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Circuit-QED with phase-biased Josephson weak links

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By coupling a superconducting phase-biased weak link to a microwave resonator, recent experiments have probed the spectrum[1,2] and achieved the coherent manipulation[3,4] of Andreev states in various systems. Noticeably, novel designs based on semiconducting nanowires[1,4] have enabled the resolution of their fine structure arising from spin-orbit interaction (Fig 1), opening a path towards Andreev spin qubits. Nevertheless, the understanding of the often complex measured Andreev spectra still remains incomplete : both *qualitatively* when it comes to the transition lines' identification and *quantitatively*, regarding the lines' intensities, pointing to the need of a general theory for the response of a resonator to changes in the occupancies of a multi-level system of Andreev states. Using Bogoliubov-de Gennes formalism to describe the weak link and a general formulation of the coupling to a resonator[5], we calculate the resonator frequency shift as a function of the levels occupancies[6] and describe how transitions are induced by means of a phase or electric field microwave drive.

In this talk, I will apply this formalism to recent experimental results, obtained using circuit-QED techniques on superconducting atomic contacts and semiconducting nanowire junctions, and show how it describes features of the measured spectra, in particular the transition lines intensity and the existence of selection rules associated to the spin. Finally, I will briefly report on signatures in the Andreev spectrum of electron-electron interactions and discuss how they provide a new framework to understand so far unidentified transition lines in nanowire weak-link spectra.

[1] L. Tosi et al., Phys. Rev. X **9**, 011010 (2019)
[2] L. Bretheau et al., Nature **499**, 312 (2013)
[3] C. Janvier et al., Science **349**, 1199 (2015)
[4] M. Hays et al., Nature Phys. **16** (2020)
[5] S. Park et al, Phys. Rev. Lett. **125**, 077701 (2020)
[6] C. Metzger et al, Phys. Rev. Res **3**, 013036 (2021)

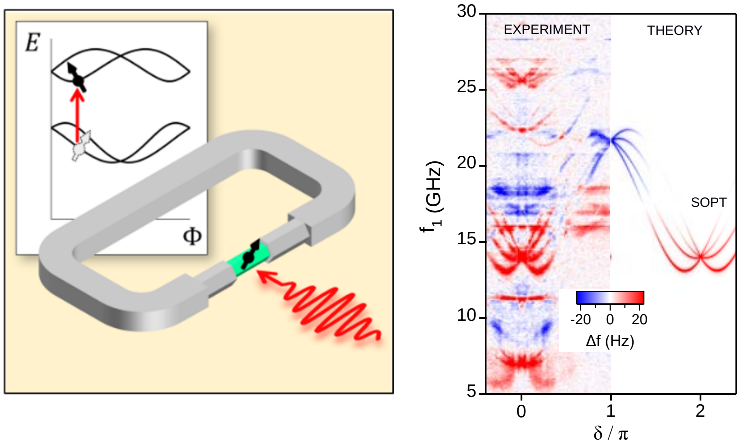

Figure 1 : Microwave spectroscopy of Andreev states in a phase-biased InAs-Al nanowire weak link[1] revealing single quasiparticle transitions (SQPT) : atomic-like excitations of a quasiparticle from one spin-split Andreev level to another. Shift Δf of the resonator's frequency due to changes in the occupancies of the Andreev levels induced by a microwave drive at frequency f_1 vs the superconducting phase difference δ across the nanowire.