Dispersion Engineering for Complete Coherent Conversion

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Generalizing well-established concepts in spontaneous parametric down-conversion and single-photon up-conversion, coherent photon conversion (CPC) [Fig. 1(a)] provides a nonlinear module that enables deterministic multiphoton gates, high-quality heralded single- and multiphoton states free from higher-order imperfections, and robust, high-efficiency detection [1]. Initial analysis suggested that dispersion might limit the performance of CPC-based operations for broadband photons [2]. However, it remained an important open question to identify the ultimate limitations to high-efficiency CPC operations.

In this work, we show how dispersion engineering can be used to tune the photon-conversion process [3]. This addresses a key open goal in this context, which is to study the optimal conditions for achieving deterministic photon conversion both from a single photon to a pair, as well as backwards. We investigate a range of dispersion scenarios and show that one can reach 100% forward [Fig. 1 (b)] and backward [Fig. 1 (c)] conversion efficiency at a finite propagation length. We also show that it is possible to realise robust conversion between one and two photons, where high conversion efficiencies can be realised over a large propagation distance range [Fig. 1 (d)]. These are nontrivial results due to the complex dynamics involving the one- and two-photon states across a broad optical frequency spectrum.

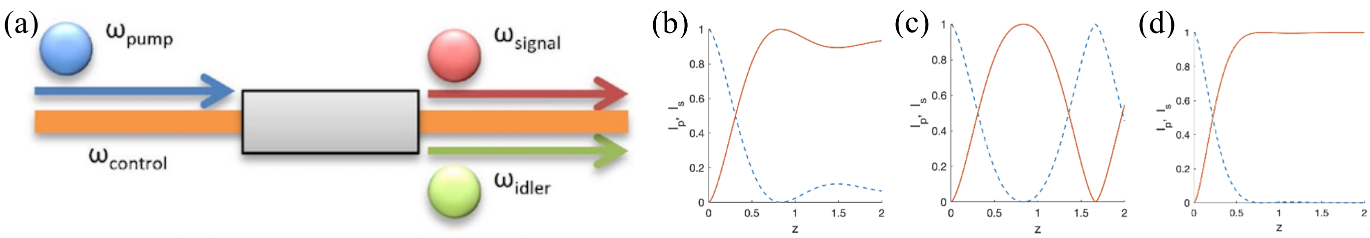

Fig. 1. (a) Coherent conversion of a pump photon into signal and idler photons. (b) Complete conversion of one photon into two at a finite distance for quadratic waveguide dispersion. (c) Forward and backward conversion between one- and two-photon states achieved by reversing the sign of the dispersion. (d) Robust conversion between one and two photons achieved through engineering higher-order frequency dispersion.

[1] N. K. Langford, S. Ramelow, R. Prevedel, et al., *Nature* **478**, 360 (2011).

[2] B. Viswanathan and J. Gea-Banacloche, *Phys. Rev. A* **92**, 042330 (2015).

[3] A. Solntsev, S. Batalov, N. Langford, A. A. Sukhorukov, *New J. Phys* **24**, 065002 (2022).