Master in Photonics – “PHOTONICS BCN”
Master ERASMUS Mundus “EuroPhotonics”

<u>MASTER THESIS PROPOSAL</u>

Dates: April 2023 – July or September 2023

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):

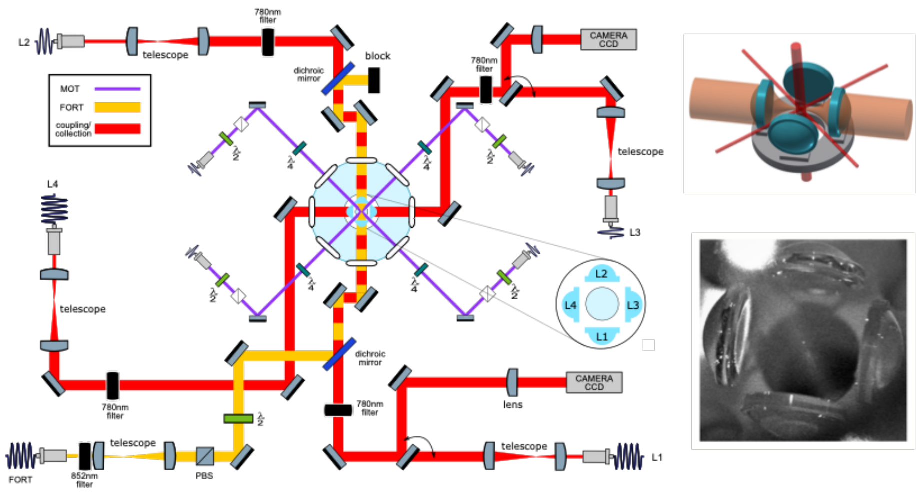

Figure 1 Experimental system for trapping individual cold atoms at the mutual focus of four high-NA aspheric lenses. Image adapted from [1]. Left: optical systems for cooling (violet), trapping (orange), and probing/collection (red). Upper right: drawing of in-vacuum four-lens geometry. Lower right: image of four-lens system with cold atom cloud (white dot, produced by a magneto-optical trap) at the centre of the four lenses.

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We trap and cool individual ^{87}Rb atoms, holding them at the centre of an assembly of four high-numerical aperture lenses, each viewing the atom from a different direction [1] [2], see Figure 1. This arrangement efficiently collects light from the single atom, allowing us to see if the atom is there, and even to detect which state it is in, see Figure 2.

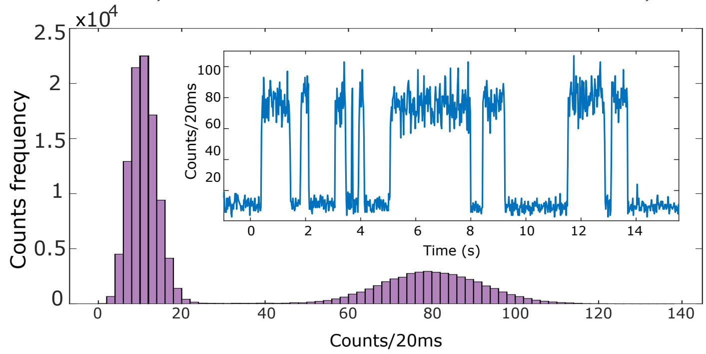

Figure 2 Fluorescence signals collected with the system shown in Figure 1. Inset shows fluorescence counts as a function of time, showing transitions between zero and one atoms in the trap. Main graph shows histogram of counts. The observed distribution shows that within a single observation window, here 20 ms, the presence/absence of a single fluorescing atom can be determined with high fidelity.

In the same lab, we have an entangled photon source that uses cavity-enhanced spontaneous parametric down-conversion (a nonlinear optical process in a crystal). We study the interaction of these photons with the single atom. One of our current topics is the use of the single atom as an extremely selective single-photon detector, using our ability to see state changes in the atom.

[1] L. C. Bianchet *et al.*, Open Research Europe **1**, 102 (2021).
[2] N. Bruno *et al.*, Opt. Express **27**, 31042 (2019).

Objectives:

As in any laboratory, there are many things to be done. We have ideas for projects on the atom side, such as using microwaves to drive transitions between the F=1 hyperfine ground state (which does not fluoresce when illuminated with the lasers used to cool the atom) and the F=2 hyperfine ground state (which does). Coherently driving this transition before "reading out" using the fluorescence will allow us to detect arbitrary superposition states, making a single-qubit analyser for the atomic state.

We also have ideas for projects on the photons side, for example using the entangled photon pair source to test the randomness of quantum physics.

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

Additional information (if needed):
* Required skills: Experimental experience is desirable but not absolutely required. Hard working, good knowledge of optics, quantum optics and laser principles.
* Miscellaneous: Project will be done at ICFO.