Measurement of the heralded efficiency and the purity of a heralded single photons source

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Introduction

In quantum optics, the production of single photons is an important topic of research due to their multiple applications[1]. Heralded single photons (HSP) are difficult to produce, an alternative is to use a Spontaneous Parametric Down Conversion source (SPDC) since the detection of one photon heralded the existence of the other photon. This pair of photons have spectral and spatial correlations[2]. To have pure HSP with high heralded efficiency it is necessary to break this correlations. One alternative is to use spatial and spectral filters. In this work, we break the spatial correlation using spatial filters, the spectral filtering effects on the heralding efficiency and the purity of the heralded photon are experimentally study by measuring the joint spectrum (JS) under different filtering conditions. The experimental results for the purity and the heralding efficiency of the heralded photons are presented.

Entanglement Photon Source

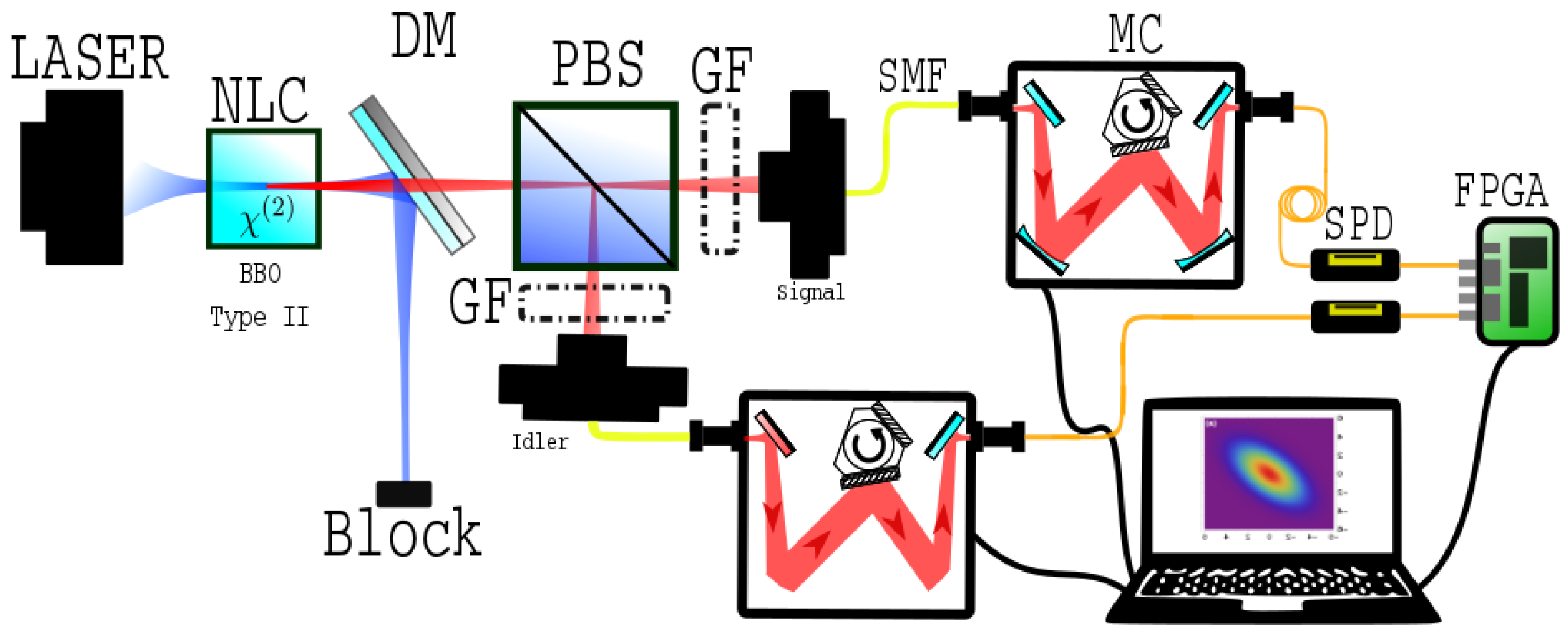


Figure 1: *Experimental setup for the measurement of the correlation in entangled photon pairs produced thought SPDC process. GF: Gaussian Spectral filters, NLC: Non Linear Crystal, DM: Dicroic Mirror, PBS: Polarized Beam Splitter, SMF: single-mode fibers, MC: Monochromators, SPD: Single Photon Counters, FPGA: Field-Programmable Gate Array.*

The state of the entangled photon pairs is given by

$$|\psi\rangle = \int\int d\Omega_s d\Omega_i\, \phi(\Omega_s,\Omega_i)\Gamma(\Omega_s)\Gamma(\Omega_i)\; |\Omega_i\rangle\, |\Omega_s\rangle\,, \tag{1}$$

where $\phi(\Omega_s, \Omega_i)$ is the spectral amplitude of $SPDC$ photons and $\Gamma_x = e^{-\frac{\Omega_x^2}{4\sigma_x^2}}$ with $x = i, s$ represents the functions of the spectral gaussian filters set in *idler* or *signal* arm. Using these filters to measure the JS (eq. 2), we can see the correlation between the pairs of photons for different filtering conditions, Fig. 2a-2d.

$$|\phi(\Omega_s,\Omega_i)|^2 = Ne^{-\frac{\Omega_p^2}{4\sigma_p^2}-\frac{\Omega_i^2}{4\sigma_i^2}-\frac{\Omega_s^2}{4\sigma_x^2}-\gamma\frac{\Delta k^2(\Omega_i,\Omega_s)L^2}{4}} \tag{2}$$

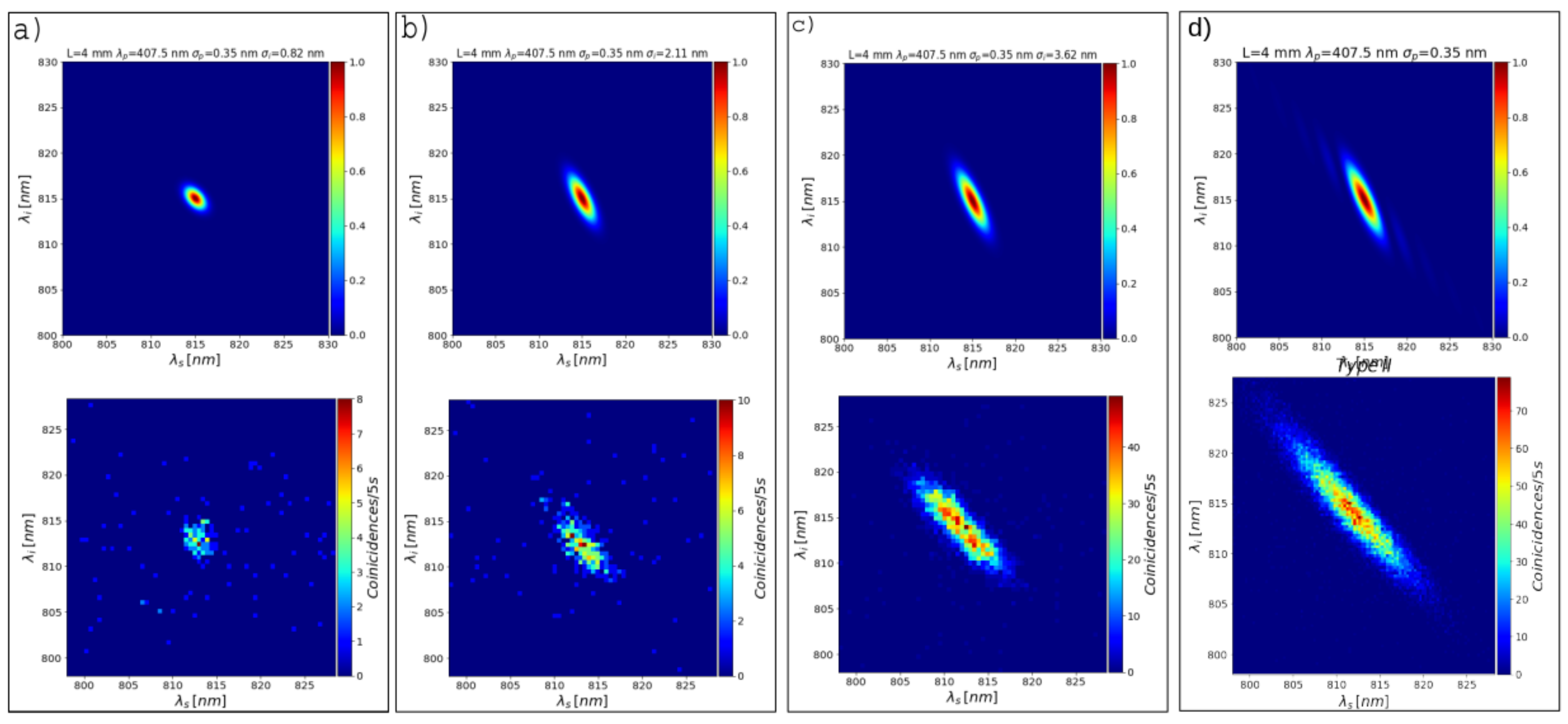
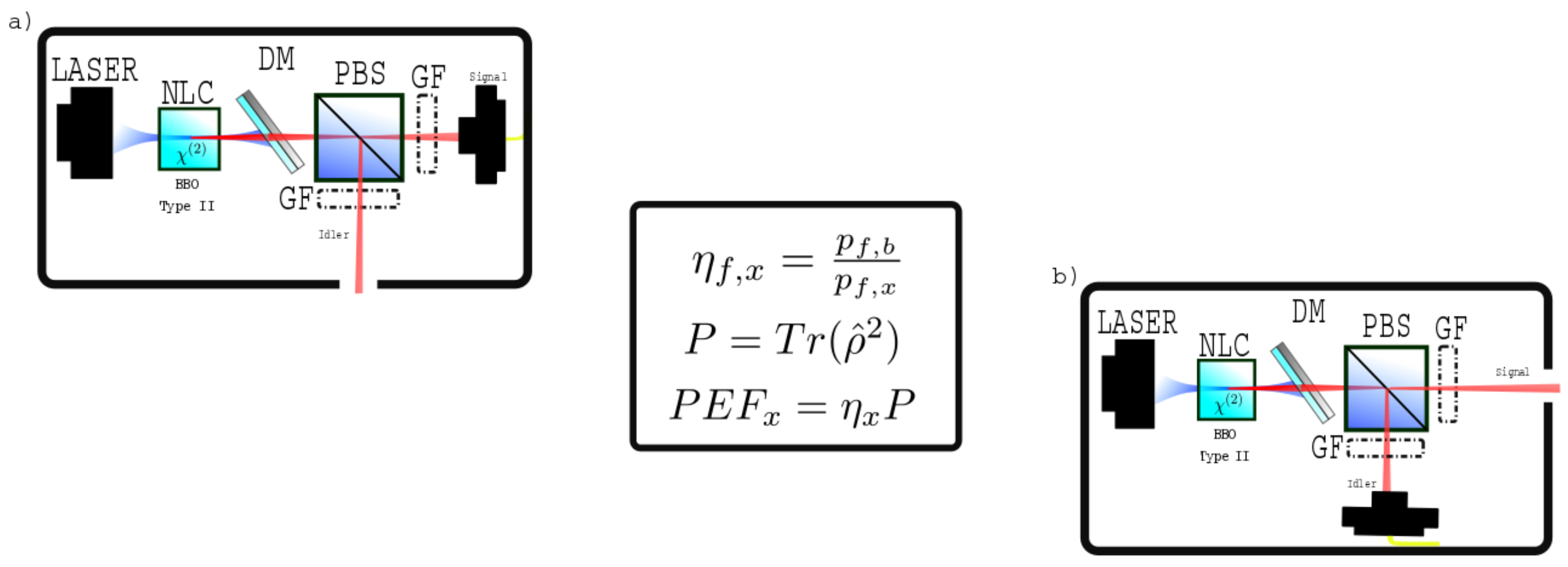


Figure 2: *Theoretical and experimental JS that show the control of the correlation of the entangled photon pairs using filters in the idler's arm with a bandwith of pump $\sigma_p = 0.35\,nm$ and filter bandwidth σ and central wavelenght λ_o.* ***a)*** *$\sigma_i = 0.82\,nm$ and $\lambda_o = 810\,nm$,* ***b)*** *$\sigma_i = 2.11\,nm$ and $\lambda_o = 814\,nm$,* ***c)*** *$\sigma_i = 3.62\,nm$ and $\lambda_o = 810\,nm$,* ***d)*** *Unfiltered.*

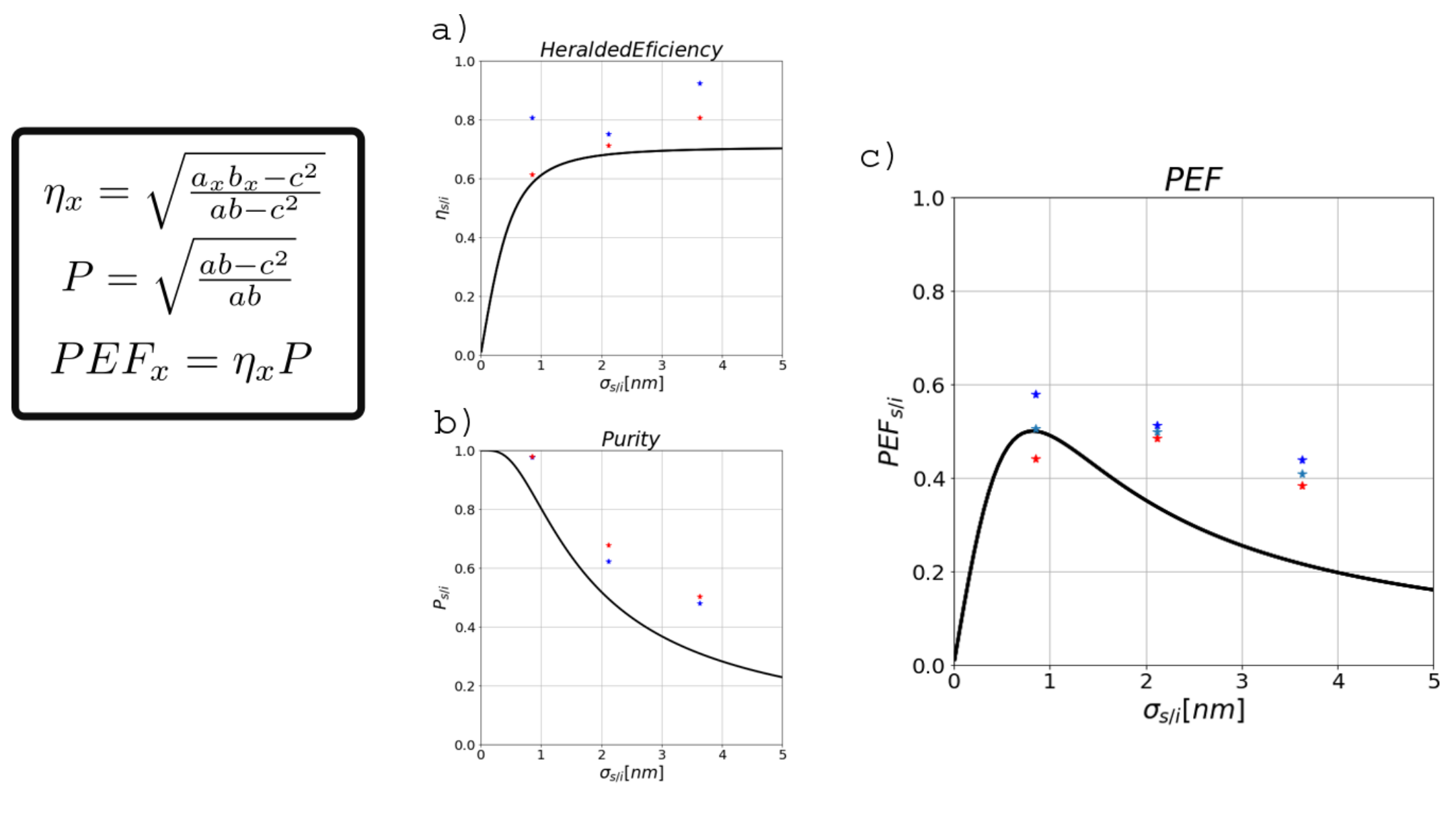
Heralded Single Photon Source

To break the spatial correlations and to work only with the spectral ones we use single-mode fibers. To control the frequency correlations and to obtain a *HSPS* we use spectral filters with bandwidth σ_x of $0.82\,nm$, $2.11\,nm$ and $3.62\,nm$, then we fitted the *JS* controlled in order to characterize the *HSPS* with 3 parameters: *Heralded Efficiency* η_x, *Purity* P and *PEF* [3][4].



$$\eta_{f,x} = \frac{p_{f,b}}{p_{f,x}}$$
$$P = Tr(\hat{\rho}^2)$$
$$PEF_x = \eta_x P$$

Figure 3: *Heralded single photon source.* ***a)*** *Idler photon is announce by signal and* ***b)*** *vice versa. The η_x is defined as the probability to detect a heralded photon when both photons pass its filters ($p_{f,b}$) over the probability to detect a heralded photon when the x photon pass its filter ($p_{f,x}$). The Purity P is the trace over the exterior product of the state of pairs photons. And PEF is η_x times P.*



$$\eta_x = \sqrt{\frac{a_x b_x - c^2}{ab - c^2}}$$
$$P = \sqrt{\frac{ab - c^2}{ab}}$$
$$PEF_x = \eta_x P$$

Figure 4: *Fitting the JS controlled with the function $f(\Omega_s,\Omega_i) = Ae^{(-\frac{a}{2}\Omega_s^2-\frac{b}{2}\Omega_i^2+c\Omega_s\Omega_i)}$ as in ref.[4], we can calculate η, P and PEF with the equations of the box. The red dots are using spectral filters in signal's arm and the blue ones are using spectral filters in idler's arm. Solid line correspond to the theoretical calculus from eq. of box fig. 3.* ***a)*** *Behaviour of η_x* ***b)*** *P and* ***c)*** *PEF factors.*

Conclusions

- From figure (2), we evidenced that the use of spectral filters change the correlation between the pair of entangled photons.
- From figure (4), we visualize that the purity, heralded efficiency and PEF factors have a similar behaviour to the expected theoretical results.
- In the figure (4), the optimal filter bandwidth to maximize the Purity and Heralded Efficiency simultaneously is around $1\,nm$.
- In general we need to perform more measurements to increase the statistical and to include bandwidths less to $1\,nm$ to obtain the behaviour in this region.

References

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