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Supporting Online Material for

A High-Brightness Source of Narrowband, Identical-Photon Pairs

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A High-Brightness Source of Narrowband, Identical-Photon Pairs: Supporting Online Material

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The cavity mode waist and the optical wavelength are $w = 110$ μm and $\lambda = 852$ nm respectively. The relevant frequency scales are the single-particle vacuum Rabi coupling $2g_R/2\pi = 0.36$ MHz; the cavity power decay constant $\kappa/2\pi = 8.6$ MHz; and the Cs excited-state linewidth $\Gamma/2\pi = 5.2$ MHz. The collective cooperativity parameter is $NC = 3NF\lambda^2/(2\pi^3 w^2) = Ng_R^2/(\kappa\Gamma) \approx 5$. The nearly frequency-degenerate write and read photons exit the cavity in the same spatial mode, and are polarization separated before delivery via single-mode optical fibers to up to four separate single photon counting modules Perkin-Elmer SPCM-AQR-13-FC. The absolute detection time of each photon is recorded with 1 to 2 ns resolution using a Fast ComTec P7888 card.

Following (*1,2*), the CHSH Bell parameter S would be measured by splitting the two photons using a 50/50 beam splitter and recording the coincidence count rates $C(\alpha, \beta)$ between the output ports after passing through independent polarizers set to angles α and β. The scheme relies on post selection since two photons in a single detector are not included in the measurement record. The Bell parameter can be written as

$$S = E\left(\alpha,\beta\right) + E\left(\alpha',\beta\right) + E\left(\alpha,\beta'\right) - E\left(\alpha',\beta'\right) \tag{1}$$

where

$$E(\alpha,\beta) = \frac{C(\alpha,\beta) + C(\alpha^{\perp},\beta^{\perp}) - C(\alpha^{\perp},\beta) - C(\alpha,\beta^{\perp})}{C(\alpha,\beta) + C(\alpha^{\perp},\beta^{\perp}) + C(\alpha^{\perp},\beta) + C(\alpha,\beta^{\perp})} \quad . \tag{2}$$

The Bell's inequality is said to be violated if $|S| > 2$. For our photon-pair source, the maximum possible violation $S = 2\sqrt{2}$ would occur at the set of angles $\{\alpha = -\pi/2$, $\beta = -\pi/8$, $\alpha' = -\pi/4$, $\beta' = \pi/8\}$.

Many experiments have shown violations of the Bell's inequality indicating the validity of quantum mechanics (*2*–*5*), and we do not expect an actual measurement with this system would close any additional loopholes. Therefore, we predict the degree of violation of the inequality only to parameterize the quality of the two-photon source. The set of coincidence measurements $C(\alpha,\beta)$ can be written as the expectation values of creation and annihilation operators expressed in the polarization bases used for the two-photon interference experiment. If the present photon source were used to perform the set of actual Bell's measurements of above, the predicted value of Bell's parameter can then be written as

$$S(\tau) = 2\sqrt{2}\left(1 - \frac{\mathcal{R}_{45}\left(\tau\right) + \mathcal{R}_{45}\left(-\tau\right) + \mathcal{R}_{ww}\left(\tau\right) + \mathcal{R}_{rr}\left(-\tau\right)}{\mathcal{R}_{wr}\left(\tau\right) + \mathcal{R}_{wr}\left(-\tau\right) + \mathcal{R}_{ww}\left(\tau\right) + \mathcal{R}_{rr}\left(-\tau\right)}\right) \quad . \tag{3}$$

Here $\mathcal{R}_{wr}$, $\mathcal{R}_{ww}$, and $\mathcal{R}_{rr}$ are respectively the rates for write-read, write-write, and read-read coincidence counts as measured in the initial non-interfering basis. The rate $\mathcal{R}_{45}$ is the coincidence count rate between the output ports of the polarizing beam splitter when measured in the interfering basis. In the present work we find $\mathcal{R}_{wr} \gg \mathcal{R}_{ww}, \mathcal{R}_{rr}$, and the Bell parameter S

is then determined by (1) the degree of coincidence suppression compared to what one would expect in the absence of any Hong-Ou-Mandel interference (i.e. the terms involving $\mathcal{R}_{45}$) and (2) the rate of background coincidences arising either from stray light or, for an ideal source, other photon pairs (i.e. terms involving $\mathcal{R}_{ww}$ and $\mathcal{R}_{rr}$).

References and Notes

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