PhD thesis project at NEEL INSTITUTE

New Quantum States of Light

Context: This position concerns Triple Photons Generation (TPG: $\lambda_0 \rightarrow \lambda_1+\lambda_2+\lambda_3$). It is based on a third order nonlinear optical interaction which is the most direct way to produce pure quantum states of light, called three-photons states. These states exhibit three-body quantum entanglement and their statistics go beyond the usual Gaussian statistics relevant to coherent sources and optical parametric twin-photon generators, offering thus outstanding potential applications in the field of quantum information. Undoubtedly, three-photons states are new quantum tools to study the non-intuitive properties of quantum mechanics [*K. Bencheikh, M.F.B. Cenni, E. Oudot, V. Boutou, C. Félix, J.C. Prades, A. Vernay, J. Bertrand, F. Bassignot, M. Chauvet, F. Bussières, H. Zbinden, A. Levenson, and B. Boulanger, Demonstrating quantum properties of triple photons generated by $\chi^{(3)}$ processes, European Physical Journal D - Topical Issue on "Quantum Optics of Light and Matter: honoring Alain Aspect", 2022, **76**:186*].

Research topic: In 2024, we have succeeded in performing the first stimulated TPG on a single mode of the triplet as shown in Fig. 1 [J. *Bertrand, V. Boutou, C. Felix, D. Jegouso, and B. Boulanger, Experimental demonstration and modeling of near-infrared nonlinear third-order triple-photon generation stimulated over one mode, arXiv:2412.19348 [quant-phy*]. The objective of the PhD thesis is to go further by performing a spontaneous TPG. Such a new configuration is of prime importance in the framework of quantum information since it allows heralded two photons states to be generated, which can be used in a qubit amplifier or in a device independent quantum key distribution protocol.

The most symptomatic feature of spontaneous TPG is that, for a fixed direction of propagation and a given pump wavelength λ_0, the triple (λ_1, λ_2, λ_3) is not unique but is spread over a broad continuum, which contributes to a strong energy dilution. Then a relevant way to select a single triplet, which is necessary for practical applications, is to implement a third-order optical parametric oscillator (OPO) resonant on the targeted triplet, for example in the Telecom range. Such an OPO has never been investigated and will required specific strategies to reach the oscillation threshold. This generation step will be followed by the quantum characterizations of the three-photon states by investigating their three-body coincidence using a superconducting nanowire single photon detector (SNSPD), as well as by measuring their entanglement.

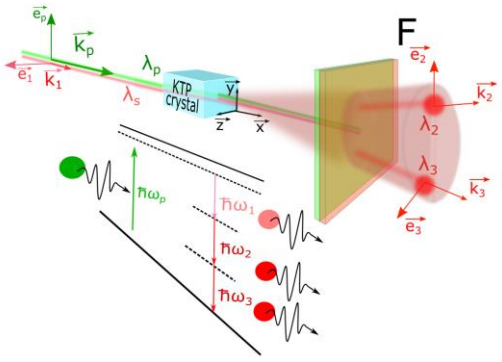

Figure 1: *Schematic view of a TPG stimulated on one triplet mode, at $\lambda_s = \lambda_1$, the two other triplet modes being at $\lambda_2 = \lambda_3$. The pump beam is at λ_p. The nonlinear medium is a phase-matched x-cut KTP crystal*

Possible collaboration and networking: This work will be realized in close collaboration with University of Tel Aviv for the quasi-periodically poling of nonlinear crystals, the company Cristal Laser SA (Nancy) for single domain bulk KTP crystals, and the company IDQuantique (Genève) for SNSPD purpose. Other groups of quantum optics (C2N, LCFIO, INP) could be involved.

Required skills: A background in laser optics, nonlinear optics, quantum mechanics or quantum optics will be useful.

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