Measurement of work and heat in the classical and quantum regimes

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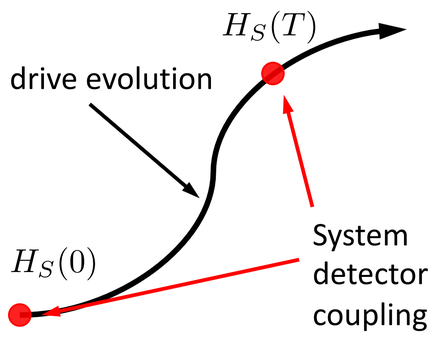
Being variations of energies, quantum work ***W***, heat ***Q*** and internal energy variation ***ΔU*** cannot be associated to an Hermitian operators.

To give a meaningful and operational definition, we need to include the description of the detector.

[P. Talkner *et al*. Phys. Rev. E 75, 050102R (2007)]
[P. Solinas and S. Gaspartinetti Phys. Rev. E 92, 042150 (2015)]

Measurement scheme

- Non-destructive system-detector coupling
- Two couplings to store information about the energy variation
- Measure the detector phase



- The final detector phase is associated to a characteristic function

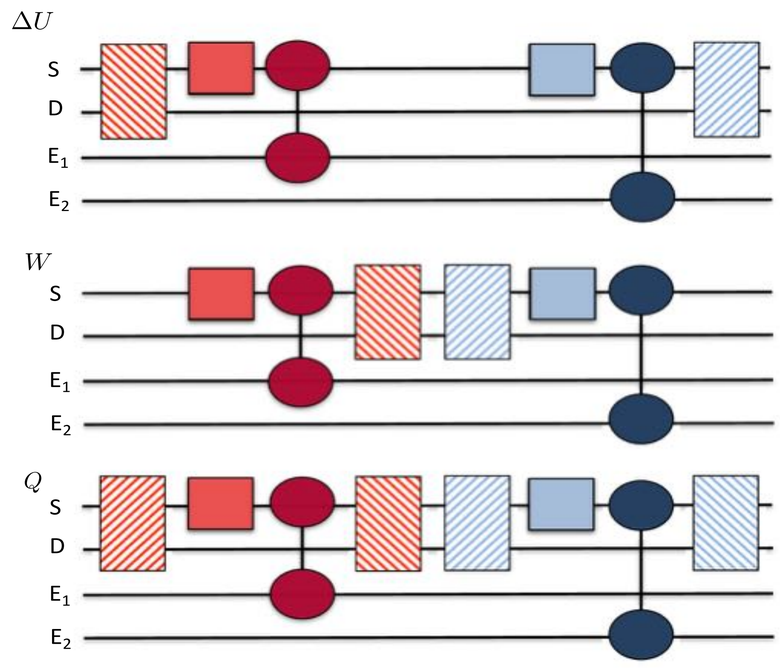
$$\mathcal{G}_{\chi,\mathcal{F}} = \frac{{}_D\langle 0|\rho_D(\mathcal{T})|1\rangle_D}{{}_D\langle 0|\rho_D^0|1\rangle_D} = \mathrm{Tr}_{S,E}\left[\mathcal{U}_{\chi,\mathcal{F}}\rho_S^0\mathcal{U}^\dagger_{-\chi,\mathcal{F}}\right]$$

- From the characteristic function we can obtain a quasi-probability distribution

$$\mathcal{P}(\mathcal{F}) = \int d\chi\, \mathcal{G}_{\chi,\mathcal{F}} e^{i\chi\mathcal{F}}$$

- As for the Wigner distribution, negative regions are associated to pure quantum processes, i.e., non-classical.

Implementation in the IBM Quantum computers



Simulation of unitary and dissipative dynamics

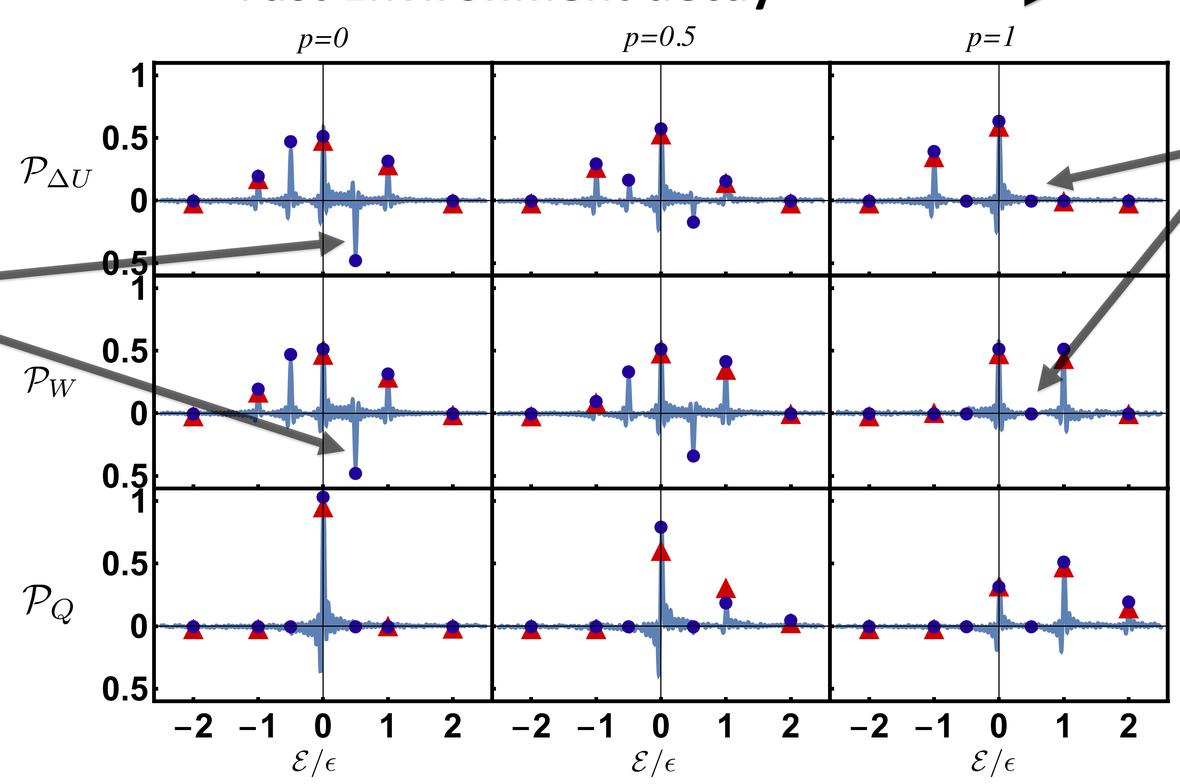
S = system qubit

D = detector qubit

The dissipation is simulated with two additional qubits E_1 and E_2

Quasiprobability distributions

Fast Environment decay →



Negative peaks - Pure quantum process

No negative peaks in the fast dissipation region: emergence of classical limit

The heat distribution has not quantum regime

The system has reached the classical regime because of the interaction with the environment

This scheme can be used to

- Identify pure quantum energy exchanges
- Look for quantum advantages in these processes

References:

[P. Solinas *et al*., Phys. Rev. A 103, L060202 (2021)]
[P. Solinas *et al*., Phys. Rev. A 105, 032606 (2022)]