Supplementary Material: Towards giga-counts-per-second detected pair rates in polarization entangled photon sources

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Multiplexed accidental rate

Assuming a source rate R and detection efficiencies of η_1 and η_2 in a channel, we can estimate the ratio of accidental to true coincidence detections[1] (this ratio is the inverse of the commonly used coincidence-to-accidental ratio, CAR). The rate of accidental coincidences, C_a, can be approximated by the single event rates on the single photon detectors (including background events, excluding real coincidences), S_1 and S_2 via $C_a = \tau S_1 S_2$, where τ denotes the coincidence time window. The coincidence rate, C, is $C = \eta_1 \eta_2 R$. This yields the accidental-to-pair ratio,

$$\frac{C_a}{C} = \frac{\tau S_1 S_2}{\eta_1 \eta_2 R}.$$

Neglecting dark and background events, this reduces to $\frac{C_a}{C} = \tau R$, which fundamentally limits the visibility of the system.

To overcome this limit, the entangled pair can be split in N dedicated frequency channels. In the source presented in the current work this multiplexing is permissible without loss of efficiency, since the pairs are correlated with respect to their wavelength. For a multiplexed link, the accidental and pair rates can be written as:

$$C' = \sum_i^N \eta_1^i \eta_2^i R^i,$$

$$C_a' = \tau \sum_i^N S_1^i S_2^i.$$

Assuming the same efficiencies and singles rates over all channels, $S_{1,2}^i = S_{1,2}/N$. The multiplexed accidental-to-pair ratio, to first order, becomes:

$$\frac{C_a'}{C'} = \frac{\tau S_1 S_2}{\eta_1 \eta_2 R N}.$$

Using the performance parameters of the source presented in this work, it is possible to estimate the resource requirements to achieve the detection of 1 billion pairs per second in a single spatial mode with acceptable quantum state fidelity (acceptable here refers to a quantum bit error rate of a few percent). For the source, it is assumed that a 1 W free-running laser diode is used which enables the production of 10 billion pairs per second with high intrinsic visibility.

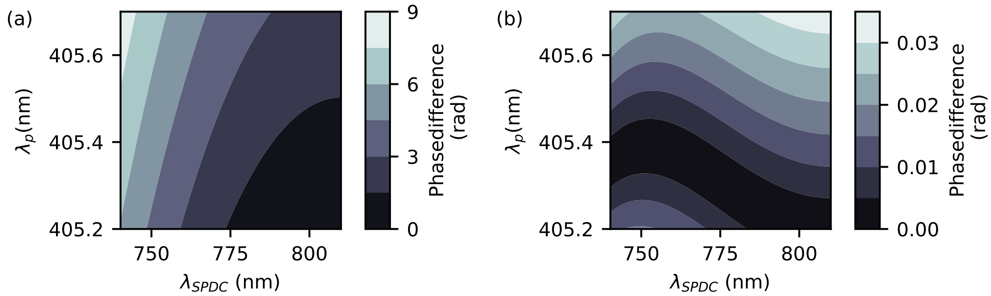

FIG. S1. Phase difference of the $|HH\rangle$ and $|VV\rangle$ pairs as a function of pump and SPDC wavelength (a) before and (b) after compensation using only the SPDC wavelength below the degenerate case.

For the detection part, we assume that the pair is multiplexed across N different channels. Each channel employs a pair of superconducting nanowire detectors[2], with a dead time of 10 ns, a detection jitter of 15 ps, a dark count rate of 50 Hz and a total detection efficiency of 45% including the coupling efficiency. Further, a total system coincidence window of 50 ps is assumed. Using these parameters, the number of detectors for the detection of 1 billion pairs per second is approximately 25. This number of detectors is feasible with current technologies.

Temporal compensation

The phase difference $\Delta\varphi$, is a function of the pump (λ_p) and SPDC (λ_{SPDC}) wavelengths. In the absence of phase compensation elements, $\Delta\varphi$ has a strong dependence on these wavelengths, as shown in Fig. S1(a). It is desirable to flatten this phase map to accommodate a broadband pump and to utilize a broader SPDC spectrum. Moreover, even if a narrowband pump is used, a flat phase difference ensures phase stability in the presence of a drifting pump wavelength. The choice of the right YVO_4 lengths is crucial to generate a uniform quantum state over the pump and SPDC spectral ranges. For the source presented in this work, we calculate ideal lengths for the precompensation crystal, $L_{pre} = 0.78$ mm and for the postcompensation crystal, $L_{post} = 0.97$ mm. The resultant phase map shown in Fig. S1(b) does not vary significantly over the range of SPDC and pump wavelengths.

However, due to manufacturing constraints the lengths of the crystals used in the experiments are slightly different, as indicated in Fig. S2 (red cross). This explains the slightly

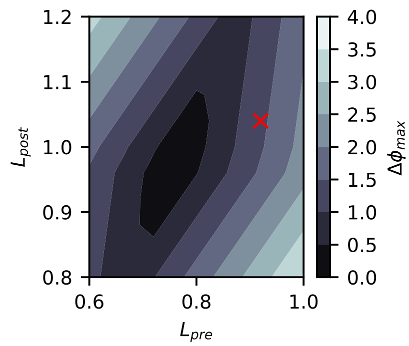

FIG. S2. Maximum of phasedifference between $|HH\rangle$ and $|VV\rangle$ pairs in the spectral window considered in Fig. S1 as a function of the compensation crystal lengths. The red cross indicates the lengths that were used in the experiment.

lower visibility measured for the broadband pump.

REFERENCES

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