Triplet blockade in a Josephson junction with a double quantum dot

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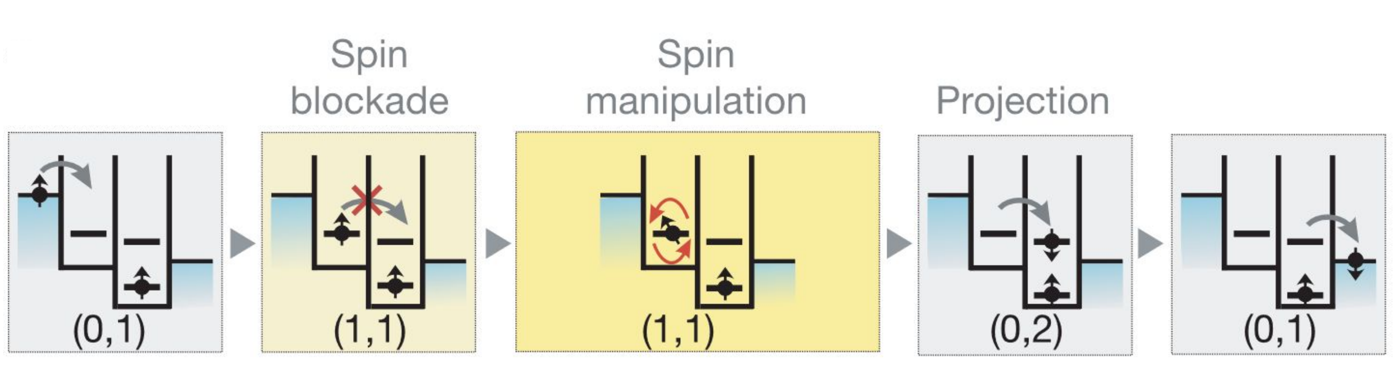
Abstract

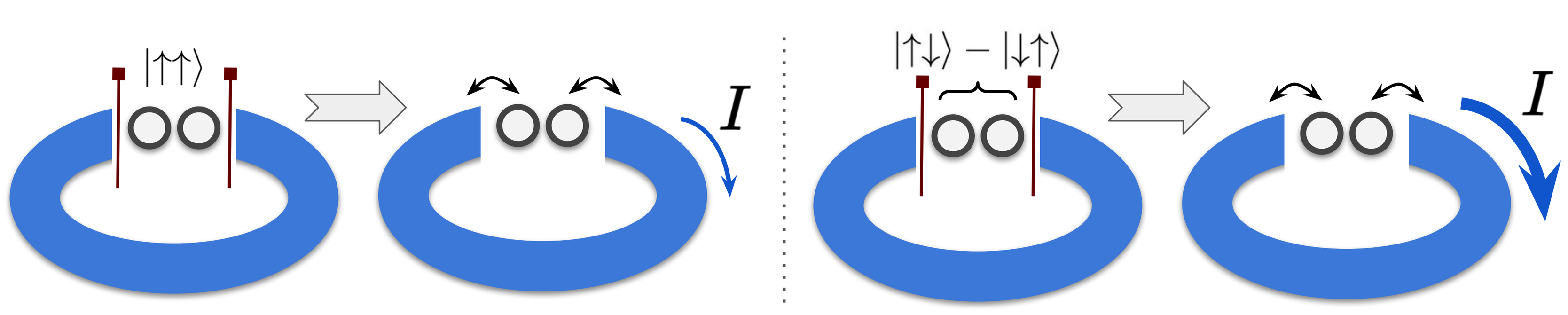
Topological superconductors are promising building blocks for future quantum computers, although their experimental realization remains a challenging task. Here we present theory results [1] on a Josephson junction with a double quantum dot, a minimal model system toward engineered topological superconductivity based on quantum dot chains [2]. In the (1,1) charge sector of the serially coupled double quantum dot, we illustrate a magnetically induced singlet-triplet ground-state transition via triplet blockade: the Josephson current carried by the triplet ground state at high magnetic field is much suppressed compared to the current carried by the singlet ground state at low magnetic field. The theory results we present are based on the zero-bandwidth approximation [3,4]. We provide simple arguments for a strong triplet blockade in the strong-Coulomb-repulsion limit, using perturbation theory [5]. We also present experimental data (of an InAs nanowire double quantum dot with superconducting leads) showing the triplet blockade predicted by the theory [1]. The demonstrated triplet blockade mechanism could provide a coupling mechanism between spin qubits, and (topological or non-topological) superconducting qubits.

Motivation: spin-to-supercurrent conversion

Pauli blockade: spin-to-charge conversion [6]

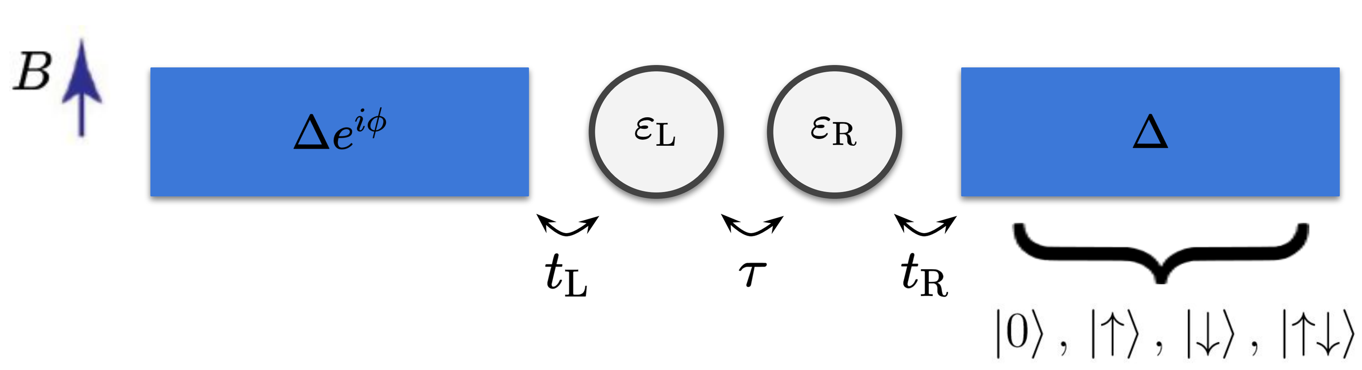


Triplet blockade: spin-to-supercurrent conversion



Simple model of the double-dot Josephson junction

$$H = H_{\mathrm{BCS}} + H_{\mathrm{DQD}} + H_{t\mathrm{L}} + H_{\tau} + H_{t\mathrm{R}}$$



$$H_{\mathrm{BCS}} \approx H_{\mathrm{ZBW}} = \sum_{j=\mathrm{LL,RL}} \left(\Delta_j c^\dagger_{j\uparrow} c^\dagger_{j\downarrow} + \mathrm{h.c.}\right)$$

zero-bandwidth approximation

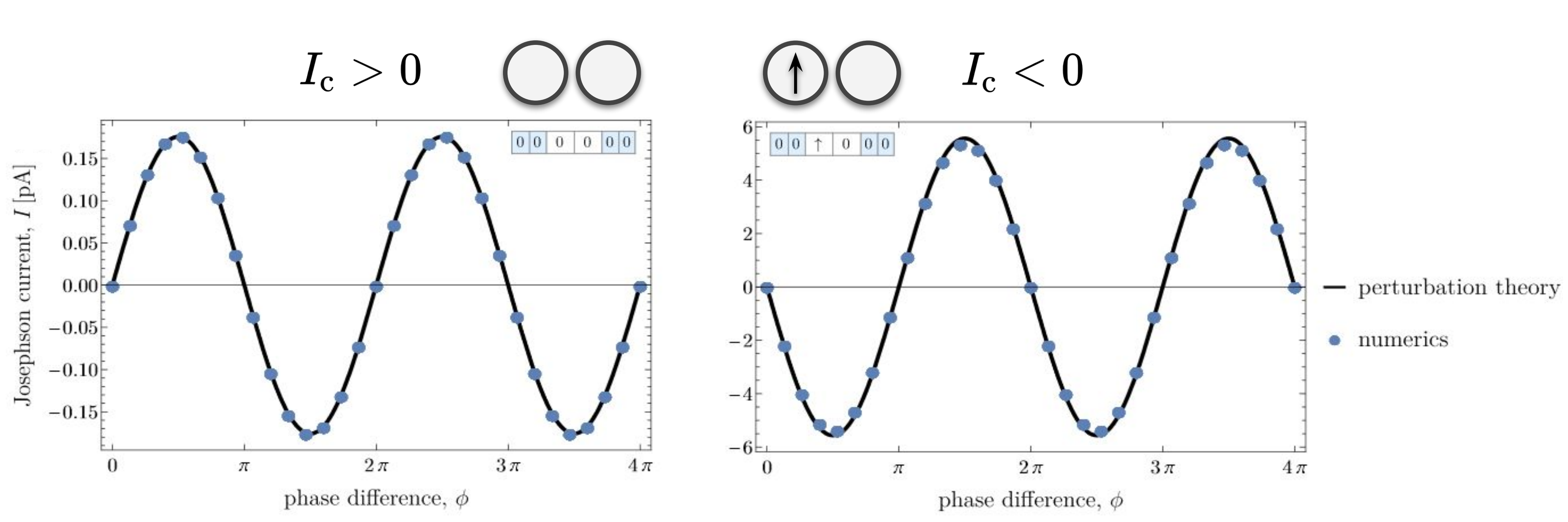
$$H_{\mathrm{DQD}} = \sum_{\ell=\mathrm{L,R}} \left(\varepsilon_\ell n_\ell + \frac{1}{2} U_\ell n_\ell (n_\ell - 1) + \frac{1}{2} g\mu_B B (n_{\ell\downarrow} - n_{\ell\uparrow})\right)$$

τ : spin-conserving + spin-flip hopping

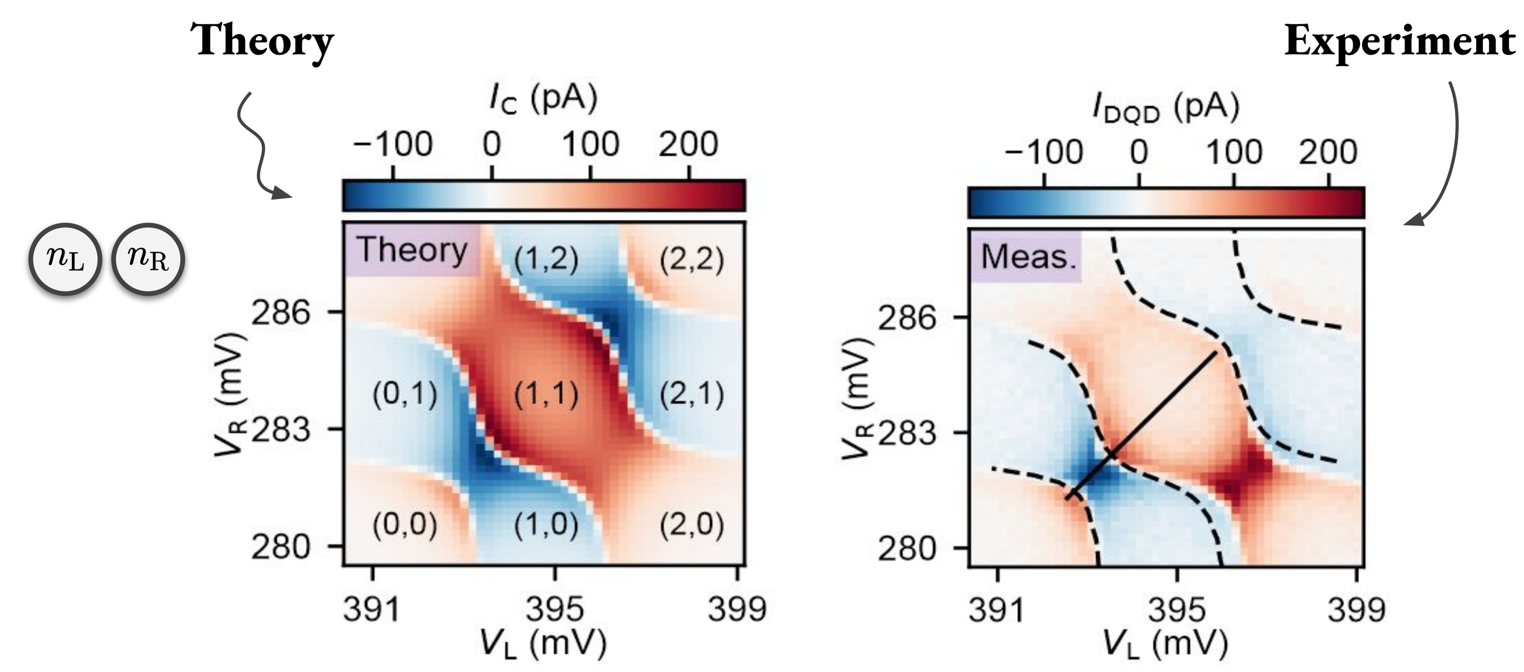
- Current-phase relation shows even-odd effect

$$I(\phi) = \frac{2e}{\hbar}\frac{\partial E_0}{\partial \phi} \quad \Rightarrow \quad \boxed{I(\phi) = I_c \sin(\phi)}$$

in the weak tunneling regime $t_{\mathrm{L/R}} \ll \Delta, U$

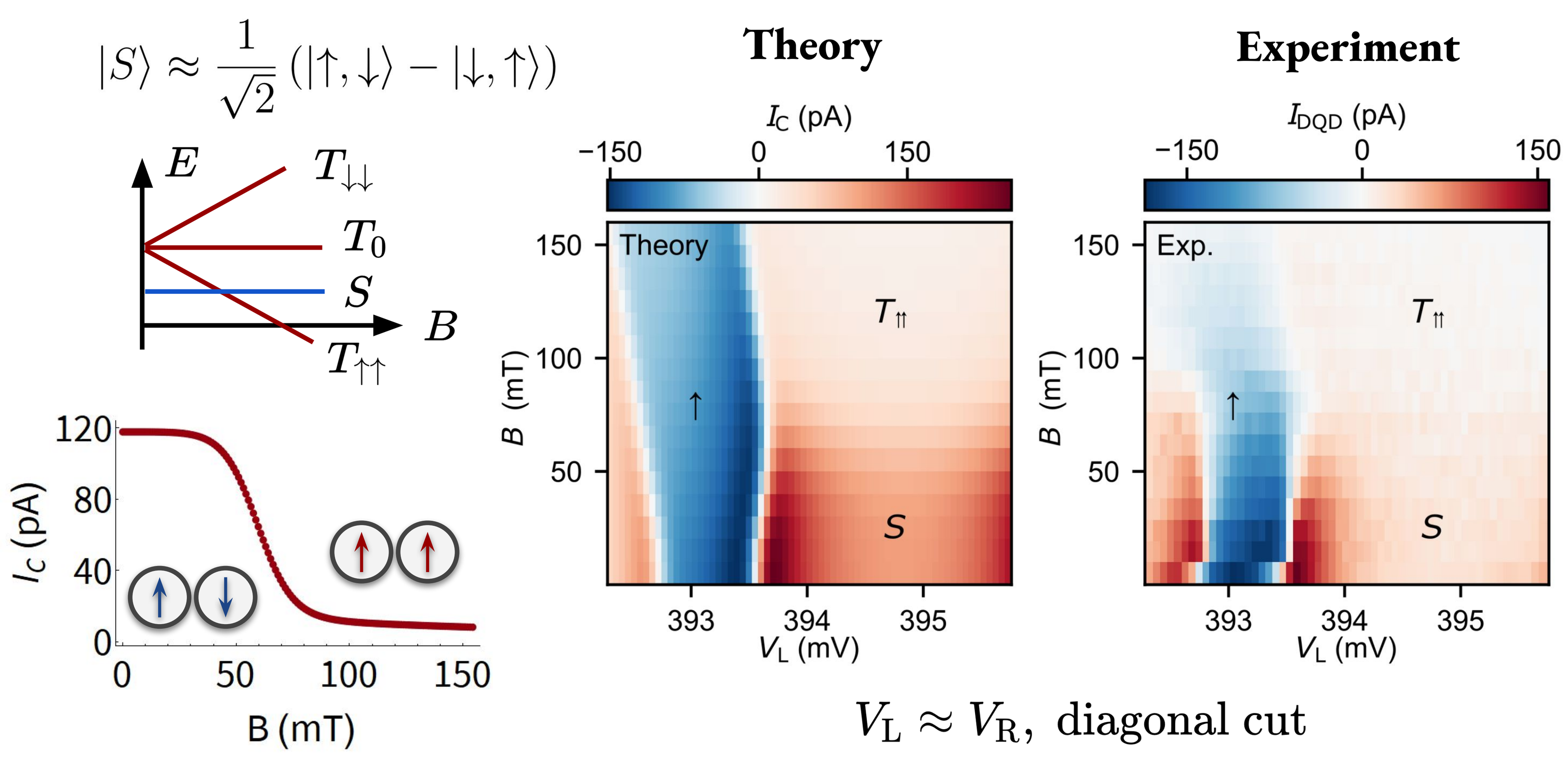


- Josephson stability diagram: even-odd effect



- Magnetic stability: triplet blockade

$$|S\rangle \approx \frac{1}{\sqrt{2}}(|\uparrow,\downarrow\rangle - |\downarrow,\uparrow\rangle)$$



$V_{\mathrm{L}} \approx V_{\mathrm{R}}$, diagonal cut

- Triplet blockade argument based on perturbation theory

Each contribution to the leading order critical current is a six-step process [5]: a Cooper pair is transferred through the junction.

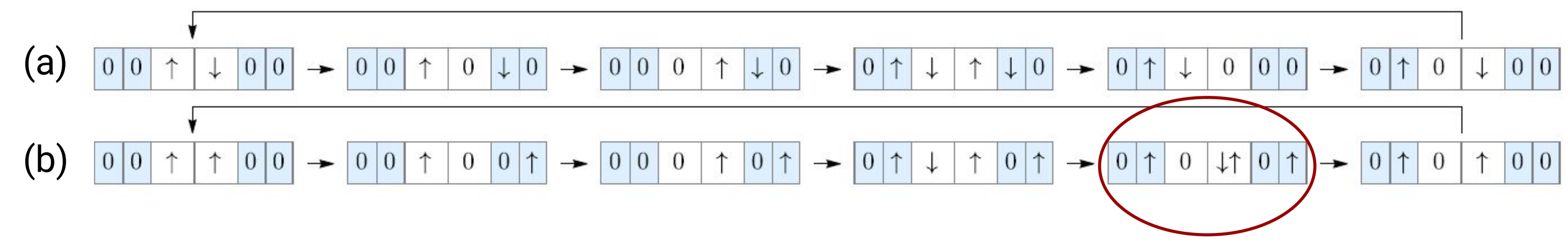
In the experiment: $U \gg \Delta$ strong Coulomb-repulsion limit

double occupancy ⟷ energy penalty of U

(a) $|\uparrow\downarrow\rangle$: there are processes with only singly occupied quantum dots

(b) $|\uparrow\uparrow\rangle$: at least one intermediate state has a doubly occupied quantum dot

$\Rightarrow$ the ratio of the $|\uparrow\uparrow\rangle$ and $|\uparrow\downarrow\rangle$ critical currents is suppressed by U^{-1}



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