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Individual Spin Detection for Hybrid Superconducting Quantum Computing

The internship is part of a research project aiming at using impurities trapped in solids as quantum bits integrated as a very high fidelity memory in superconducting quantum processors.

The crystalline defects of silicon and diamond can be apprehended as naturally trapped ions in an inert crystalline environment close to vacuum. Due to their immobility and their isolation in the crystal lattice, the electronic and nuclear spins of these ions exhibit excellent coherence times, ranging from a few seconds for electrons[1] to a few hours for nuclei. These systems are thus excellent candidates for encoding quantum information. On the other hand, superconducting circuits constitute one of the most successful technological platforms for quantum computation. Quantum bits are encoded in artificial electromagnetic oscillators, they are easily controllable and integrable. However their coherence time does not exceed a few hundreds of microseconds and their manufacture is not reproducible, this is one of the main barriers toward the development of processors of more than 100 qubits.

Our group, a pioneer of superconducting circuits, is engaged in a long-term research project which aims at interfacing circuits with the electronic and nuclear spin of a unique crystal defect and thus combines the robustness of natural elements with the integrability of artificial circuits. The internship is based on recent results [1,2,3,4] of our team. For the first time, we have demonstrated the detection of a small spin ensemble (100-1000 spins) with a microwave photon detector based on a superconducting qubit processor. Our new type of microwave detector[4] enabled us to reach unprecedented sensitivity surpassing the standard quantum limit and has paved the way toward the detection and control of individual spins for quantum computing integration.
The goal will be first to optimize the coupling between the circuit and a single spin trapped in the silicon lattice and second to successfully detect the unique microwave photon generated by the de-excitation of the electron spin. This single photon will be captured and detected based on a superconducting qubit of the transmon type, a key element of the superconducting quantum processor, thus laying the foundations for this new architecture.

Methods and techniques:

This experimental internship will be co-supervised by two permanent researchers who are experts in the field, together with a PhD student working on the subject. It will provide a solid introduction to superconducting quantum technologies and the physics of defects in solids, including defects optical characterization, quantum circuit design, and nanofabrication as well as microwave measurement at cryogenic temperatures (10 mK).

[1] E. Albertinale et al., *in preparation* (2020)
[2] Rajan et al., *arXiv2005.09275* (2020)
[3] A. Bienfait et al., *Nature* (2016)
[4] R. Lescanne et al., PRX (2020)

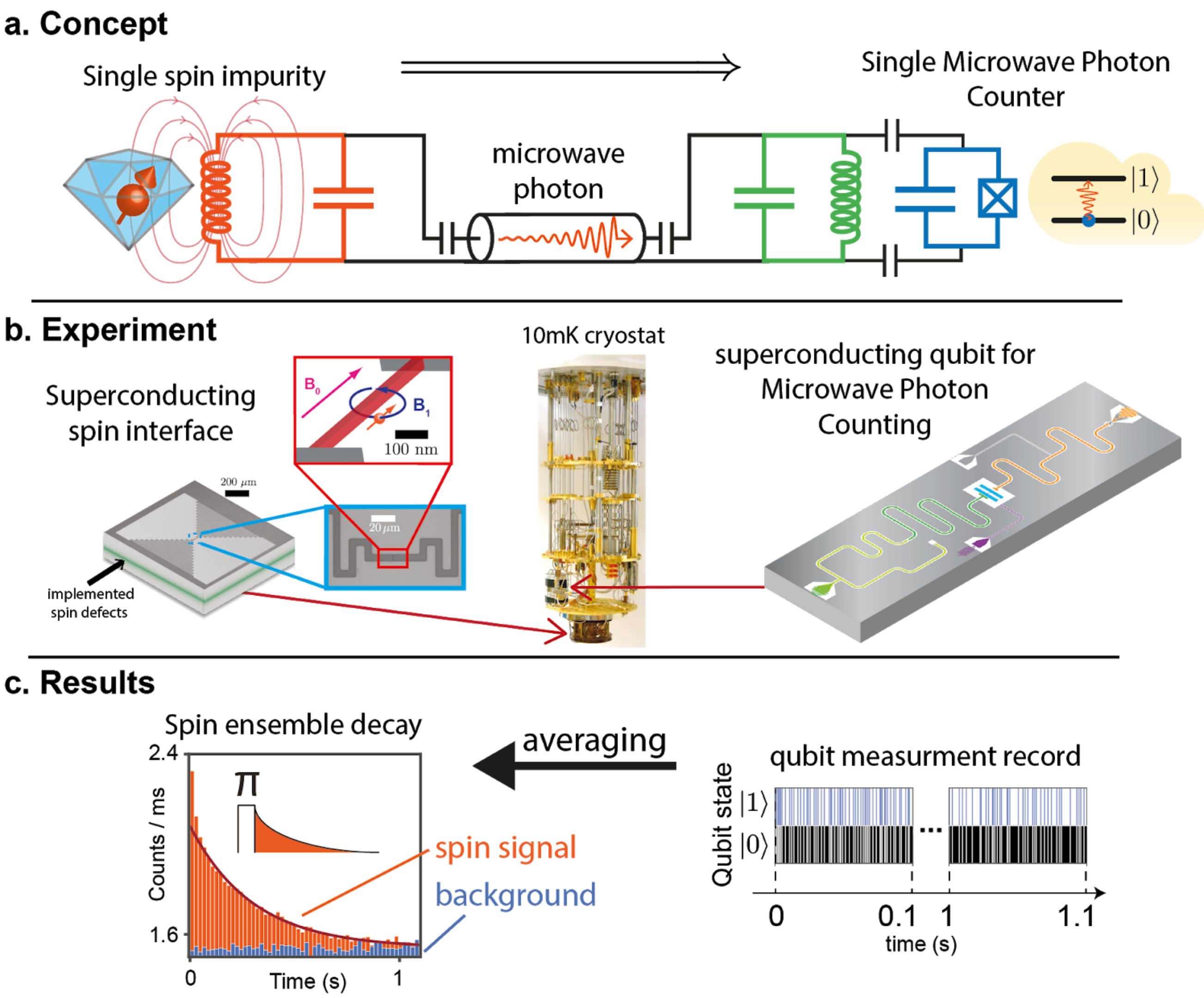

figure 1 - Concept, design, and measurement for the spin detection based on a superconducting qubit detector. a. Circuit schematic for spin detection based on superconducting circuit technologies. A photon is emitted by the spontaneous spins relaxation, the photon is collected and propagates to the superconducting qubit for photon detection. **b.** The experiment is performed at 10mK, the key components are state-of-the-art nanofabricated superconducting circuits. **c.** Experiemenal results for the decay of a spin ensemble based on single microwave photon detection based on a qubit (to appear in [2]), the measurement records corresponds to an ensemble of click of the detector. After averaging, the signature of the spin spontaneous decay is revealed.