Pump-probe scheme for electron-photon dynamics in hybrid conductor-cavity systems

T. L. van den Berg, C. Bergenfeldt, and P. Samuelsson
Physics department, Lund University, Box 118, S-221 00 Lund, Sweden
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Recent experiments on nanoscale conductors coupled to microwave cavities put in prospect transport investigations of electron-photon interplay in the deep quantum regime. Here we propose a pump-probe scheme to investigate the transient dynamics of individual electron-photon excitations in a double quantum dot-cavity system. Excitations pumped into the system decay via charge tunneling at the double dot, probed in real time. We investigate theoretically the short-time charge transfer statistics at the dot, for periodic pumping, and show that this gives access to vacuum Rabi oscillations as well as excitation dynamics in the presence of double dot dephasing and relaxation.

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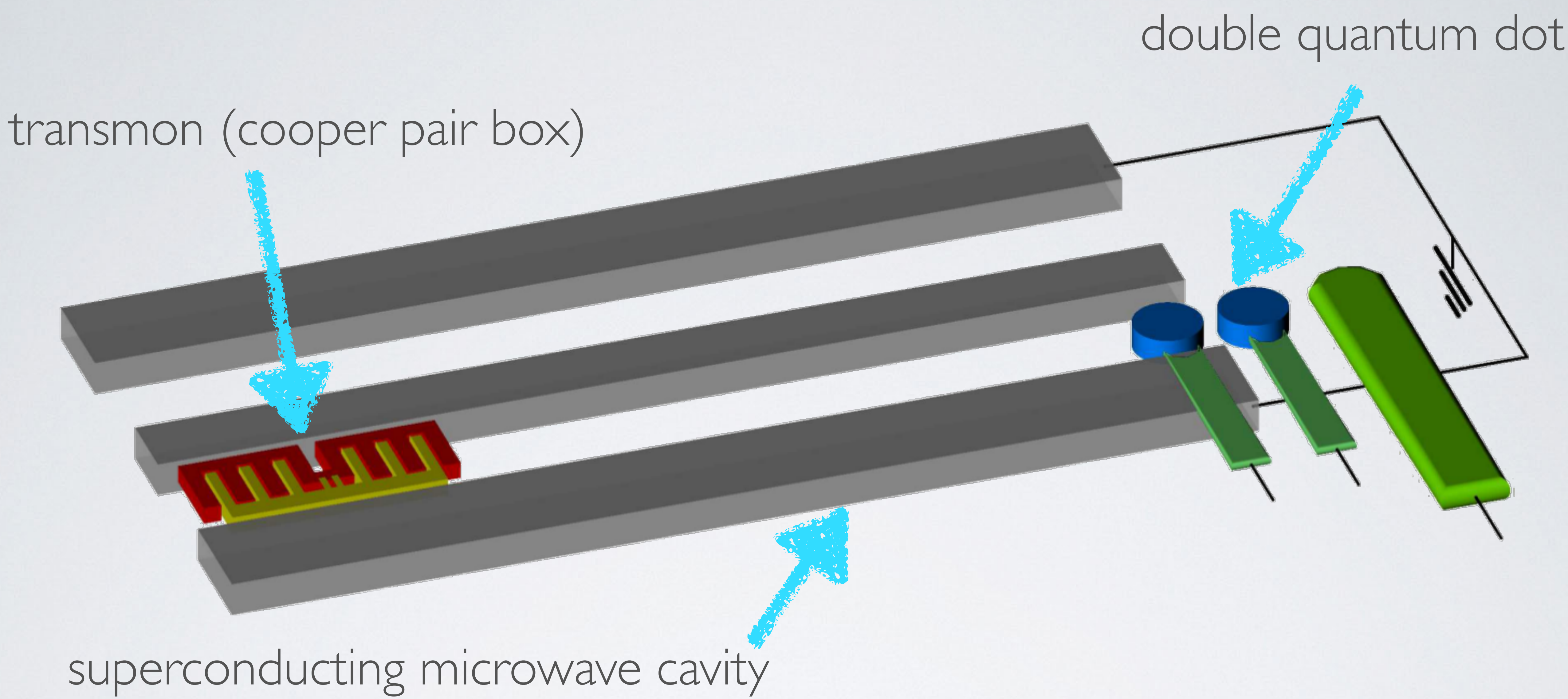
Hybrid System



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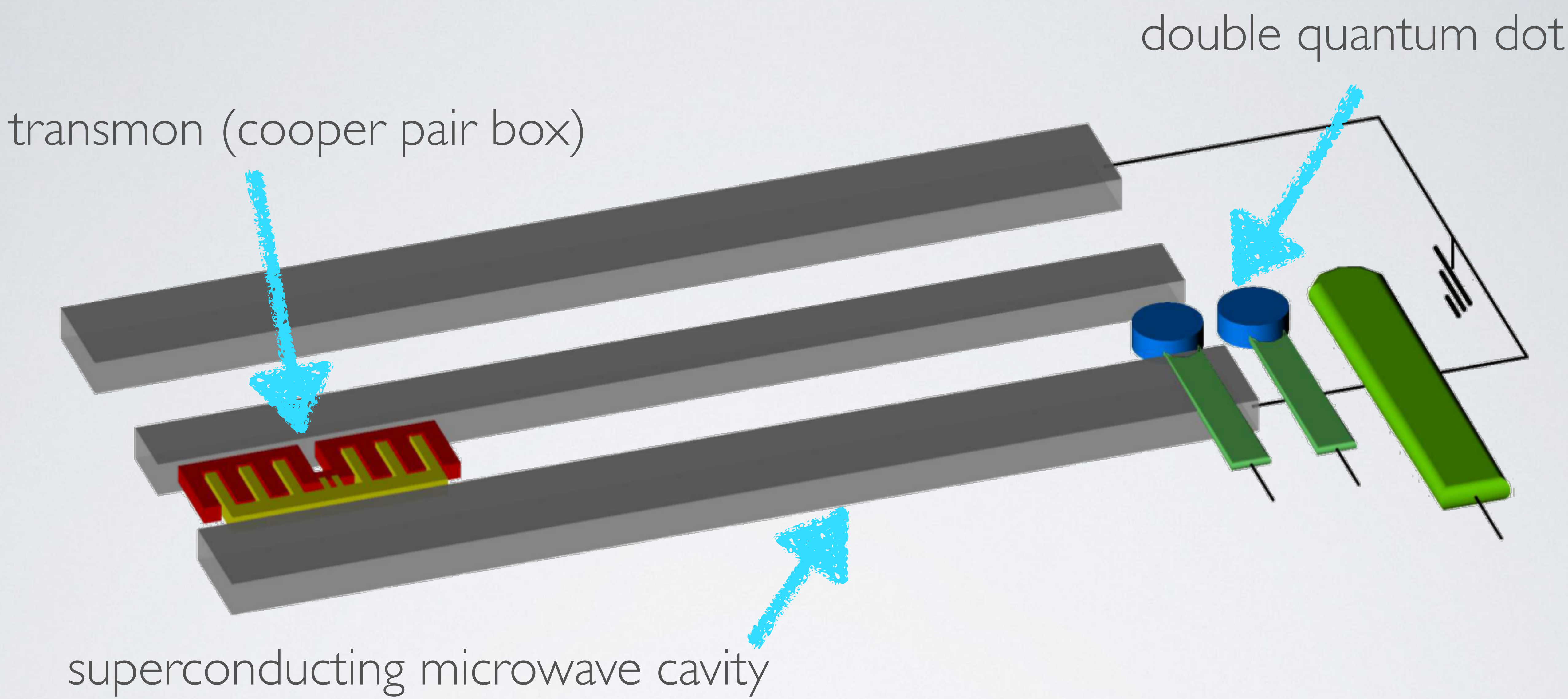

- System Hamiltonian (Tavis-Cummings)

$$\hat{H}_S = \hbar\omega_0 \hat{a}^\dagger \hat{a} + \frac{\hbar\omega_0}{2}\left(\hat{\sigma}_z + \hat{d}_e^\dagger \hat{d}_e - \hat{d}_g^\dagger \hat{d}_g\right) + \hbar g_0 \left[\hat{a}^\dagger(\hat{\sigma}_- + \hat{d}_g^\dagger \hat{d}_e) + \hat{a}(\hat{\sigma}_+ + \hat{d}_e^\dagger \hat{d}_g)\right]$$

System Dynamics

- Isolated system (vacuum Rabi oscillations)

$$t = 0 : \quad |-g0\rangle \;\rightarrow\; |+g0\rangle$$

$$|\Psi(t)\rangle = (1/\sqrt{2})\left[\cos^2\left(g_0 t/\sqrt{2}\right)|+g0\rangle + \sin^2\left(g_0 t/\sqrt{2}\right)|-e0\rangle + (i/\sqrt{2})\sin\left(\sqrt{2}g_0 t\right)|-g1\rangle\right]$$

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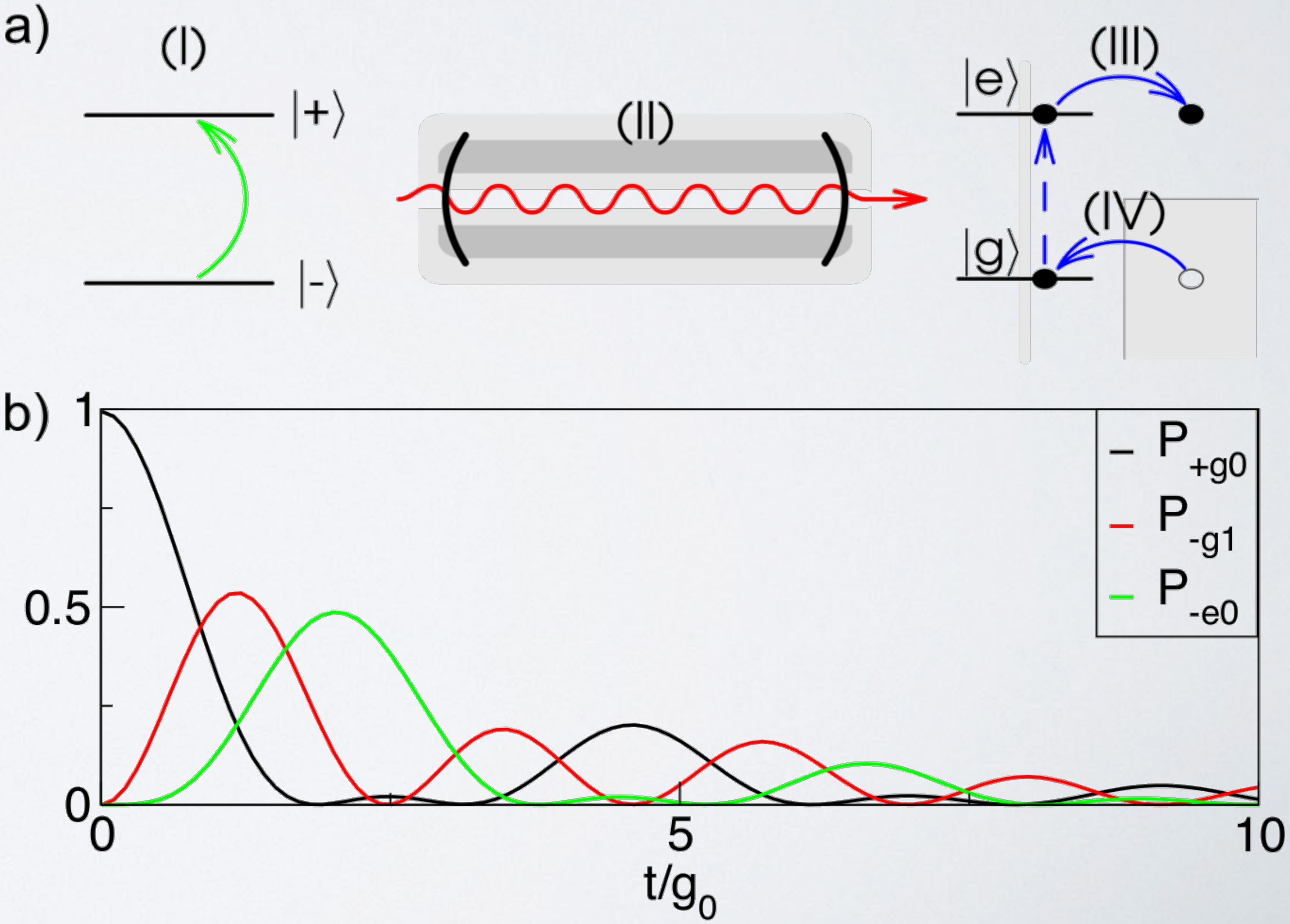
- DQD coupled to a lead electrode

$$\hat{H}_L = \sum_k \epsilon_k \hat{c}_k^\dagger \hat{c}_k$$

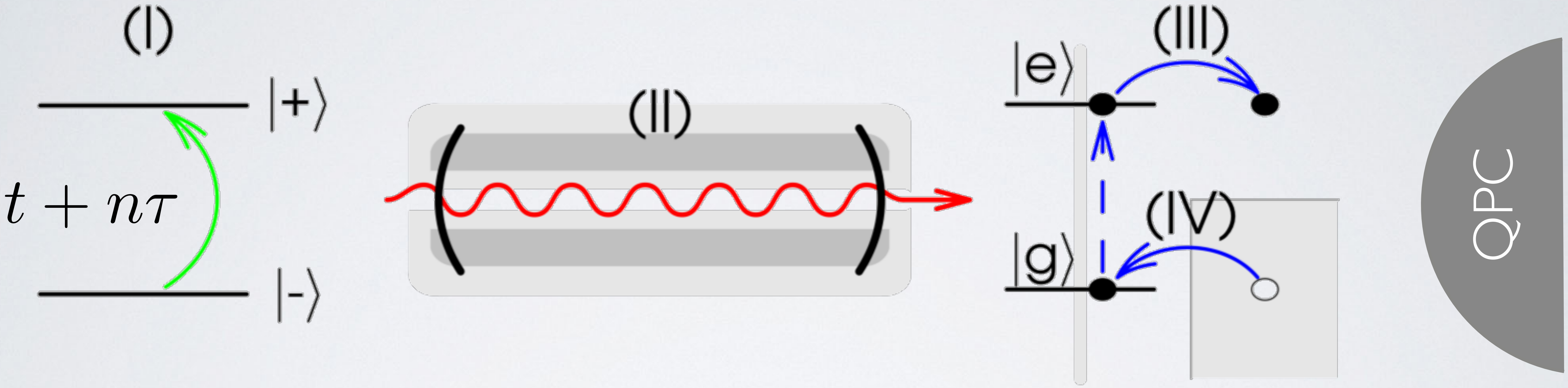
$$\hat{H}_T = \sum_{k,\alpha=e,g} t_k \hat{c}_k^\dagger \hat{d}_\alpha + H.c.$$

$$\Gamma = 2\pi \sum_k |t_k|^2 \delta(\epsilon_k \pm \hbar\omega_0/2)$$



Pump-probe Scheme

- Drive the system periodically and monitor dot-lead tunnelling events



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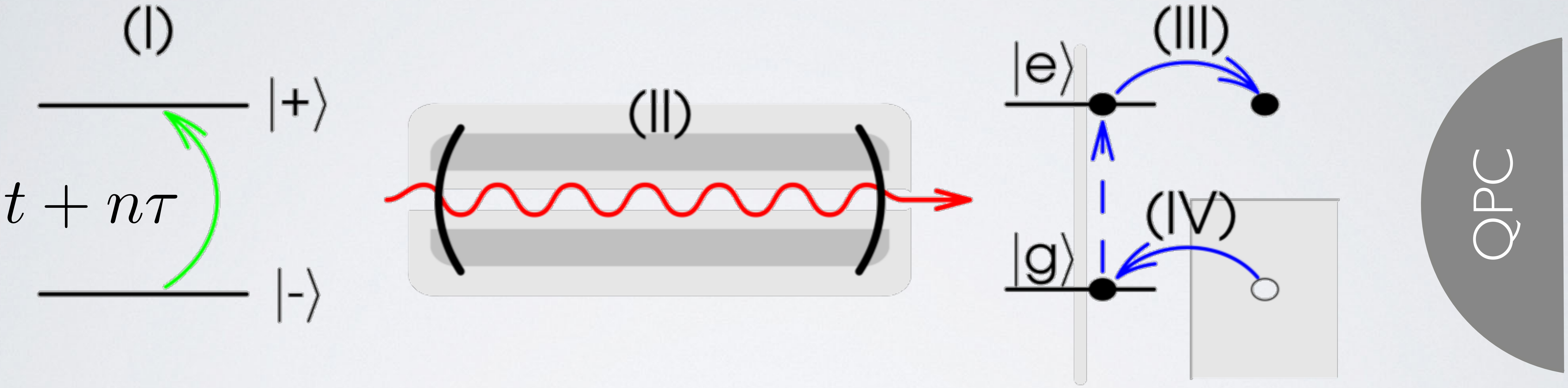
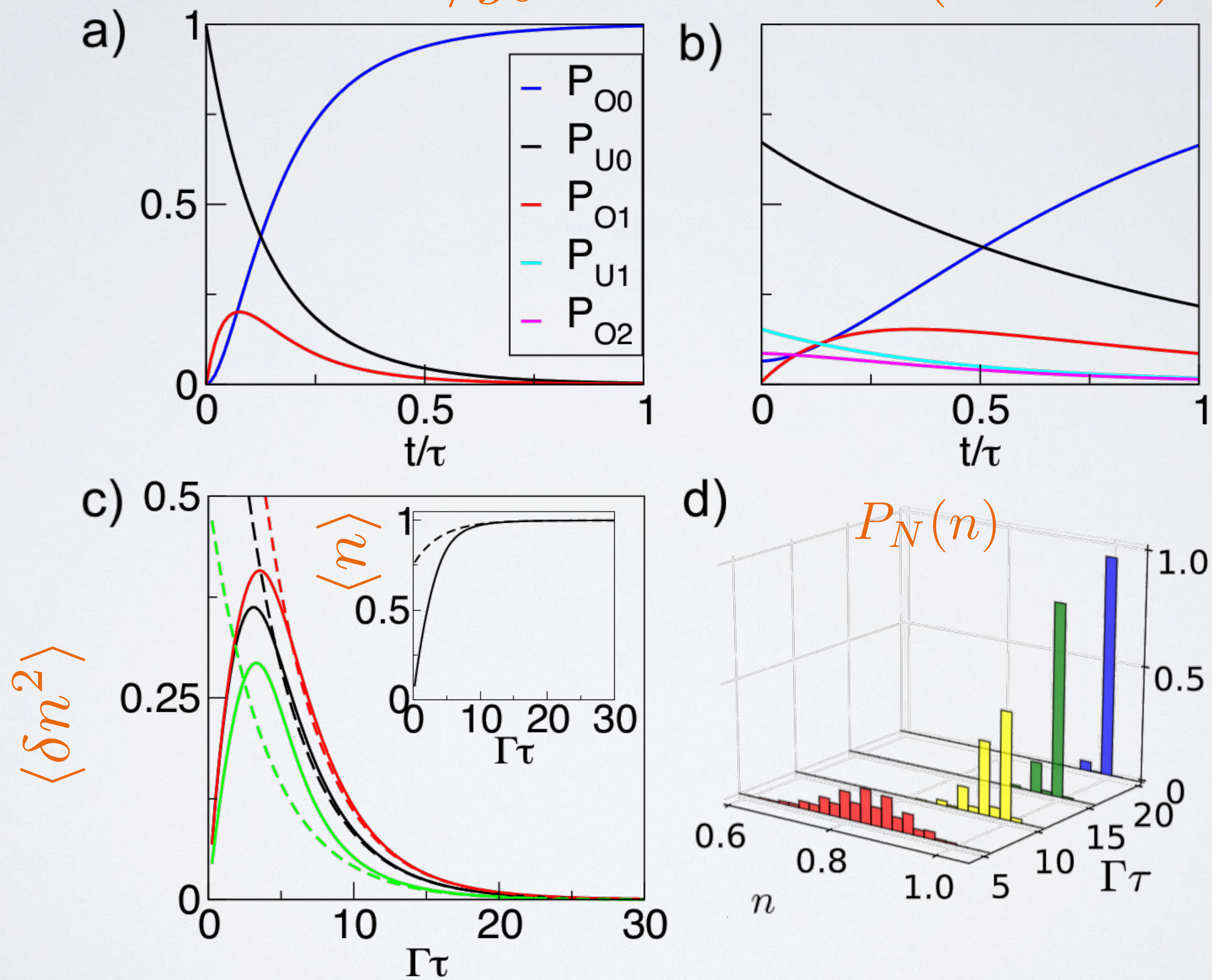


τ is a tool to explore different dynamics regimes

Strong Coupling Regime

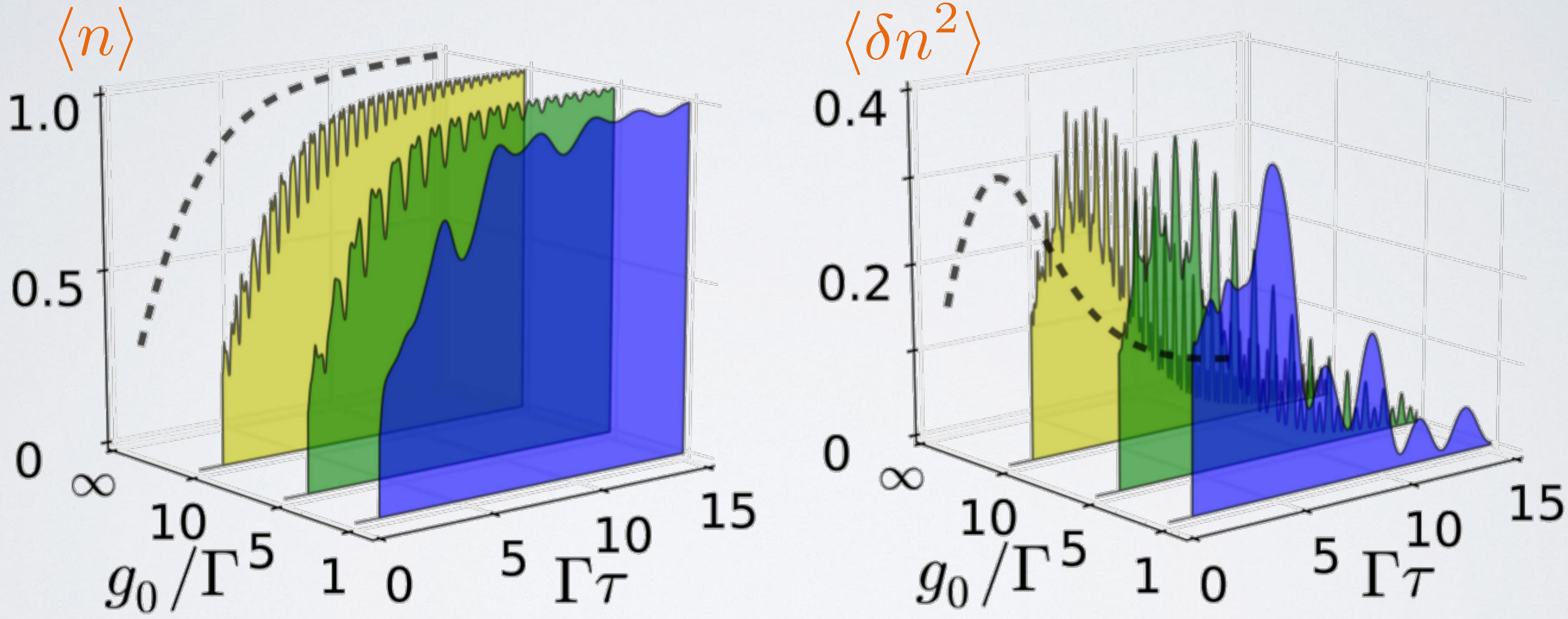
- $g_0 \gg \Gamma$

$\tau \gg 1/g_0$ $\qquad$ $\tau = ?(\text{smaller})$



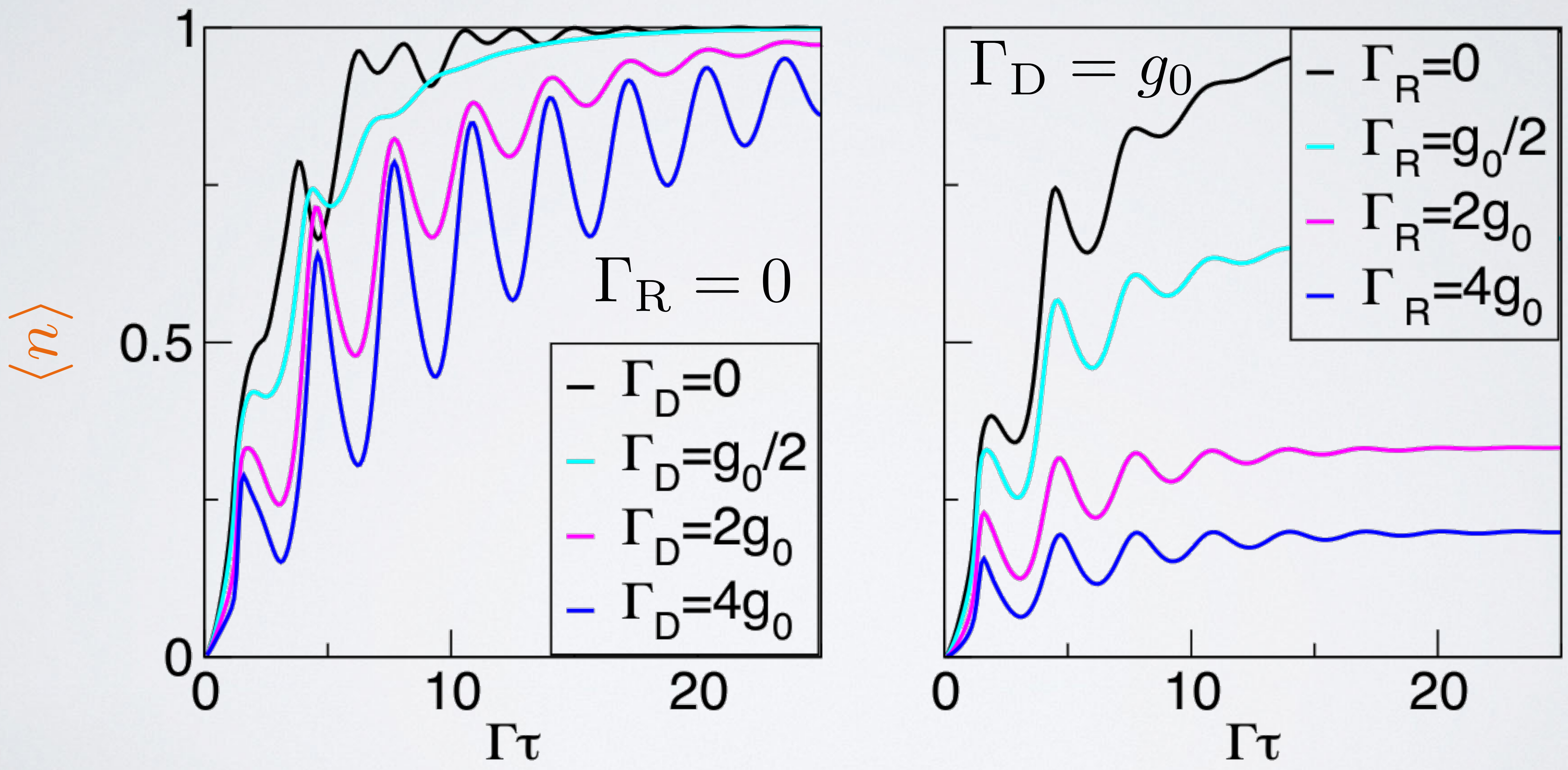
Coherent Photon-Electron Dynamics

- $g_0 \sim \Gamma$ $\qquad \tau \sim 1/\Gamma, 1/g_0$

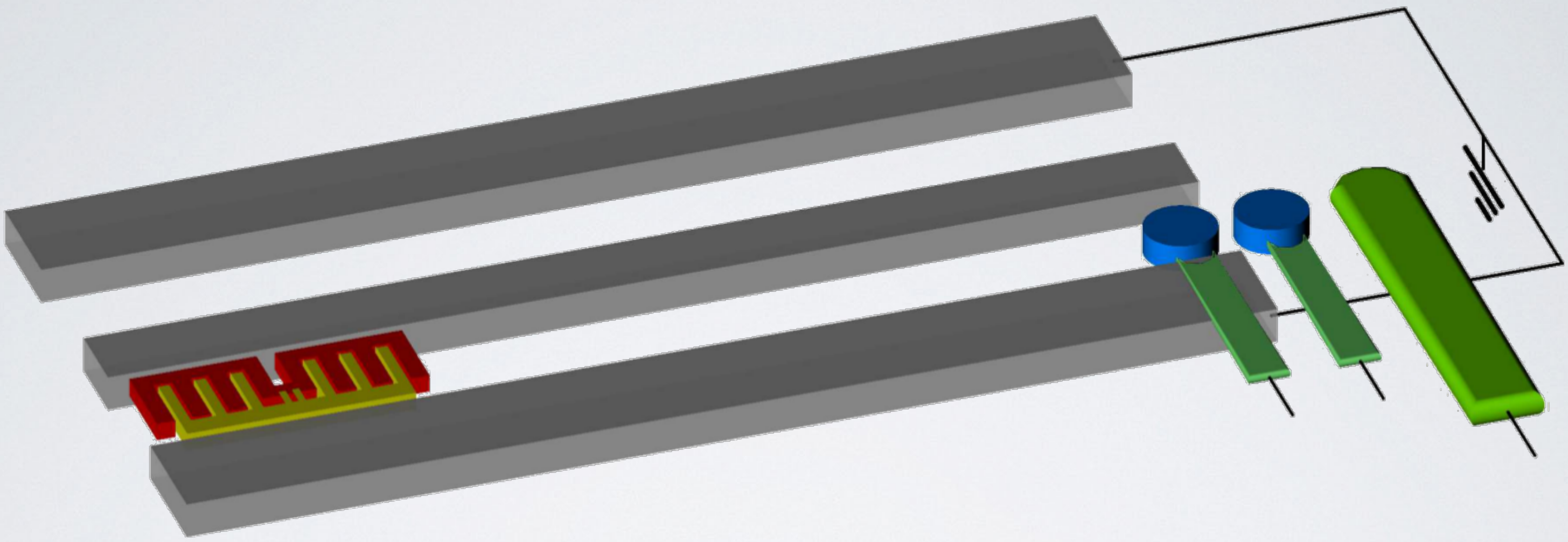


And with a Real DQD?

- Quantum dot with relaxation and dephasing



Conclusions



Dynamics can be investigated via charge transfer