Spectral Two-Photon Quantum Interference via Electro-optic Modulation Between Light States Of Different Photon Statistics

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Abstract: Frequency-domain two-photon quantum interference between a thermal field and a heralded-state is studied theoretically and experimentally, revealing the dependency of visibility on the multiphoton components within the heralded-state.

Photonic frequency-encoded quantum information processing can pave the way for the realization of global-scale quantum networks [1], integral to which is the scalable implementation of the Hong-Ou-Mandel (HOM) effect between independent light states of different photon statistics [2, 3]. In this work we demonstrate the first-time experimental implementation of the spectral HOM effect between independent single photons as well as the quantum interference between a thermal and a heralded state. To this end, an intrinsically stable and reconfigurable frequency processing circuit was used, which consisted of a mode-locked pulsed laser, two programmable filters, an electro-optic phase modulator (EOPM) – acting as a frequency counterpart of a conventional spatial domain beam splitter – and four superconducting nanowire single photon detectors (SNSPD) (see Figure 1a). The synchronized collection of coincidence events with the pulsed laser repetition-rate allowed for on-the-fly acquisition of the HOM effect. For the HOM effect between single photon states we measured a visibility of 74.31% ± 3.57% (see Figure 1b), which falls well beyond the classical limit of 50%, offering an appropriate candidate for quantum communication and information applications. In the case of the HOM effect between a thermal field and a heralded state, we derived a theoretical relation,

$$V_{\text{theory}} = \frac{1}{1 + \left(\bar{n}_{1,\text{th}}^2 + \bar{n}_2^2 + \bar{n}_{1,\text{th}} \bar{n}_2 + \bar{n}_2 \bar{n}_{1,\text{th}}\right)/\left(\bar{n}_{1,\text{th}} \bar{n}_2 + \bar{n}_2 \bar{n}_{1,\text{th}}\right)}$$

where \(\bar{n}_{1,\text{th}}\) and \(\bar{n}_2\) are the thermal mean photon numbers per pulse period, describing the dependency of the visibility on the fields’ thermal components in the heralded state get engaged in quantum interference. Experimentally, by assuming the absence of the HOM effect at zero delay, we defined a reference point (see Figure 1c), revealing a visibility of \(V_{\text{experiment}} = 43.20% \pm 4.28%\), which is in good agreement with the predicted theoretical value \(V_{\text{theory}} = 47.30% \pm 0.66\%\). Our results enable the implementation of important concepts such as quantum teleportation, entanglement swapping and complex states in large-scale frequency-domain quantum circuits, and thus provides a key element for future frequency-multiplexed quantum networks.

Figure 1. a) Experimental setup employed for HOM effect between two single photon states. (The setup for HOM between a thermal field and heralded state is not shown here.) b) Four-fold and c) three-fold coincidence counts as function of delay expressed as multiples of the pulse period.

References