STATISTICS of ELECTRON TRANSPORT & INTERPRETATION of QUANTUM MECHANICS

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1. Noise and Statistics.

- From ~~flicker~~ noise to shot noise
- Statististics- most complete description of Quantum system.
- „Quantum" and „Classical" Binomial distributions
- 2. Deterministic Quantum theories
- Check of Bell inequalities in Quantum conductors
- Sensitivity of Noise to weak perturbations

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Equilibrium noise FDT

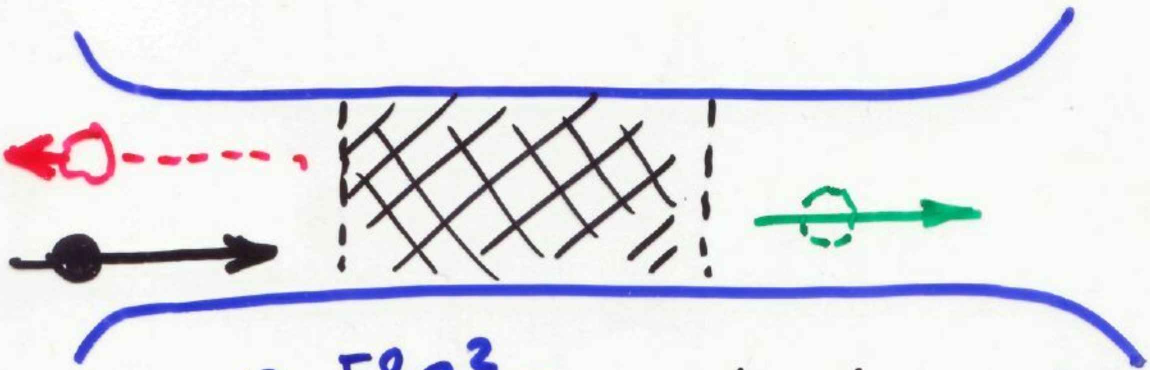
$$S_{II}(0) = 2 k_B T G$$ established

1/f - flicker noise $S(\omega) \propto \frac{1}{\omega}$

$$\int \frac{\gamma P(\gamma) d\gamma}{\gamma^2 + \omega^2} \sim \frac{1}{\omega}$$ most popular until late 1980th

Shot noise $S(0) = e\langle I \rangle$ Schottky form.

Meso- Nano- conductors



$$G = \sum_n \frac{2e^2}{h} T_n$$ Landauer, Anderson et al, Imry, Büttiker

$$S(0) = \sum_n \frac{2e^2}{h} T_n (1 - T_n) eV$$ Lesovik 1989

Buttiker 1990

Martin, Landauer 1992

Yurke, Kochanski 1990

Khlus 1987

Lesovik JETPL 70 208 (1999)

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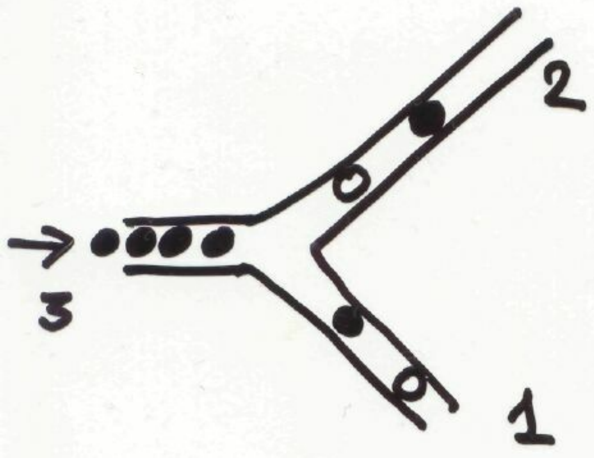


Cross-correlations.

$$I_1 I_2 = -\frac{2e^2}{h} eV\, T_{(1)} T_{(2)}$$

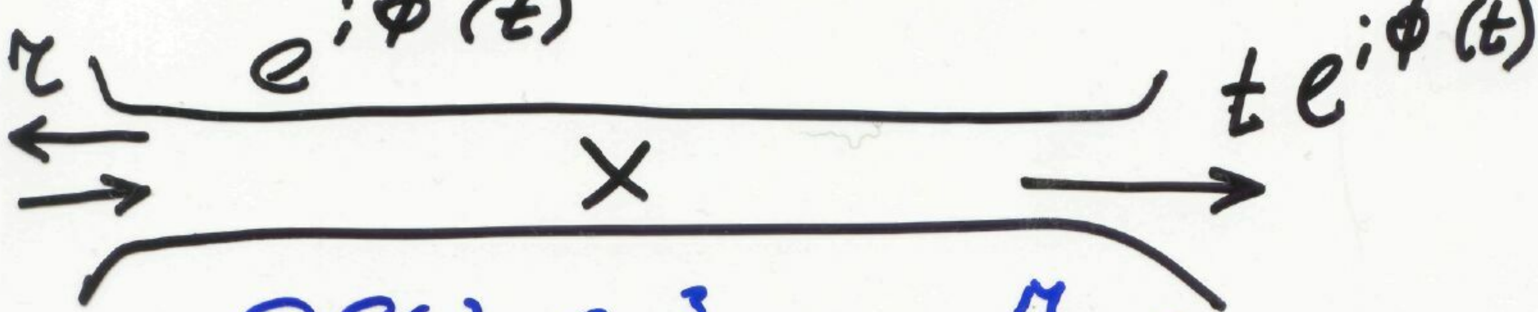
$$T_{(1)} \equiv T_{31}$$
$$T_{(2)} \equiv T_{32}$$

Martin Landauer 1992
Buttiker 1990, 1992

- Discreteness of Charge
- Fermi stat (Pauli principle)
- Partitioning (Wave Functions Collapse)
  Reduction of Wave Packet

Experiment Glattli et al
Reznikov et al

Nonstationary AB in Noise (Photon-assisted Noise)



$$\frac{\partial S(0)}{\partial V} \approx \frac{2e^3}{h} T(1-T) \sum_{m=-M}^{M} J_m^2(\Phi_a)$$

Lesovik Levitov 1994

Lesovik Martin Torres 1995

Exper- Prober group.

$$M = [eV/\hbar\Omega]$$

$$\Phi_a = \frac{eV_1}{\hbar\Omega} = \frac{e^* V_1}{\hbar\Omega}$$

$$\delta Q_t^2(\phi) \simeq 2e^2 T(1-T)\left[\frac{2}{\pi^2}\sin^2\frac{\pi\phi}{\phi_0} \ln t/\tau + \phi/\phi_0\right] + \ldots$$

$\delta Q \gg \langle Q \rangle$ if $T \ll 1$

$$\langle Q \rangle = 2\frac{\phi}{\phi_0} T e$$

Lee, Levitov 1994

P(Q) ⑤

Two Binomial Distributions

$$\chi(\lambda) = \left(\cos[\lambda e\sqrt{T}] + i\sqrt{T}\sin[\lambda e\sqrt{T}]\right)^N, \quad N = \frac{eVt}{h}$$

$$\langle\langle Q_t^3 \rangle\rangle = -2T^2(1-T)\, t\, eV \frac{2e^2}{h}$$

$$\langle\langle I_0^3 \rangle\rangle = -2T^2(1-T) eV \frac{2e^2}{h}$$

Levitov Lesovik 1992

$$\chi(\lambda) = \left(R + Te^{i\lambda}\right)^N$$

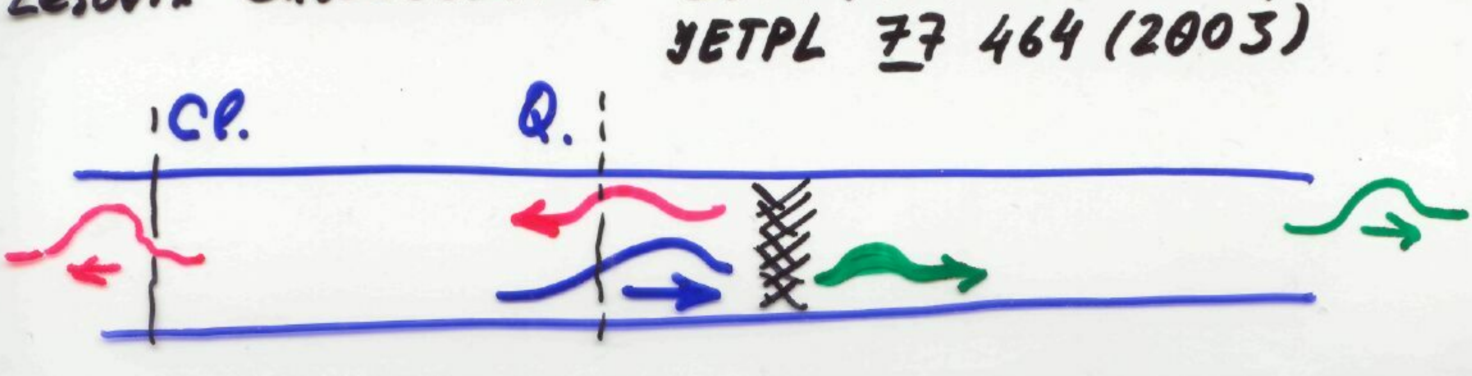
$$\chi(\lambda) = \langle \tilde{T} e^{i\lambda/2 \int \hat{I} dt}\, T e^{i\lambda/2 \int \hat{I} dt} \rangle$$

$$\langle\langle Q_t^3 \rangle\rangle = T(1-T)(1-2T) eV \frac{2e^2}{h} t$$

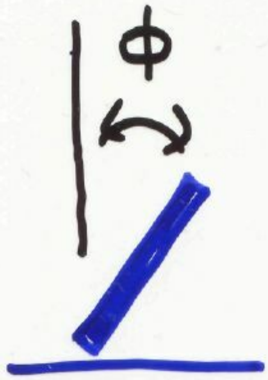
Levitov Lesovik 1993

$$\langle\langle I_{\omega_1}(x) I_{\omega_2}(x) I_{\omega_3}(x) \rangle\rangle = T(1-T) \cdot \left[1 - 2T - e^{-2\omega_2 x / v_F}\right] \cdot eV \frac{2e^3}{h}$$

Lesovik Chtchelkatchev cond-mat/0303024
JETPL $\underline{77}$ 464 (2003)

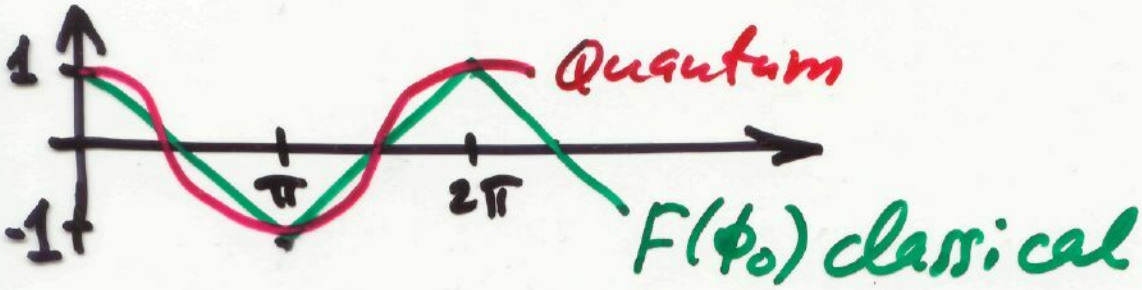


$$\phi = \phi_0 + \omega_j t$$



$$\langle \delta N^2 \rangle = \frac{1}{2}\langle N \rangle + O\left(\frac{f(\phi_0)}{\Delta\omega t}\right)$$

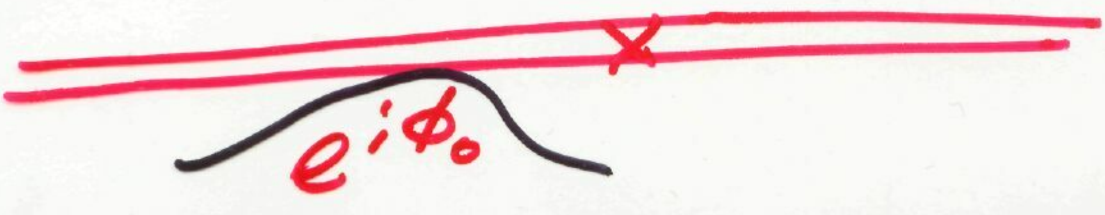
$$\left\langle \delta N(0)\,\delta N(\phi_0) \right\rangle = F(\phi_0)\,\frac{1}{2}\langle N \rangle$$



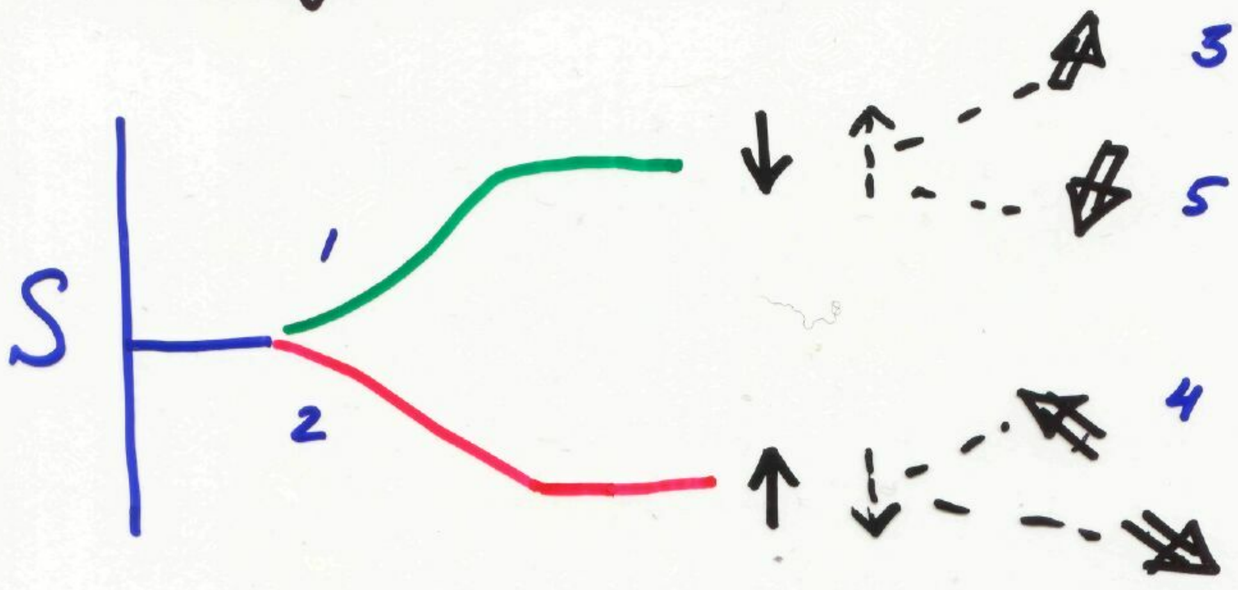
$$\left\langle \left(\delta N(0) - \delta N(\phi_0)\right)^2 \right\rangle = 2\left(1 - F(\phi_0)\right)\langle \delta N^2 \rangle$$

$$\left\langle \left(\delta \hat{N}(0) - \delta \hat{N}(\phi_0)\right)^2 \right\rangle = 4\sin^2(\phi_0/2)\,\langle \delta \hat{N}^2 \rangle$$

$$\hat{N} = \int_0^t \hat{I}(t')\,dt'$$



Entanglement and Bell inequalities



$$\langle N_\alpha(\tau) N_\beta(\tau) \rangle \simeq \langle I_\alpha \rangle \langle I_\beta \rangle \tau^2 + \\ + \tau S_{\alpha\beta}(0)$$

$\tau \gg \tau_{corr.}$

Chtchelkatchev et al 2001
Samuelsson et al 2003
Beenakker et al 2003

Unitary deterministic theory and sensitivity of the measurement result to small perturbation.

$$a_k \tilde{\sum_{k=1}} \varphi_k \otimes \Psi_{Res}(\xi) \to \varphi_n \cdot \psi_n(\xi)$$

U?

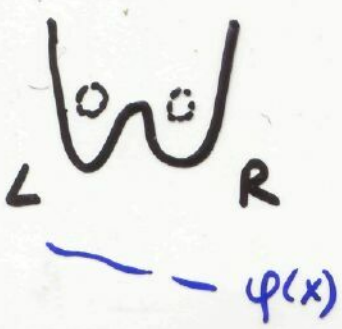
R?

$$\langle \delta N_t^2 \rangle = 4\int \frac{S(\omega)\sin^2 \omega t/2}{\omega^2}\frac{d\omega}{2\pi} \sim t^2 \sim N^2$$

$$\frac{\delta N_t}{\langle N \rangle} \not\to 0 \qquad 1/f$$

Lesovik JETPL <u>74</u> 471 (2001)

von Oppen Stern (1997)



Andrei Lebedev et al.