INTERNSHIP PROPOSAL

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Thesis possibility after internship: YES
Funding: YES If YES, which type of funding: QuantumPS/ANR

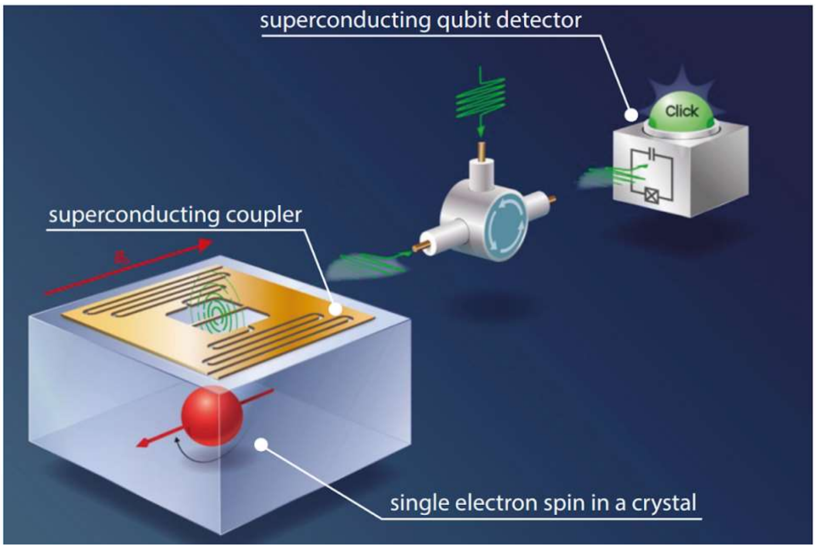
Developing a Hybrid Superconductor-Spin Quantum Processor

Utilizing superconducting circuits as a resource for quantum information processing, circuit Quantum ElectroDynamics (cQED) has made incredible advances in recent years, but still faces enormous challenges in scaling and most devices are limited to sub-millisecond coherence times [1]. Using the spin of a defect in a crystalline substrate as a qubit promises access to thousands of qubits with coherence times of seconds or more, but such systems lack the fast addressability and level of control available with cQED.

A hybrid architecture, using superconducting circuits to control and read out an impurity spin in a crystal lattice [2], leverages the advantage of both. With recent advances in superconducting single microwave photon detectors (SMPDs), the detection of spins via their fluorescence into a superconducting resonator has enabled single-spin detection and coherent manipulation. This was recently demonstrated in the quantronics group in the form of an electron spin bound to a single Erbium ion embedded in a calcium tungstate (CaWO4) crystal coupled to a superconducting resonator and a transmon-based SMPD [3–6].

We aim to use a single electron spin of an Er ion to control and read out a register of neighbouring nuclear spins naturally present in the CaWO4 host lattice with coherence times exceeding seconds. This will involve demonstrating high fidelity two-qubit gates between nuclear spins and quantum non-demolition readout via the electron spin. Such a system offers the possibility to implement quantum algorithms such as error correction [7], or to explore waveguide QED via coherent emission of highly entangled photonic quantum states into the resonator [8]. The system is unique in that it may be scaled beyond a single electron and its neighbouring nuclei by coupling multiple electron spins to one another via the superconducting resonator.

The candidate will learn about cQED device design and techniques, the physics of defects in solids, nanofabrication, microwave measurements and design and operation of experiments operating at millikelvin temperatures in dilution refrigerators.



(Left) Figure 1. A single spin embedded in a crystal is coupled to a superconducting coupler resonator. A drive pulse (top, green) is sent to the spins via a circulator and the resulting spin fluorescence signal is read out via a superconducting single photon detector. This architecture enables coherent control and readout of single electron spins.

[1] Wang et. al., npj Quantum Information, 8(1):3, January 2022.
[2] Bienfait et. al., Nature, 531(7592):74–77, 2016.
[3] Wang et. al., Nature, 619(7969):276–281, July 2023.
[4] Lescanne et. al., Phys. Rev. X, 10:021038, May 2020.
[5] Albertinale et. al., Nature, 600(7889):434–438, Dec 2021.
[6] Billaud et. al., Phys. Rev. Lett., 131:100804, Sep 2023
[7] Abobeih et. al., Nature, 606(7916):884–889, June 2022.
[8] Russo et. al., New Journal of Physics, 21(5):055002, May 2019.

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:
Condensed Matter Physics: YES Soft Matter and Biological Physics: NO
Quantum Physics: YES Theoretical Physics: NO