Exploiting Polarization for Quantum Imaging with Undetected Photons

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Abstract: We propose a scheme for exploring polarization features in quantum imaging with undetected photons using nonlinear crystals sensitive to specific polarization, offering an efficient approach that minimizes resource requirements

The potential of quantum imaging lies in its significant advantages, such as reducing noise below standard limits, minimizing sample exposure to light, and enhancing sensitivity with better precision. A notable benefit of quantum imaging with undetected photons (QIUP) is the ability to access higher wavelengths without requiring detectors at those wavelengths [1].

Our focus is on exploring the polarization aspects of QIUP, which makes it suitable for examining birefringent samples. Polarization tomography using QIUP has been demonstrated by a few studies [2,3], requiring nonlinear crystals (NLCs) sensitive to both horizontal and vertical polarizations. We aim to construct a QIUP setup with NLCs sensitive to a single polarization, enabling the study of sample polarization features.

The proposed scheme, illustrated in Fig. 1, uses idler photons (purple) undergoing polarization manipulation via a combination of a half-wave plate (HWP) and a quarter-wave plate (QWP). Signal-idler pairs generated from the second NLC pass through a modified Mach-Zehnder interferometer (MZI) along with idler photons from the first NLC. The modified MZI, incorporating an HWP in one arm, generates photons with both polarizations, eliminating the need for additional crystal types. We developed a mathematical formulation to determine the idler photons' density matrix, encoding the sample's polarization information.

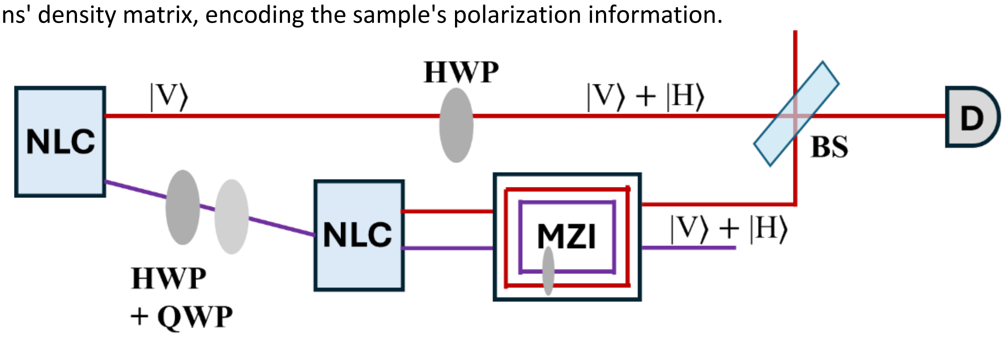

Fig. 1 The scheme of polarization tomography using QIUP with non-linear crystals sensitive to vertical polarization, with notations NLC non-linear crystal, HWP half-wave plate, QWP quarter-wave plate, MZI Mach-Zehnder interferometer, BS beam splitter, and D detector.

If the density matrix of the idler photons is represented as

$$\rho_I = \begin{pmatrix} |A_1|^2 & A_1 B_1^* \\ A_1^* B_1 & |B_1|^2 \end{pmatrix} \quad (1)$$

Depending on the angles (ɵ) of HWP used in MZI, the horizontal counts measured in the detector are given below

Case 1: ɵ = 0; $\langle N_{H1} \rangle = 4\,|b_1|^2 \sin^2(2h_2)\,|B_1|^2$ (2)

Case 1: ɵ = 90 deg; $\langle N_{H2} \rangle = 4\,|b_1|^2 \sin^2(2h_2)\,|A_1|^2$ (3)

Here b_1 accounts for the generation of signal-idler pair from the first crystal, h_2 is the HWP's fast axis angle placed in the sole signal's arm. In conclusion, the proposed scheme efficiently determines the horizontal and vertical polarization probabilities while offering the added advantage of requiring limited resources.

Example References

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