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Interfacing scalable photonic platforms: solid-state based multi-photon interference in a reconfigurable glass chip: supplementary material

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This document provides supplementary information to "Interfacing scalable photonic platforms: solid-state based multi-photon interference in a reconfigurable glass chip," https://doi.org/10.1364/optica.6.001471. It includes details on single-photon purity and indistinguishability, experimental characterization of the photonic tritter, and a model of imperfect single photon purity.

1. SINGLE PHOTON PURITY AND INDISTINGUISHABILITY

The single photon purity of the source is deduced from the $g^{(2)}(\Delta t)$ histograms shown in Figs. S1(a,b) for the normal repetition rate of the laser, 81 MHz, and for the $\times 4$ increased repetition rate used for the experiment. In this second case, the limited time resolution of our detectors ($\sim$700 ps) results in some temporal overlap of the neighbouring peaks. We deduce the values of $g^{(2)}(0)$ by integrating the coincidence counts over a 2 ns time bin. The values deduced from the histograms presented in Figs. S1(a,b) are respectively $g^{(2)}(0)$=0.035$\pm$0.003 and $g^{(2)}(0)$=0.071$\pm$0.003, respectively.

For the three photon experiments, we use photons delayed by respectively $\sim$48 ns and $\sim$98 ns. We thus study the photon indis-

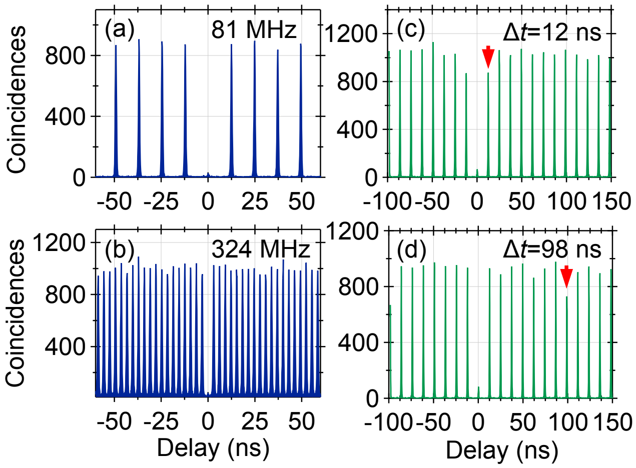

Fig. S1. (a)/(b) Second order correlation function $g^{(2)}(\Delta t)$ versus delay for an excitation repetition rate of 81/324 MHz, respectively. (c)/(d) Coincidence histogram versus delay resulting from the Hong-Ou-Mandel interference of two photons in an unbalanced Mach-Zehnder interferometer, with 12/98 ns temporal delay, respectively. The red arrows indicate the corresponding delay of the peak whose area is 3/4 times smaller than the one of the uncorrelated peaks.

tinguishability for various delays. This is achieved by interfering in an unbalanced Mach-Zehnder interferometer two photons delayed by 12, or 98 ns, rendering the correlation counts presented in Figs. S1 (c,d), respectively (see Ref. 11 of the main text for further details). The raw Hong-Ou-Mandel visibility V_{HOM} and corrected mean-wavepacket overlap deduced from the histograms are respectively $V_{\mathrm{HOM}}^{12\mathrm{ns}}=0.850\pm0.007$, $M_{12\mathrm{ns}}=0.920\pm0.007$ and $V_{\mathrm{HOM}}^{98\mathrm{ns}}=0.810\pm0.009$, $M_{98\mathrm{ns}}=0.880\pm0.009$.

2. EXPERIMENTAL CHARACTERIZATION OF THE PHOTONIC TRITTER

The experimental unitary matrix of the tritter $\mathcal{U}^{\mathrm{exp}}$ is determined following the method describe in Ref. [1]. In this procedure, the absolute value of the matrix element $|\mathcal{U}_{jk}^{\mathrm{exp}}|$ is determined by inserting a continuous-wave laser (set at the same wavelength as the QD emission) in the tritter input j and measuring the laser intensity in each tritter output k.

The four phases θ_{jk} of the matrix elements $|\mathcal{U}_{jk}^{\mathrm{exp}}|e^{i\theta_{jk}}$, with $jk=\{22,23\}$ ($jk=\{32,33\}$), are measured by splitting the laser beam in two path and connecting them to the in inputs $j=1,2$ ($j=1,3$); the variation of the laser phase between the two inputs (for example, slowly displacing the position of one of the input fiber couplers) produces oscillations in the intensity outputs $k=1,2,3$. Setting the oscillation of output 1 as a reference, the phase shift with respect to outputs 2 and 3 will determine the experimental phase values θ_{22},θ_{23} (θ_{32},θ_{33}). For the sake of clarity and as an example, we show in Fig. S2 the measure of θ_{22},θ_{23}: the laser light has been injected in inputs 1 and 2, the relative phase shift between the two inputs produce constant oscillations in the three output modes intensities, from where the matrix phases are directly extracted.

We deduce the following experimental matrix:

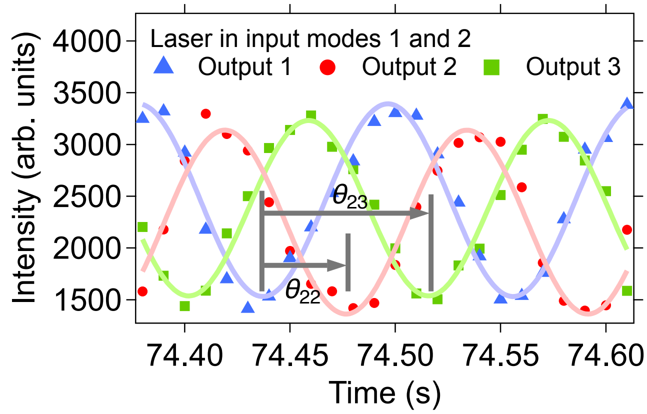

Fig. S2. Experimental obtention of the phases θ_{22},θ_{23} of $\mathcal{U}^{\mathrm{exp}}$: the laser is injected in modes 1 and 2, a controlled phase shift is applied between the two inputs, rendering the phases θ_{22},θ_{23} observed as relative phase shifts in the output modes oscillations. The full lines are a guide to the eyes.

$$U^{\mathrm{exp}} = \frac{1}{\sqrt{3}}\begin{pmatrix} 0.971 & 1.011 & 0.979 \\ 1.023 & 0.950\times e^{i2\pi\times0.322} & 1.028\times e^{i2\pi\times0.656} \\ 1.005 & 1.036\times e^{i2\pi\times0.670} & 0.993\times e^{i2\pi\times1.331} \end{pmatrix} \tag{S1}$$

The average errors of $|\mathcal{U}_{jk}^{\mathrm{exp}}|$ and θ_{jk} are less that 0.1% and 1%, respectively.

Following the procedure described in Ref. [2], the fidelity of the experimental tritter to the ideal matrix $\mathcal{U}^{\mathrm{th}}$ is calculated as $\mathcal{F}=1-\sum_{i<j}\sum_{k<l}|(\mathcal{V}^{\mathrm{th}})_{i,j;k,l}-(\mathcal{V}^{\mathrm{exp}})_{i,j;k,l}|/18$, where the visibility $\mathcal{V}_{i,j;k,l}$ is given by the ratio $\mathcal{V}_{i,j;k,l}=(P^{\mathrm{C}}_{i,j;k,l}-P^{\mathrm{Q}}_{i,j;k,l})/P^{\mathrm{C}}_{i,j;k,l}$, and each of these probabilities are $P^{\mathrm{C}}_{i,j;k,l}=|\mathcal{U}_{i,k}\mathcal{U}_{j,l}|^2+|\mathcal{U}_{i,l}\mathcal{U}_{j,k}|^2$ and $P^{\mathrm{Q}}_{i,j;k,l}=|\mathcal{U}_{i,k}\mathcal{U}_{j,l}+\mathcal{U}_{i,l}\mathcal{U}_{j,k}|^2$.

3. MODEL OF IMPERFECT SINGLE PHOTON PURITY

In this section we derive the fraction of residual laser light in the source. As discussed in the main text, the imperfect single photon purity reveals the presence of scattered laser photons mixed with the single photon emission arising from the quantum dot (QD). We make the assumption that the presence of this two photon distributions in the collection fiber (and in the subsequent parts of the tritter setup) are independent and statistically mixed. Under such conditions, the photon-number probability distribution of the laser and QD mixture can be analytically reconstructed by the probability generating function formalism [3].

The probability generating function is defined as $G(s)=\sum_n s^n p_n$, where p_n are the different photon number Fock states probabilities. For an statistical mixture of two independent photon distributions (laser and QD), the probability generating function of the mixed ensemble, $G_{\mathrm{tot}}(s)$, is calculated as the product of the corresponding laser and QD components, $G_{\mathrm{L}}(s)$ and $G_{\mathrm{QD}}(s)$, respectively, i. e., $G_{\mathrm{tot}}(s)=G_{\mathrm{L}}(s)G_{\mathrm{QD}}(s)$. The QD single photon emission is $G_{\mathrm{QD}}(s)=p_0^{\mathrm{QD}}+p_1^{\mathrm{QD}}s=(1-\mu_{\mathrm{QD}})+\mu_{\mathrm{QD}}s$ (where $\mu_{\mathrm{QD}}=p_1^{\mathrm{QD}}$ is the average photon number of the QD emission), and the laser is $G_L(s) = \sum_n^\infty s^n p_n^L = \sum_n^\infty s^n \frac{\mu_L^n e^{-\mu_L}}{n!} = e^{-\mu_L(1-s)}$ (where μ_L is the average photon number of the scattered laser).

The analytical expression of the second order correlation of function of the ensemble, $g^{(2)}_{\text{tot}}(0)$ is given by $g^{(2)}_{\text{tot}}(0) = \frac{d^2 G_{\text{tot}}(s)}{ds^2}|_{s=1}/(\mu_{\text{tot}})^2$ (where the total average photon number is $\mu_{\text{tot}} = \mu_L + \mu_{QD}$). The resulting second order correlation function is $g^{(2)}_{\text{tot}}(0) = \chi(2+\chi)/(1+\chi)^2$, where $\chi = \mu_L/\mu_{QD}$, see dark blue trace in Fig. S3.

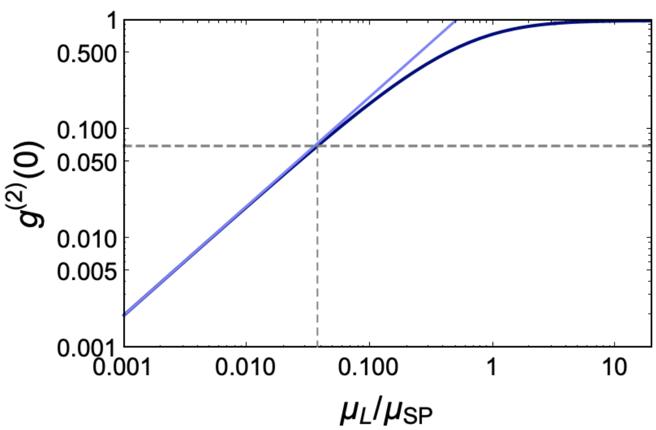

Fig. S3. Second order correlation function $g^{(2)}_{\text{tot}}(0)$ versus the ration of average photon number of laser and QD μ_L/μ_{QD}; in a light blue full trace, the approximation of the $g^{(2)}_{\text{tot}}(0) \simeq 2\mu_L/\mu_{QD}$. The dashed grey lines mark the value of the experimental $g^{(2)}_{\text{tot}}(0)$ and the corresponding ratio of μ_L/μ_{QD}.

As expected, the value of $g^{(2)}_{\text{tot}}(0)$ saturates to unity (poissonian statistics), when $\mu_L \gg \mu_{QD}$. For low $g^{(2)}_{\text{tot}}(0)$ values, it can be approximated by $g^{(2)}_{\text{tot}}(0) \simeq 2\mu_L/\mu_{QD}$, as shown by the light-blue line in Fig.S3 for $\mu_L \ll \mu_{QD}$. Considering the experimental value of single photon purity, $g^{(2)}(0) = 0.071 \pm 0.003$, we deduce the fraction of laser photon normalized to the fraction of photons emitted by the QD to $\frac{p_1^L}{p_1^{QD}} \simeq (g^{(2)}_{\text{tot}}(0)/2) \simeq 0.038 \pm 0.003$, where we have assumed that higher order Fock terms from the laser $p^L_{n>1}$ are completely negligible since $\mu_L \ll \mu_{QD}$.

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