Optimal distillation of photonic indistinguishability

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Abstract: In this work, we propose and experimentally implement a protocol for the distillation of single photons. In particular, we show the possibility to increase the indistinguishability between two photons by interfering them with a third one.

The performance and scalability of photonic quantum communication and computation are constrained by the imperfect indistinguishability of photons, a critical parameter for high-fidelity quantum interference. To address this limitation, distillation protocols—conceptually inspired by entanglement purification—have been proposed to enhance photonic indistinguishability by leveraging multi-photon quantum interference within linear optical circuits.

In this work, we introduce an optimized three-photon distillation protocol specifically engineered to achieve the maximum possible visibility gain. This optimization necessitates a rigorous accounting for complex multi-photon interference effects, most notably the influence of collective photonic phases which significantly impact the distillation process. Furthermore, we design our interferometric structures to utilize a minimal number of optical modes, thereby maximizing the protocol's success probability while maintaining experimental feasibility. The developed protocol is experimentally validated using a state-of-the-art platform that integrates a high-performance demultiplexed quantum dot source with a programmable, eight-mode integrated photonic processor fabricated via femtosecond laser writing. Our experimental results demonstrate the successful distillation of indistinguishable photons across a variety of multi-photon distinguishability scenarios, even when operating under conditions of limited photonic resources. Ultimately, this work substantiates the role of distillation as a robust and practical tool for advancing the capabilities of next-generation photon-based quantum technologies.

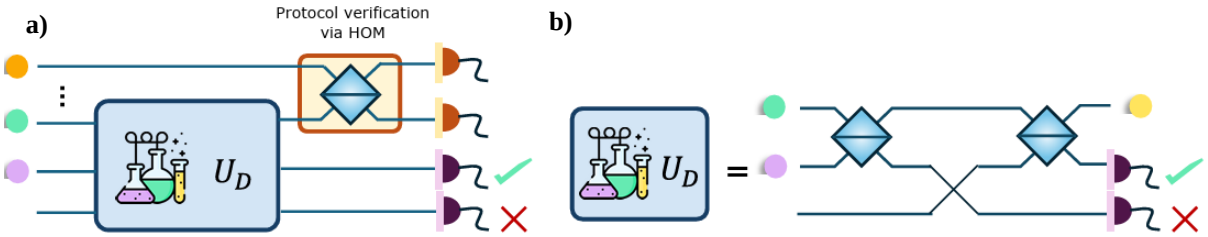

Fig. 1 a) In a distillation protocol, the indistinguishability of input single-photon resource states is enhanced by having a subset of them interfere with auxiliary photons in a linear optical circuit. Photon-counting measurements in the auxiliary modes herald the generation of distilled photons displaying higher mutual indistinguishability with the upper photons. This effect can be verified via a direct measurement of the HOM visibility. b) The optimal distillation circuit proposed in in the work, which takes as input two single-photon states with real-valued pairwise inner products associated with the HOM visibilities. Figure adapted from [1]

References

[1] F. Hoch et a. “Optimal distillation of photonic indistinguishability”, arXiv:2509.02296, 2025