Detection of single ions in a nanoparticle coupled to a fiber cavity

Eduardo Beattie, ICFO
Chetan Deshmukh, ICFO
Bernardo Casabone, ICFO
Samuele Grandi, ICFO
Diana Serrano, CNRS
Alban Ferrier, CNRS/Sorbonne Université
Philippe Goldner, CNRS
David Hunger, KIT
Hugues de Riedmatten, ICFO/ICREA

The Institute of Photonic Sciences
Castelldefels (Barcelona), Spain

Eduardo.Beattie@icfo.eu

Rare earth ion-doped crystals constitute a promising platform for quantum information processing and networking. They feature exceptional spin coherence times to store information, narrow optical transitions to act as an interface to optical photons, and possibilities to realize quantum gates between single ion qubits through electric dipole interactions. As with other quantum emitters, by coupling them to optical cavities we can channel their emission into the cavity mode while also decreasing their emission lifetime, which allows for efficient and high-rate spin-photon interfaces to be realized.

In order to detect single ions, the total number of ions interacting with the cavity mode must be kept small enough to guarantee spectral distinguishability. At the same time, high ion densities are desired to increase interaction strengths between ions for the implementation of gates. These two requirements motivate us to confine all the ions in a volume as small as possible, which in previous demonstrations has been limited by the optical mode to an order λ^3.

In this work we demonstrate the first detection of single rare earth ions in nanoparticles—a novel material in which the ions are concentrated in a volume over two orders of magnitude smaller than in previous realizations. We couple these nanoparticles into a high-finesse open fiber microcavity which allows for complete tunability both in space and frequency, and as a result observe a 120-fold shortening of the emission lifetime. We report the detection of individual spectral features presenting saturation of the emission count rate and linewidth, as expected by two-level systems, and confirm their single-ion nature by showing that the second-order autocorrelation function of the emitted light is consistent with our expectation for a perfect single photon emitter (Fig. 1). These results pave the way towards photonically networkable quantum information processing nodes based on single rare earth ions.

References

[1] Kinos, A., et. al. *Phys. Rev. A* **105**, 032603 (2022).
[2] Casabone, B. et al. *Nat Commun* **12**, 3570 (2021).

Figures

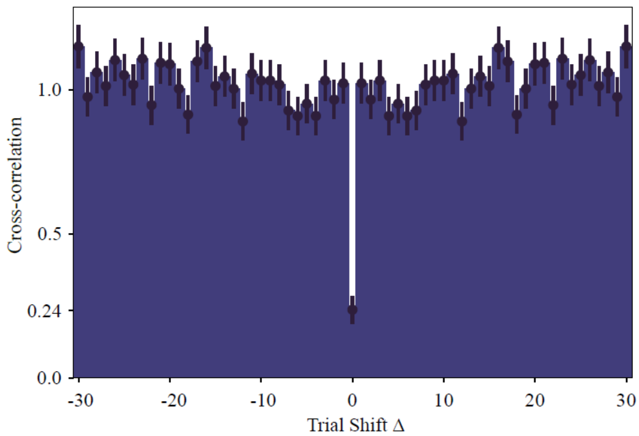

Figure 1: Autocorrelation function of the light collected from the cavity, showing a clear antibunching dip at zero delay. The value at zero delay is compatible with the observed signal-to-noise arising from the dark counts of the detectors.