

Field-effect metallic superconducting electronics

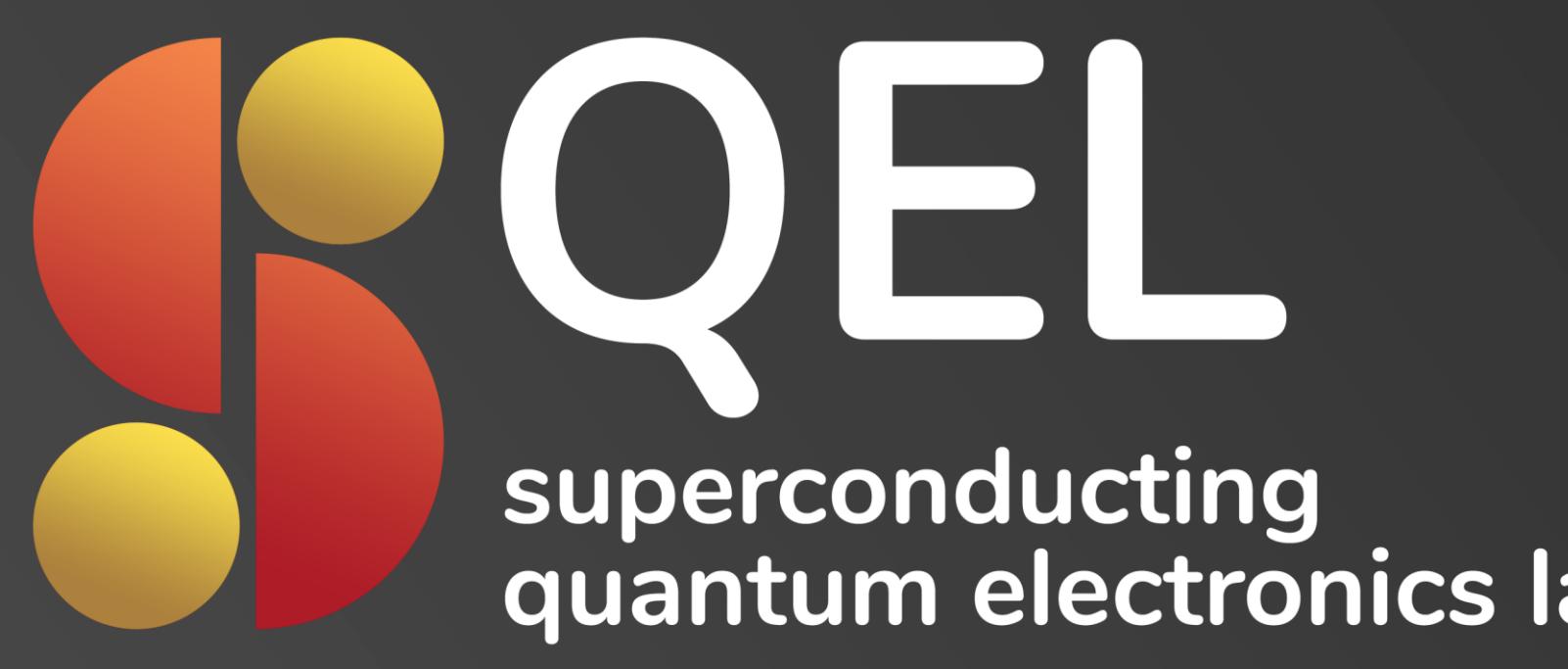
C. Puglia^{1-2*}, F. Vischi^{1-2*} G. De Simoni¹, F. Paolucci¹⁻³, E. Strambini¹, N. Ligato¹, A. Braggio¹, P. Virtanen¹, C. Guarcello¹ and F. Giazotto¹

¹NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Piazza S. Silvestro 12, I-56127 Pisa, Italy

²Dipartimento di Fisica dell'Università di Pisa, Largo Pontecorvo 3, I-56127 Pisa, Italy

³INFN Sezione di Pisa, Largo Bruno Pontecorvo, 3, I-56127 Pisa, Italy

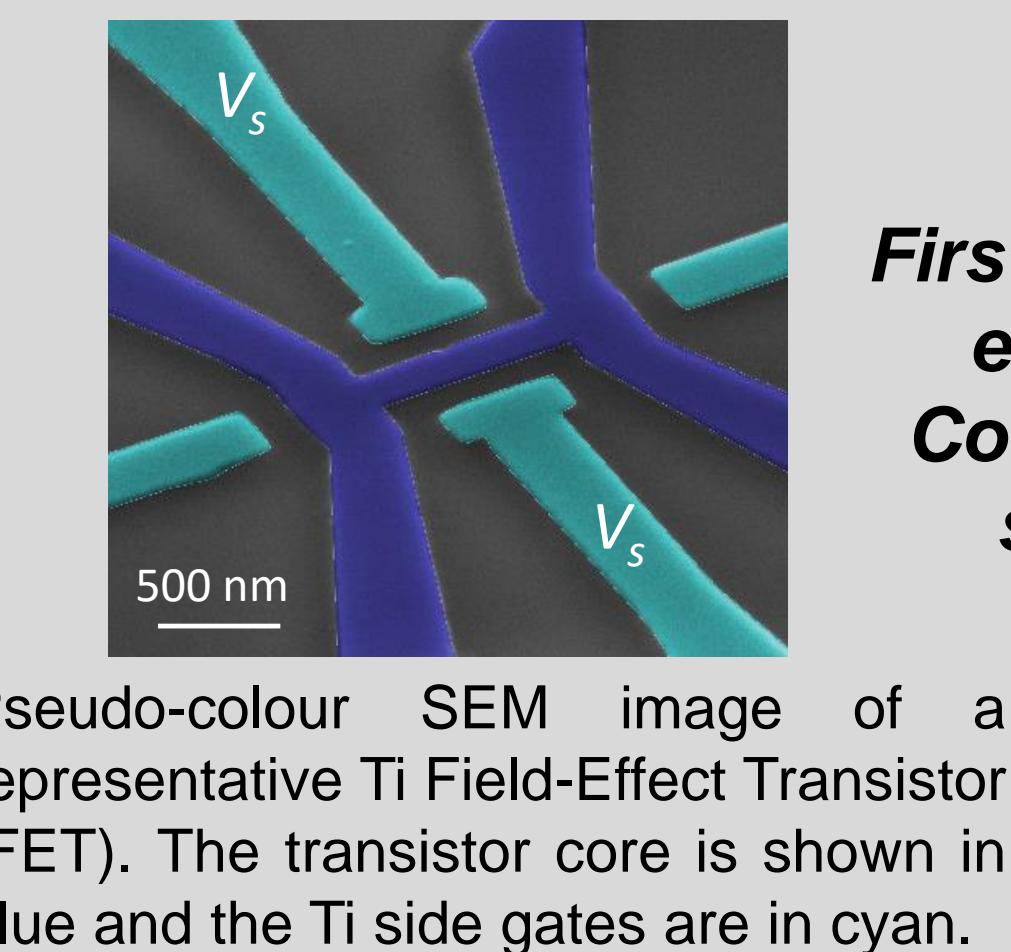
* E-mail: Claudio.Puglia@df.unipi.it, Francesco.Vischi@df.unipi.it



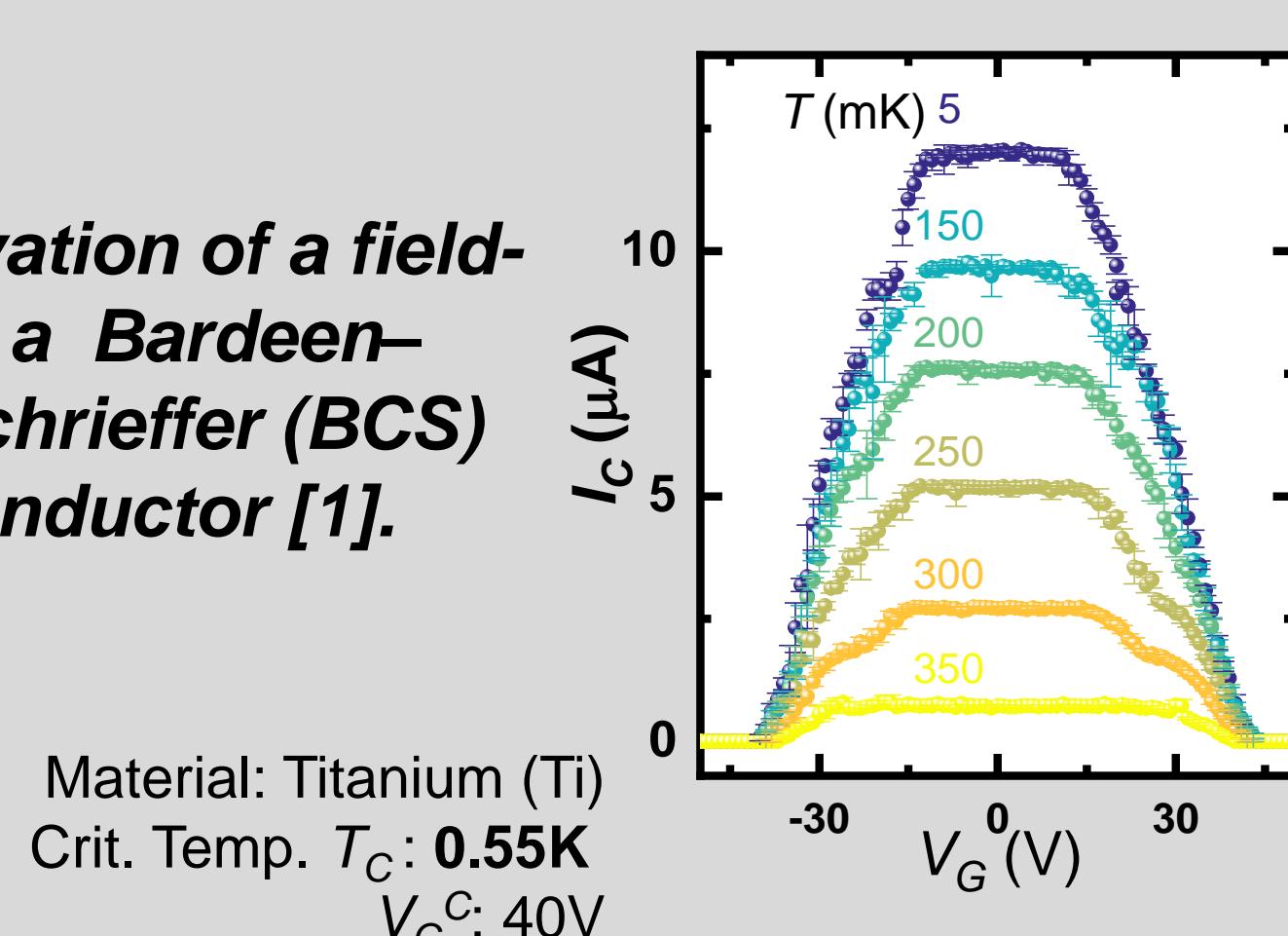
Motivations

Until now no clue has been provided on the possibility to affect metallic superconductors via field-effect. Here we present some results about the suppression of the supercurrent in metallic superconductor devices due to the application of an electrostatic field [1,2,3]. In particular, we analyze the effect on two types of Josephson junction: Dayem bridge constrictions [4,5] and Superconducting/Normal metal/Superconductor (SNS) junctions [3]. Moreover, recent experimental works [2] seem to suggest that the field-effect affects the macroscopic phase of the Cooper pair condensate in a new fascinating way.

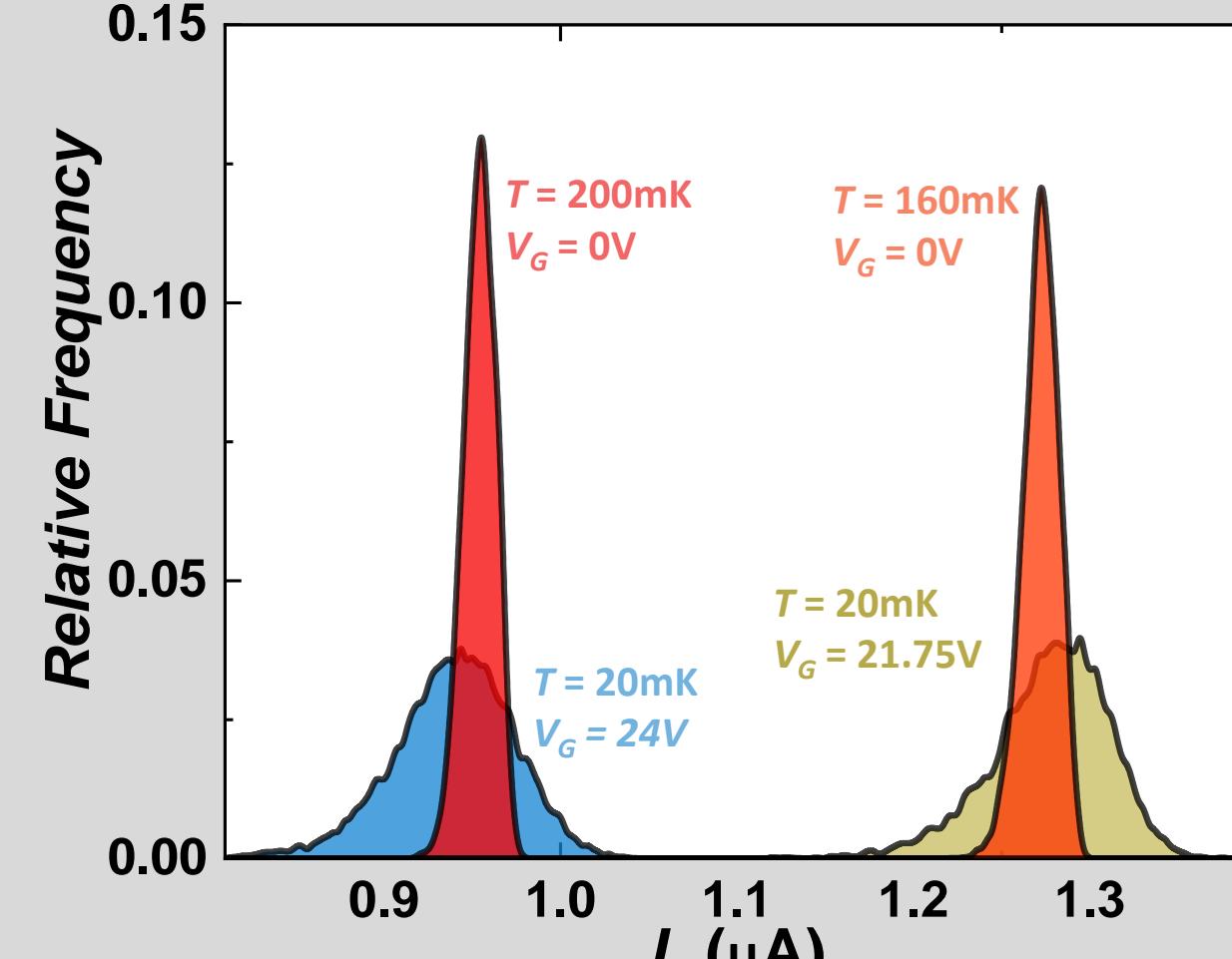
I. Discovery of the field-effect on superconductors



First observation of a field-effect on a Bardeen–Cooper–Schrieffer (BCS) superconductor [1].



III. Heating effect?

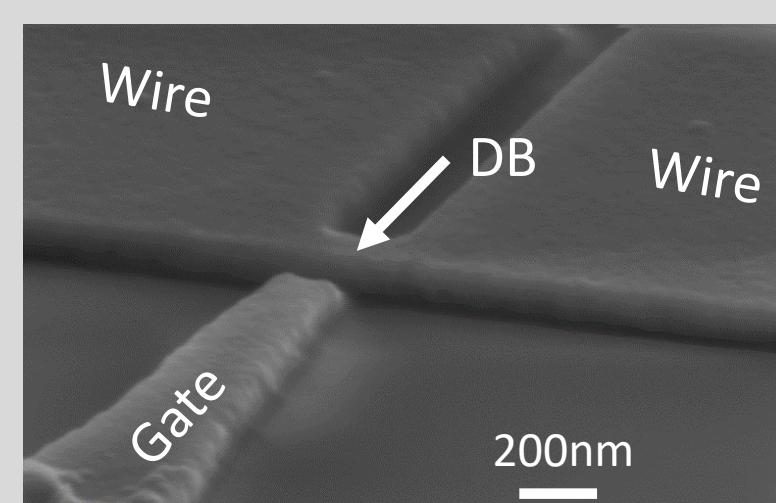


The effect of gating on the switching current probability distribution cannot be explained in term of a heating effect. In particular, the standard deviation is larger than in the absence of gating.

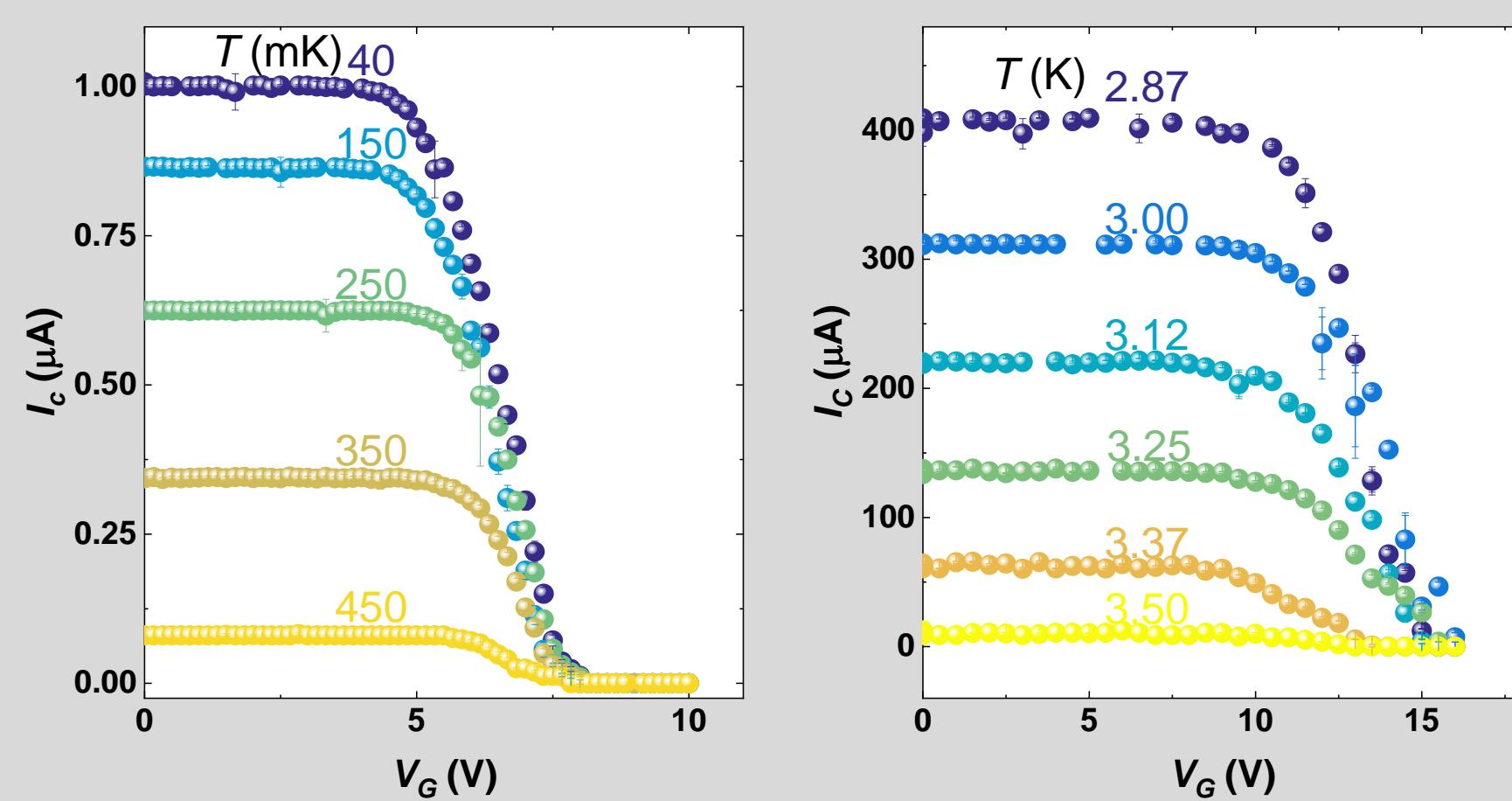
II. Universality of the effect

We report the effect in different materials (Ti [4,5], Al[4], V, NbN) and different geometries like wires [1], Dayem bridges (DB) and Superconductor/Normal metal/Superconductor (SNS) junctions [3].

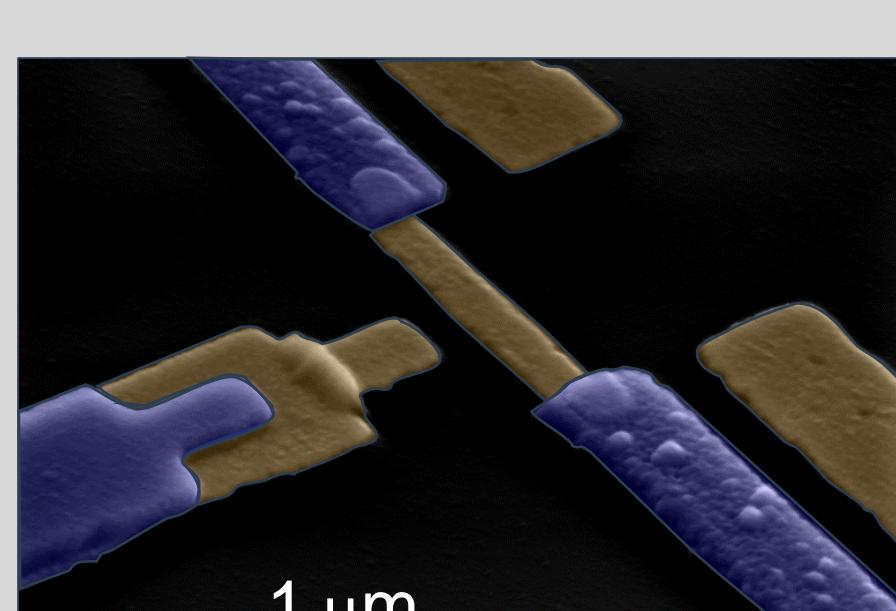
A Dayem bridge (DB) is a thin-film Josephson junction made up of a wire interrupted by a short constriction with smaller lateral dimensions



SEM image of a typical Dayem bridge junction.

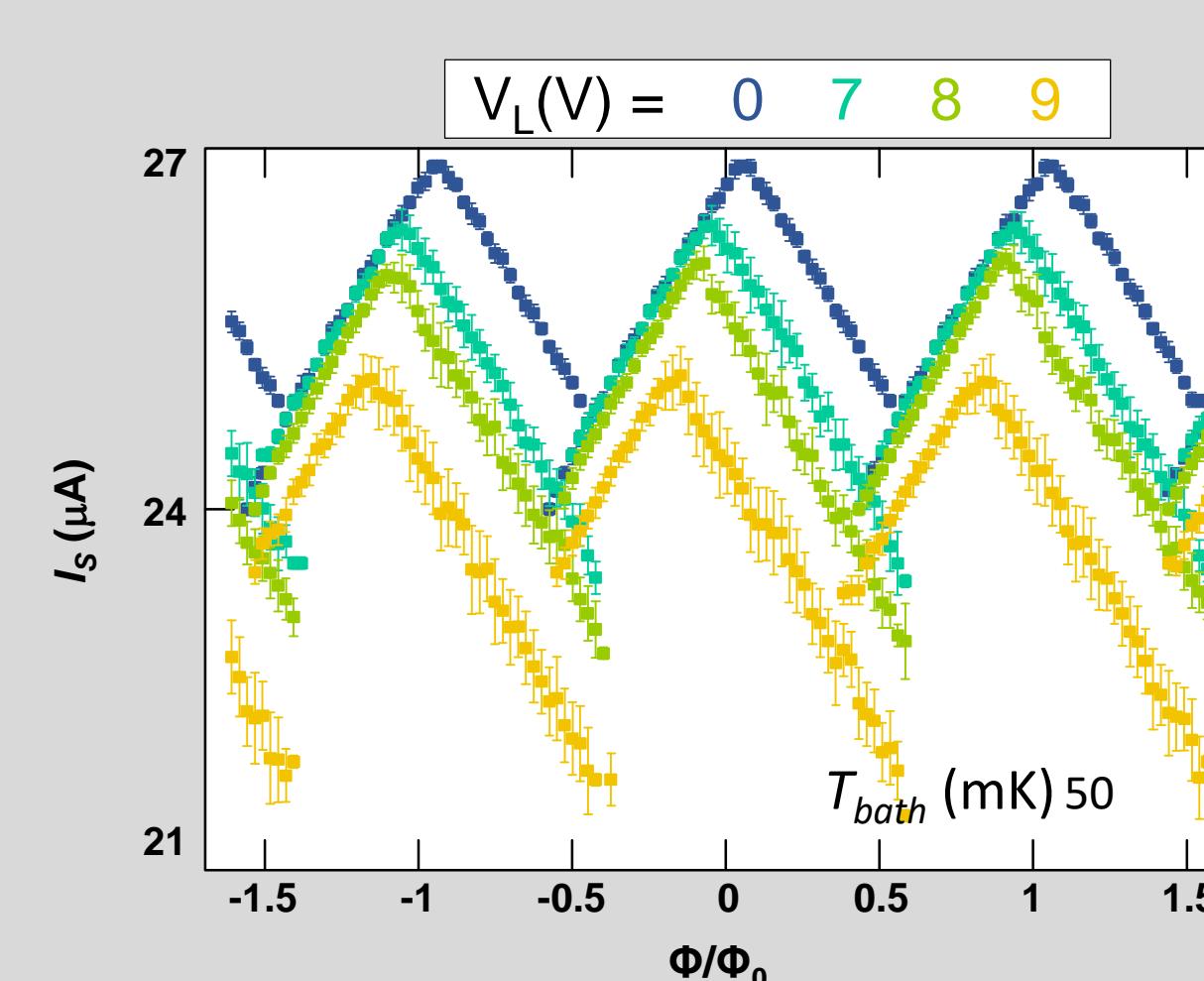
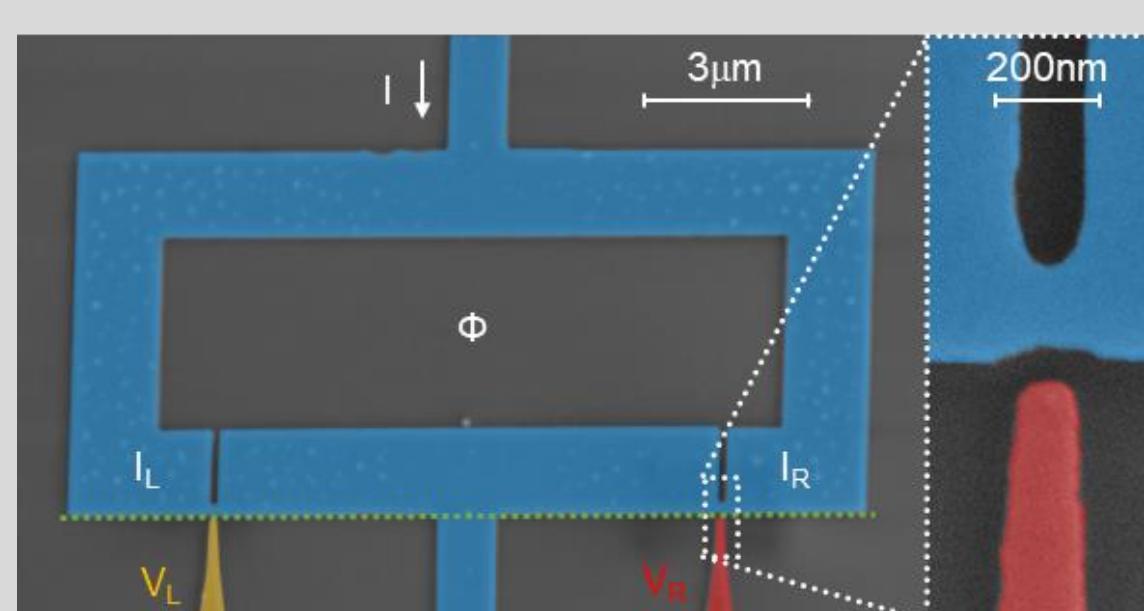


Our results on a SNS junction [3] suggest that the field effect is quite general and does not rely on the existence of a true pairing potential, but rather the presence of superconducting correlations.



SEM image of the SNS junction. In blue it is shown the superconducting material (Al); in orange the normal metal (Cu)

IV. Coupling of electric field and superconducting phase



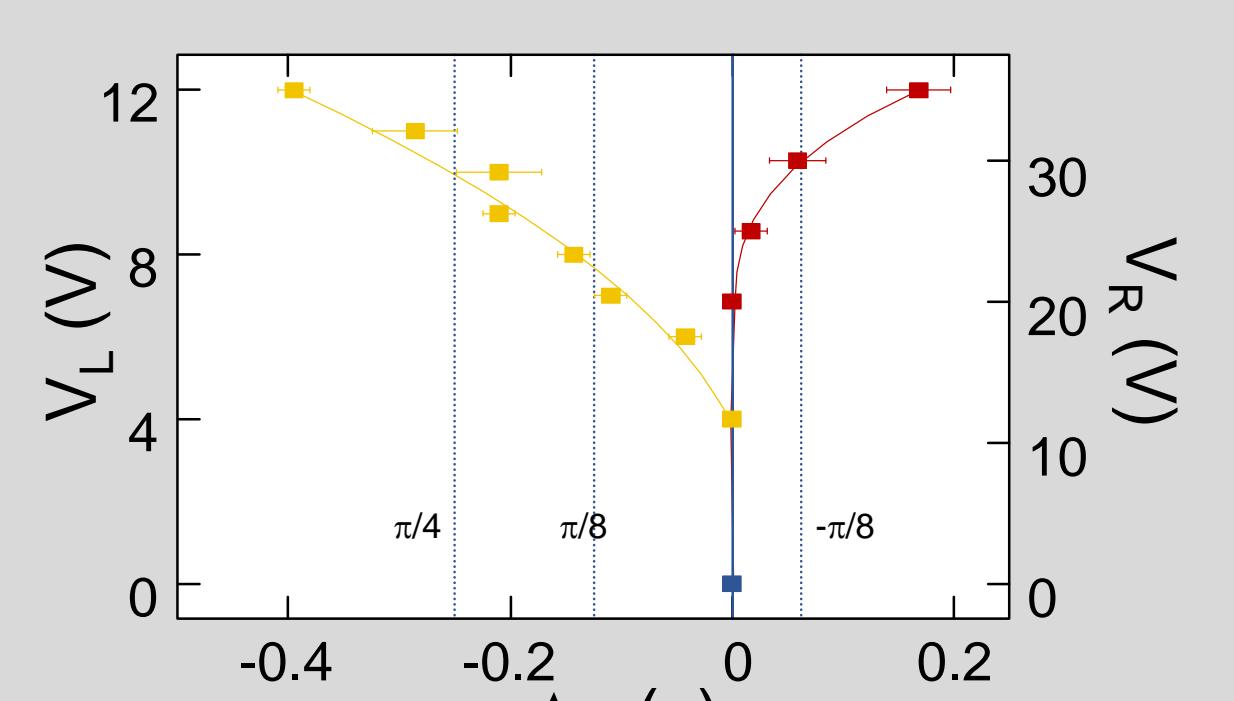
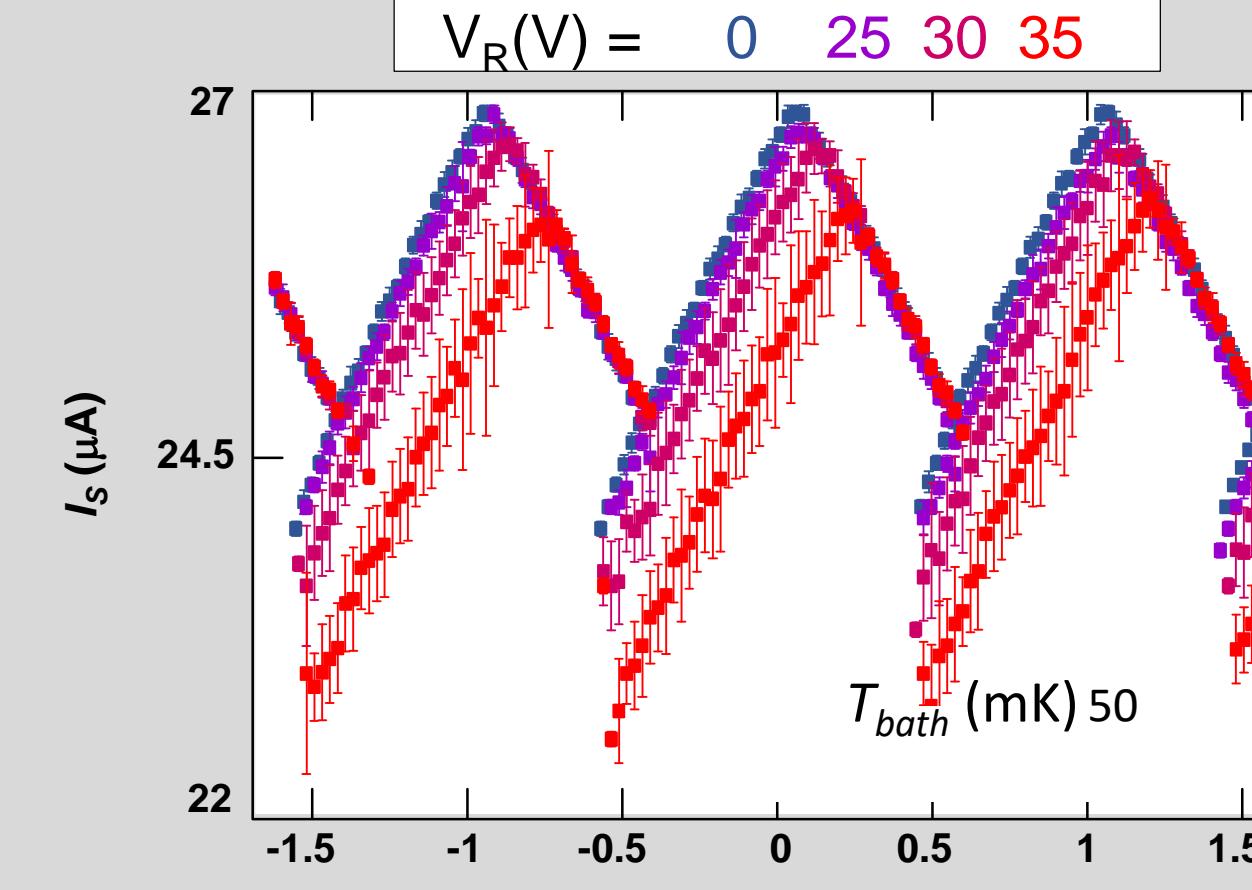
We have fabricated a Superconducting Quantum Interference Device based on two Dayem bridges by a single-step of lithography followed by titanium evaporation [2]. The two junctions are gated independently by correspondent electrodes.

We found the presence of field-effect, affecting the characteristics of switching current VS magnetic flux $I_s(\Phi)$.

At low gate voltages, the $I_s(\Phi)$ curve slides along one branch meanwhile fluctuations appear in the other branch. The sliding direction depends on which junction is gated.

At higher voltages, the I_s is suppressed below the single junction critical current and the fluctuations are present in both the branches. This can be modelled by a field-induced phase fluctuations.

The device can be used as phase shifter for classical or quantum computation [2].



V. Future perspectives

- Quantum Information Applications: field-effect control of phase/flux Qubits, Gatemons.
- High sensitivity Sensors: single photon detectors, bolometers etc.
- All-metallic high-speed superconducting electric field-controlled electronics RSFQ logic.
- Caloritronics: interferometers, etc.

Bibliography

- G. De Simoni *et al.* Nature Nanotechnology 13, 802–805 (2018)
- F. Paolucci, F. Vischi *et al.* Arxiv 1904.08349
- G. De Simoni *et al.* Arxiv 1903.03435
- F. Paolucci *et al.* Phys. Rev. Applied 11, 024061
- F. Paolucci *et al.* Nano Lett. 20181874195-4199