Current correlations in the interacting Cooper-pair beam-splitter

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Using a conserving many-body treatment, we propose an approach allowing the computation of currents and their correlations in interacting multi-terminal mesoscopic systems involving quantum dots coupled to normal and/or superconducting leads. We illustrate our method with the Cooper-pair beam-splitter setup recently proposed [1, 2], which we model as a double quantum dot with weak interactions, connected to a superconducting lead and two normal ones. Our results suggest that even a weak Coulomb repulsion tends to favor positive current cross-correlations.

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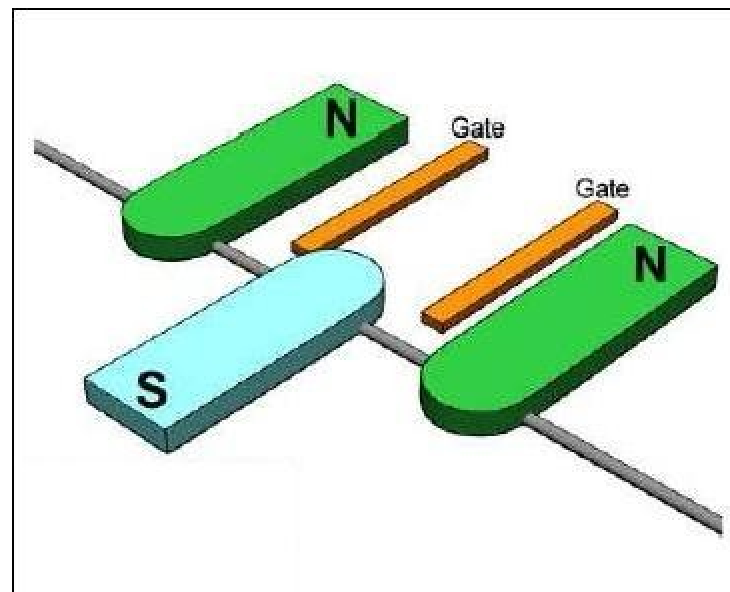


The Hamiltonian

$$H = \sum_{j,\alpha} \left(H_\alpha + H_j + H_{j\alpha} \right)$$

$$H_\alpha = \epsilon_\alpha \hat{d}_\alpha^\dagger d_\alpha + \sum_{\beta \neq \alpha} \left(\frac{t_{\alpha\beta}}{2} d_\alpha^\dagger \sigma_z d_\beta + h.c. \right) + U_\alpha n_{\alpha\uparrow} n_{\alpha\downarrow}$$ (dots)

$$H_j = \sum_k \hat{\Psi}_{jk} \left(\xi_k \sigma_z + \Delta_j \sigma_x \right) \hat{\Psi}_{jk}$$ (leads)

$$H_{j\alpha} = \sum_k \left(\hat{\Psi}_{jk}^\dagger T_{j\alpha}(t) \hat{d}_\alpha + h.c. \right)$$ (hopping)

where

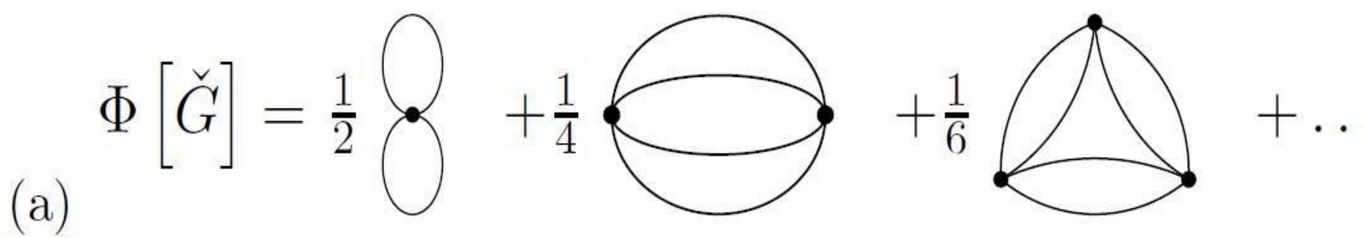
$$\hat{d}_\alpha^\dagger = \left(d_{\alpha\uparrow}^\dagger d_{\alpha\downarrow} \right)$$

$$\hat{\Psi}_{jk}^\dagger = \left(\Psi_{jk\uparrow}^\dagger \Psi_{j-k\downarrow} \right)$$

$$T_{j\alpha}(t) = t_{j\alpha} \sigma_z e^{i \sigma_z V_j t}$$

Numerical method

Based on Kadanoff-Baym-Keldysh perturbation theory
The Luttinger-Ward functional: (function of single-particle Green function and sum of all closed-loop two-particle irreducible diagrams



The interacting self-energy is function of V_L, but not of the frequency
From these the single- and two-particle Green functions can be derived

Calculating the current

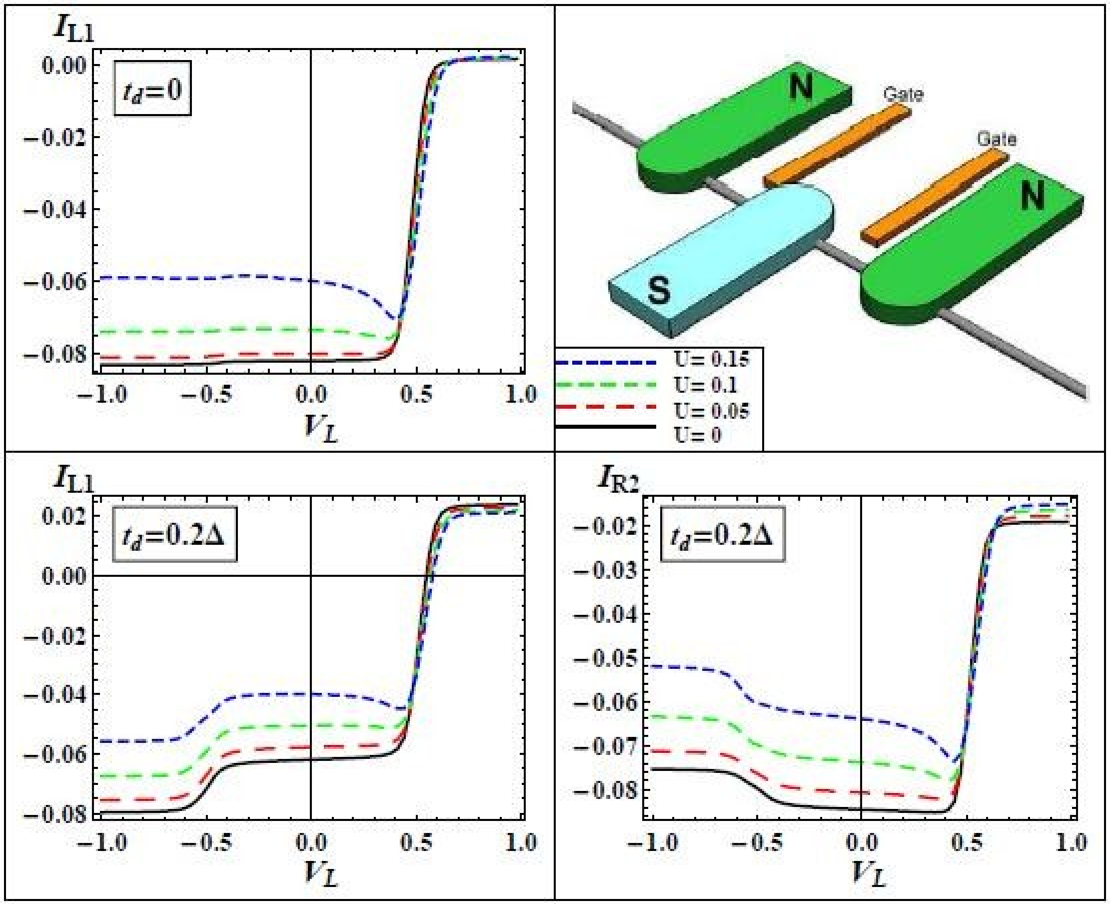
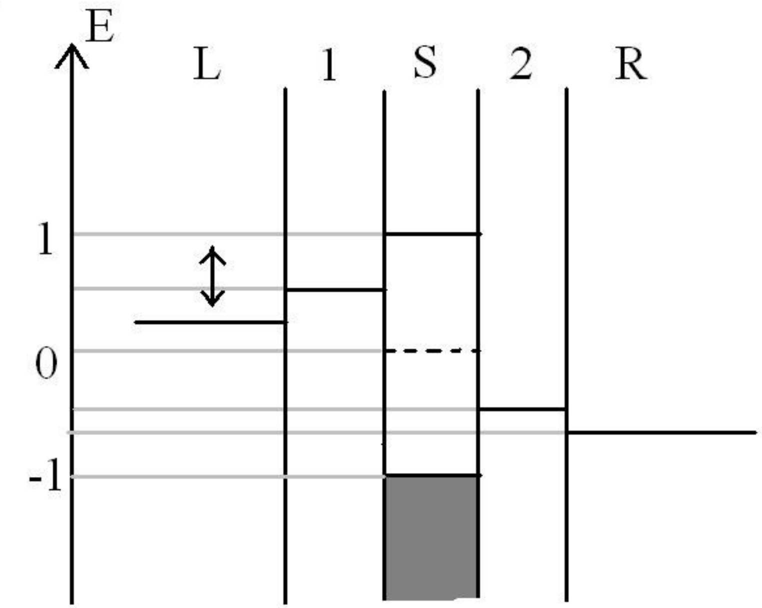


FIG. 2: Currents I_{L1} and I_{R2} (arbitrary units) as a function of V_L, for different values of the interaction $U = 0, 0.05, 0.1, 0.15\Delta$, and the parameters (in units of Δ) $\beta = 100$, $\epsilon_1 = 0.5$, $\epsilon_2 = -0.5$, $V_R = -0.7$ and $t_{L1} = t_{S1} = t_{S2} = t_{R2} = 0.2$. The upper left panel corresponds to $t_d = 0$, while the lower panels are computed for $t_d = 0.2\Delta$. The upper right panel shows a representation of the setup.



Crossed Andreev Refl. (CAR) regime

B=100 ?

- Strong U dependence
- Similar effect if the direct tunneling is present or not

Zero frequency current-current correlation without direct interdot tunneling

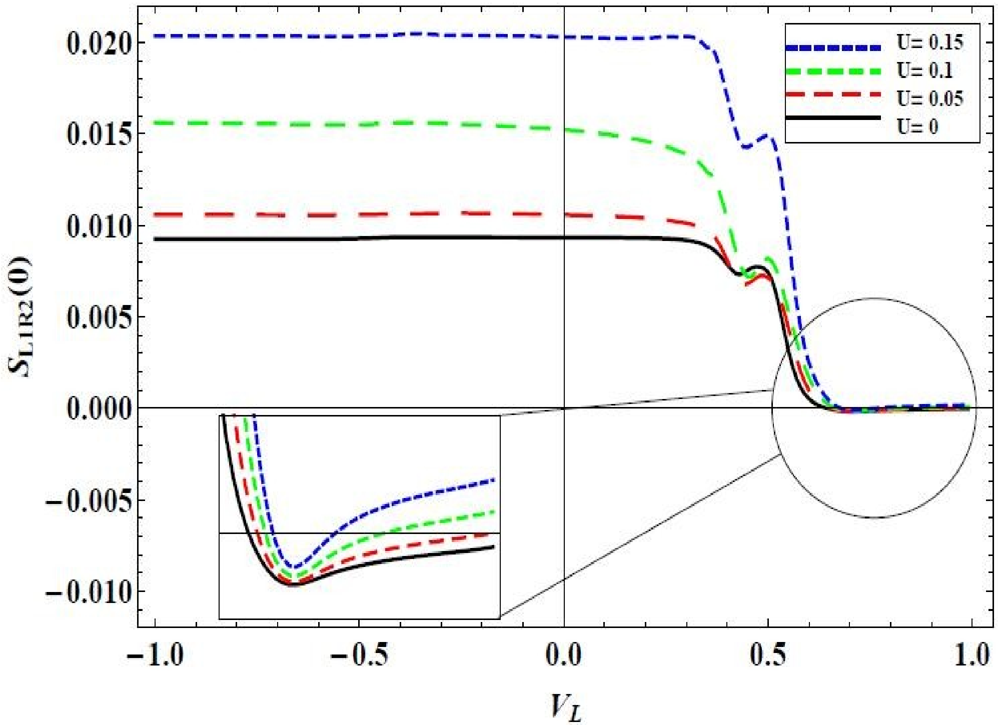


FIG. 3: Current cross-correlations (arbitrary units) as a function of V_L, for $U = 0, 0.05, 0.1, 0.15\Delta$, and the same parameters as in Fig. 2, in the absence of direct tunneling.

- $V_L < \varepsilon 1$: positive, approx. const correlation, strongly enhanced by interaction (due to the two-particle effects)
- $V_L > \varepsilon 1$: CAR is unfavored, electron co-tunneing expected (negativ correlation), but the interaction changes the sign of the correlation

Zero frequency current-current correlation with direct interdot tunneling

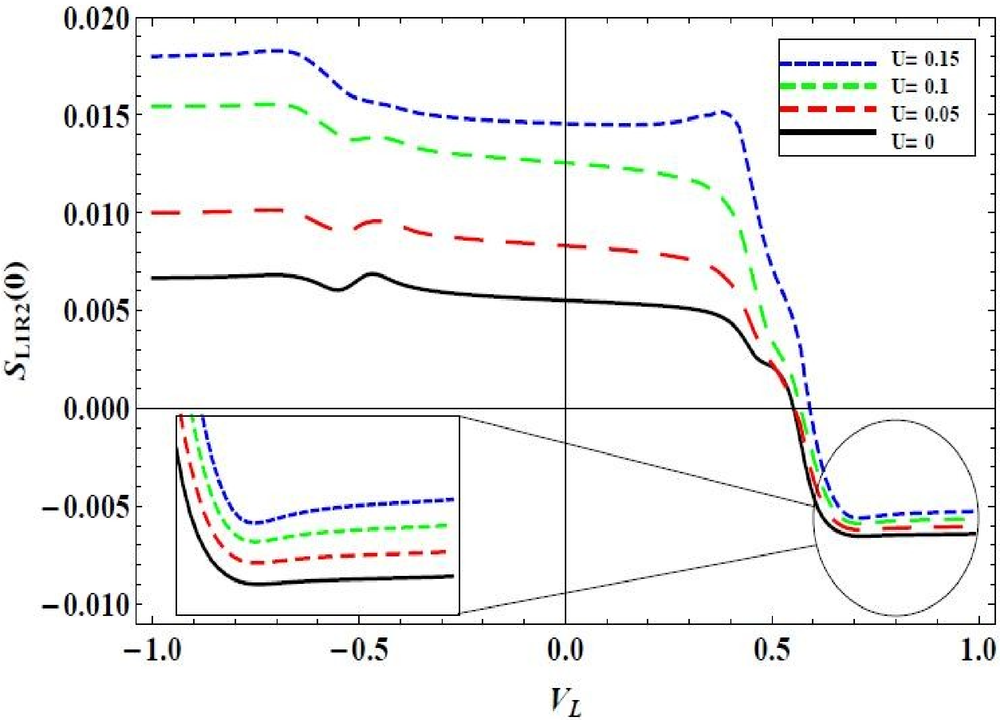
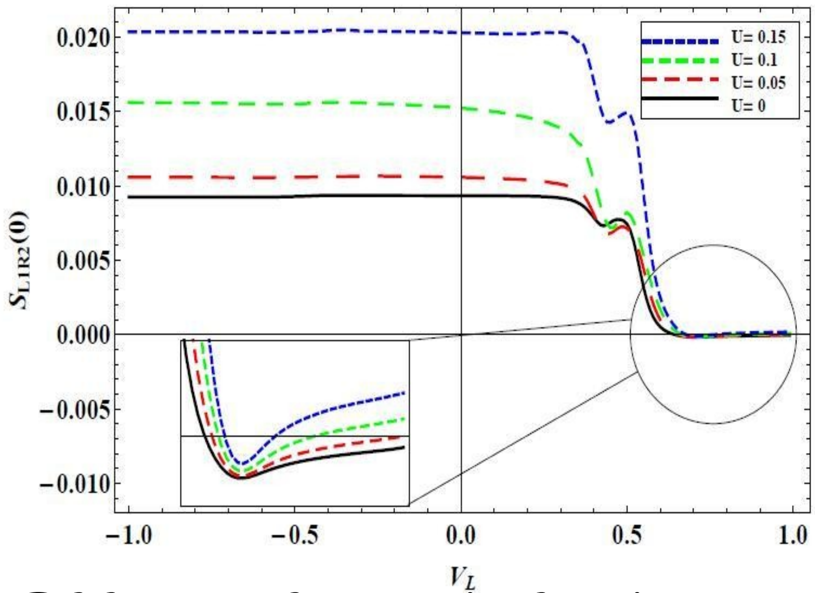
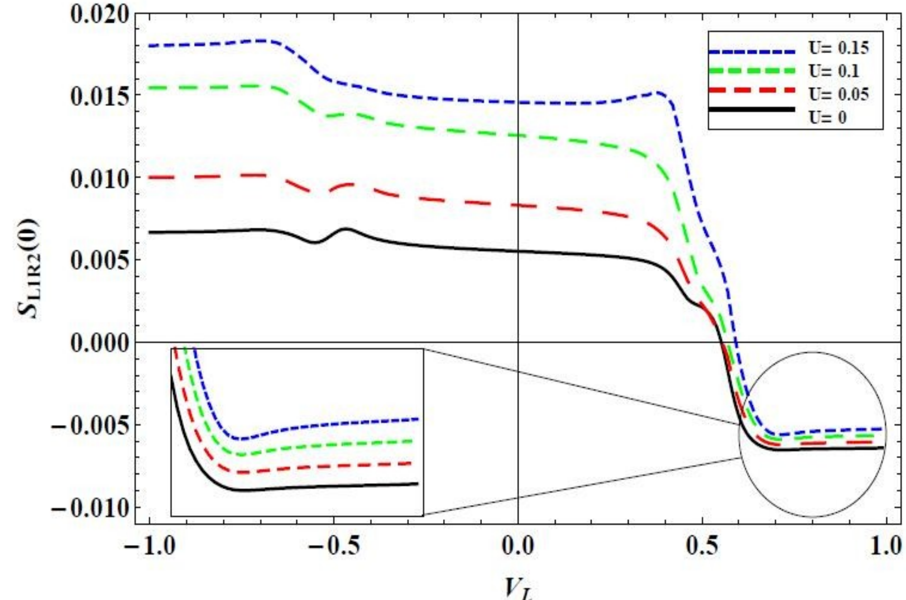


FIG. 4: Current cross-correlations (arbitrary units) as a function of V_L, for $U = 0, 0.05, 0.1, 0.15\Delta$, and the same parameters as in Fig. 2, in the presence of direct tunneling, $t_d = 0.2\Delta$.

- Low voltage: still positive, enhanced by interaction, but more feature at $V_L \approx -\varepsilon 1$ (because of DOS)
- $V_L > \varepsilon 1$ interactions have weaker effect (reduce the correlations)

Current cross-correlations





Effect of t_d: Shift the correlations to negativ values

Effect of U: Shift the correlations to positive values

→ Competition between direct interdot tunneing and local Coulomb interaction

Possible extension

- Non local Coulomb interaction (between dots)
- Include second set of diagrams into the LWf
  - Freq dependent interacting self-energy