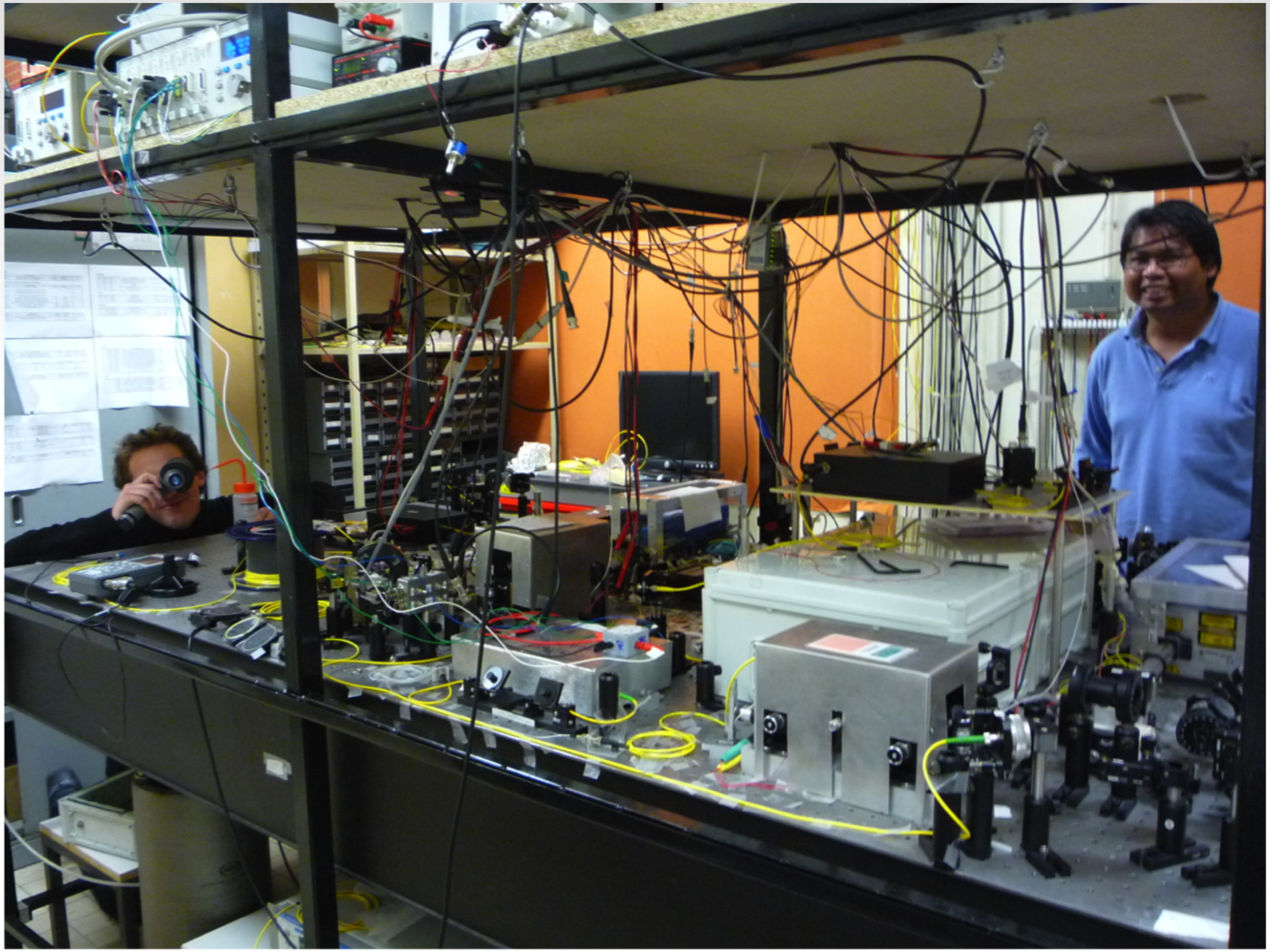
Some "quantum" pictures from LPMC



Some "quantum" pictures from LPMC



Some "quantum" pictures from LPMC



Some "not-so-quantum" pictures from LPMC