Giant super-poissonian Fano factors in shuttle devices

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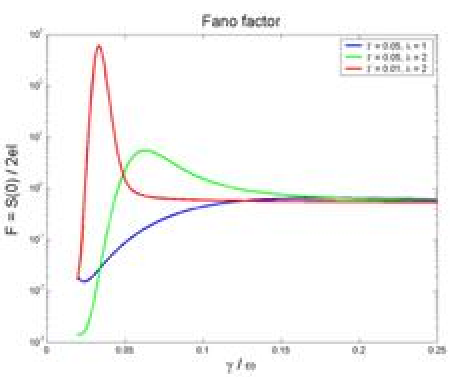
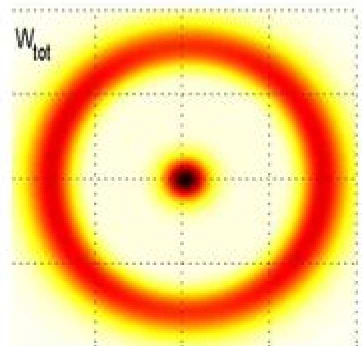
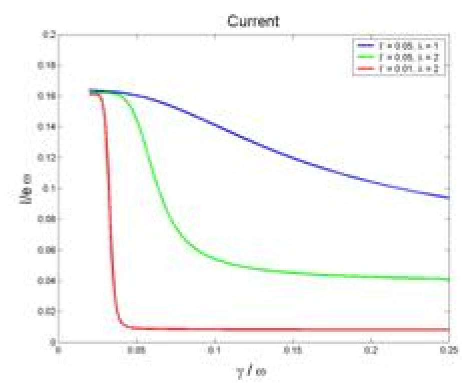
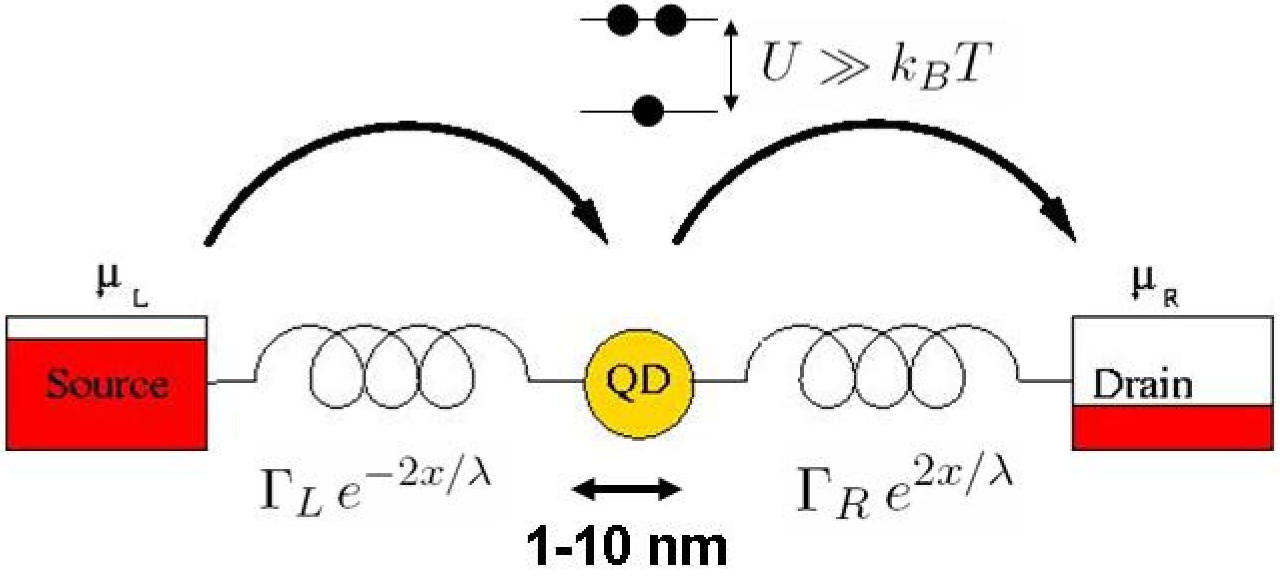






DPG-meeting 2005, Berlin

Shuttle device*



- QD has a nanometric diameter: combined with low temperature, this implies **Coulomb blockade**
- Excess of charge on QD produces an electrostatic force that influences the **mechanical dynamics** of the QD
- Position of the QD influences the **electrical dynamics** via the tunneling amplitudes

* L. Y. Gorelik et al., PRL. 80, 4526 (1998)

Hamiltonian

The Hamiltonian for the model reads:

$$H = H_{sys} + H_{leads} + H_{bath} + V + H_{int}$$

where

$$H_{sys} = \frac{p^2}{2m} + \frac{1}{2}m\omega^2 x^2 - eEx|1\rangle\langle 1|$$

$$H_{leads} = \sum_{k;\alpha=L,R} (\epsilon_{k\alpha} - \mu_\alpha) c^\dagger{}_{k\alpha} c_{k\alpha}$$

$$V = \sum_{k;\alpha=L,R} T_{k\alpha}(x) c^\dagger{}_{k\alpha} |0\rangle\langle 1| + h.c.$$

$$H_{bath} + H_{int} = \text{generic heat bath}$$

Electrostatic force

Mechanical back-action

Method

We express the dynamics in terms of the Generalized Master Equation:

$$\dot{\sigma}_{00}^{(n)} = -\frac{i}{\hbar}[H_{osc}, \sigma_{00}^{(n)}] + \mathcal{L}_{damp}\, \sigma_{00}^{(n)} - \frac{\Gamma_L}{2}\{e^{-\frac{2x}{\lambda}}, \sigma_{00}^{(n)}\} + \Gamma_R\, e^{\frac{x}{\lambda}}\, \sigma_{11}^{(n-1)}\, e^{\frac{x}{\lambda}}$$

$$\dot{\sigma}_{11}^{(n)} = -\frac{i}{\hbar}[H_{osc} - eEx, \sigma_{11}^{(n)}] + \mathcal{L}_{damp}\, \sigma_{11}^{(n)} - \frac{\Gamma_R}{2}\{e^{\frac{2x}{\lambda}}, \sigma_{11}^{(n)}\} + \Gamma_L\, e^{-\frac{x}{\lambda}}\, \sigma_{00}^{(n)}\, e^{-\frac{x}{\lambda}}$$

Novotný et al. PRL 92 (2004)

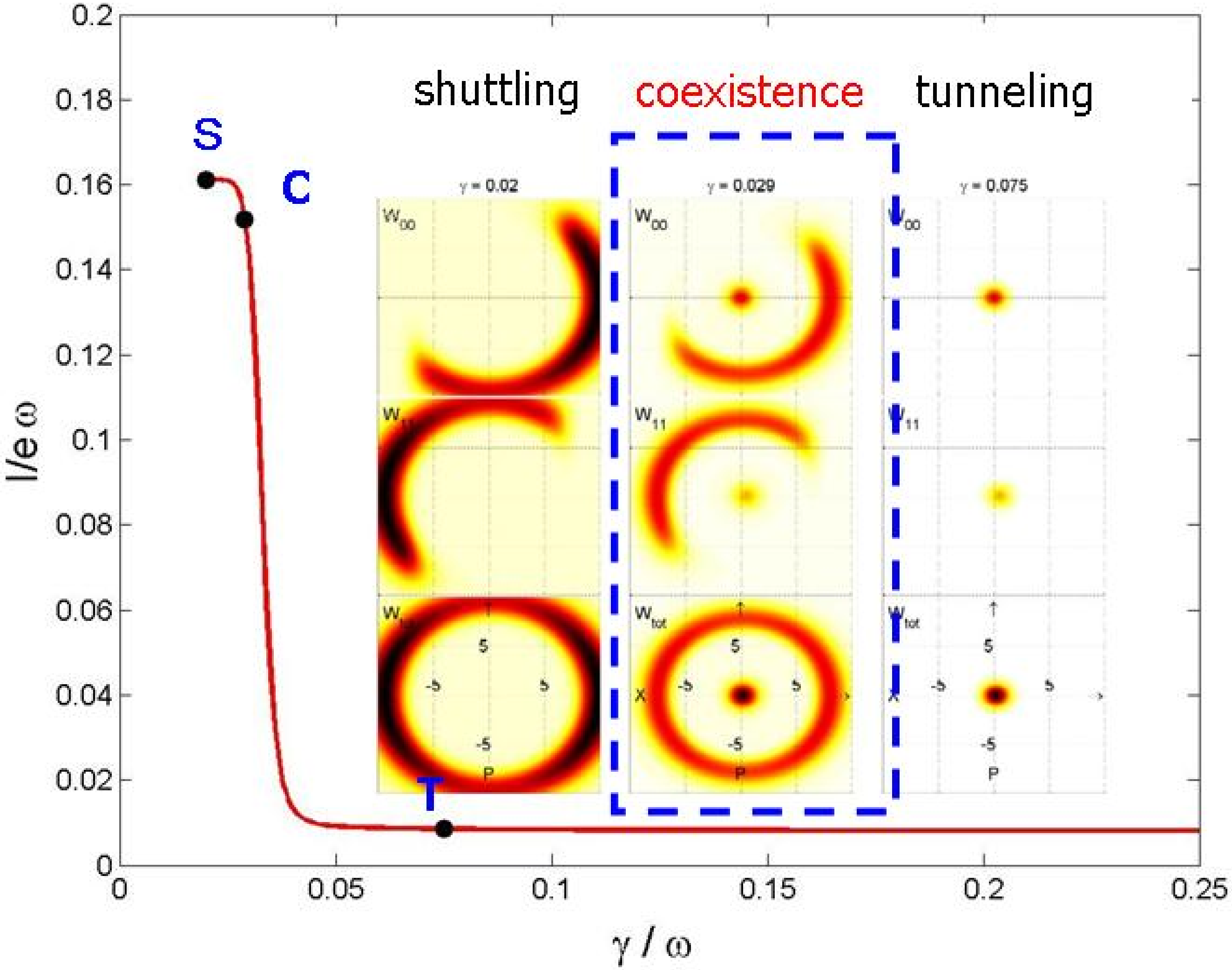
resolved with respect to the number of electrons collected in the right lead.

We look for the stationary solution of the GME:

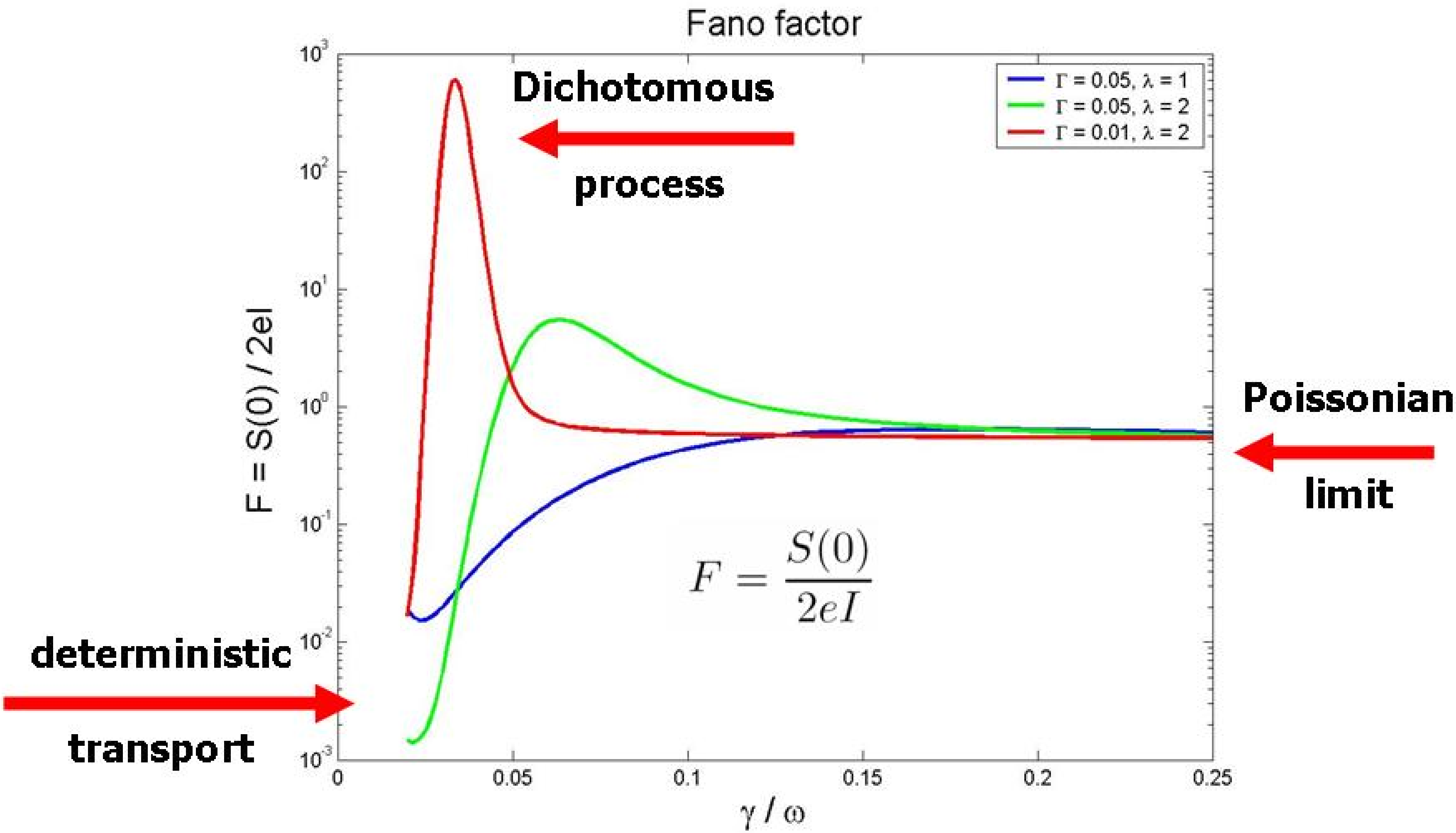
$$\mathcal{L}\sigma^{stat} = 0$$

And analyze the Wigner function, the current and Fano factor (current Noise).

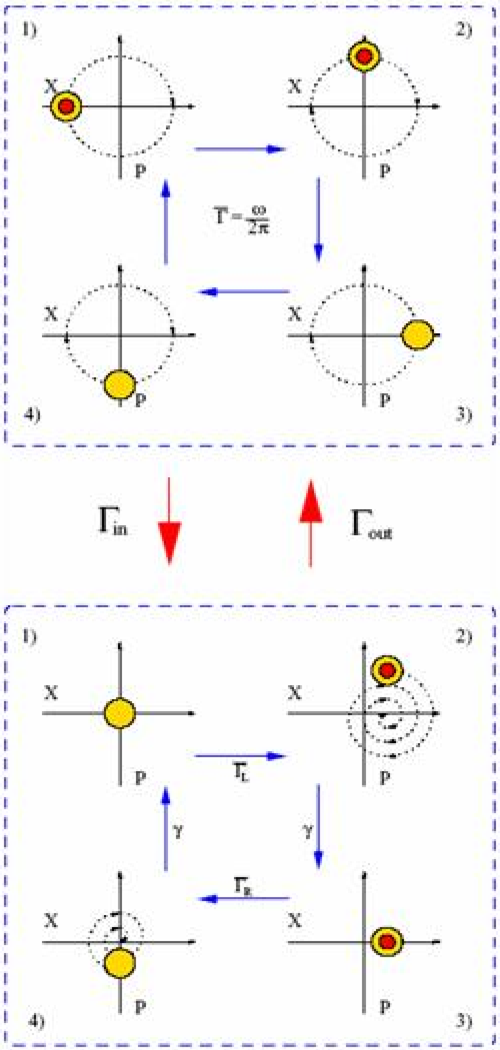
3 Operating regimes (WF)



Coexistence regime

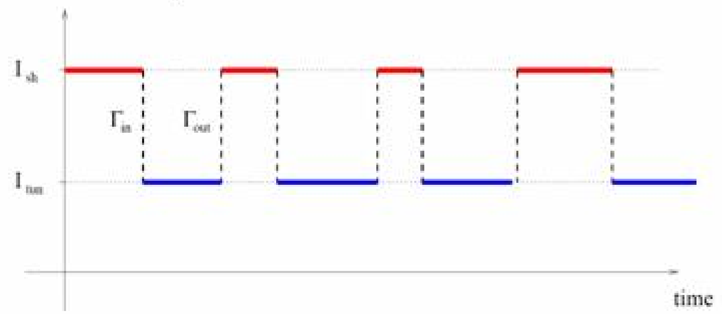


Dichotomous process



IF the switching rate is much smaller than the oscillator frequency and the average tunneling rate,

THEN the dynamics resembles:
Dichotomous process between current channels



In this limit **current** and **Fano factor** read:

$$I = e\frac{I_{sh}\Gamma_{out} + I_{tun}\Gamma_{in}}{\Gamma_{in} + \Gamma_{out}}$$

$$F = \frac{S(0)}{2eI} = \frac{(I_{sh} - I_{tun})^2}{eI}\frac{\Gamma_{in}\Gamma_{out}}{(\Gamma_{in} + \Gamma_{out})^3}$$

Donarini, PhD thesis, cond-mat/0501242

Effective potential

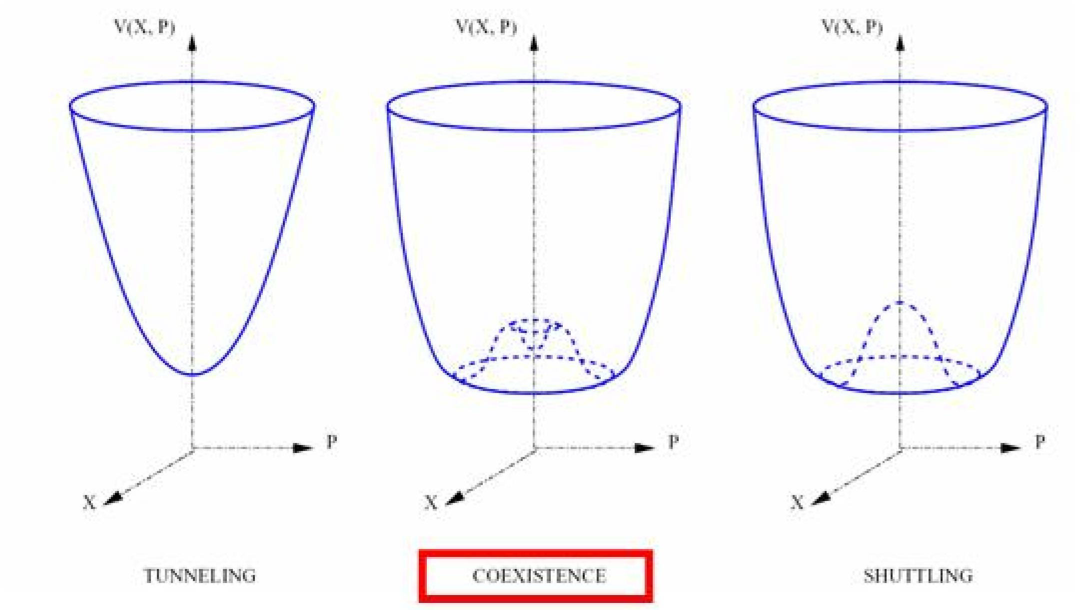
The GME is reduced to the radial Kramers´ equation

$$\frac{\partial \bar{W}_+(A,t)}{\partial t} = \frac{1}{A}\frac{\partial}{\partial A} A\left[V'(A) + D\frac{\partial}{\partial A}\right]\bar{W}_+(A,t)$$

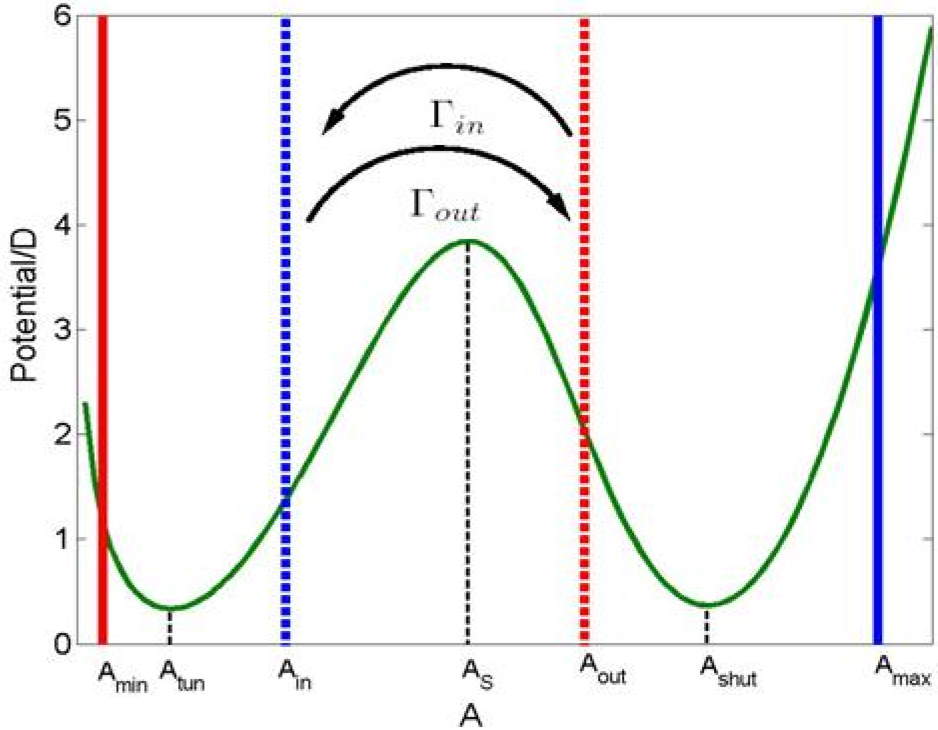
where

$$\bar{W}_+(A,t) \equiv \frac{1}{2\pi}\int_0^{2\pi} \mathrm{d}\varphi\,[W_{00}(A,\varphi) + W_{11}(A,\varphi)]$$

while the effective potential is:



Switching rates



$$\Gamma_{\rm out} = D\left(\int_{A_{\rm tun}}^{A_{\rm out}} dB\, e^{\frac{\mathcal{V}(B)}{D}} \int_{A_{\rm min}}^{B} dA\, e^{-\frac{\mathcal{V}(A)}{D}}\right)^{-1}$$

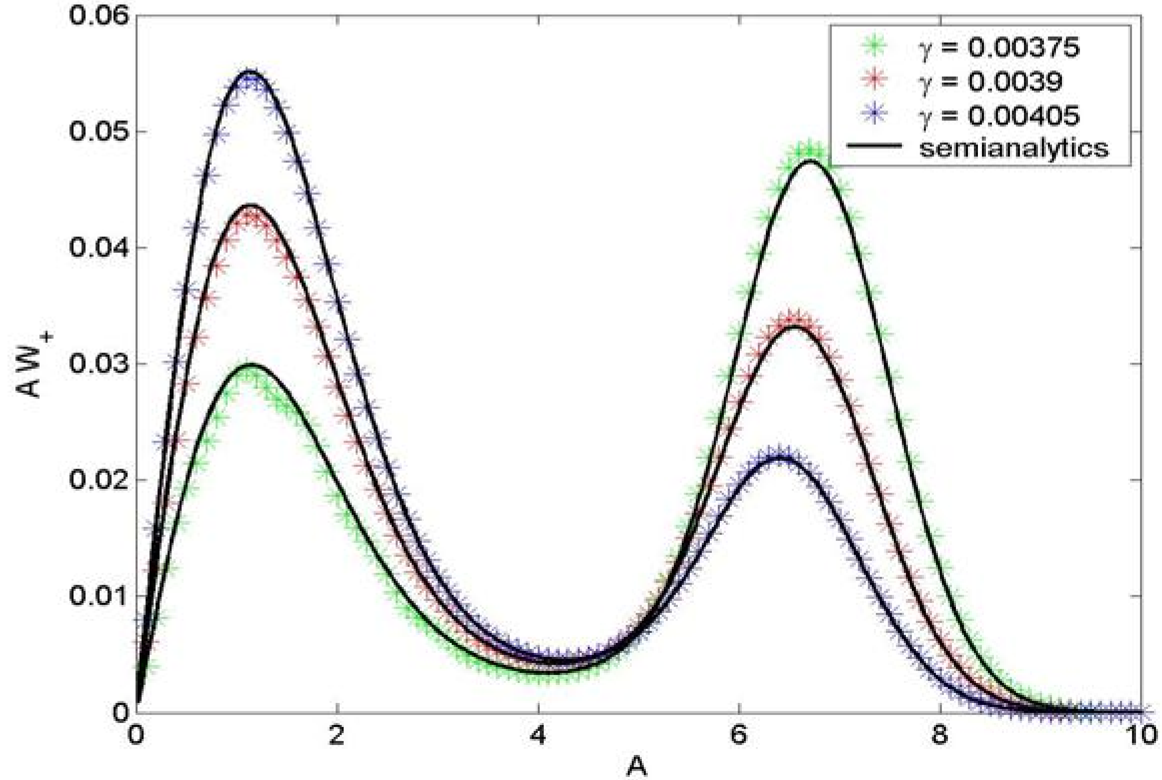
$$\Gamma_{\rm in} = D\left(\int_{A_{\rm in}}^{A_{\rm shut}} dB\, e^{\frac{\mathcal{V}(B)}{D}} \int_{B}^{A_{\rm max}} dA\, e^{-\frac{\mathcal{V}(A)}{D}}\right)^{-1}$$

Comparison (i)

classical limit

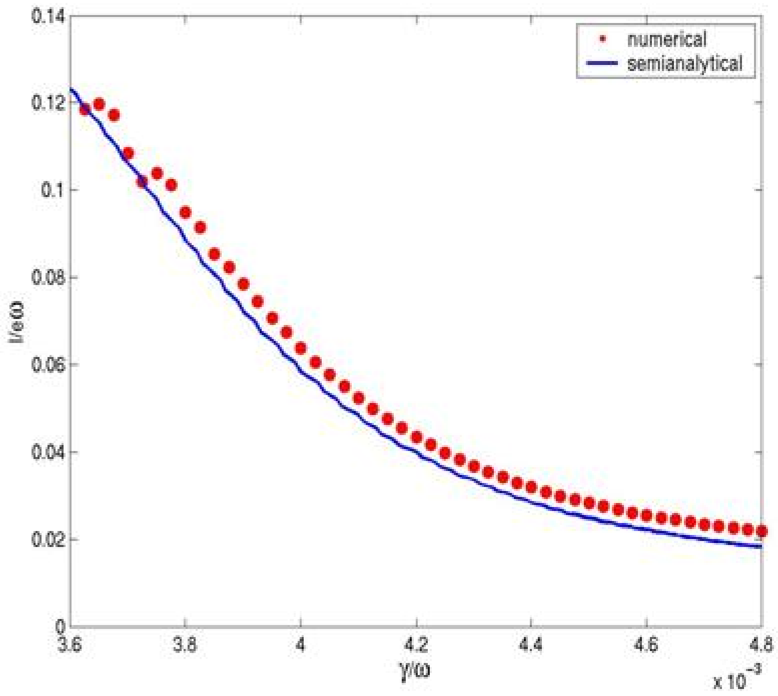
$\lambda \gg x_0$ where x_0 is the zero point uncertainty length

Wigner Function

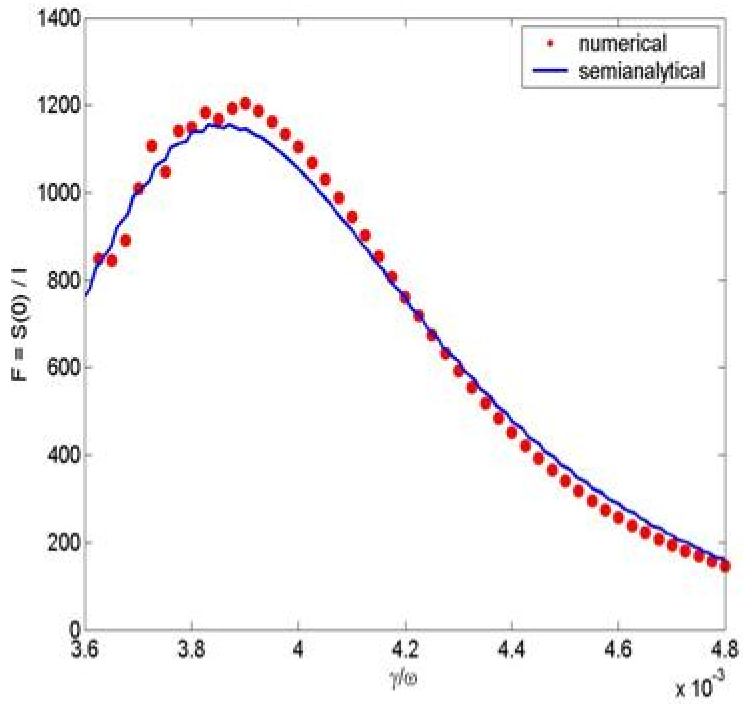


still classical (but noisy) limit

Current



Fano factor



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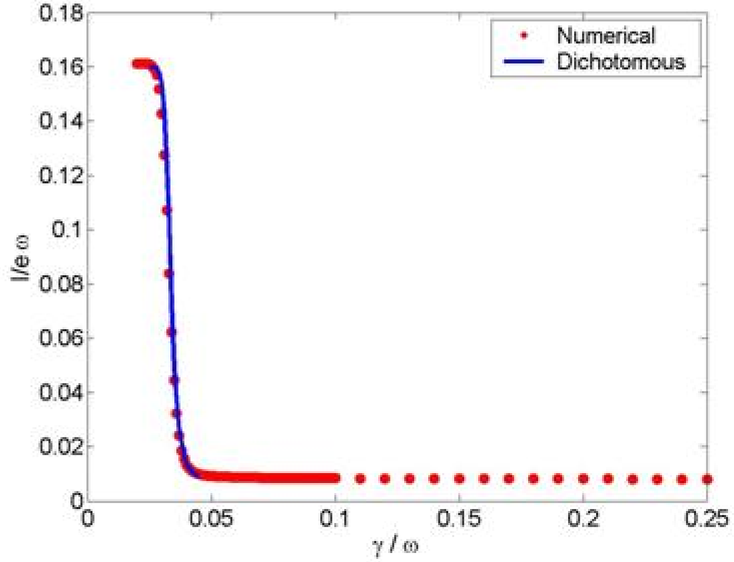
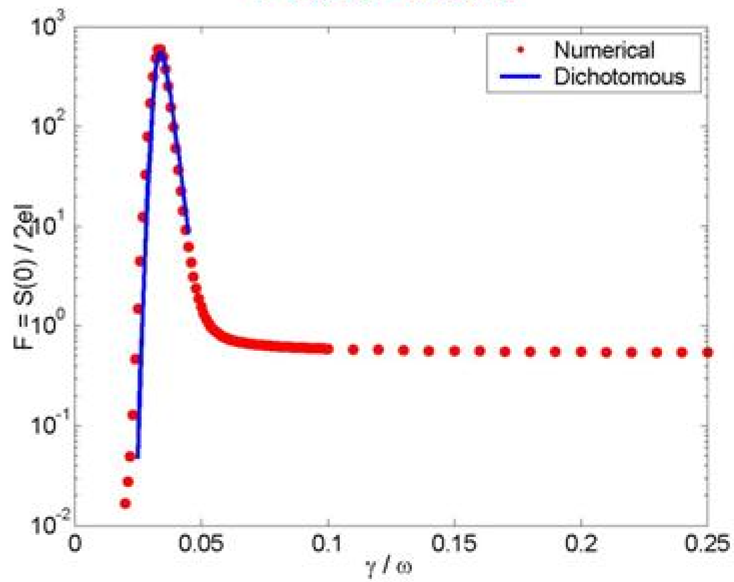
Comparison (ii)

fitted Quantum limit

Current



Fano factor



The diffusion coefficient is used as a fitting parameter

EFFECTIVE TEMPERATURE?

Summary

- The shuttling device exhibits giant Fano factors at intermediate damping;
- We interpret this feature as a signature of a coexistence regime i.e. slow switching dichotomous process between tunneling and shuttling mode;
- For this regime we propose a simplified description in terms of a bistable effective potential;
- This description captures the main features of the coexistence regime and gives also a more transparent physical insight of the device dynamics.