Frequency-Resolved Polarisation Tomography of Hyperentangled Photon Pairs

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Precise state tomography of telecom-wavelength photons is central to characterising and optimising fibre-compatible quantum resources for communication, networking and information processing applications. We present a compact, fibre-coupled platform for polarisation state tomography of photon pairs at telecom wavelengths. Four motorised and computer-controlled polarisation-analysis stages were designed and calibrated near 1550 nm, enabling polarisation projections for both single-photon and multi-photon states (see **Fig. 1(a)**). Benchmarking with linearly polarised coherent laser light confirmed high-fidelity state reconstruction [1] with fidelities exceeding 99.8% for all stages. The stages were connected to a spontaneous parametric down-conversion (SPDC) source pumped by a spectrally shaped femtosecond laser in a Sagnac-loop configuration [2], generating telecom photon pairs simultaneously entangled in polarisation and frequency bins [3]. We obtained polarisation Bell-state fidelities of up to 98.39(4)% and concurrences of up to 97.48(9)%, where statistical uncertainties were estimated via Monte Carlo simulations. When complemented by time-of-flight analysis [4], the tomography stages enabled frequency-resolved polarisation analysis of the hyperentangled state, showing polarisation-entanglement fidelities above 99% across frequency bins and concurrences above 98% (see **Fig. 1(b)-(c)**) [3].

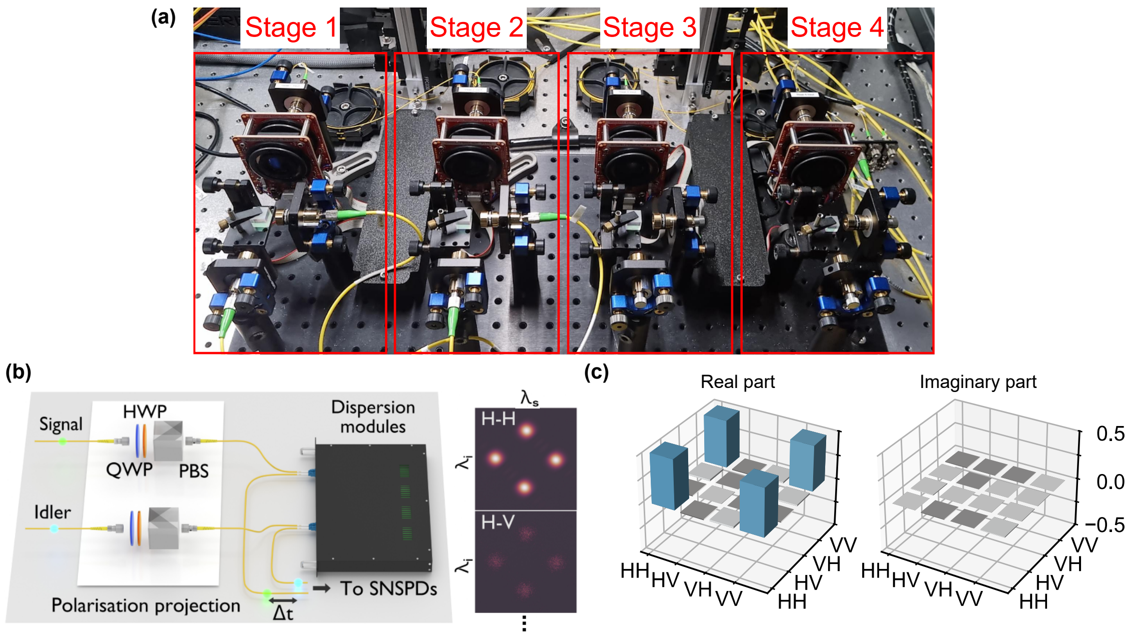

Fig. 1: **(a)** *Tomography setup: Stage 1-4.* **(b)** *Hyperentanglement characterisation via 36 polarisation projections and frequency-resolved detection. Polarisation tomography is performed separately for each frequency bin.* **(c)** *Reconstructed Bell state for one bin. Adapted from* [3].

References

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[4] M. Avenhaus *et al.*, 2009, doi: 10.1364/OL.34.002873.