Shot Noise in Transport Through Quantum Dots: Clean versus Disordered Samples

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The noise induced by the discreteness of the electron charge ("shot noise") has become one of the central issues in the field of mesoscopic transport [1]. The correlations of electrons in quantum transport experiments lead to a suppression of shot noise, S, relative to the Poissonian value of uncorrelated electrons, S_P. This suppression is customarily expressed in terms of the Fano factor, $F = S/S_P < 1$.

For phase-coherent quantum transport through fully chaotic or stochastic cavities, random matrix theory predicts a universal value for the Fano factor, $F = 1/4$. However, in the quantum-to-classical crossover of high Fermi energies ($E_F \to \infty$) or short dwell times in the cavity ($\tau_D \to 0$) the Fano factor is reduced to the classical value of fully deterministic transport, $F = 0$.

Motivated by recent experiments [2], we numerically investigate shot noise in cavities with tunable openings that allow to vary the dwell time τ_D [3]. Employing the modular recursive Green's functions method [4], we reach the regime of short electron wavelengths where many open lead modes contribute to transport. We include a random bulk disorder potential inside the cavity. Varying the strength of this disorder potential we investigate the regular-to-disordered crossover of shot noise explicitly. We find the Fano factor to be very close to the RMT-result ($F = 1/4$), even in regular systems without disorder, for which RMT is not expected to hold (for an independent verification of this assessment see [5]). We argue that in the case of regular dynamics in the cavity, diffraction at the lead openings is the dominant source of shot noise. To quantify this conjecture, we develop a quasi-classical transport model for shot noise suppression which agrees with the numerical data. Furthermore our model accurately predicts the amount of shot noise suppression for stadium-shaped, rectangular, and circular billiards which are prototypical for chaotic and regular classical motion, respectively. These examples demonstrate that the chaotic-to-regular crossover in F can be correctly described, provided that diffractive scattering in the cavity is properly accounted for.

We also investigate the presence of the previously predicted "noiseless scattering states" [6] and their influence on the transport characteristics [7]. Our numerical data indeed display clear signatures of these classical (i.e. fully deterministic) states which contribute to transmission but not to the noise. We confirm previous studies [8] predicting a strong suppression of such noiseless states due to stochastic scattering resulting from a bulk disorder.

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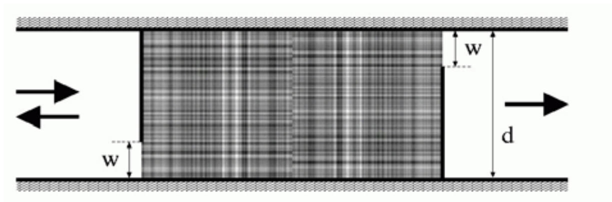

Fig. 1. Rectangular quantum billiard with shutters and disorder potential (gray shaded area). Tuning the opening of the shutters and the strength of the disorder potential the onset of the crossover from quantum-to-classical and disorderd-to-regular scattering can be investigated.

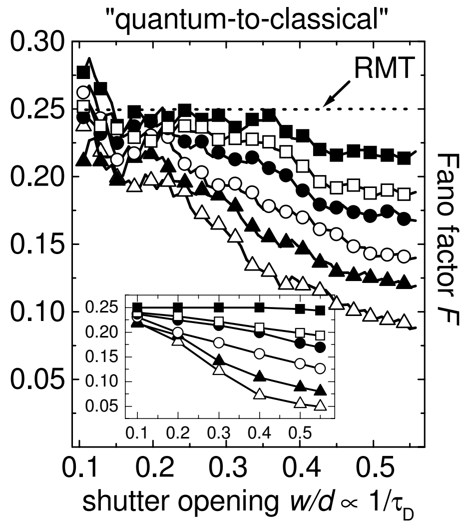

Fig. 2. Fano factor F as a function of the shutter opening ratio w/d. Curves for different disorder amplitudes: $V_0/E_F = 0.1\,(\blacksquare),\quad 0.07\,(\square),\quad 0.05\,(\bullet),\quad 0.03\,(\circ),\quad 0.015\,(\blacktriangle),\quad 0\,(\triangle)$. Inset: The fit parameter free prediction (quasi-classical model) with diffractive corrections.