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Characterization of two-photon interference between a weak coherent state and a heralded single photon state

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Abstract: We experimentally investigate two-photon interference between a weak coherent state and a heralded single-photon state, producing from a spontaneous parametric down conversion. Both the unequal spectrum linewidth and average photon number ratio in a given time interval are considered in our model. We obtained excellent agreement between our experimental data and prediction from our model. Furthermore, the range of observing high visibility two-photon interference is significantly extended by isolating coincidence events from two-photon contributions in the weak coherent state. These results may throw some new light on quantum information technology when the two-photon interference with independent sources is required.

The Hong-Ou-Mandel (HOU) interference is one of the most famous phenomena in quantum optical experiments. The HOM dip can be understood as destructive interference between the two quantum probability amplitudes for paths where both photons are transmitted and both are reflected emerging in each of the two output ports when two identical photons are fed in. It can also be explained as the production of quantum entanglement between two output fields. Originally, the HOM interference was observed by two strongly correlated fields produced by spontaneous parametric down-conversion (SPDC) [1]. Because it involves special sources [2,3] and potential applications in quantum information, such as quantum cryptography [4], quantum computation [5] and precision measurements [6], this type of interference between two-photon states has been attracting much attention. Its potential application has also bolstered efforts toward the experimental observation of two-photon interference with high visibility between independent sources for quantum network applications [7,8]. Up to now, this operation has been studied using various types of single photon sources, based on either nonlinear crystals, quantum dots, single atoms, or trapped ions [9–13]. Thus the further investigation of interference between independent sources is also of great relevance for the development of quantum information techniques.

Recently, several experiments have also demonstrated the HOM effect and violation of Bell inequality using interference of two weak coherent states [14,15]. To do this, one needs to repeat the experiment with different inputs and isolate the coincidence events from the two-photon state. This technique opens another way of implementing a high visibility two-photon interference between independent sources. From the perspective of realizing a quantum network system, its core technology is to observe a high visibility two-photon interference between independent sources in quantum nodes. At its heart, two-photon interference is quite simple to understand. But it is also rich in terms of experimental performance once two independent sources are

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employed. Consideration must be given to many different parameters of the incoming light, such as the spectrum and the average photon number in a given time interval [16,17]. It has been demonstrated that the generation of pure quantum photon pairs is important for interference with two heralded single-photon states from different SPDCs [18,19].

Here, we experimentally investigate a two-photon interference between a weak coherent state and a heralded single-photon state produced from SPDC. Both unequal spectrum linewidth and average photon number ratio within a time interval are considered in our model for the first time. The two-photon interference visibility is measured as a function of the ratio of the average photon number for the coherent state to the single photon producing rate in experiment. When the coincidence events from two photons in the weak coherent state are isolated [14,15], the boundary of observing two-photon interference with visibility of 0.5 was raised significantly. We obtained an excellent agreement between experimental data and the prediction from our model. These results may give a new method to perform two-photon interference with independent sources in modern quantum information science.

We illustrate a two-photon interference between a weak coherent state and a heralded single-photon state on a 50:50 beam splitter. Considering that the weak coherent state and single photon have the arbitrary spectral amplitude function $\phi_c(\omega)$ and $\phi_s(\omega)$, the overall input state for the BS is [20],

$$\begin{aligned}|\psi_{\text{in}}\rangle_{A,B} =&|\alpha,\omega_1\rangle_A \otimes |1,\omega_2\rangle_B \\ &\approx \cdots + \iint d\omega_1 d\omega_2 \phi_c(\omega_1)\phi_s(\omega_2)\hat{a}_c^\dagger(\omega_1)\hat{a}_s^\dagger(\omega_2)\exp(i\omega_1\tau)|0,0\rangle_{A,B} \\ &+ \int d\omega_1 \phi_c^2(\omega_1)\hat{a}_c^{\dagger 2}(\omega_1)\exp(i\omega_1\tau)|0,0\rangle_{A,B} + \cdots,\end{aligned} \tag{1}$$

where we omit the terms with a total photon number less than or higher than two. $\hat{a}_k^\dagger(\omega_i)(k = c, s$ and $i = 1, 2)$ represents a create operator acting on a single frequency mode ω_i. The spectral amplitude function is normalized such that $\int d\omega|\phi_c(\omega)|^2 = \int d\omega|\phi_s(\omega)|^2 = 1$. We are interested in how the coincidence probability of two outputs changes as a function of the overlap between the photons. Therefore, we introduce a time delay (τ) in the coherent beam. Using a standard method [20,21,22], the coincidence probabilities at two outputs are calculated

$$Pc^{1,1}(\tau) = \frac{1}{2} - \frac{1}{2}\int d\omega_1 \phi_c^*(\omega_1)\phi_s(\omega_1)\exp(-i\omega_1\tau)\int d\omega_2 \phi_s^*(\omega_2)\phi_c(\omega_2)\exp(-i\omega_2\tau) \tag{2a}$$

$$Pc^{2,0}(\tau) = \int d\omega_1 |\phi_c^*(\omega_1)\phi_c(\omega_1)|^2, \tag{2b}$$

for the input state of $|1,1\rangle_{A,B}$ and $|2,0\rangle_{A,B}$, respectively.

Considering two states with Gaussian spectral amplitude functions

$$\phi_k(\omega) = \frac{1}{\sqrt[4]{\pi}\sqrt{\delta\omega_k}}\exp\Big(-\frac{(\omega-\bar{\omega}_k)^2}{2\delta\omega_k^2}\Big), \qquad (k = c, s) \tag{3}$$

where $\bar{\omega}_k$ is the central frequency of the field, $\delta\omega_k$ defines its spectral linewidth, the coincidence probabilities in of Eq. (2) simplify to

$$Pc^{1,1}(\tau) = \frac{1}{2} - \frac{\delta\omega_A\delta\omega_B}{\delta\omega_A^2+\delta\omega_B^2}\exp(-\frac{\delta\omega_A^2\delta\omega_B^2}{\delta\omega_A^2+\delta\omega_B^2}\tau^2), \tag{4a}$$

$$Pc^{2,0}(\tau) = \frac{1}{2}, \tag{4b}$$

where the two states with the same central frequency $(\bar{\omega}_A = \bar{\omega}_B)$ have been taken. When $\bar{\omega}_A \neq \bar{\omega}_B$, a quantum beat signal will appear with carrier frequency of $\Delta = |\bar{\omega}_A - \bar{\omega}_B|$ in the interference

[23]. The probability of finding n photons in a weak coherent state is given by the Poisson distribution. Hence the probability of finding a pair of Fock states $|1,1\rangle_{A,B}$ and $|2,0\rangle_{A,B}$ at the input mode is given by

$$P(1,1) = \mu_A\mu_B \exp(-\mu_A), \tag{5a}$$

$$P(2,0) + P(2,1) = \frac{\mu_A^2 \exp(-\mu_A)}{2}, \tag{5b}$$

when a weak coherent state with an average photon number of μ_A in a given time interval and a single photon state with a production probability of μ_B in the same time interval feed the BS. The number of coincidence events at two outputs can be calculated as

$$N_c(\mu_A,\mu_B,\tau) \propto \mu_A\mu_B Pc^{1,1}(\tau) + \frac{\mu_A^2}{4}, \tag{6}$$

using Eqs. (4) and (5). Once again, we ignore the probability of more than two photons. The state $|2,1\rangle_{A,B}$ is also included in the second term. The visibility of two-photon interference is defined as

$$V(\mu_A,\mu_B,\tau) = \frac{N_c(\mu_A,\mu_B,\infty) - N_c(\mu_A,\mu_B,\tau)}{N_c(\mu_A,\mu_B,\infty)}. \tag{7}$$

Finally, we have

$$V(\rho,\tau) = \frac{4}{\rho+2}\frac{\delta\omega_A\delta\omega_B}{\delta\omega_A^2+\delta\omega_B^2}\exp(-\frac{\delta\omega_A^2\delta\omega_B^2}{\delta\omega_A^2+\delta\omega_B^2}\tau^2), \tag{8}$$

where $\rho = \mu_A/\mu_B$ is the ratio of the average photon number of a weak coherent state to the production probability of single photons in the same time interval. The maximum visibility always occurs at $\tau = 0$. It also gives that a linewidth ratio ($\delta\omega_A/\delta\omega_B$) between two fields is another important parameter to obtain a high visibility two-photon interference. An unequal spectral linewidth ($\delta\omega_A \neq \delta\omega_B$) leads to a decrease in visibility. In the case of $\delta\omega_A = \delta\omega_B$, a visiblity of more than 0.5 can be obtained when $\rho<2$ and an interference with visibility of near 1 can be observed under the condition of $\mu_A \ll 2\mu_B$ ($\rho \ll 2$). The significant reduction of interference visibility can be understood by the coincidence events caused by the input state of $|2,0\rangle_{A,B}$, the two-photon contribution of the coherent state. Recently, a successful experimental technique was developed to extract these coincidence events [14,15]. In our case, we measured the number of coincidence events when the single photon state is blocked,

$$N_c(\mu_A,0,\tau) \propto \frac{\mu_A^2}{4} + O(\mu_A^3). \tag{9}$$

Subtracting this coincidence events leads to the visiblity

$$V(\tau) = \frac{N_c(\mu_A,\mu_B,\infty) - N_c(\mu_A,\mu_B,\tau)}{N_c(\mu_A,\mu_B,\infty) - N_c(\mu_A,0,\infty)} = 2\frac{\delta\omega_A\delta\omega_B}{\delta\omega_A^2+\delta\omega_B^2}\exp(-\frac{\delta\omega_A^2\delta\omega_B^2}{\delta\omega_A^2+\delta\omega_B^2}\tau^2), \tag{10}$$

The term of $O(\mu_A^3)$ is ignored since $\mu_A \ll 1$. It indicates that the visibility is independent of the average photon number and approaches 1 when the two input states have the same spectral width as the same as the result of Ref. [14].

In experiments, we need to also consider the dark noise since it has a significant contribution for low average photon interference. Furthermore, the dark noise is not only restricted by the three-fold coincidence for three photon detectors in an interference experiment with a heralded single-photon state. Taking N_{sys} as the total noise three-fold coincidence event, the visibility is given by

$$V_{\exp}(\mu_A, \mu_B, \tau) = \frac{N_c(\mu_A, \mu_B, \infty) - N_c(\mu_A, \mu_B, \tau)}{N_c(\mu_A, \mu_B, \infty) + N_{\mathrm{sys}}}. \quad (11)$$

and the measured experiment visibility can be expressed as

$$V(\rho, \tau)_{\mathrm{mea}} = \frac{4}{\rho + 2 + N_{\mathrm{sys}}/\mu_A\mu_B} \frac{\delta\omega_A\delta\omega_B}{\delta\omega_A^2 + \delta\omega_B^2} \exp(-\frac{\delta\omega_A^2\delta\omega_B^2}{\delta\omega_A^2 + \delta\omega_B^2}\tau^2). \quad (12)$$

$N_{\mathrm{sys}}/\mu_A\mu_B$ represents the coincident probability, which is weighted by that of two-photon interference between two input states. It indicates that there is an optimum coherent state average photon number for a given single photon state production rate of the to observe two-photon interference. We also emphasize that the inclusion of detection efficiency does not alter the above conclusion because the μ_A and μ_B absorb the non-unit efficiency. However, the low detection efficiency will clearly reduce the total number of coincidence events. In the above analysis, we ignored the higher-order photon (more than three) contributions. This imperfection will significantly reduce visibility at a higher average photon number coherent state.

The schematic diagram of the experimental setup enables observing HOM-type of two-photon interference as shown in Fig. 1. A mode-locked Ti: Sapphire laser, operating at 798 nm wavelength with a pulse duration of 2 ps and a pulse repetition rate of 82 MHz, is prepared as the fundamental laser source. Most of the laser power (650 mW) is sent into a single-pass second harmonic generator (SHG), of which a 15-mm-long type-I LBO nonlinear crystal is used to produce the maximum 35 mW of the pump light with a wavelength of 399 nm for generating the orthogonal two-photon state by the SPDC process. A dichromatic mirror and two short pass filters are used to filter the rest of the 798 nm laser source from SHG. In the SPDC process, a 5-mm-long type-II BBO nonlinear crystal is used to generate an orthogonal two-photon state, two long-pass filters are employed to eliminate the residual pump light and a 1 nm bandpass filter is placed to shape the spectrum of the SPDC two-photon state. After the polarizing beam splitter (PBS), one of them, named the heralding photon, is injected into fiber coupler A. The other SPDC photon, named the heralded single photon, after an optical delay, is prepared for HOM-type two-photon interference with a weak coherent state. The heralded single photon is also injected into a fiber coupler B. Furthermore, a smaller remaining portion of the laser is prepared as the weak coherent state after traveling through a strong attenuator. A single-mode fiber beam splitter (FBS, Thorlabs TW805R5F2) is used to observe the HOM-type two-photon interference. When we switch the FBS inputs from coupler C to coupler A and leave coupler B, the two-photon interference between SPDC photon pairs can be observed. Meanwhile, when its inputs are connected to coupler B and coupler C and the pump light is blocked, the two-photon interference between two weak coherent states can be investigated when the coupler B is switched to a phase-randomized weak coherent state. The inserted half-wave plates (HWF) are used to control the polarization of light for interference. The outputs of FBS are connected to two single-photon counter modules (Excelitas Technologies, SPCM-AQRH14) and two-fold or three-fold coincidence events are recorded with an electronic coincidence circuit and counter. The interference between the weak coherent state and heralded single photon state was confirmed by three-fold coincidence when coupler A, coupler B, and coupler C were coupled by heralding, heralded, and weak coherent state, respectively.

In the first experiment, we aim to determine the spectral linewidth ratio between the weak coherent state and the single photon state. We investigate HOM-type interference with SPDC photon sources by carefully controlling the amplitude of the pump light. Thus, we only need to switch the input of FBS from coupler A to coupler C and leave coupler B to record two-fold coincidence events. Figure 2 shows a typical two-photon interference fringe measured at input of two SPDC photons. We fixed the pump power at 35 mW and the two-fold coincidence count

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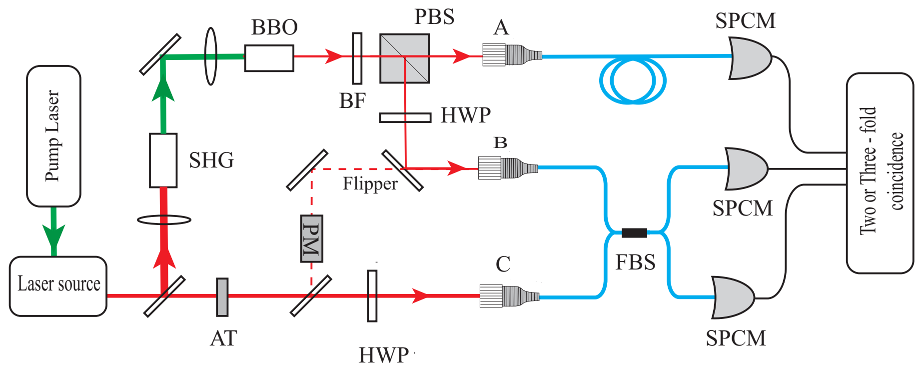

Fig. 1. Scheme of the experimental setup. SHG: second harmonic generation; HWP: half-wave plates; FBS: fiber beam splitter, BF, interference bandpass filter (1 nm), PBS: polarizing beam splitter, AT: attenuator, PM: phase modulator, SPCM: single photon counting module.

is around 1500 counts per second. The net visibility was found to be 98% from the fit of a Gaussian function. The full width of half maximum (FWHM) of fringe was determined to be approximately 1.0 ps, which corresponds to the Gaussian-shaped interference filter with 1 nm bandwidth (spectral linewidth 0.47 THz). In order to determine the spectral linewidth of the weak coherent state, we also implemented two-photon interference between two phase-randomized weak coherent state. In this measurement, the laser beam was split into two beams and coupled into the FBS. The results give a spectral linewidth of 0.22 THz (bandwidth 0.45 nm), which is almost the same as the predicted value with a pulse duration of 2 ps. It gives a spectral linewidth ratio of 2.2 between the weak coherent state and the single-photon state. Next, we carry out the two-photon interference between the weak coherent state and the heralded single-photon state. In this performance, one of the SPDC photons is performed as a trigger and three-fold coincidence events are recorded with an electronic coincidence circuit and counter. The three-fold coincidence count is around 20 counts per second when the pump power is kept at 30 mW with a suitably weak coherent state. One of the typical interference fringes is shown in Fig. 3. It gives visibility of more than 60% and a fringe width of around 1.7 ps was observed. The low interference visibility is only limited by unequal linewidth between the weak coherent state and the single-photon state. The reasonable fringe width is also calculated using Eq. (8) and the spectral linewidth ratio between interfered fields.

To further investigate and characterize the interference, interference visibility without optical delay is recorded when the intensity of the weak coherent state is changed. In Fig. 4, our measured raw data are plotted as black dots. It is obvious that there is a maximum visibility achieved with an optimum ratio. The visibility of less than 0.5 on two sides is mainly due to the system noise and coincidence events from the two-photon state contributing in the weak coherent state. The two-photon state can be subtracted by measuring the coincidence events when the single-photon state is blocked [14,15]. In this experiment, it was recorded by the three-fold coincidence events when the heralded photon is blocked. It has a range from 0.03 to 3 counts per second depending on the intensity of the input coherent state. The red squares in Fig. 4 indicates HOM visibility when the corresponding two-photon contributing events are subtracted. For comparison, two-photon interference with a single photon and the coherent state using Eq. (8) is also calculated with a spectral ratio of 2.2 and shown as the magenta curve in Fig. 4. Obviously, the HOM interference visibility is significantly improved at the high ρ side because the coincidence event from the two-photon state in the weak coherent state is subtracted. However, there is an obvious discrepancy between the corrected HOM visibility and

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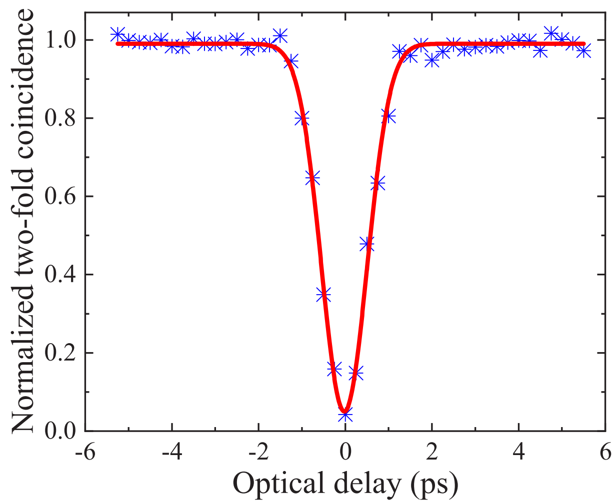

Fig. 2. The measured HOM dip of type II SPDC. The width of the dip and corresponding visibility are shown by fitting the data with Gaussian function.

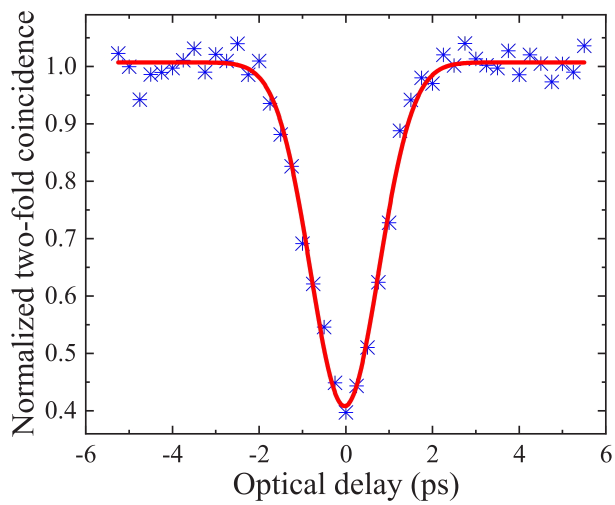

Fig. 3. The measured interference results between a heralded single photon and a weak coherent state. We collect three-fold coincidence event at the width of the dip and the corresponding visibility are shown by fitting the data with a Gaussian function.

the predicted visibility at the low ρ side. We attribute it to system noise, which includes not only the dark noise of SPCMs but also the imperfect correlation of the SPDC photon pairs. In our experiment, the produced photon pairs are only several percent compared to the detected counts with single SPCM. Hence, we measure the system noise of 0.24 counts per second by a three-fold coincidence event when the interfered weak coherent state is blocked. We plotted the HOM visibilities (blue triangles) again when both the system noise and two-photon events were subtracted. It clearly indicates that the two-photon state contribution events can be ignored when the intensity of the weak coherent state is low. On the other hand, we can use recent experimental techniques to improve the HOM visibility [14,15] at the range of high intensity. A predicted result from Eq. (12), which includes the system noise, is also shown in Fig. 4 when we take the ratio of dark noise to single photon-producing probability as a fitting parameter. It agrees with the experiment very well as a parameter of 0.09, which is reasonable from the measured coincidence events of system noise and photon pairs.

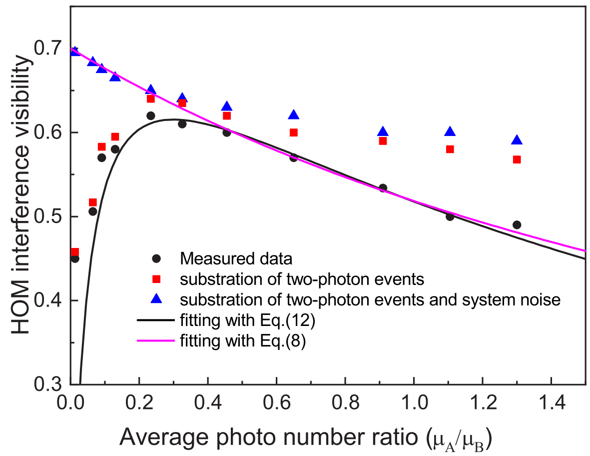

Fig. 4. HOM visibility as a function of the ratio between average photon numbers of the weak coherent state and the production probability of single photon. The measured data are represented by black dots. Predicted results from Eq. (12) and Eq. (8) are shown by the black curve and magenta curve, respectively. The HOM visibility after considering the system noise and two photon contribution events is also shown by blue triangles and red squares.

In conclusion, we experimentally investigated two-photon interference between a weak coherent state and a heralded single-photon state produced from a SPDC. It is the first time that both unequal spectral linewidth and average photon number ratio in a time interval are considered in our model. We obtained an excellent agreement between experimental data and the prediction from our model when the system noise was considered. The range of observing two-photon interference visibility of more than 0.5 is extended when the coincidence events from two photons in the weak coherent state are isolated. These results pave the way for the realization of a quantum net system, in which one core challengement is the observation of high visibility two-photon interference with independent sources.

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Disclosures. The authors declare no conflicts of interest.

Data availability. Data underlying the results presented in this paper are not publicly available at this time but may be obtained from the authors upon reasonable request.

References

1. C. K. Hong, Z. Y. Ou, and L. Mandel, "Measurement of subpicosecond time intervals between two photons by interference," Phys. Rev. Lett. **59**(18), 2044–2046 (1987).
2. F. Bouchard, A. Sit, Y. Zhang, R. Fickler, F. M. Miatto, Y. Yao, F. Sciarrino, and E. Karimi, "Two-photon interference: the Hong-Ou-Mandel effect," Rep. Prog. Phys. **84**(1), 012402 (2021).
3. Z.-Y. Ou, "Multi-photon quantum interference," (Springe, 2007).
4. N. Gisin, G. Ribordy, W. Tittel, and H. Zbinden, "Quantum cryptography," Rev. Mod. Phys. **74**(1), 145–195 (2002).
5. P. Kok, W. J. Munro, K. Nemoto, T. C. Ralph, J. P. Dowling, and G. J. Milburn, "Linear optical quantum computing with photonic qubits," Rev. Mod. Phys. **79**(1), 135–174 (2007).
6. I. Afek, O. Ambar, and Y. Silberberg, "High-NOON states by mixing quantum and classical light," Science **328**(5980), 879–881 (2010).
7. S. Wehner, D. Elkouss, and R. Hanson, "Quantum internet: a vision for the road ahead," Science **362**(6412), eaam9288 (2018).

8. S. H. Wei, B. Jing, X. Y. Zhang, J. Y. Liao, C. Z. Yuan, B. Y. Fan, C. Lyu, D. L. Zhou, Y. Wang, G. W. Deng, H. Z. Song, D. Oblak, G. C. Guo, and Q. Zhou, "Towards real world quantum networks: a review," Laser Photonics Rev. **16**(3), 2100219 (2022).
9. J. G. Rarity, P. R. Tapster, and R. Loudon, "Non-classical interference between independent sources," J. Opt. B: Quantum Semiclassical Opt. **7**(7), S171–S175 (2005).
10. T. B. Pittman and J. D. Franson, "Violation of Bell's inequality with photons from independent sources," Phys. Rev. Lett. **90**(24), 240401 (2003).
11. R. B. Patel, A. J. Bennett, I. Farrer, C. A. Nicoll, D. A. Ritchie, and A. J. Shields, "Two-photon interference of the emission from electrically tunable remote quantum dots," Nat. Photonics **4**(9), 632–635 (2010).
12. H. Vural, S. L. Portalupi, J. Maisch, S. Kern, J. H. Weber, M. Jetter, J. Wrachtrup, R. L. Ilja Gerhardt, and P. Michler, "Two-photon interference in an atom-quantum dot hybrid system," Optica **5**(4), 367 (2018).
13. K. Toyoda, R. Hiji, A. Noguchi, and S. Urabe, "Hong-Ou-Mandel interference of two phonons in trapped ions," Nature **527**(7576), 74–77 (2015).
14. A. Aragoneses, N. T. Islam, M. Eggleston, A. Lezama, J. Kim, and D. J. Gauthier, "Bounding the outcome of a two-photon interference measurement using weak coherent states," Opt. Lett. **43**(16), 3806–3809 (2018).
15. M. Mahdavifar and S. M. Hashemi Rafsanjani, "Violating Bell inequality using weak coherent states," Opt. Lett. **46**(23), 5998–6001 (2021).
16. A. K. Kashi and M. Kues, "Spectral Hong-Ou-Mandel interference between indepnedently generated single photons for scalable frequency-domain quantum processing," Laser Photonics Rev. **15**(5), 2000464 (2021).
17. T. Kobayashi, R. Ikuta, S. Yasui, S. Miki, T. Yamashita, H. Terai, T. Yamamoto, M. Koashi, and N. Imoto, "Frequency-domain Hong-Ou-Mandel interference," Nat. Photonics **10**(7), 441–444 (2016).
18. P. J. Mosley, J. S. Lundeen, B. J. Smith, P. Wasylczyk, A. B. U'Ren, C. Silberhorn, and I. A. Walmsley, "Heralded generation of ultrafast single photons in pure quantum states," Phys. Rev. Lett. **100**(13), 133601 (2008).
19. R.-B. Jin, K. Wakui, R. Shimizu, H. Benichi, S. Miki, T. Yamashita, H. Terai, Z. Wang, M. Fujiwara, and M. Sasaki, "Nonclassical interference between independent intrinsically pure single photons at telecommunication wavelength," Phys. Rev. A **87**(6), 063801 (2013).
20. A. M. Branczyk, "Hong-Ou-Mandel interference," arXiv, arxiv:171100080 (2017).
21. T. Legero, T. Wilk, A. Kuhn, and G. Rempe, "Time-resolved two-photon quantum interference," Appl. Phys. B **77**(8), 797–802 (2003).
22. T. F. Silva, G. C. do Amaral, D. Vitoreti, G. P. Temporao, and J. P. von der Weid, "Spectral characterization of weak coherent state sources based on two-photon interference," J. Opt. Soc. Am. B **32**(4), 545–549 (2015).
23. R.-B. Jin, J. Zhang, R. Shimizu, N. Matsuda, Y. Mitsumori, H. Kosaka, and K. Edamatsu, "High-visibility nonclassical interference between intrinsically pure heralded single photons and photons from a weak coherent field," Phys. Rev. A **83**(3), 031805 (2011).