비국소성에 기반한 얽힘광원의 분산제어

Nonlocal Dispersion Cancellation using Entangled Photons

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Classically, a pair of optical pulses traveling through two dispersive media will become broadened and, as a result, the degree of coincidence between the optical pulses will be reduced. Surprisingly, for a pair of entangled photons, nonlocal dispersion cancellation in which the dispersion experienced by one photon cancels the dispersion experienced by the other photon is possible(1). In this paper, we report the first experimental demonstration of nonlocal dispersion cancellation using entangled photons(2). The degree of two-photon coincidence is shown to increase beyond the limit attainable without entanglement. Our results have important applications in fiber-based quantum communication and quantum metrology.

Consider a pair of spontaneous parametric down-conversion (SPDC) photons generated at a BBO crystal pumped by a monochromatic pump, see Fig. 1. The wave number of the photon can be expressed as $k_i(\Omega_i \pm \nu) = k_i(\Omega_i) \pm \alpha_i \nu + \beta_i \nu^2$ $(i=0,1)$. Here ν is the detuning frequency from the central frequency and α and β are the first-order and second-order dispersion which are responsible for the wave packet delay and the wave packet broadening, respectively. The joint detection probability of the two detectors D1 and D2 is proportional to the Glauber second-order correlation function which are given as,

$$G^{(2)}(t_1 - t_2) = \left| \int_{-\infty}^{\infty} d\nu\, S(\nu)\, e^{i\nu(t_1 - t_2)} e^{(\alpha_1 z_1 - \alpha_2 z_2)\nu} e^{i(\beta_1 z_1 + \beta_2 z_2)\nu^2} \right|^2 .$$

Where the two-photon joint detection probability, $S(\nu) = \mathrm{sinc}(\nu DL/2)$ for collinear nondegenerate type-I SPDC. Here, L and $D \equiv 1/u_2 - 1/u_1$ are the BBO crystal thickness and the inverse group velocity difference between the photon pair in the BBO crystal, respectively.

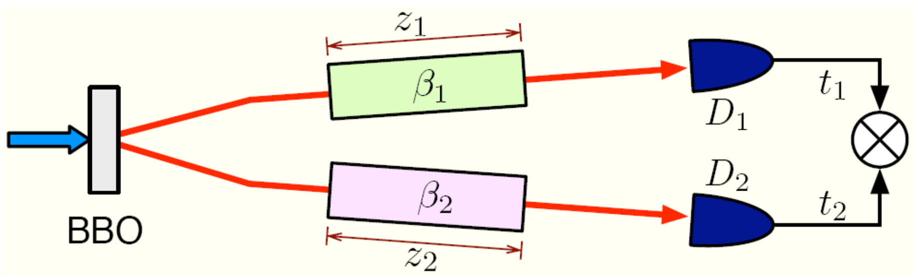

Fig. 1: Each photon of the entanged photon pair is subject to different dispersion β_1 and β_2. The coincident circuit measures $G^{(2)}(t_1 - t_2)$.

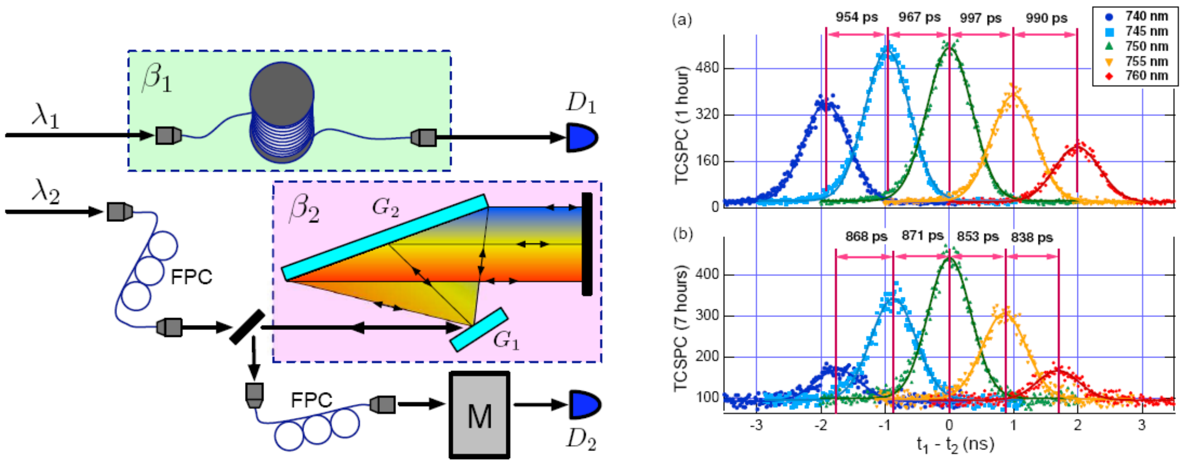

Fig. 2: Left: Outline of the experiment. Right: Experimental data. (a) With positive dispersion β_1 only. (b) With both positive dispersion β_1 and negative dispersion β_2. Solid lines are Gaussian fit to the data. The nonlocal dispersion cancellation effect is clearly demonstrated.

By approximating the joint spectral amplitude as a Gaussian function $S(\nu) \approx e^{-\gamma(\nu DL)^2}$ $(\gamma = 0.04822)$, the full width at half maximum value of the temporal width of $G^{(2)}$ function is given as

$$\triangle t \approx 2\sqrt{\frac{2\ln 2}{\gamma D^2 L^2}}(\beta_1 z_1 + \beta_2 z_2).$$

The above equation shows precisely the effect we have been looking for: a positive dispersion β_1 experienced by photon 1 can be cancelled by a negative dispersion β_2 experienced by photon 2. Such nonlocal dispersion cancellation effect is theoretically shown to occur only if photon 1 and photon 2 are in a specific entangled state[(1)].

The experimental setup to implement the nonlocal dispersion cancellation effect is schematically shown in Fig. 2 (Left). $\lambda_1 = 896\,nm$ photons are coupled into a $1.6\,km$ long single-mode optical fiber which introduces positive dispersion β_1 to the photon. The effect of a positive dispersion material to the entangled photon is to broaden the biphoton wave packet[(3)-(4)]. To demonstrate the nonlocal dispersion cancellation effect, we have used the grating pair method to introduce negative dispersion to $\lambda_2 = 750\,nm$. The experimental data are shown in Fig. 2 (right). Comparing (a) and (b), we observe that the temporal spacings between the spectrally resolved components are reduced when the idler photon is subject to negative dispersion. The reduction of the temporal spacing is $478\,ps$ and it agrees very well with the theoretically calculated value of the reduction of the biphoton wave packet, which is calculated as $\triangle t_{NDC} \approx 2\sqrt{\frac{2\ln 2}{\gamma D^2 L^2}}(\beta_1 z_1 + \beta_2 z_2) = 496\,ps$.

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