Master in Photonics – "PHOTONICS BCN"
Master ERASMUS Mundus "EuroPhotonics"

MASTER THESIS PROPOSAL

Starting full time from April 2025
Presentation at the end of July or beginning of September 2025

Laboratory: Atomic Quantum Optics (Mitchell group)
Institution: ICFO
City, Country: Barcelona, Spain

Title of the master thesis: Quantum photonics with individual atoms and entangled photons

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Keywords: Quantum Optics, Atomic Physics

Summary of the subject (maximum 1 page):

We aim at studying one- and two-photon effects in a single quantum system to study for instance the atomic Hong-Ou-Mandel effect or stimulated emission at the single quanta level. In that purpose, one of our current topics is the use of the single-atom as an extremely selective single-photon detector, using a quantum jump detection technique [3] to read the atomic state.

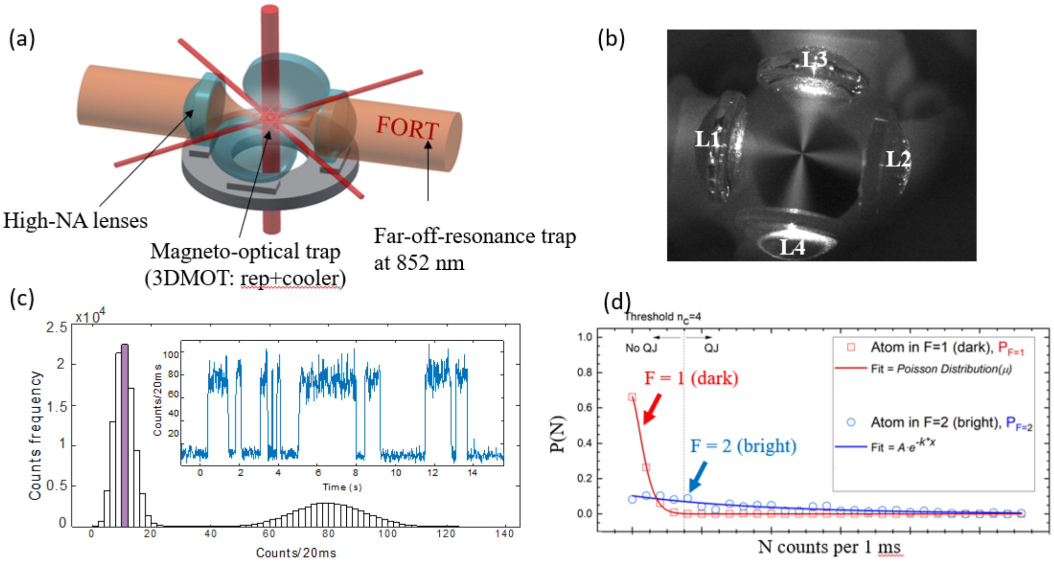

Figure 1 (a) Experimental setup for trapping individual cold atoms at the mutual focus of four high-NA aspheric lenses. (b) Top view of the setup showing a Maltese-Cross geometry crossing at a single spatial point. (c) The inset is the collected *fluorescence as a function of time. The resulting histogram of counts shows a distinct threshold between 0 atom and 1 atom levels which guarantees the preparation of a single-atom in the trap. (d) Hyperfine state detection by measuring the probability distributions of the number of counts.*

Experimentally, we trap and cool individual ^{87}Rb atoms, holding them at the centre of an assembly of four high-numerical aperture lenses (Fig. 1a,b), each viewing the atom from a different direction [1], [2]Figure 1. This arrangement efficiently collects light from a single atom which enables us to deterministically prepare a single-atom (Fig. 1c). The atomic state can be read using a quantum jump technique (Fig. 1d).

We generate photon pairs using cavity-enhanced spontaneous parametric down-conversion in a nonlinear crystal (Fig. 2). The produced photons are narrowband and frequency-tunable to the D1-line of the Rubidium atom.

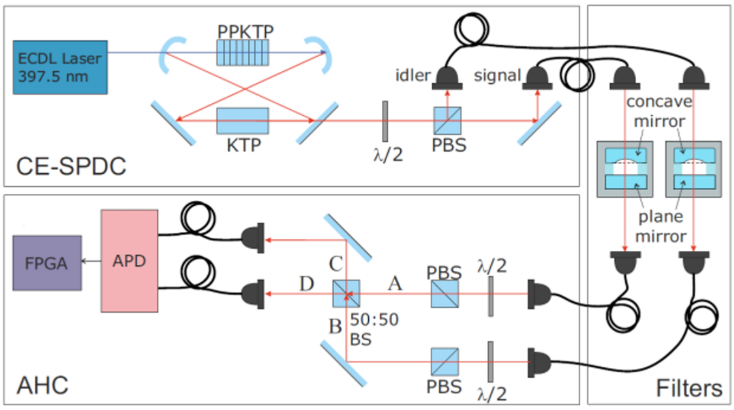

Figure 2 Atom-resonant narrowband photon-pairs by cavity-enhanced spontaneous parametric down-conversion (CE-SPDC). The frequency spectrum is filtered by cavities and an AHC technique is used to characterised the photon-pairs.

Objectives:

We have projects on each part of the setup for MSc:

On the single-photon setup, we would like to investigate experimentally atom-induced phase shifts using an autoheterodyne characterization technique of narrowband photon pairs that has been developed in the group [4]. A collaboration with the hot atomic vapor team in the group is expected for the implementation of an atomic vapor cell to induce the phase shifts. In addition, the student will be involved into the current team projects which requires the use of photon pairs and single-atoms.

On the single-atom setup, we would like to perform a microwave spectroscopy between the two hyperfine ground states of ^{87}Rb. It will allow us to detect arbitrary superposition states, making a single-qubit analyser for the atomic state. This would enable us to precisely cancel the magnetic field at the atom position which is a necessary condition to perform efficient optical pumping of atomic states. It would improve the photon absorption probability for single-atom/single-photon experiments.

There may be other possible projects; come and talk to us.

Additional information:

* Required skills: Experimental experience is desirable but not absolutely required. Hard working, good knowledge of optics, quantum optics and laser principles.

[1] L. C. Bianchet *et al.*, Open Research Europe **1**, 102 (2021).
[2] N. Bruno *et al.*, Opt. Express **27**, 31042 (2019).
[3] L. C. Bianchet *et al.*, PRR **4**, L042026 (2022).
[4] V. Prakash et al., Phys. Rev. Lett. **127**, 043601 (2021).