Four-Photon Interference with a High-Efficiency Quantum Dot Source

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Multi-photon interference forms the foundation of optical quantum technologies, including computing, simulation, and metrology. While probabilistic parametric down-conversion (SPDC) sources have driven immense progress in these areas, scaling these experiments is often constrained by their intrinsic brightness-purity trade-off. In the multi-photon regime, this can lead to low signal-to-noise ratios (SNRs) that can obscure the details of higher-order interference. To overcome this limitation, we combine a state-of-the-art deterministic single-photon source based on a quantum dot (QD) in an open microcavity with active, low-loss demultiplexing. This efficient architecture yields high single-photon purity ($g^{(2)}(0) < 0.02$) and indistinguishability ($I > 0.97$), whilst achieving order-of-magnitude enhancements in N-photon coincidence rates over comparable SPDC experiments [1].

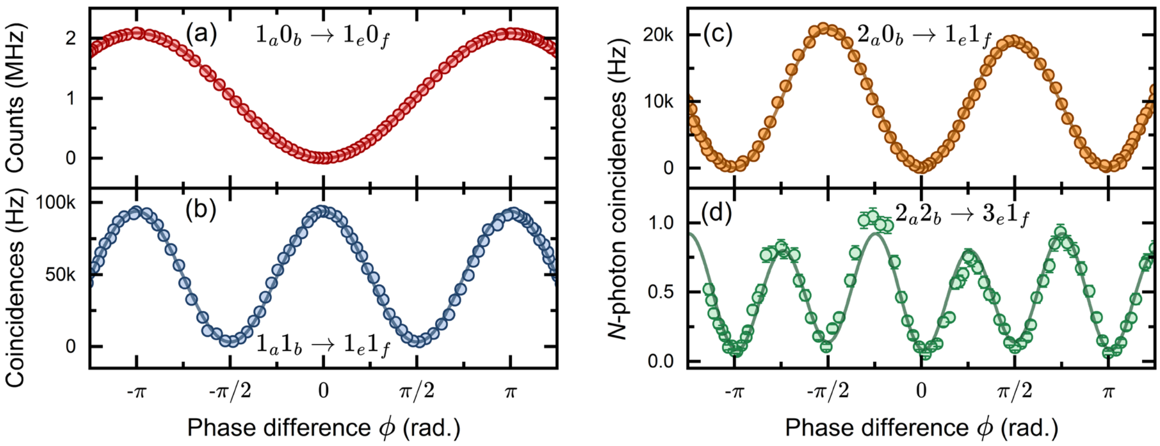

Fig. 1: *Interference fringes from injecting (a) one, (b,c) two or (d) four photons into the input modes (a/b) of a displaced Sagnac interferometer, detecting (a) single photons or (b,c) two- or (d) four-photon coincidences at the output modes (e/f) as a function of phase (φ). Solid lines – theory model.*

Combining high-rate experiments with a comprehensive theoretical model (Fig. 1), we reveal new harmonic structure in four-photon interference fringes [2] that was previously masked by noise (Fig. 1(d)). Crucially, we report the discovery of "deep fringes" [2] — robust interference minima that render four-photon interference contrast remarkably insensitive to photon distinguishability, deviating strongly from the well-known two-photon case. A Fisher information analysis reveals that these fringe structures can exhibit phase sensitivity beyond the Standard Quantum Limit [2], with the "deep fringes" greatly reducing the photon indistinguishability required for quantum advantage.

Furthermore, our results show that four-photon interference fringes exhibit distinct signatures arising from distinguishable photons and multi-photon emission events [2]. As these processes are extremely challenging to separate in standard two-photon measurements, the structure of multi-photon fringes provides a powerful new diagnostic for source characterization. This offers the potential to develop efficient benchmarking protocols for technologies such as photonic quantum computers. Ultimately, our results establish that solid-state emitters have matured to outperform probabilistic sources in the multi-photon regime, providing a scalable platform for generating complex photonic states.

References

[1] T. Nagata *et al., Science*, **316**, 726 (2007).
[2] A.J. Brash *et al.*, *arXiv:2601.00966*, (2026).