Quantum Cryptography: A Source of Single Photons for Quantum Key Distribution in Space

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Introduction

Quantum Key Distribution (QKD) is a secure cryptographic information transmission method that relies on quantum properties of photons. QKD in space imposes challenges: atmospheric absorption and turbulence. Motivated by a comprehensive model to simulate a satellite-to-ground link, we address these problems with a tunable heralded single-photon source with signal photons ranging from 1064 to 2300 nm in free-space. The photons are produced via spontaneous parametric down-conversion (SPDC) in a seven-grating periodically poled lithium niobate (PPLN) crystal.

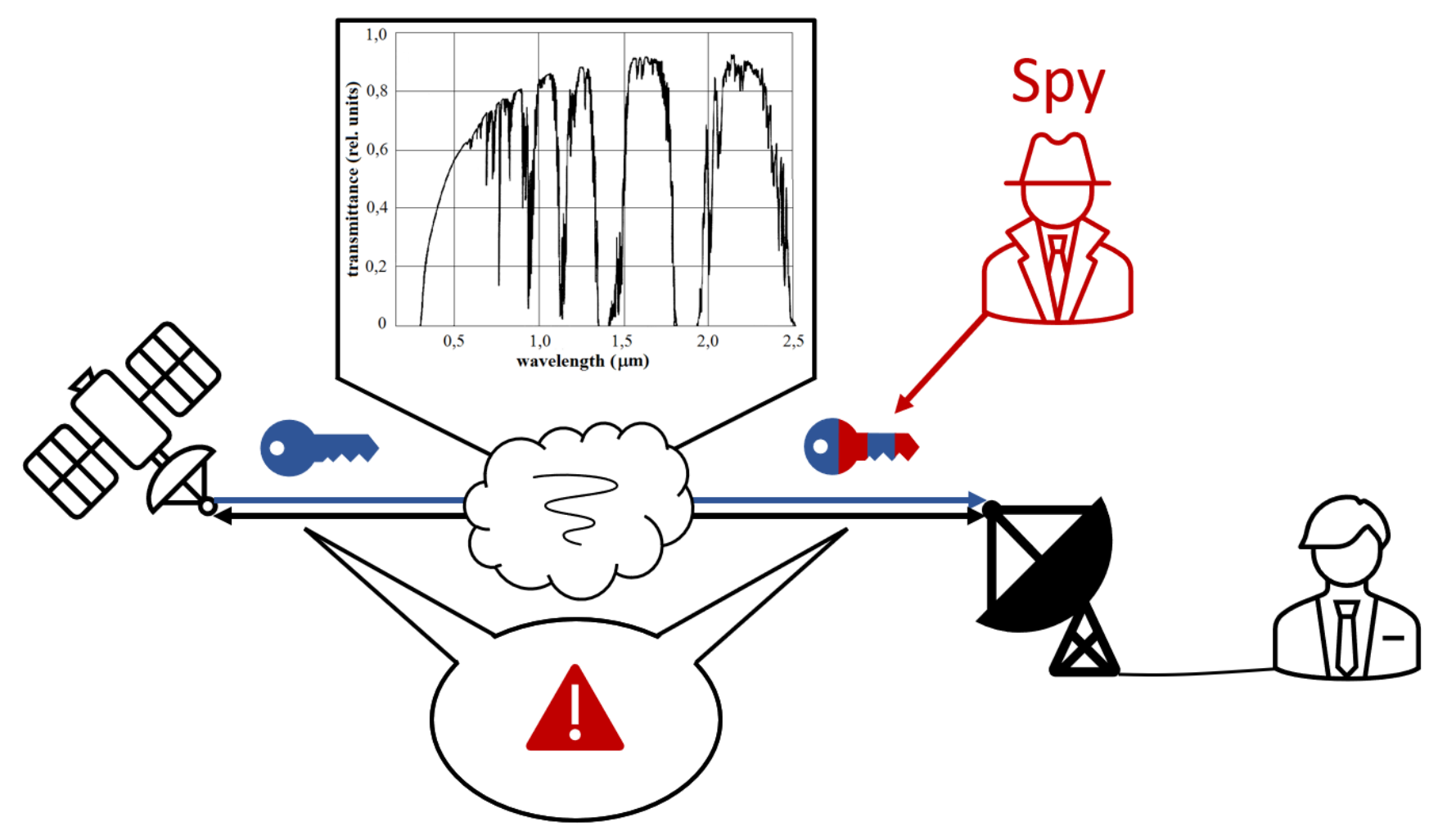


Fig. 1: A QKD scheme for space with the atmospheric transmittance over the wavelength [1].

Methods

- With our heralded single-photon source, we can study many signal wavelengths thanks to the idler photons [2].
- Pump laser: mode-locked, 1064 nm, 7.9 ps pulses, 32.45 MHz, 300 pm linewidth

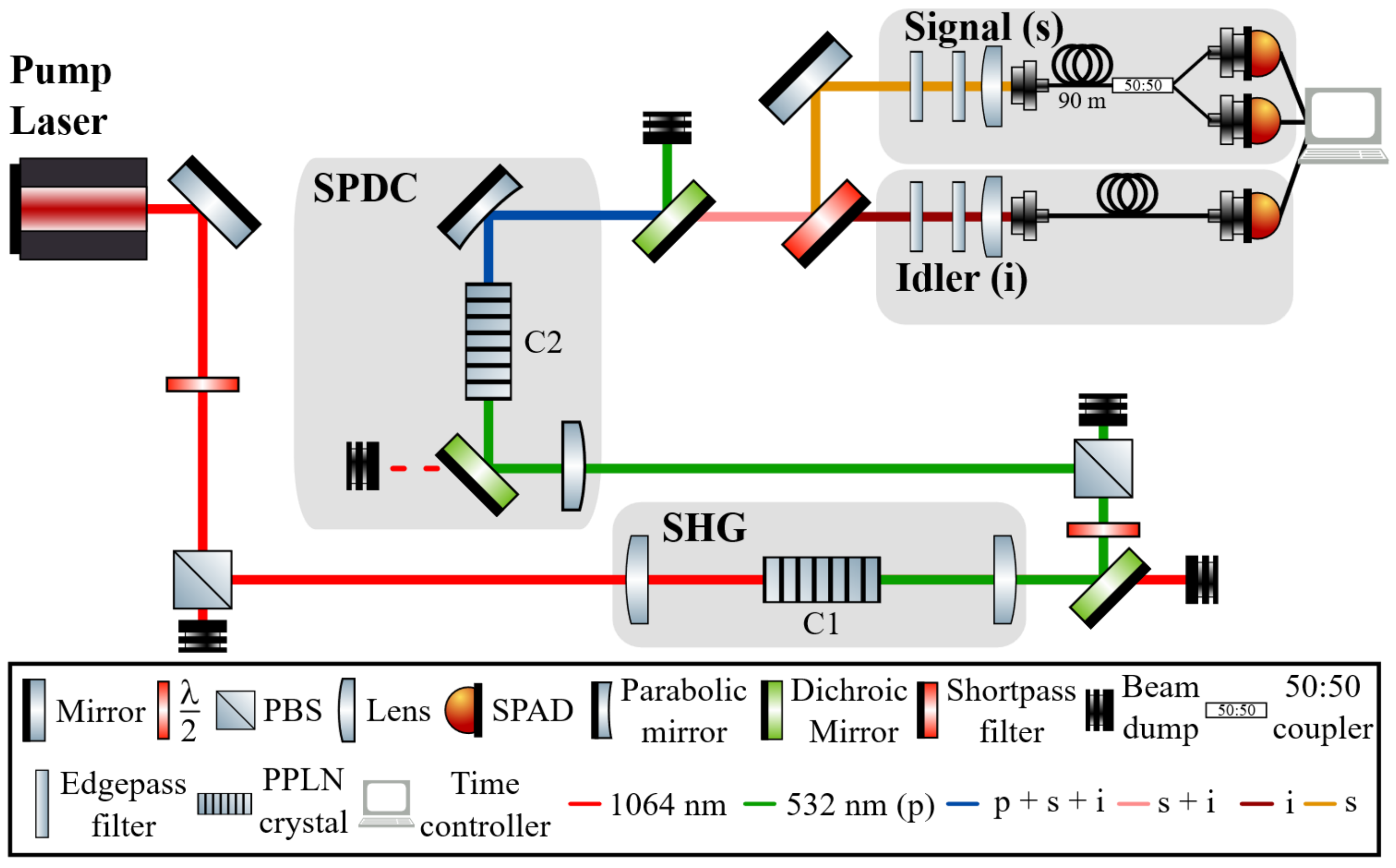


Fig. 2: Schematic representation of the optical set-up. PBS: polarisation beamsplitter, SHG: second harmonic generation, C1: PPLN crystal, DM: dichroic mirror, C2: multi-grating PPLN crystal, SPDC: spontaneous parametric down-conversion, LP: longpass filter.

Spectral output

(1) Energy conservation $\lambda_p^{-1} = \lambda_i^{-1} + \lambda_s^{-1}$

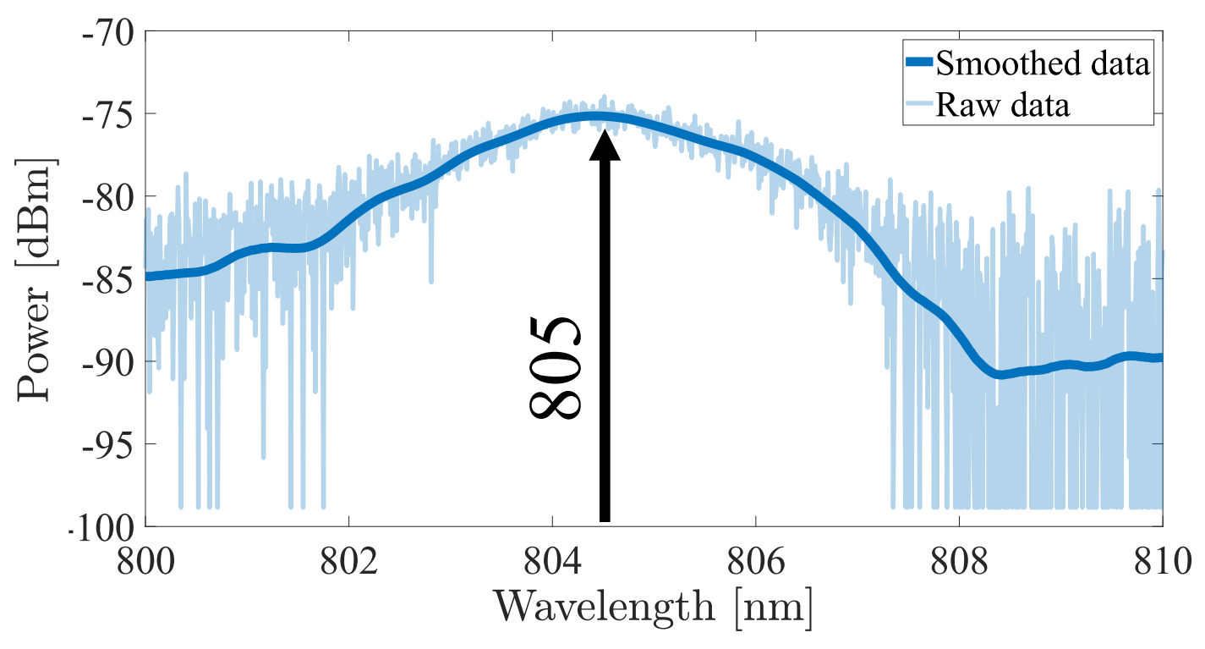


Fig. 3: Spectrum of the idler photon out of the fourth crystal channel (T = 121°C).

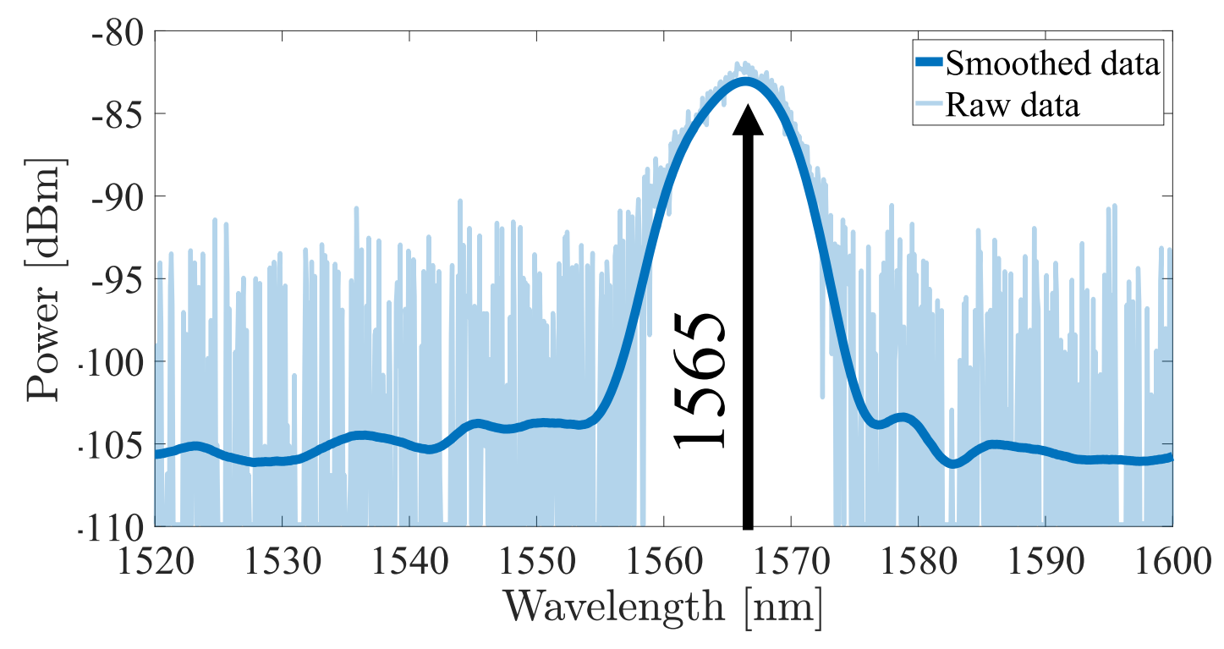


Fig. 4: Spectrum of the signal photon out of the fourth crystal channel (T = 121°C).

(2) Phase matching condition $k_p = k_i + k_s + \frac{2\pi}{\Lambda}$

$$\Lambda = f\left(\overbrace{T}^{\text{Fine tuning by thermal expansion}},\ \underbrace{\Lambda_j}_{\text{Discrete tuning thanks to different channel periods}}\right)$$

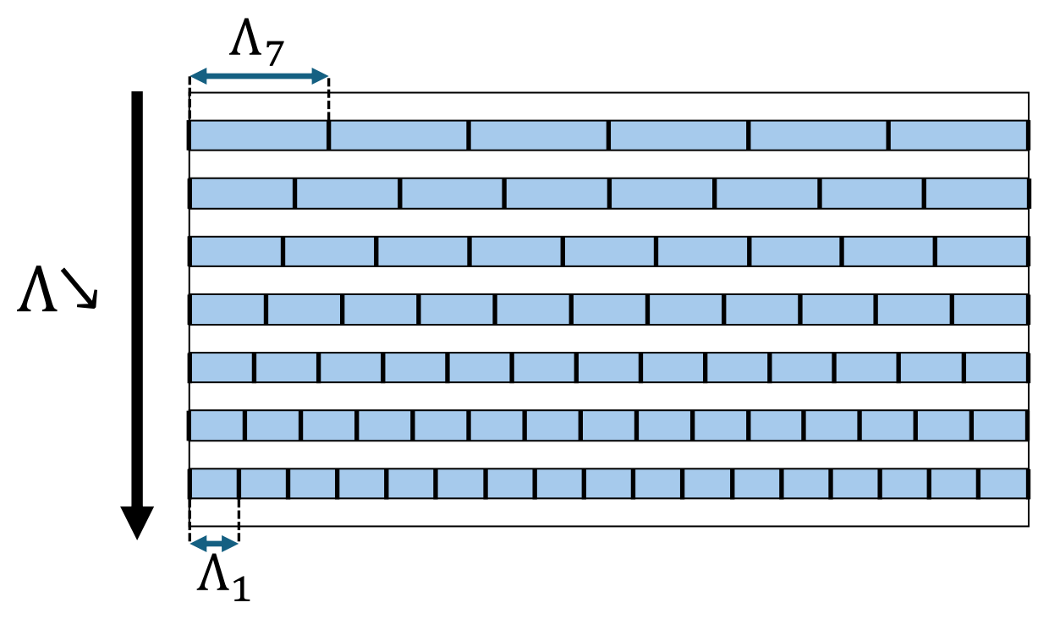


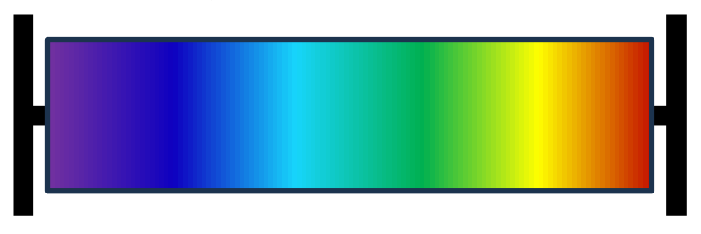
Fig. 5: Representation of the PPLN crystal, top view

(1) + (2) → (3) Spectral coverage

Energy conservation and phase matching enable a continuous spectral coverage

λ_s between

1064 nm



2300 nm

Temporal output

Heralding

If coincidences between signal and idler channels, emission of photon pairs (heralding).

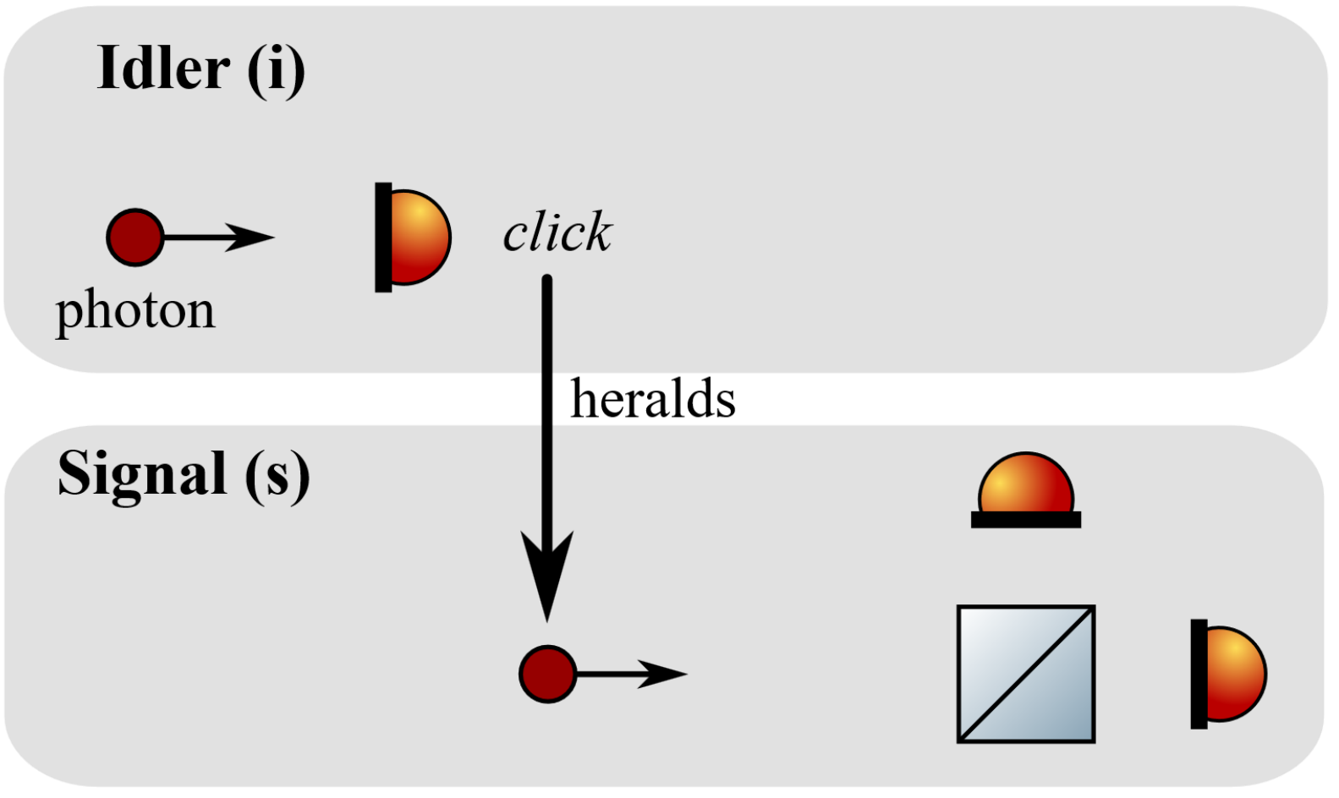


Fig. 6: Heralded single-photon generation via idler–signal correlations

Coincidences !

→ **Heralding**

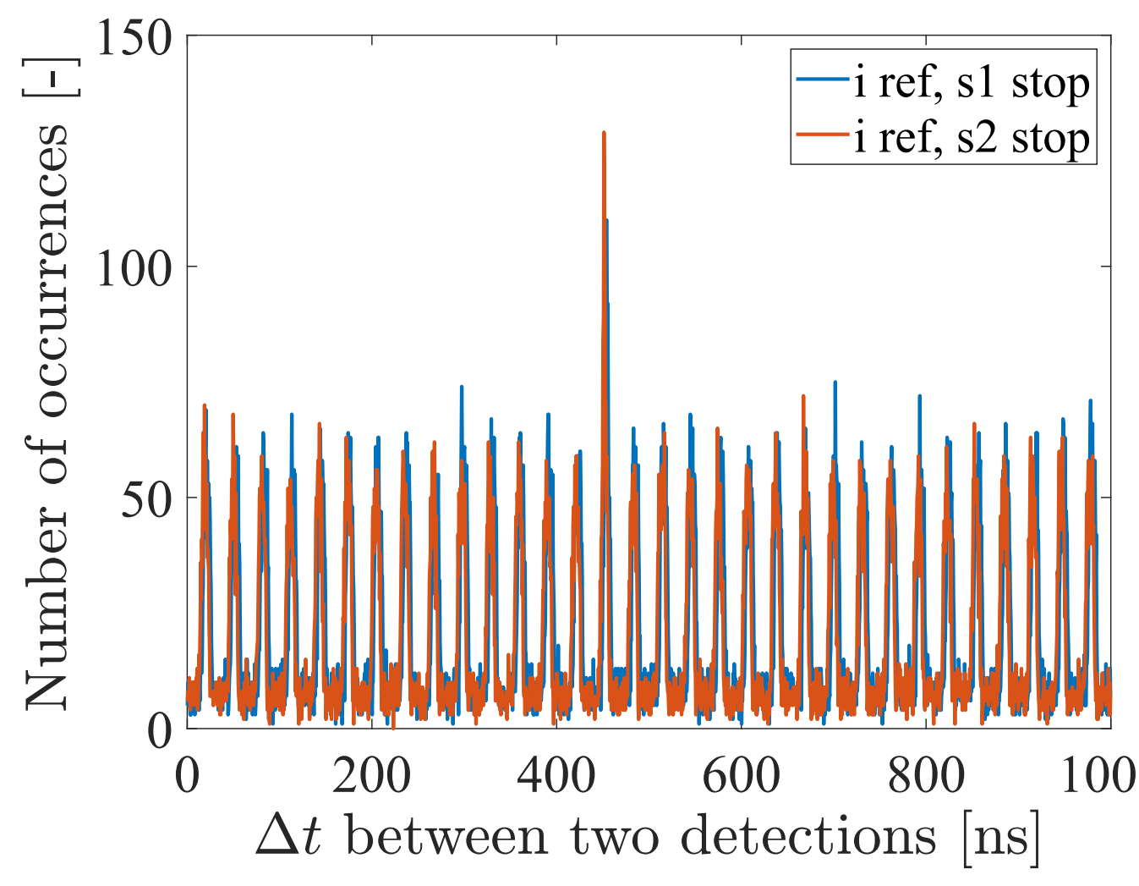


Fig. 7: Histogram of time intervals between consecutive detections in the idler and signal channels.

Single photons

If coincidences in the signal channel, emission of multiple photon pairs.

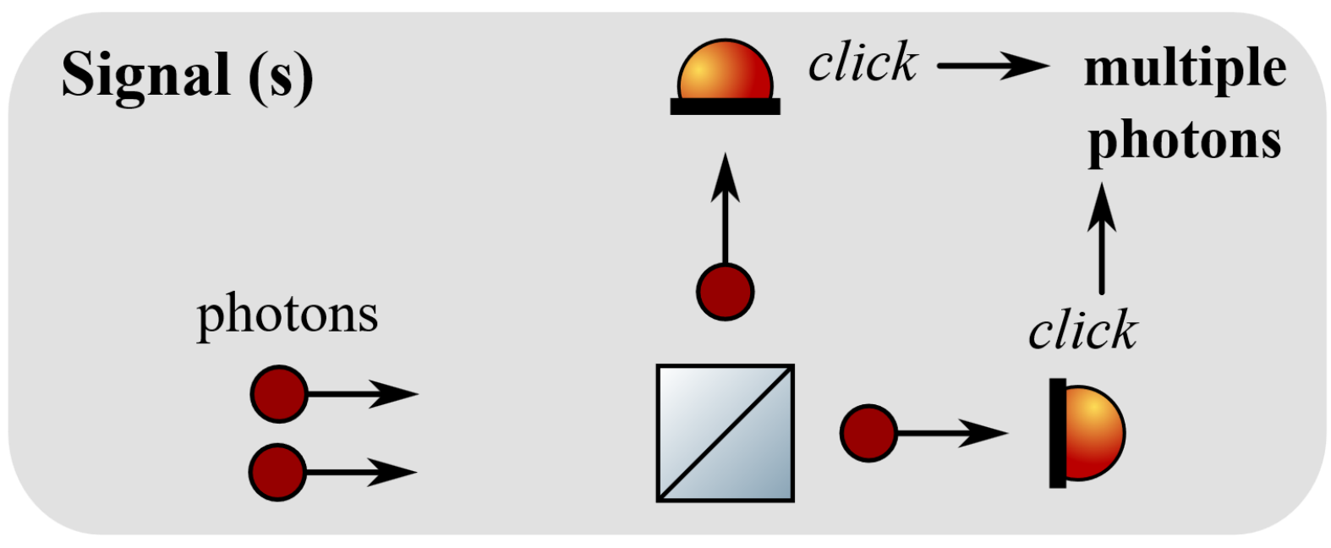


Fig. 8: Coincident detection of multiple photons.

No coincidence

→ **Single photons**

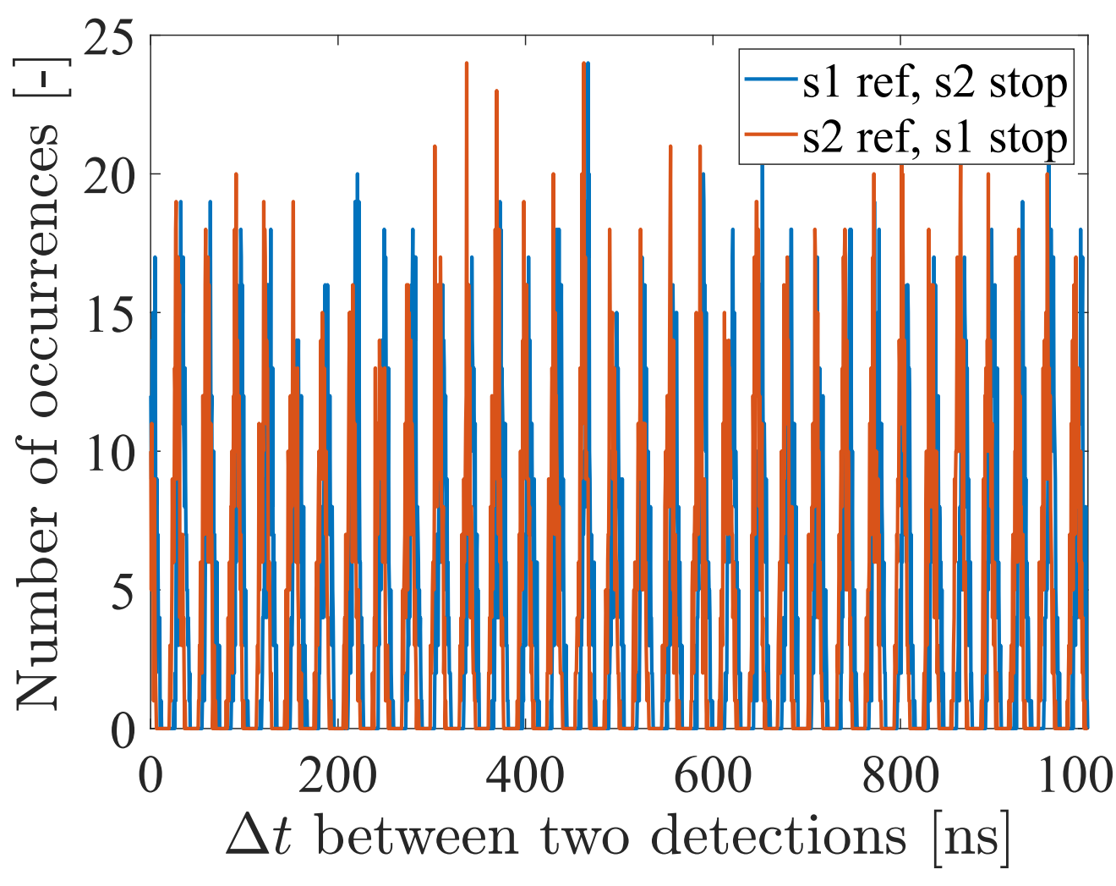


Fig. 9: Histogram of time intervals between consecutive detections in the signal channel.

Conclusions

- Very good agreement between measured and simulated spectra [3]
- Generation of wavelength tunable photon pairs
- Successful demonstration of heralding and single pair emission

Perspectives

- Optimisation of heralding and single photon rate
- Characterisation of the source at further wavelengths
- Mounting the source on a movable platform for real-field tests

References

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