Coupling-energy driven pumping through quantum dots: the role of coherences

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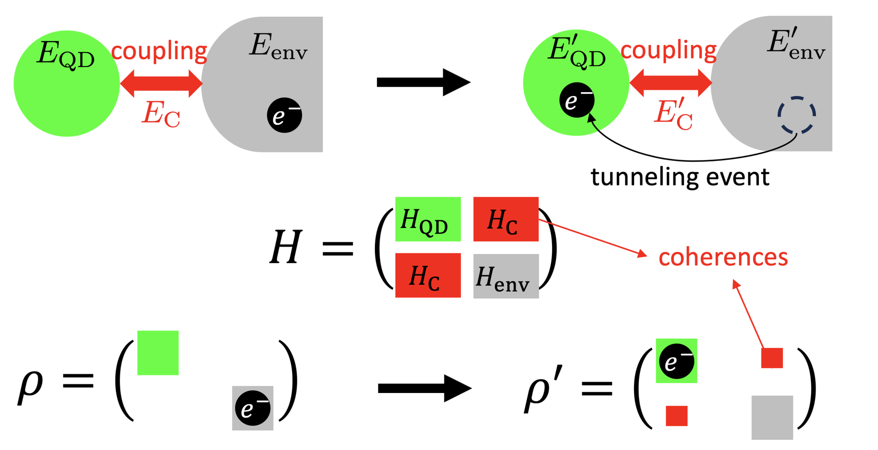
Motivation

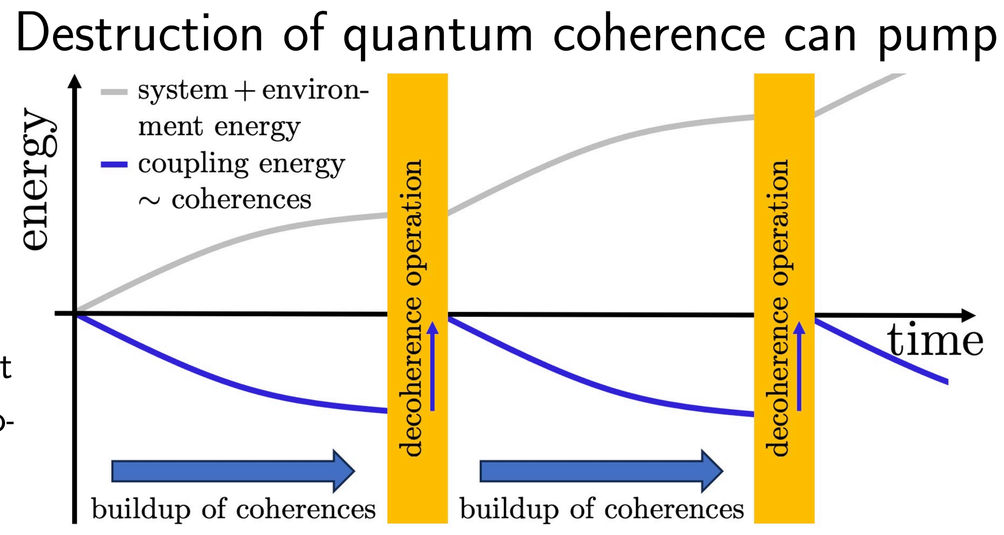
Energy conservation of a tunneling event



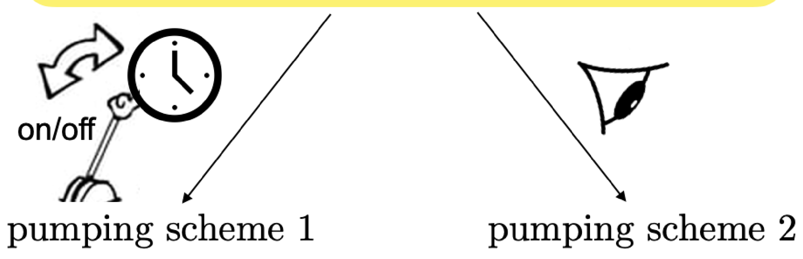
- coupling energy E_C has to be taken into account $E_{QD} + E_{env} + E_C = E'_{QD} + E'_{env} + E'_C$
- coupling energy E_C
  - is related to coherences between QD and environment
  - enables off–resonant and higher–order tunneling processes LL *et al.*, PRB **111**, 085103 (2025)

Destruction of quantum coherence can pump energy into a system

Schulman *et al.* PRL **97** 240405 (2006)



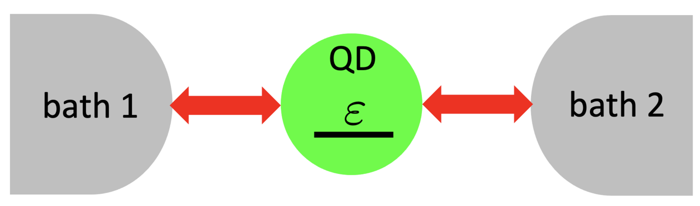
Idea:
Is it possible to drive electron pumping by decoherence operations?



Model and method

- non–interacting single–level QD coupled to two fermionic and baths:

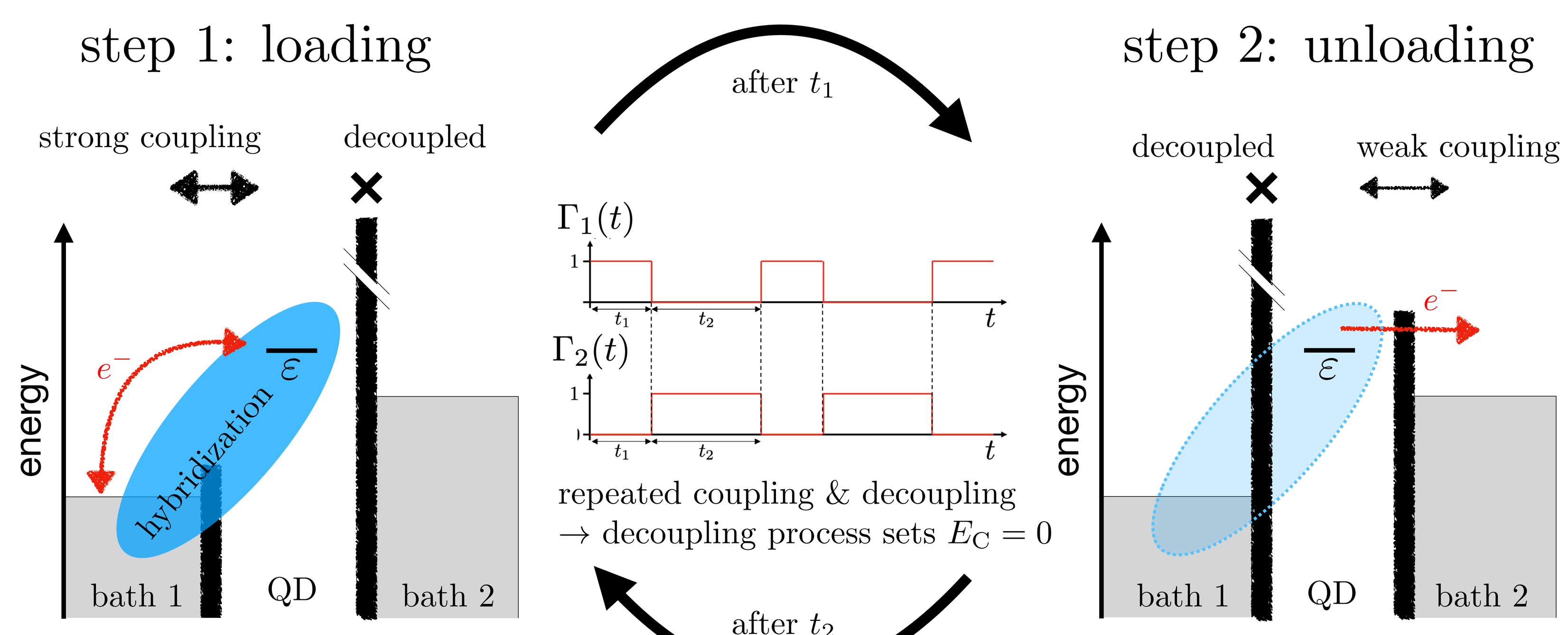
$$H = \underbrace{\varepsilon c^\dagger c}_{\equiv H_{QD}} + \underbrace{\sum_{\nu=1}^{2}\sum_k \left(\gamma_{\nu,k}(t)\, a^\dagger_{\nu,k} c + \text{h.c.}\right)}_{\equiv H_C(t)} + \underbrace{\sum_{\nu,k} \varepsilon_{\nu,k} a^\dagger_{\nu,k} a_{\nu,k}}_{\equiv H_{env}}$$

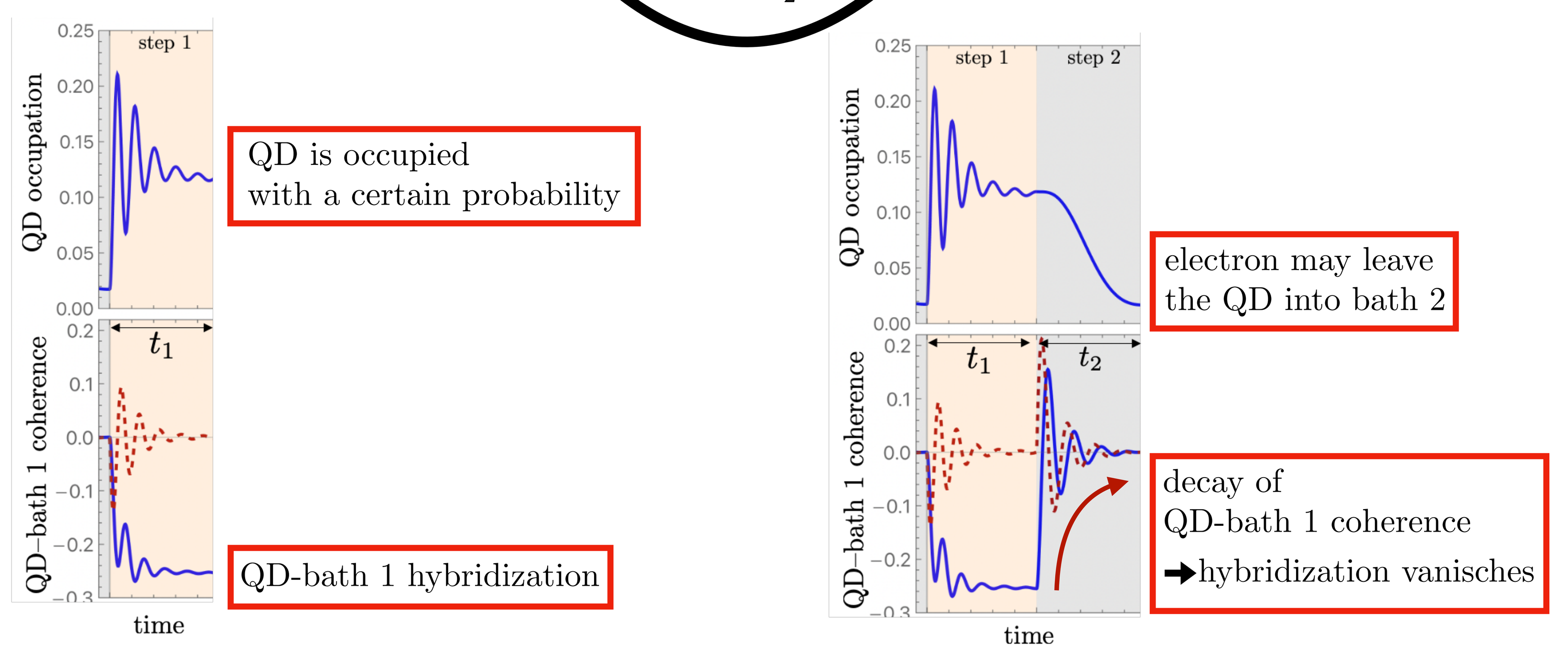


- exact solution with Heisenberg equation and Laplace transform technique Topp *et al.* EPL **110** 67003 (2015)

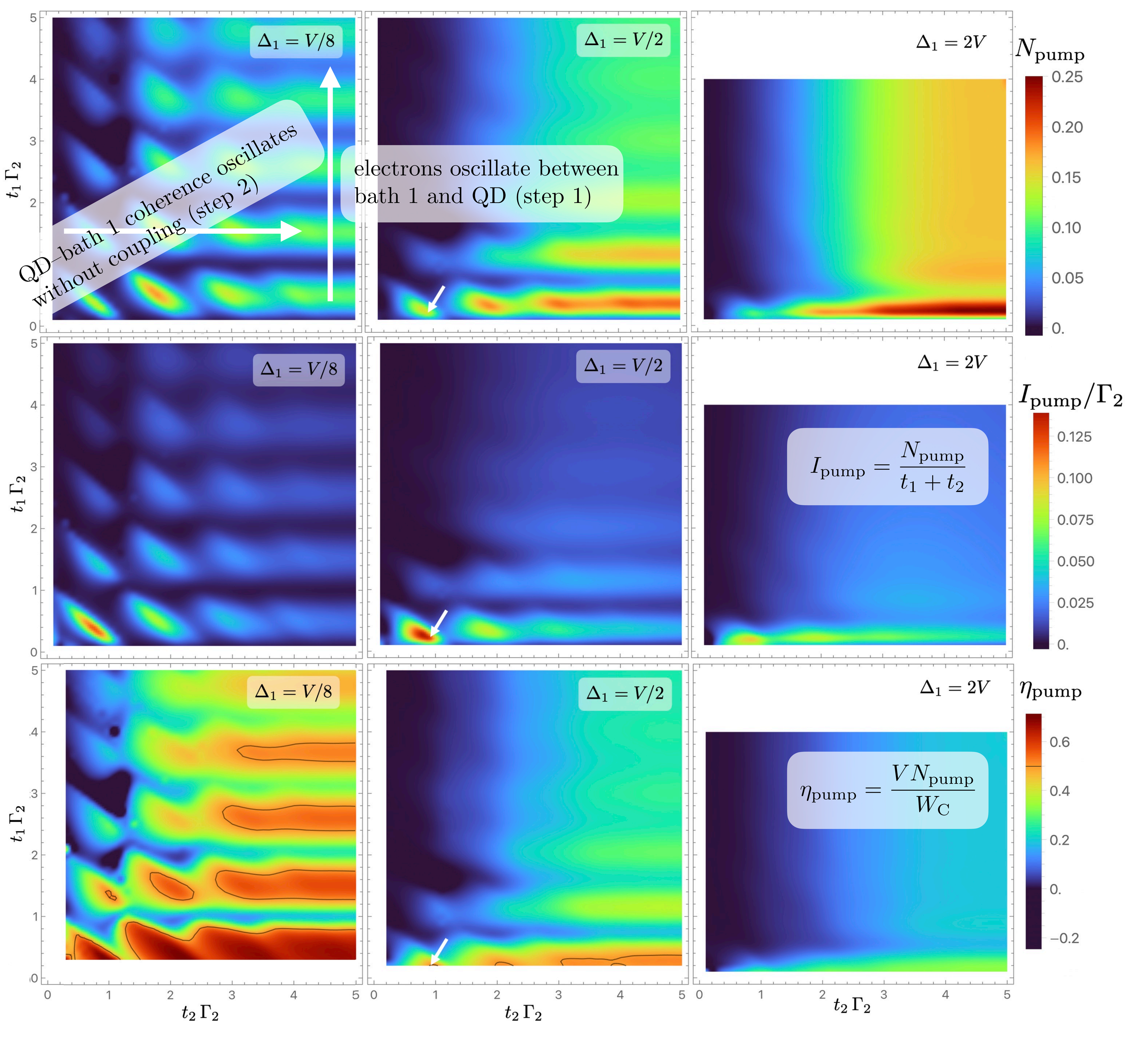
$$\left.\begin{aligned} \tfrac{d}{dt} c_H(t) &= \tfrac{i}{\hbar}[H, c_H(t)] \\ \tfrac{d}{dt} a_{H,\nu,k}(t) &= \tfrac{i}{\hbar}[H, a_{H,\nu,k}(t)] \end{aligned}\right\} \xrightarrow{\text{Laplace trans.}} \text{solve linear equations} \xrightarrow{\text{inv. Laplace trans.}} c_H(t)\ \&\ a_{H,\nu,k}(t)$$

Pumping scheme I: Coupling/Decoupling





- current I_{pump} against applied voltage if $\Gamma_1 \gg \Gamma_2 \leftrightarrow$ driven by off–resonant tunneling processes

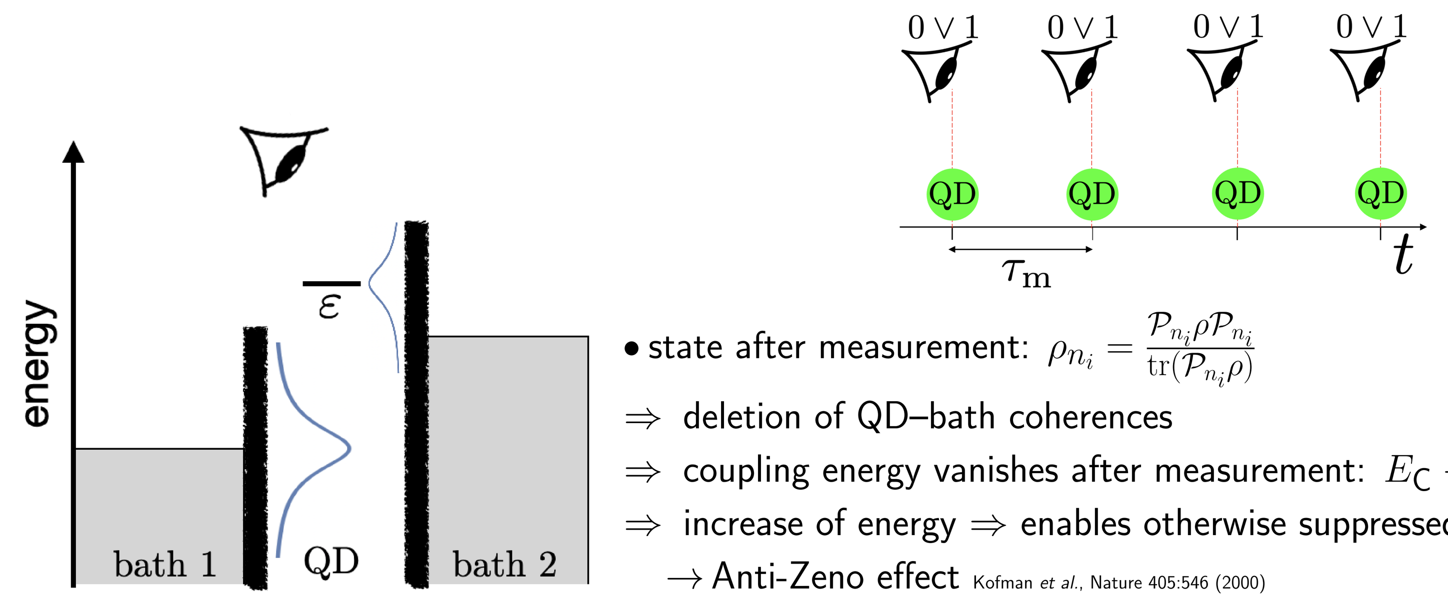


- pumping against bias
- oscillations with t_1 and t_2

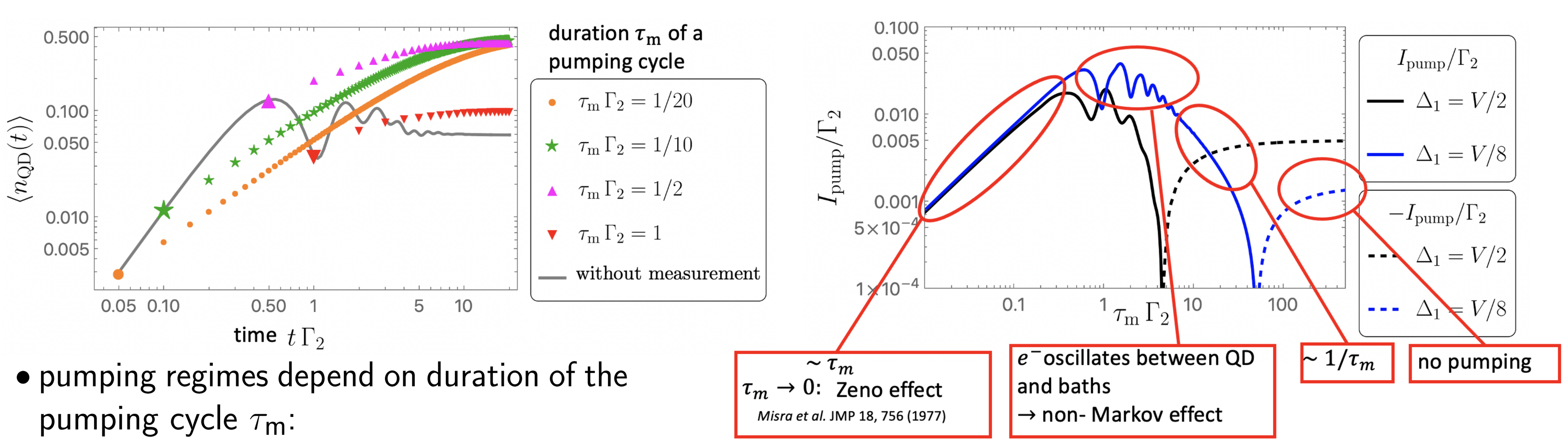
Pumping scheme II: Measurement induced pumping

Projective measurements:

- stroboscopically repeated measurements of the particle number



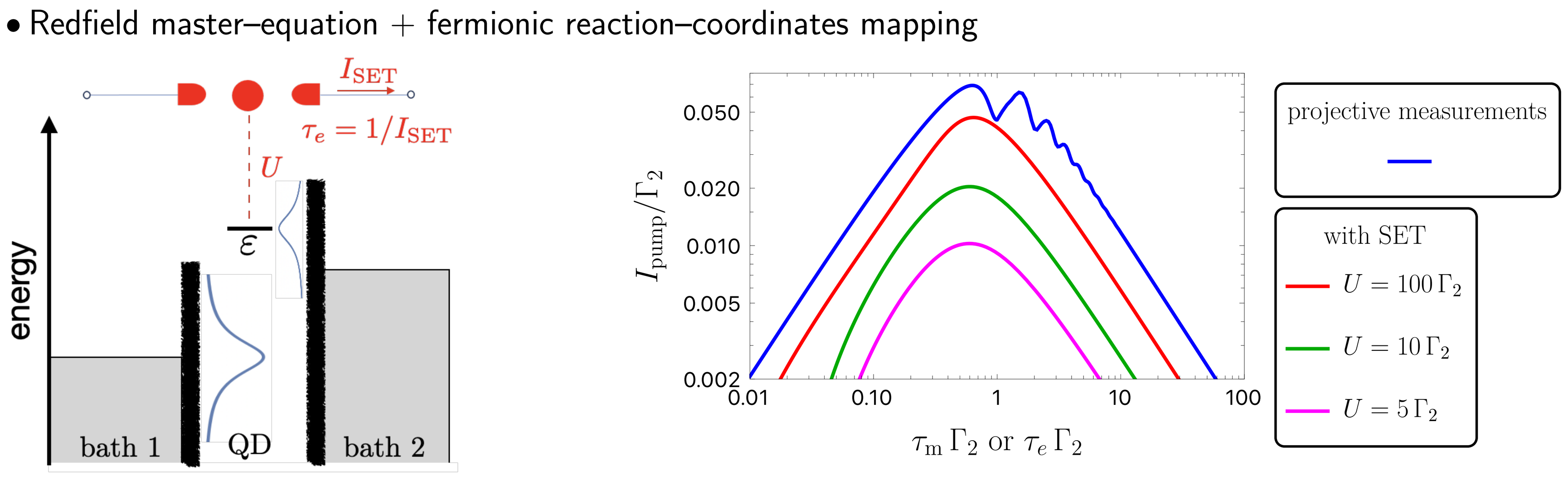
- state after measurement: $\rho_{n_i} = \frac{\mathcal{P}_{n_i}\rho\mathcal{P}_{n_i}}{\text{tr}(\mathcal{P}_{n_i}\rho)}$
  - ⇒ deletion of QD–bath coherences
  - ⇒ coupling energy vanishes after measurement: $E_C \to 0$
  - ⇒ increase of energy ⇒ enables otherwise suppressed transitions → Anti-Zeno effect Kofman *et al.*, Nature 405:546 (2000)
- well chosen $\Gamma_\nu(\omega)$ ⇒ current I_{pump} against bias



- pumping regimes depend on duration of the pumping cycle τ_m:

Weak measurement via a single–electron transistor (SET):

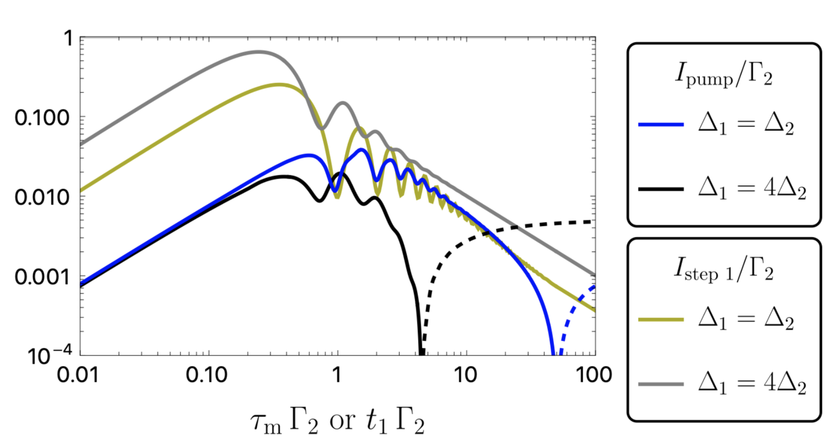
- projective measurement is unrealistic → simulating weak continues measurement via SET
- Redfield master–equation + fermionic reaction–coordinates mapping



- I_{pump} is not an artefact of the projective measurement.
- weak measurement (small U) ⇒ small I_{pump}; strong measurement (large U) ⇒ large I_{pump}

Conclusion

- pumping against bias is possible
  - both schemes rely on the same mechanisms → "pure quantum–effect"
- Non–Markovian effects enhance efficiency
  - clear signatures of quantum coherences



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