Indistinguishable sources of telecom and quantum memory-compatible photon pairs: towards a quantum repeater testbed

@QuantumPSA

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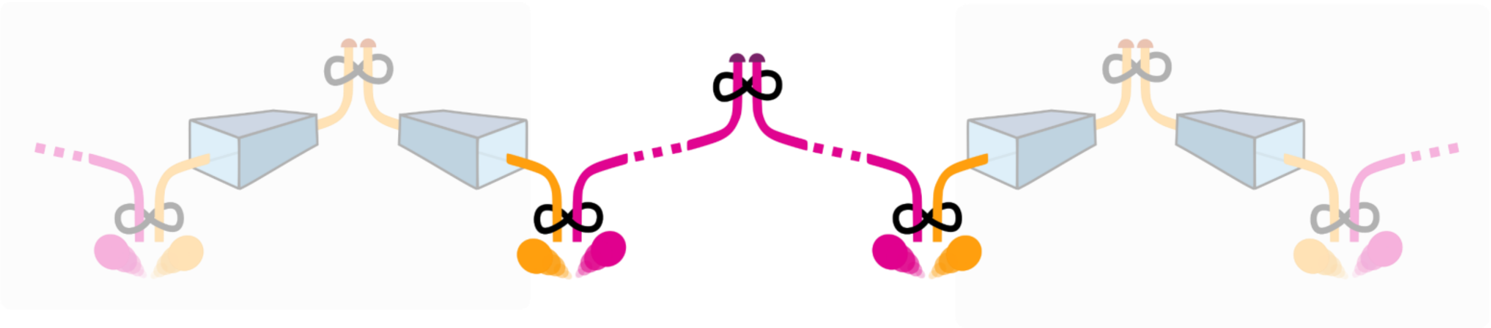
1. Fibre based quantum communication need Quantum Repeaters to reach long distances [1,2]
2. Here, we show 2 photon pair sources that fulfil all the requirements to be part of a Quantum Repeater scheme



3. We show entanglement swapping between the quantum memory compatible photonic modes, heralded by those at the telecom wavelength

Our photon pair source approach

With non-degenerated sources of photon pairs we can interface

Quantum memories

1. With good coherence properties
2. Compatible with long and on-demand storage
3. Compact and easy to operate

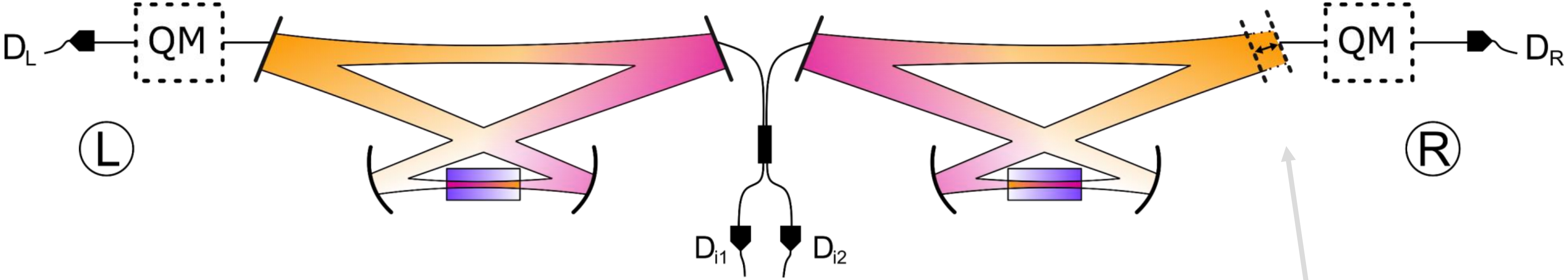
Telecommunication fibre optics

1. Low losses
2. Compatible with current telecommunication systems

1. Our set-up

2x Cavity-enhanced SPDC sources

$\Psi_L \sim |0\rangle_{sL}|0\rangle_{iL} + \sqrt{p}\,|1\rangle_{sL}|1\rangle_{iL}$ $\quad\quad$ $\Psi_R \sim |0\rangle_{sR}|0\rangle_{iR} + \sqrt{p}\,|1\rangle_{sR}|1\rangle_{iR}$



Both cavities in resonance with:
idler (1436 nm) and signal (606 nm) [3]

The signal photon can be stored in a
Pr^{3+} quantum memory: $\Delta\nu_{biph} = 1.8\ MHz$ (< 4 MHz)

To produce indistinguishable photons, both cavity lengths need to be set very precisely

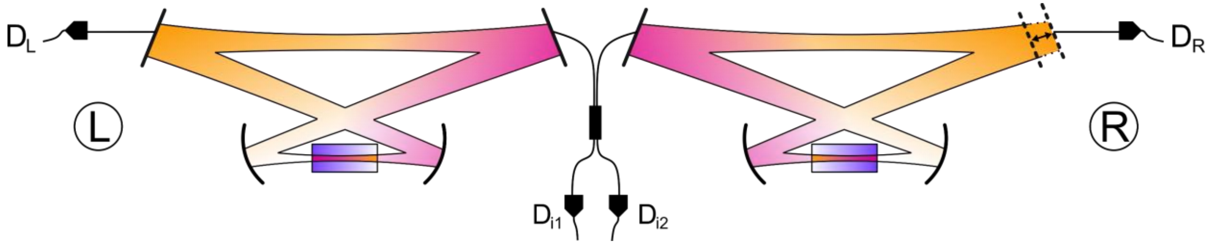
One of the cavity's mirror is on a translation stage

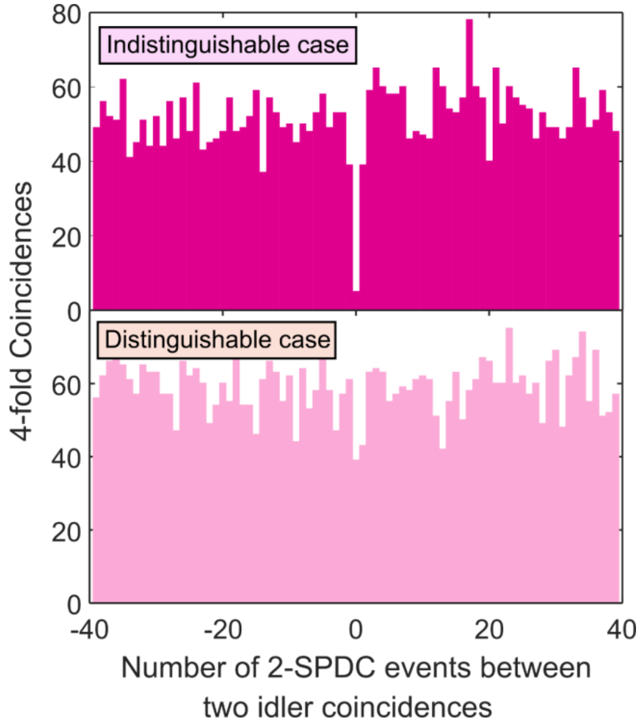
2. Hong-Ou-Mandel interference

We mix in a beam splitter the telecom photons

We look for 4-fold coincidences between [4]:

D_{i1}, D_{i2}, D_L & D_R



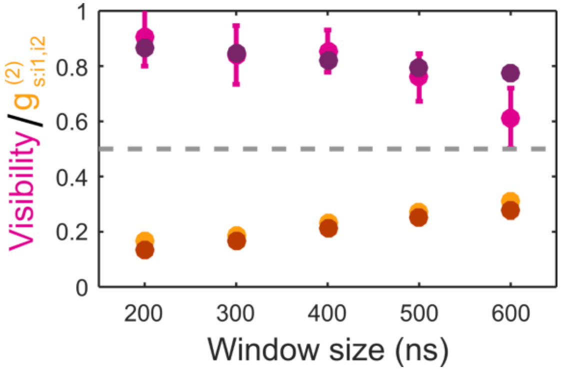


SPDC events synch. in time

SPDC events separated by 1µs

$$\mathbf{V}\,(\boldsymbol{\Delta t = 300\,ns}) = \mathbf{90(10)\%}$$

HOM visibility depends on the width of the correlation window that we consider



We can explain our visibilities just by looking at the single photon autocorrelation [5]

$$V = \eta \frac{1}{1 + g^{(2)}_{s:i_1 i_2}}$$

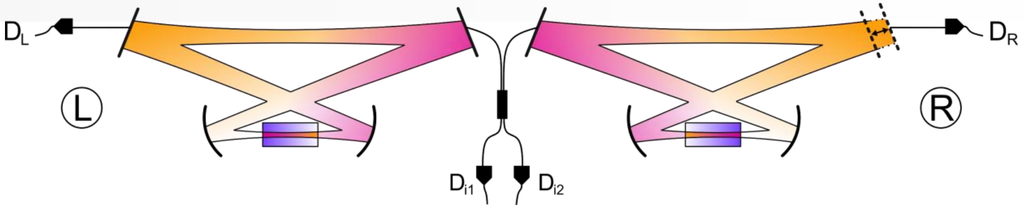
η (overlap) $\longrightarrow$ 1

3. Entanglement swapping [5]

After an idler detection we get the ideal state:

$$\Psi_{L,R} = \frac{1}{\sqrt{2}} \cdot \left(|1\rangle_L |0\rangle_R \pm e^{i\Delta\phi} |0\rangle_L |1\rangle_R \right)$$

$$\Delta\phi = \phi_{iA} - \phi_{iB} \longrightarrow$$ Needs to be controlled!



3.1. Witnessing the entanglement

We characterize the density matrix by:

1. Measuring the photon statistics
2. Measuring the coherence

We could, then, calculate the concurrence and evaluate our entanglement

$$C = \max[0, (2|d| - 2\sqrt{p_{00}p_{11}})]$$

$$|d| \sim V \frac{p_{10} + p_{01}}{2}$$

3.2. Measuring photon statistics

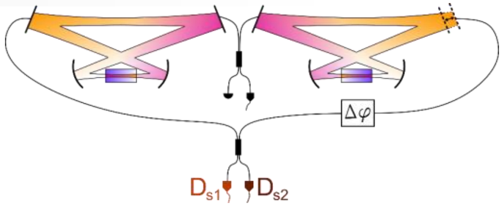
Heralded probability of having:

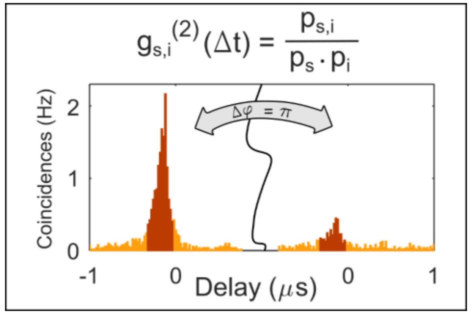
p_{00}: 0 clics at D_L & 0 clics at D_R / p_{10}: 1 clic at D_L & 0 clics at D_R

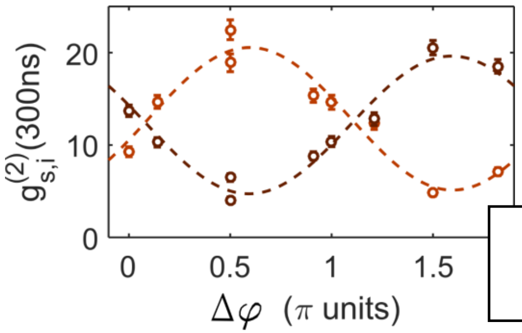
p_{01}: 0 clics at D_L & 1 clic at D_R / p_{11}: 1 clic at D_L & 1 clic at D_R

3.3. Measuring the coherence

We need to make the signal modes interfere while scanning their phase difference:



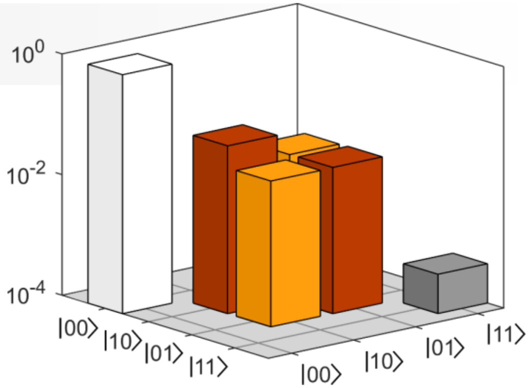




V = 60(6)%

3.4. Result

$$\boldsymbol{C = 1.2(5) \cdot 10^{-2} > 0}$$



4. Conclusions

1. Two sources of indistinguishable photons: telecom and quantum memory compatible
2. HOM visibility of 90(10) %
3. We proof entanglement swapping
4. Our concurrence violates the classical limit with 2 standard deviations

[1] L.-M. Duan et al. Nature (2001)
[2] C. Simon et al. Phys. Rev. Lett. (2007)
[3] A. Seri et al. Optica (2018)
[4] S. Fasel et al. New J. Phys. (2004)
[5] D. Felinto et al. Nat. Phys. (2006)
[6] Chou et al. Nature (2005)

QUANTUM INTERNET ALLIANCE
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