Supporting Online Material for

Determining the Dynamics of Entanglement

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Determining the Dynamics of Entanglement:
Supporting Online Material

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1 Producing Entangled Photons

The entangled bipartite state is produced in the polarization degrees of freedom of two photon-
s generated by spontaneous parametric down conversion (SPDC) using the two-crystal source
(SI) consisting of two BBO crystals (2 mm length) pumped by a 405nm diode laser. Photon
pairs are produced in either the $|HH\rangle$ state (first crystal) or the $|VV\rangle$ state (second crystal).
When these two events are indistinguishable, an entangled state is produced. Due to the short
coherence length of the diode laser and the temporal walk off in the birefringent crystals, 1.5
mm length compensating BBO crystals C1 and C2 are required in the pump beam, as shown
in Fig. 1 of our manuscript. The compensators are arranged so as to delay one polarization
component with respect to the other, so that after passing through the SPDC source the down-
converted photons are temporally indistinguishable. Small apertures (1mm) and interference filters (10nm bandwidth centered at 810nm) are used to further increase indistinguishability. Typically, we were able to produce entangled states with purity around 0.85-0.95. A state of the type \( \alpha | HH \rangle + \beta | VV \rangle \) is produced with arbitrary \( \alpha \) and \( \beta \), which can be controlled via the polarization of the pump laser with a half wave plate (HWP) and quarter-wave plate (QWP). The usual quantum state tomography (S2) procedure was used to characterize and verify the initial state produced by the SPDC crystals. The tomographic measurements were performed by registering two-photon coincidence counts, so that typical results involved hundreds of events. In this way, following the Poissonian count statistics, the error in each tomographic measurement was of a few percent. The error associated to functions of the reconstructed density matrix, such as concurrence, were estimated through Monte Carlo simulations of experimental runs obeying the same count statistics.

2 Quantum Process Tomography

Quantum Process Tomography (QPT) is a standard procedure in which a known set of quantum states is used to probe an unknown channel \( \mathcal{E} \). A detailed account of QPT in general and an explicit example for the case of qubits can be found in Ref. (S3). For QPT of qubit channels, a set of at least four states is required. In our experiment we employ the polarization states \( | H \rangle \), \( | V \rangle \), \( | + \rangle = (| H \rangle + | V \rangle) / \sqrt{2} \) and \( | R \rangle = (| H \rangle + i | V \rangle) / \sqrt{2} \), which are prepared by sending single photons through linear and circular polarizers (this yields states with purity near 100%). Individual photons in these states are repeatedly sent through the channel and, for each of the four kinds of input, quantum state tomography (2) is performed, thus determining the output state \( \rho_j \), where \( \rho_j = | j \rangle \langle j | \) for \( j = H, V, +, R \). With knowledge of \( \rho_j \) for each state \( \rho_j \), the four Kraus operators can be determined, as detailed in Ref. (S3). This is sufficient to completely characterize the quantum channel. For each value of the parameter \( p \) defined in
Eq. 2, tomographic measurements were registered for hundreds of photons, so that, following the Poissonian count statistics, the experimental error of each result was of a few percent. The error associated to the inferred concurrence $\mathcal{C}(I \otimes S|\phi_+\rangle\langle\phi_+|)$ was obtained by Monte Carlo simulations of experimental runs which obey the same photon count statistics (S2).

**References and Notes**

