A balanced Franson interferometer

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Abstract: Our balanced Franson interferometer allows observation locally of Hong-Ou-Mandel and biphoton de Broglie interference and non-local Franson interference with suppressed single-photon interference. Advantages are its size, pulsed source compatibility, and passive visibility monitoring.

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The original Franson interferometer proposal [1] and experimental demonstrations use an interferometer imbalance to remove single-photon interference. This imbalance requires post-selection of specific coincidence events to exceed 50% visibility. A post-selection-free experiment has been demonstrated [2], but the interferometer imbalance remains. Quantum key distribution [3, 4] and quantum seals [5] require the Franson interferometer visibility approach 100%. Our balanced Franson interferometer uses polarization to suppress single-photon interference and retain post-selection-free high visibility biphoton interference. Franson interferometers using a pulsed source require a time-bin entangled source or interferometer imbalance equal to the pulsing period. Our balanced configuration allows use of a pulsed source without complication. As illustrated in Fig. 1.a) 1.5 mW of 405 nm CW diode laser light pumps a PPKTP

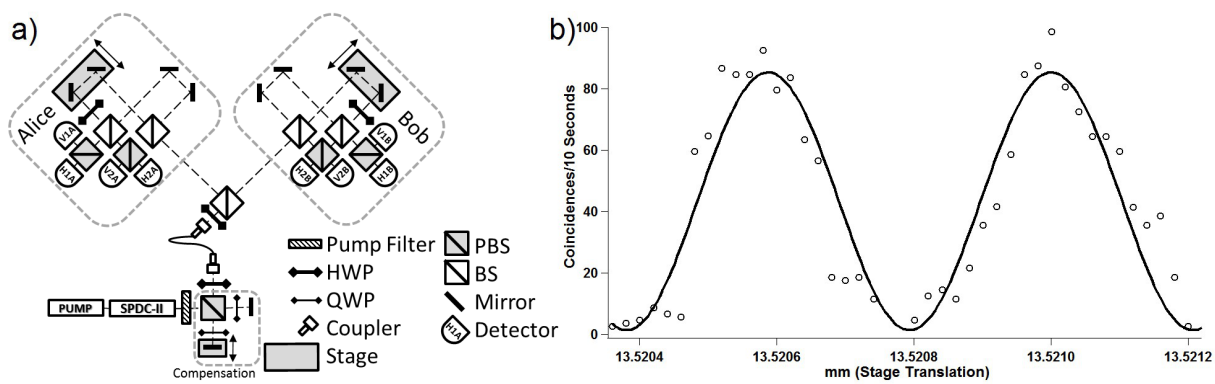

Fig. 1. a) Experimental Setup. b) Franson Interference with $96.9 \pm 6.5\%(93.8 \pm 6.5\%)$ visibility.

crystal generating 1.5×10^6 Type II SPDC pairs per second. The signal-idler pairs are spectrally degenerate at 810 nm. After compensation, the biphotons are incident on a 50/50 non-polarizing beam-splitter (BS) reflecting half the incident photons to Alice and transmitting the rest to Bob. Alice and Bob each receive a single photon or one of them receives both the signal and idler. Alice and Bob each have a balanced Mach-Zehnder interferometer with a half-wave plate in the transmitted arm rotating the polarization 90°. The polarization rotation suppresses single-photon interference. Exiting the interferometers, photons pass through a polarizing beam-splitter (PBS) before being detected. For a narrow-band pump the coincidence count normalized by singles counts for detector *jxy* and detector *suz* is

$$C^{(2)}_{\substack{jxy\\suz}} = \alpha \left[\left(\delta_{jv}\delta_{sh} + \delta_{jh}\delta_{sv}\right) \left(1 + (-1)^{x+u} V\left(\Delta_y - \Delta_z\right) \cos\left[\omega_p \left(\Delta_y + \Delta_z\right)/2\right]\right) \right.$$
$$\left. + \left(\delta_{jv}\delta_{sv} + \delta_{jh}\delta_{sh}\right) \left(1 + (-1)^{x+u} V\left(\Delta_y + \Delta_z\right) \cos\left[\omega_p \left(\Delta_y - \Delta_z\right)/2\right]\right) \right]. \quad (1)$$

Indices $j, s = \{H, V\}$ indicate the polarization, $x, u = \{1, 2\}$ the interferometer output port, and $y, z = \{A, B\}$ the interferometer. The temporal mismatch for interferometer y paths is indicated by Δ_y. The coefficient α is a constant related to the source properties and count time. The visibility term is

$$V(z) = \left(1 - |\Omega z/4\pi|\right) \theta\left(1 - |\Omega z/4\pi|\right) \quad \text{with signal and idler bandwidth } \Omega \text{ and Heaviside Function } \theta(x). \quad (2)$$

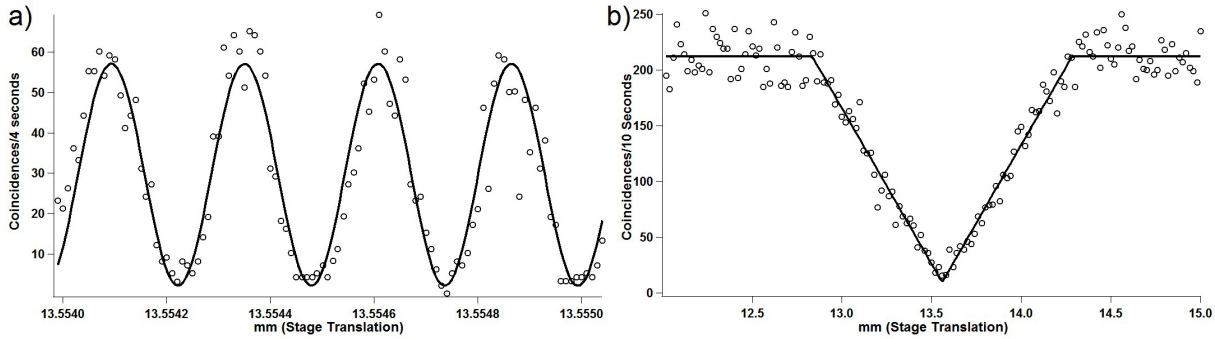

Fig. 2. a) Biphoton de Broglie Interference with $92.7 \pm 5.6\%(91.5 \pm 5.6\%)$ visibility. b) HOM Dip with $95.5 \pm 4.5\%(93.3 \pm 4.5\%)$ visibility.

There are three distinct biphoton interference types found in Eqs. 1. They include non-local Franson interference, local biphoton de Broglie interference [6, 7], and the local Hong-Ou-Mandel (HOM) Dip [8]. Experimental results for each type with accidentals subtracted are given in Fig.1.b), Fig.2.a), and Fig.2.b), respectively. The visibilities are given with(without) accidental subtraction. The three counts from Eqs.1 associated with the experimental data, respectively, are

$$C^{(2)}_{\substack{H1A\\V1B}} = \alpha\left(1 + V\left(\Delta_A - \Delta_B\right)\cos\left[\omega_p\left(\Delta_A + \Delta_B\right)/2\right]\right),$$

$$C^{(2)}_{\substack{H1B\\V1B}} = \alpha\left(1 + \cos\left[\omega_p \Delta_B\right]\right), \text{ and } C^{(2)}_{\substack{H1B\\H2B}} = \alpha\left(1 - V\left(2\Delta_B\right)\right). \tag{3}$$

Each coincidence combination is associated with one type of biphoton interference. Each biphoton is equally probable to contribute to each type of biphoton interference. A count of N coincidences statistically agrees with Eqs.1. For biphoton de Broglie visibility approaching 100% manipulation of Eqs.1 theoretically allows passive measurement of the balanced Franson visibility $V_{BF} = \sqrt{V\left(\Delta_A - \Delta_B\right)V\left(\Delta_A + \Delta_B\right)}$. Preliminary experimental data for V_{BF} is given in Fig.3.

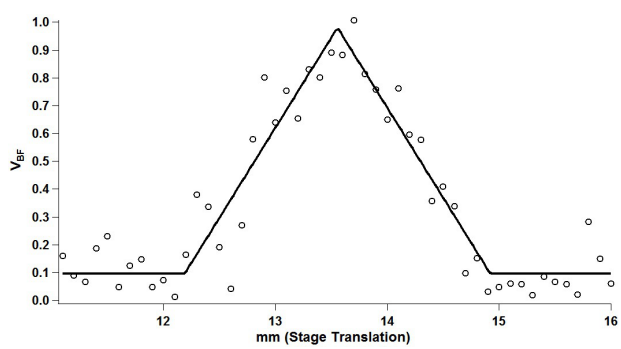

Fig. 3. Preliminary balanced Franson visibility V_{BF} measurement.

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