We present two-photon interferences with polarization-entangled twin beams created by type II spontaneous parametric down-conversion (Fig. 1). The signal photon is sent into a Mach-Zehnder interferometer, where the first beam splitter (marked PBS) is polarization sensitive. If we assume that the signal photon has either horizontal ($H$) or vertical ($V$) polarization, it is sent into one or the other arm of the interferometer and it cannot “interfere with itself”. The idler photon is sent to a detector equipped with turnable polarization filters. We select those signal and idler photons whose arrival times are consistent with a common origin in the source. In these events, due to a delay of approx. 10ns in an optical fibre, the signal photon is actually detected before the idler photon. In the coincidence signal, we can observe fringes as the path difference $\Delta l$ of the Mach-Zehnder interferometer is scanned. The phase can also be scanned by turning a birefringent crystal on the idler side, realizing a “nonlocal phase shifter” in the configuration space governed by a two-photon wave function [3]. Non-local (causally disconnected) correlations between signal and idler detection events naturally arise in this picture because the two events share a common past (the simultaneous birth of the two photons in the nonlinear crystal) and their correlations are unravelled only in a common future (when the registered clicks are binned).

We compare the experiment to related setups [4].

In the language of quantum state collapse, the detection of the idler in a tilted polarization projects the signal photon into a superposition state (oriented midway between $H$ and $V$) so that interference between the two arms becomes possible. This “collapse” picture should not be taken literally, however, since the signal photons have been detected before (“delayed choice”). To highlight this issue, we take data on the idler side with two different polarizer angles $\alpha_{1,2}$ (detectors $D_{11}$, $D_{12}$), fed randomly after splitting the beam. In the zero-contrast data of Fig. 2(right), $\alpha_1$ is set to optimize the welcher Weg information, while $\alpha_2$ is scanned. This may lead to the weird conjecture that the firings of $D_{11}$ and $D_{12}$ transmit random signals into the past that the signal photon should either behave as a wave (superposition of polarization states) or a particle (taking one of the interferometer arms tagged by $H$ or $V$) [2]. One should remember, however, that no information about wave or particle behavior can be extracted from single events on the signal side: the interference emerges only after sifting through the ensemble of detection events. An alternative description would be based on “interfering histories” in the configuration space governed by a two-photon wave function [3].

References


