Quantum collapse of charge quantization on a metallic node

A. Anthore

Z. Iftikhar, S. Jezouin, F.D. Parmentier, U. Gennser, A. Cavanna & F. Pierre

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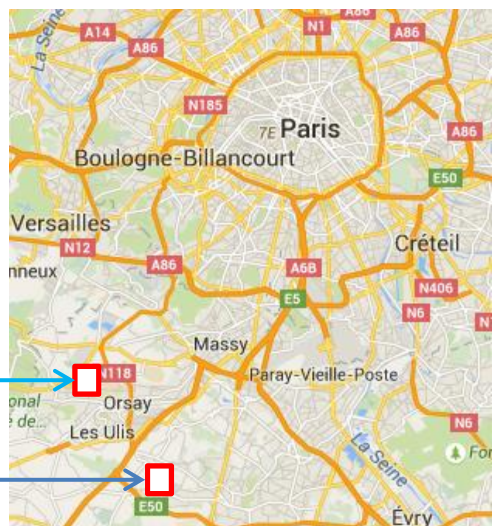

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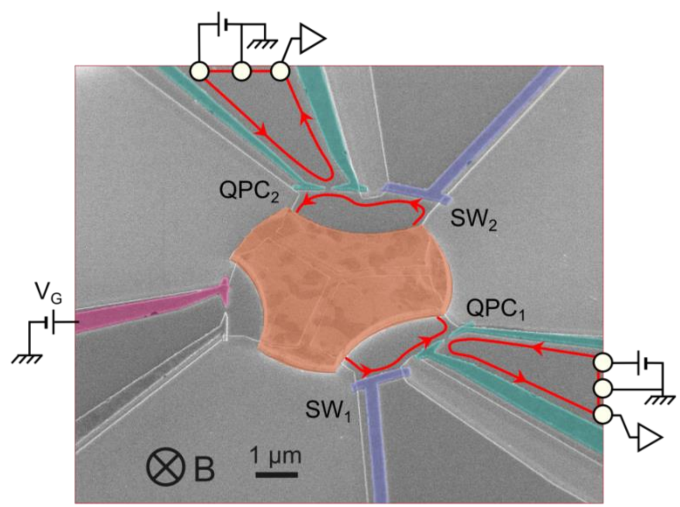
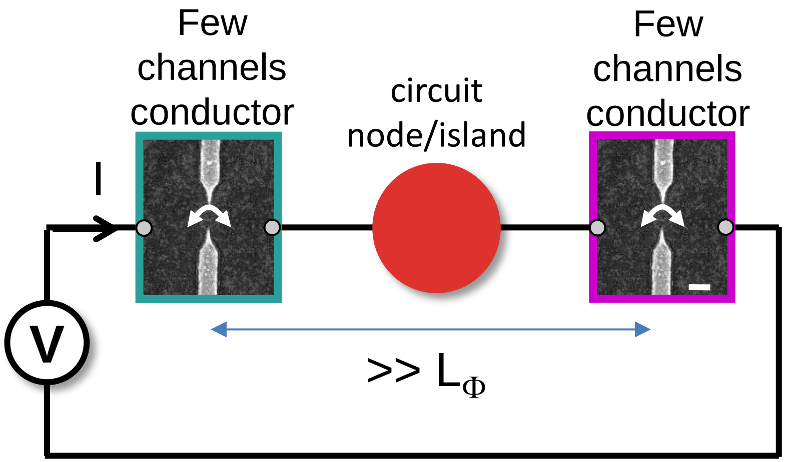
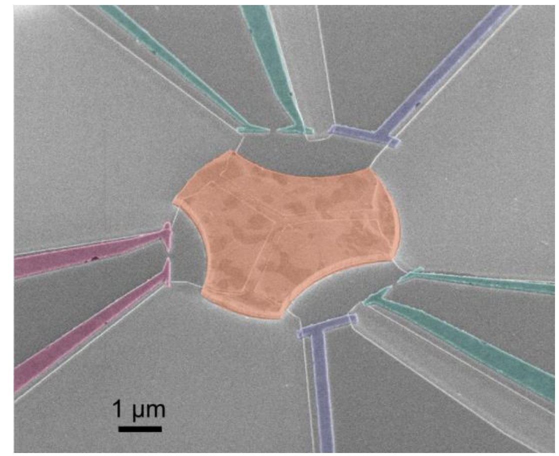


Quantum laws of electricity in composite mesoscopic circuits

Investigated at the elementary level of single channel components

Typical testbed system:





Questions addressed:

- charge quantization in circuit nodes
- conductance in-situ

When does it occur ?

now

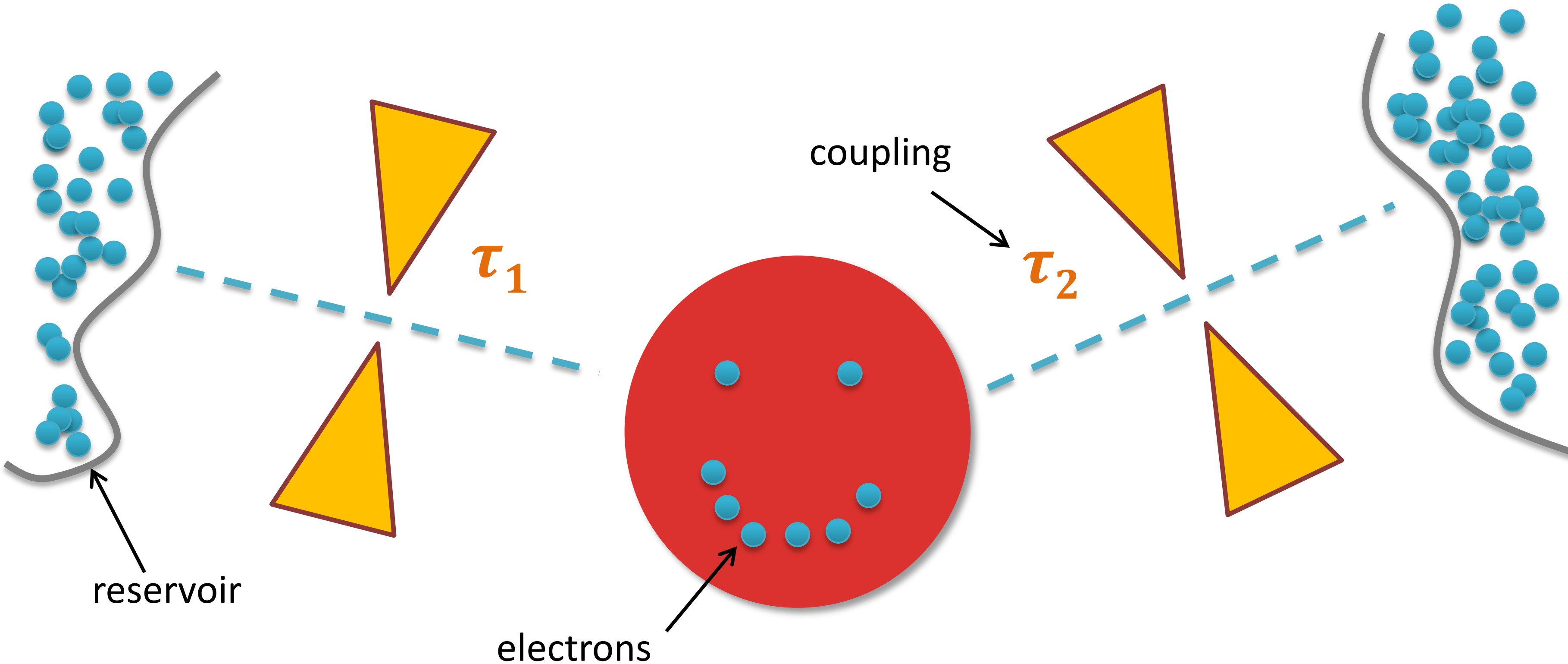
- G_{QPC} in a linear environment ? Dynamical Coulomb blockade and link with Luttinger liquids (1D e-)?

S. Jezouin *et al*, Nature Comm 4, 1802 (2013), F.D. Parmentier *et al*, Nature Physics 7, 935 (2011)

- G_{QPC} in a non linear environment? Kondo effect ?

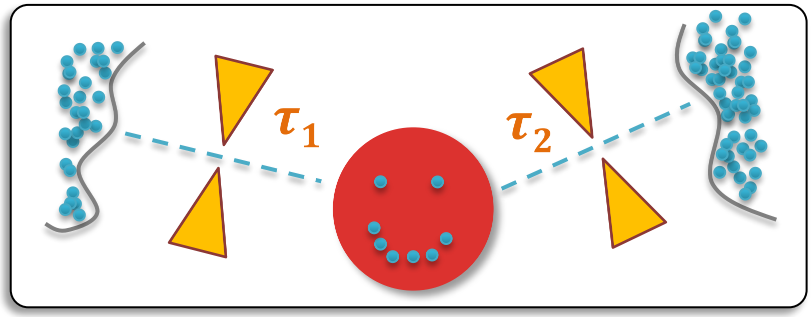
at 18:00

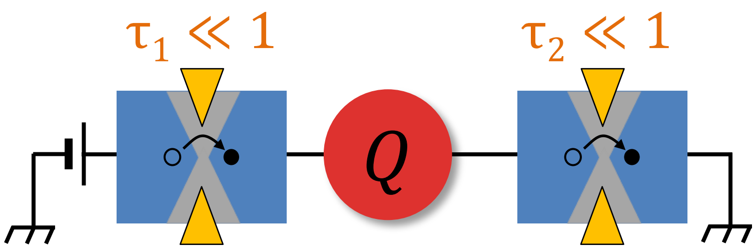
Charge quantization in metallic nodes of mesoscopic circuits



How does the quantization of the charge on the node evolve when it is connected progressively to a circuit via single channels?

Charge quantization in metallic nodes of mesoscopic circuits

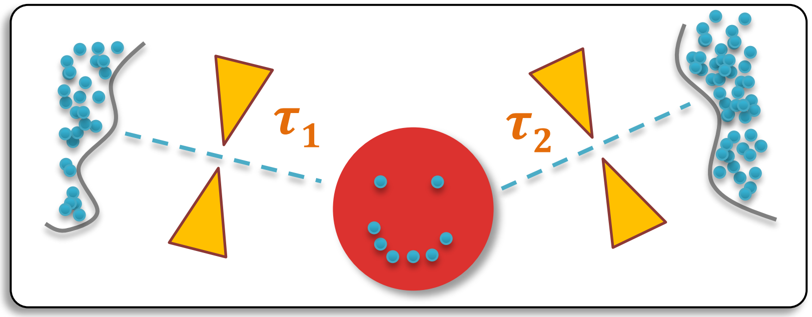


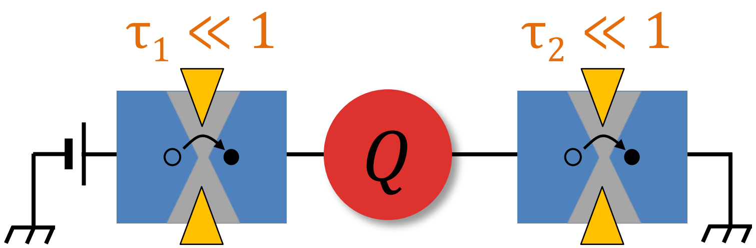


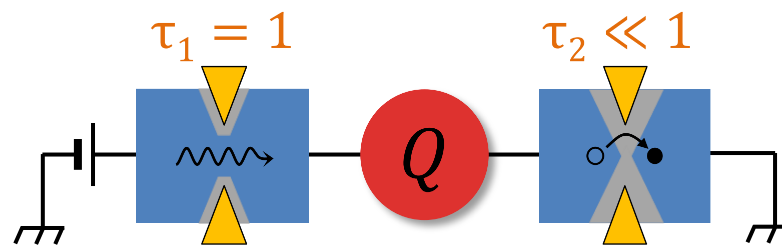
Quantized $Q = n \times e$

Very well established experimentally (Fulton & Dolan 1987)

Charge quantization in metallic nodes of mesoscopic circuits







Quantized $Q = n \times e$

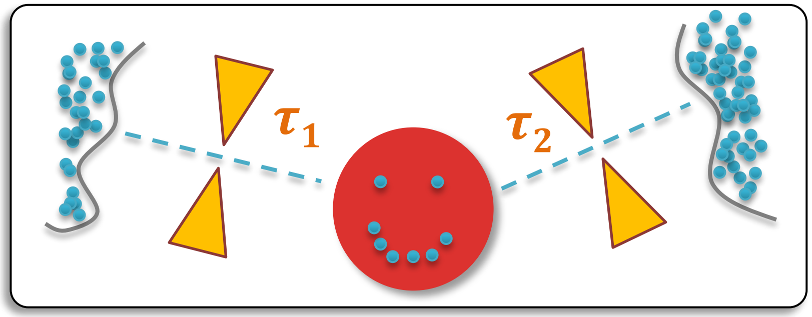
Continuous Q

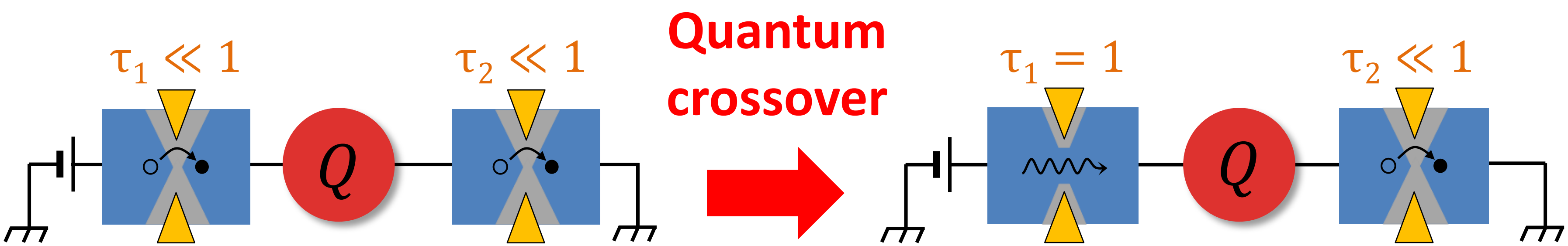
Very well established experimentally (Fulton & Dolan 1987)

Contradictory experiments :

- Quantization destroyed : Kouwenhoven, ZPB 1991; Duncan, PRL 1999; Berman, PRL 1999
- Quantization survives : Pasquier, PRL 1993; Liang, PRL 1998

Charge quantization in metallic nodes of mesoscopic circuits





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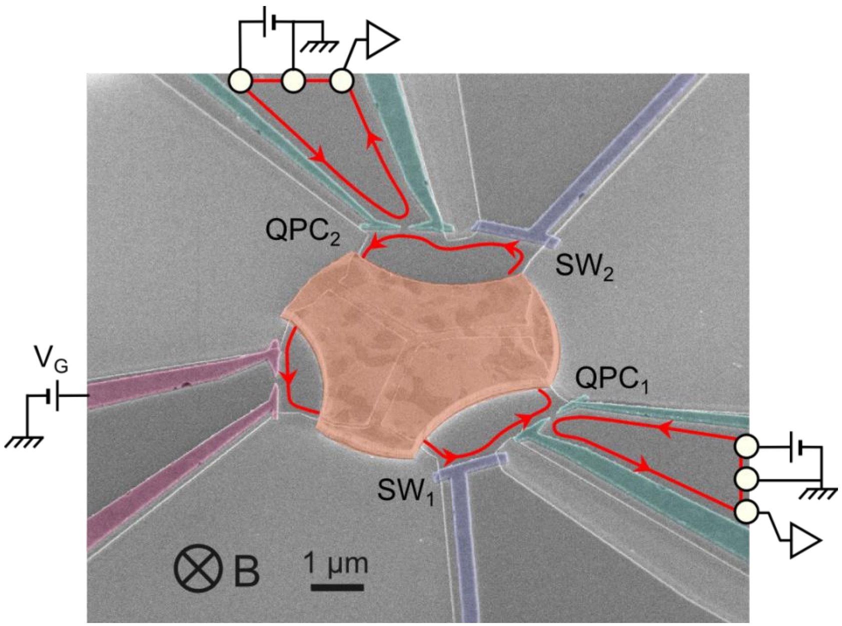
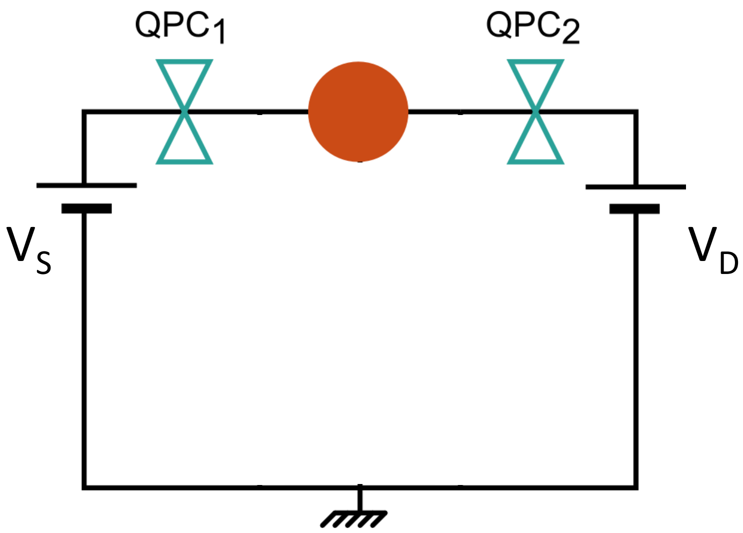
Sample and experimental principle



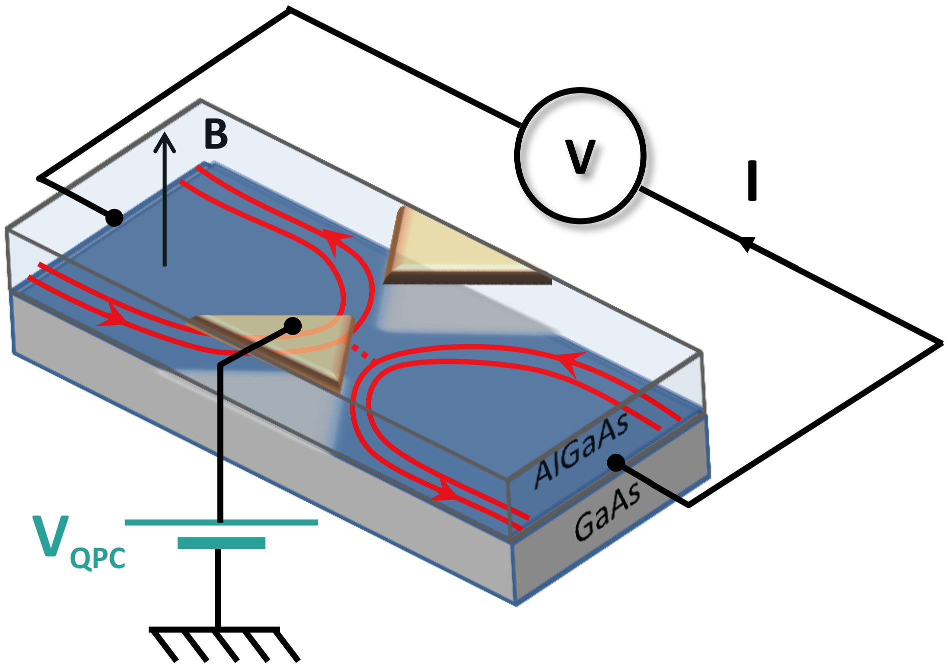


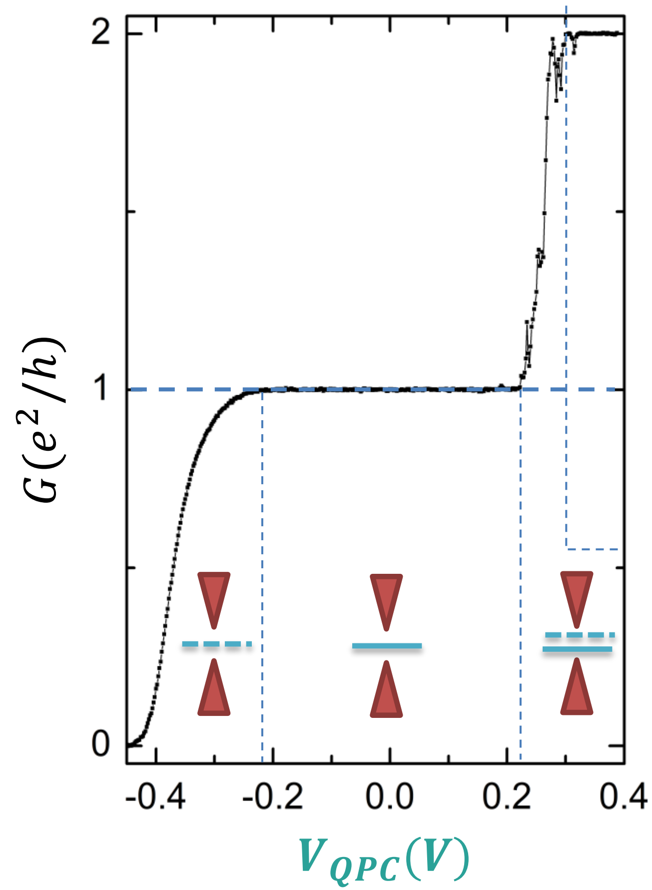
- Metallic island: - continuous density of states
  - dwell time much larger than electron quantum lifetime
- Quantum Point Contact (QPC): Tune the coupling with the circuit

Quantum point contacts

A model coherent conductor

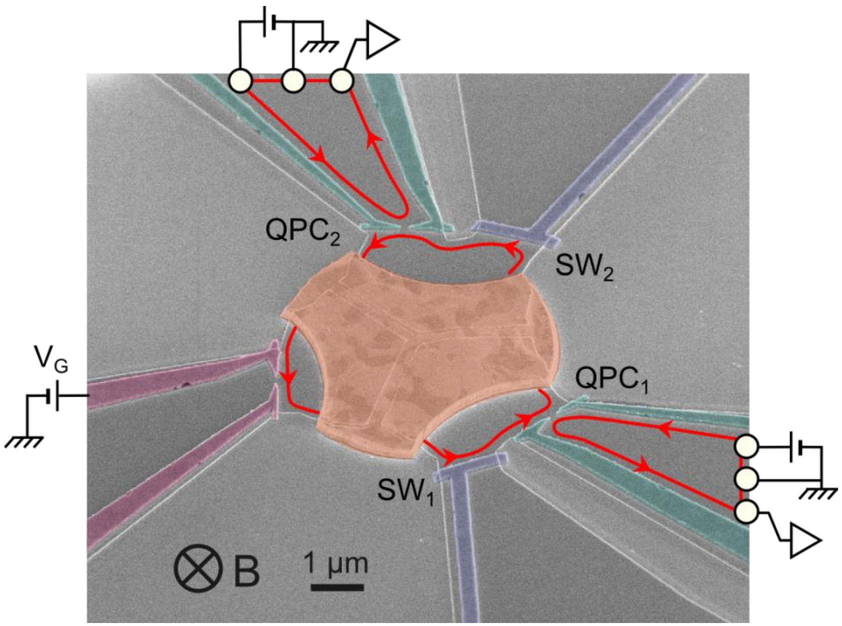
Scattering approach description of a coherent conductor
(Landauer, Büttiker, Martin)

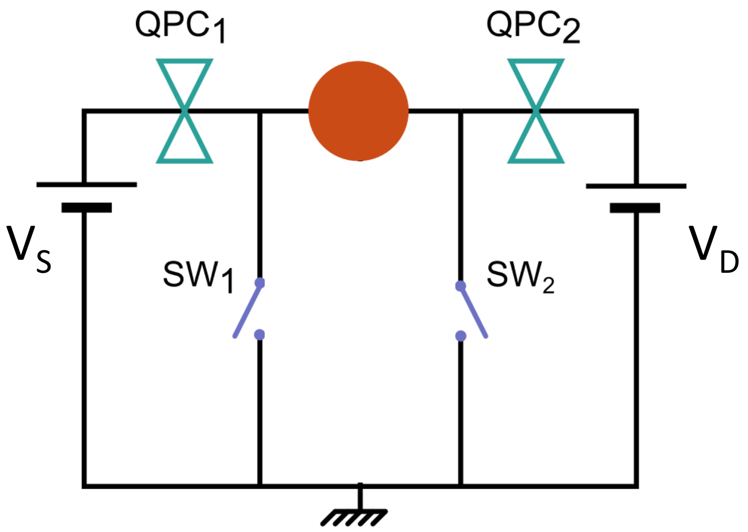




n_S=2.5 10^{15} m^{-2}, μ=10^2 $m^2V^{-1}s^{-1}$
grown @ LPN by A. Cavanna and U. Gennser

Sample and experimental principle





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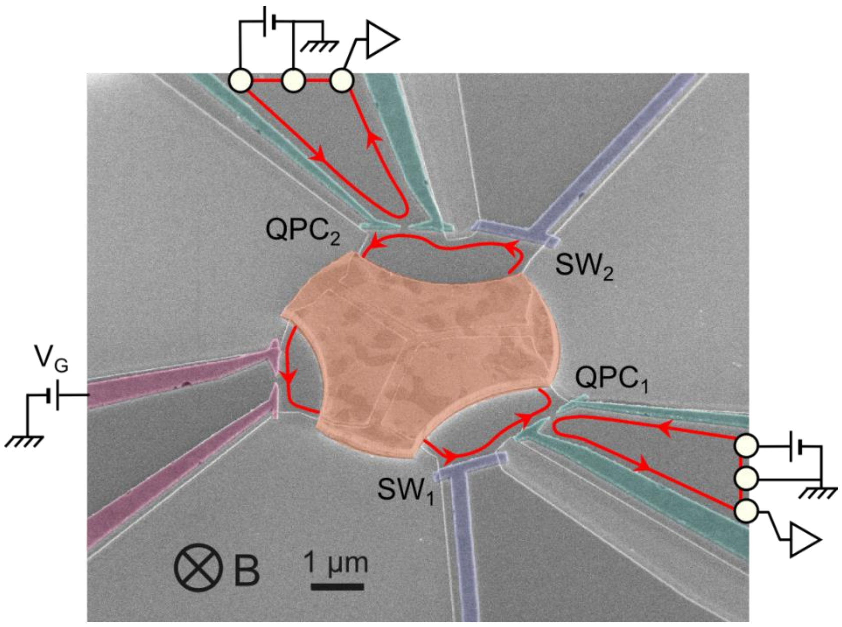
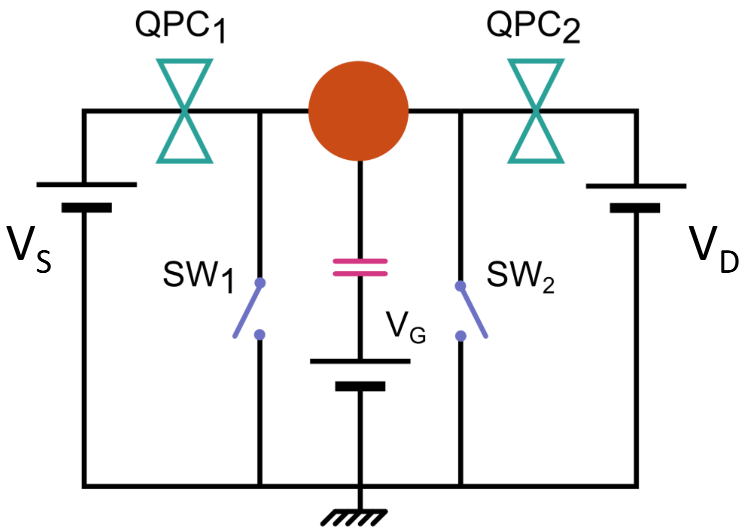
- Switches: Measurement of the "*coupling*" G_1 and G_2 of each QPC independently

Sample and experimental principle

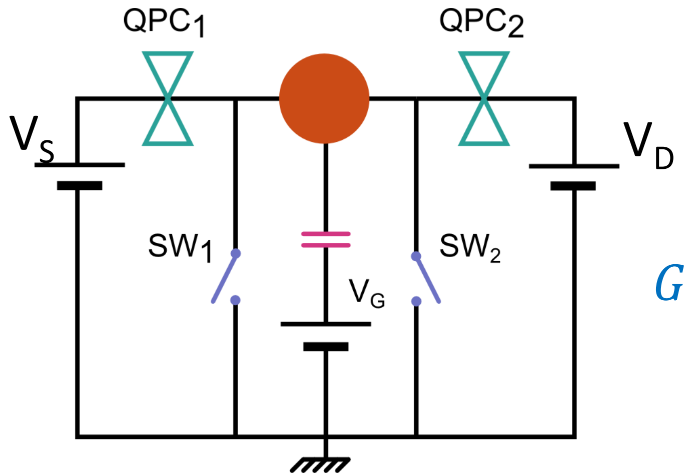




- Metallic island: - continuous density of states
  - dwell time much larger than electron quantum lifetime
- Quantum Point Contact (QPC): Tune the coupling with the circuit
- Switches: Measurement of the "*coupling*" G_1 and $\boldsymbol{G_2}$ of each QPC independently
- Gate : Measurement of $G(\Delta V_G)$ = dI / dV$_{DS}$ @ V$_{DS}$ = 0

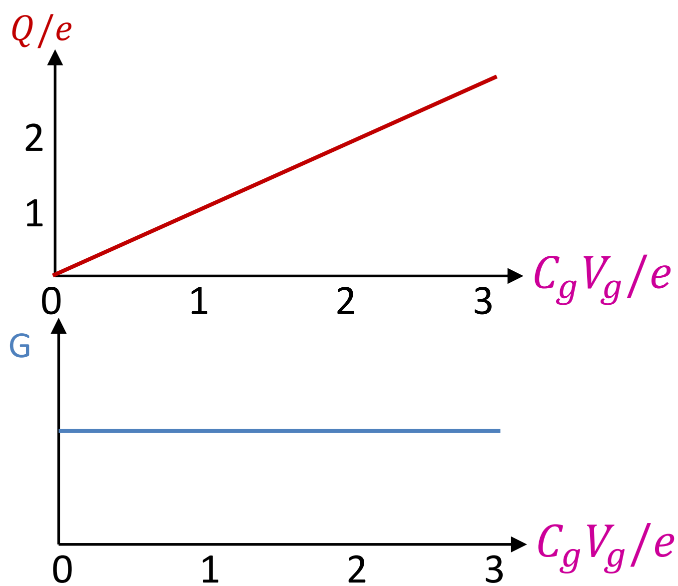
Coulomb oscillations

= charge quantization probe at low temperature

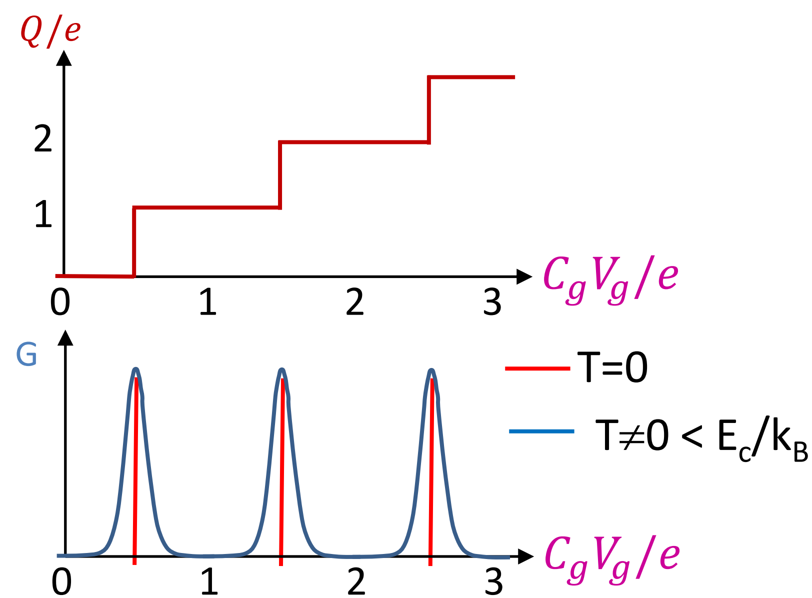


$G(\Delta V_G)$ = dI / dV$_{DS}$ @ V$_{DS}$ = 0

Continuous node charge



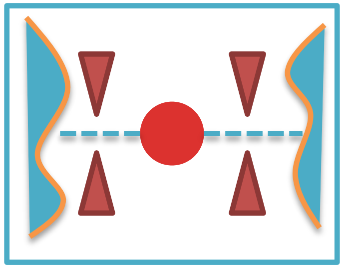
Quantized node charge



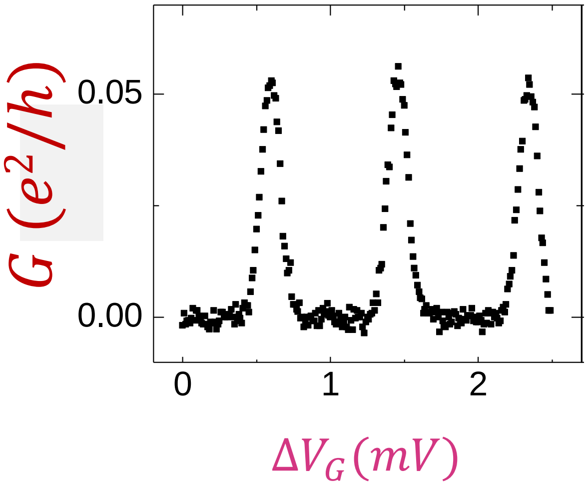
Coulomb blockade oscillations

$G_1 = 0.24\ e^2/h$

T=17 mK



$G_2 = 0.10\ e^2/h$



Coulomb blockade oscillations

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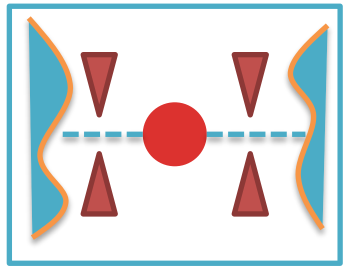
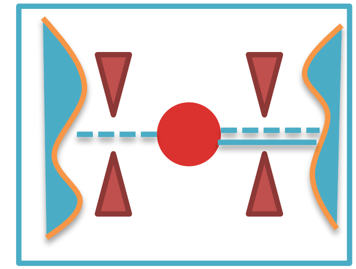
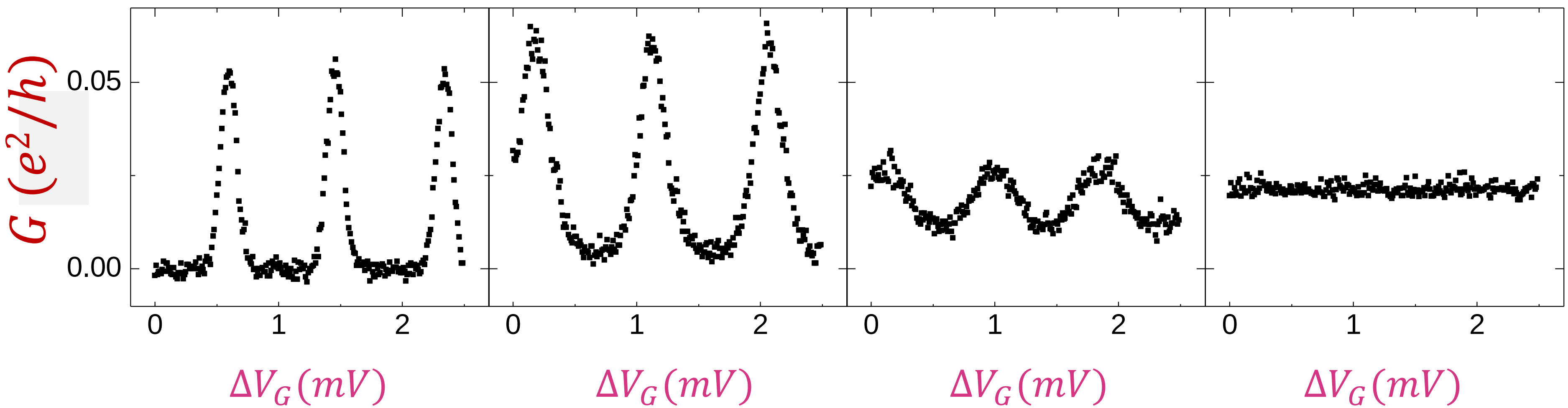
T=17 mK





$G_2 = 0.10\ e^2/h$ | $G_2 = 0.88\ e^2/h$ | $G_2 = 0.98\ e^2/h$ | $G_2 = 1.52\ e^2/h$



Main modifications when $G_2 \rightarrow e^2/h$

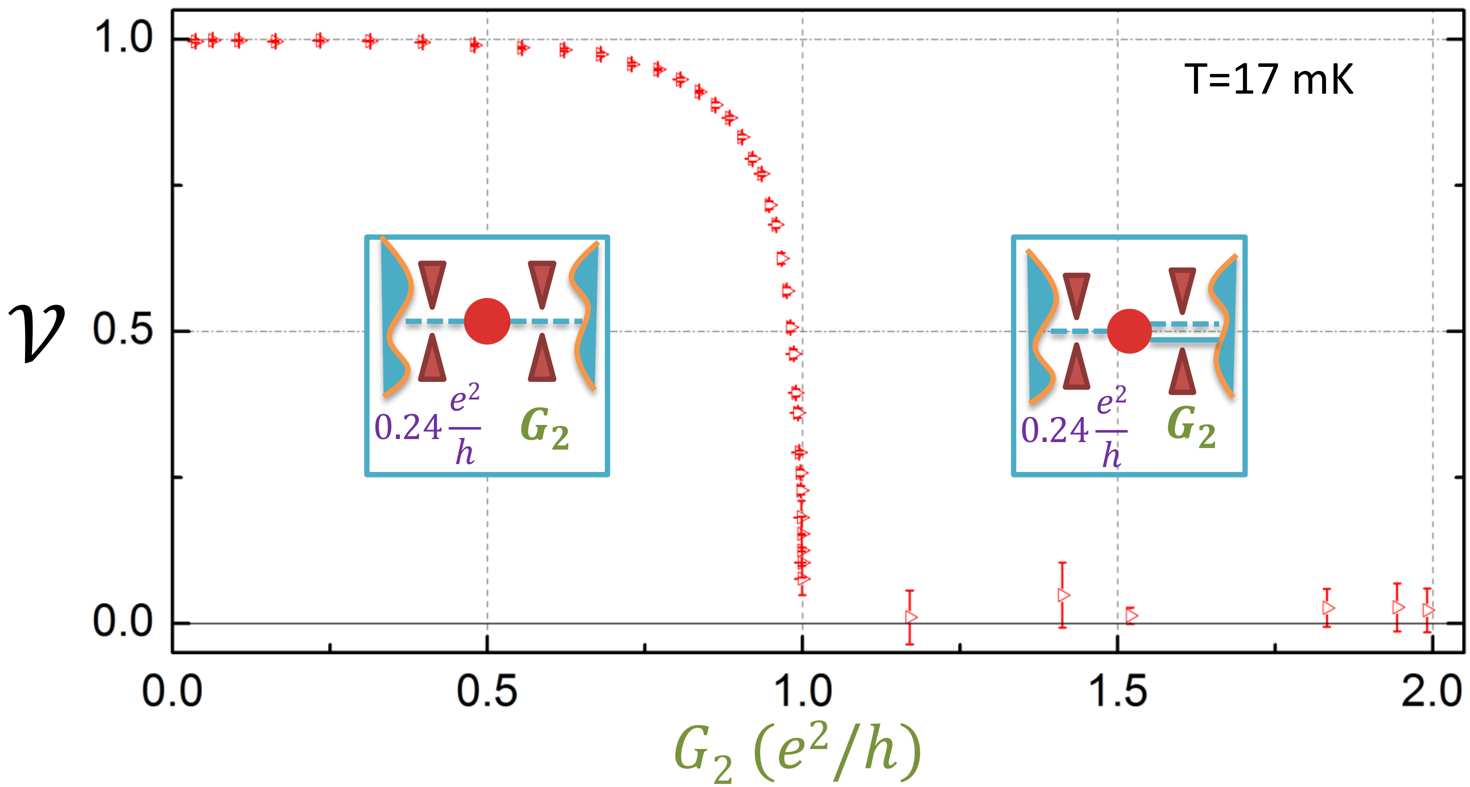
Coulomb blockade oscillations visibility

$$\mathcal{V} \overset{\text{def}}{=} \frac{\max[G] - \min[G]}{\max[G] + \min[G]}$$

For $G_1 \ll e^2/h$ & $G_2 \to e^2/h$:

$$\mathcal{V} \propto \max[Q - C_G V_G]$$

Furasaki & Matveev, *PRB 1995*



No charge quantization for $G_2 > e^2/h$

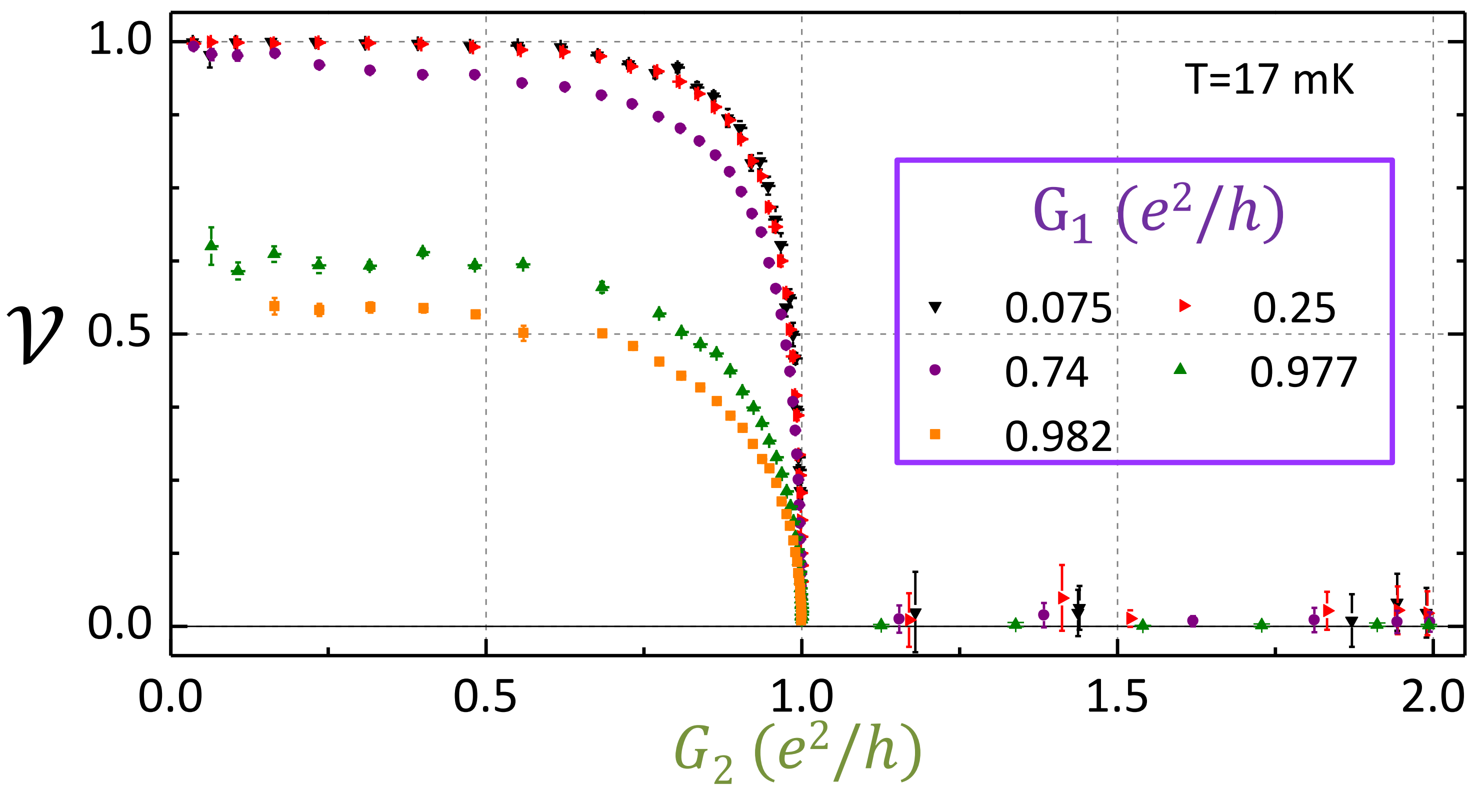
Coulomb blockade oscillations visibility

$$\mathcal{V} \stackrel{\text{def}}{=} \frac{\max[G] - \min[G]}{\max[G] + \min[G]}$$

For $G_1 << e^2/h$ & $G_2 \rightarrow e^2/h$:

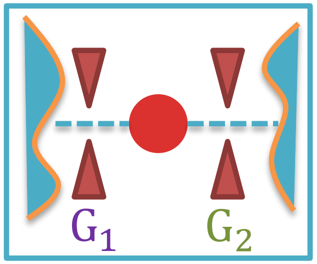
$$\mathcal{V} \propto \max[Q - C_G V_G]$$

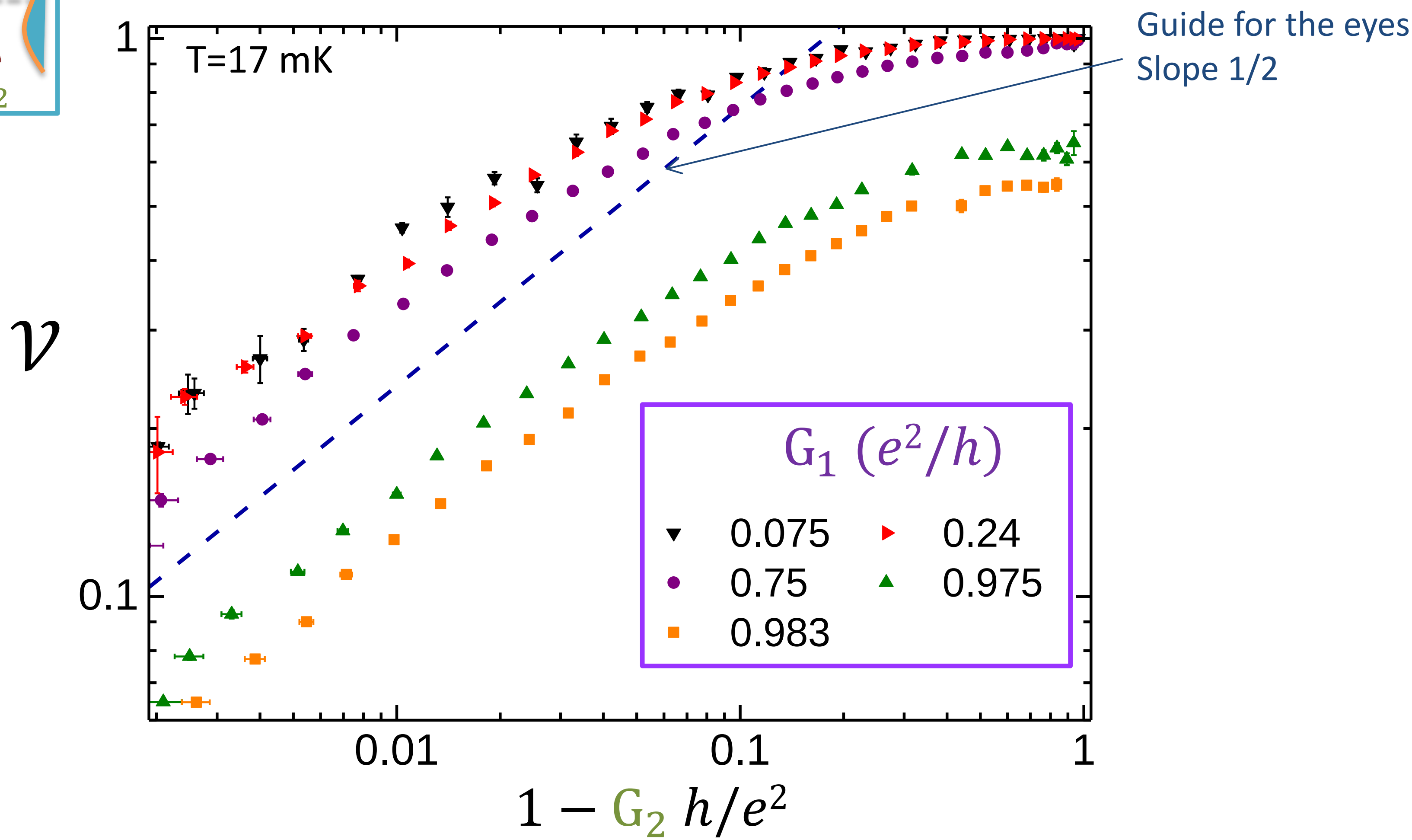
Furasaki & Matveev, *PRB 1995*



No charge quantization for $G_2 > e^2/h$ whatever G_1

Crossover from quantized to continuous charge





$\mathcal{V} \propto \sqrt{1 - G_2 h/e^2}$ when $G_2 \longrightarrow e^2/h$

Comparison with theory

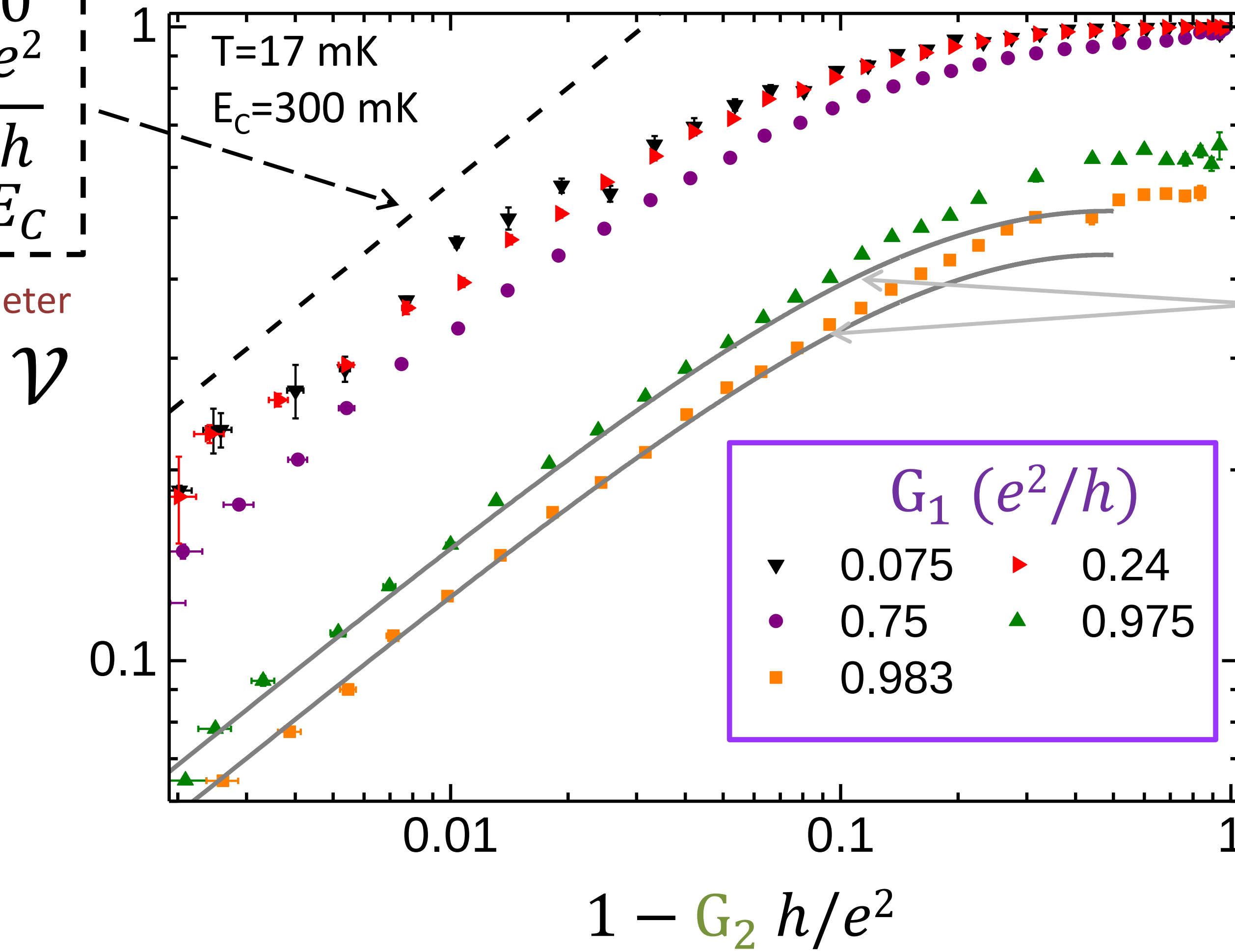
A. Furasaki and K.A.Matveev, *PRB 1995, spinless electrons*

$G_1 \longrightarrow 0$

$G_2 \longrightarrow \frac{e^2}{h}$

$k_B T \ll E_C$

No fit parameter



$G_1 \longrightarrow \frac{e^2}{h}$

$G_2 \longrightarrow \frac{e^2}{h}$

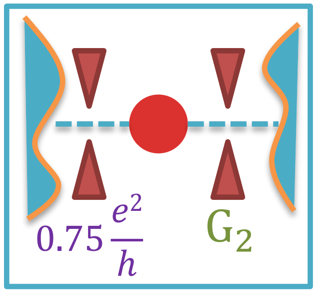
$k_B T \ll E_C$

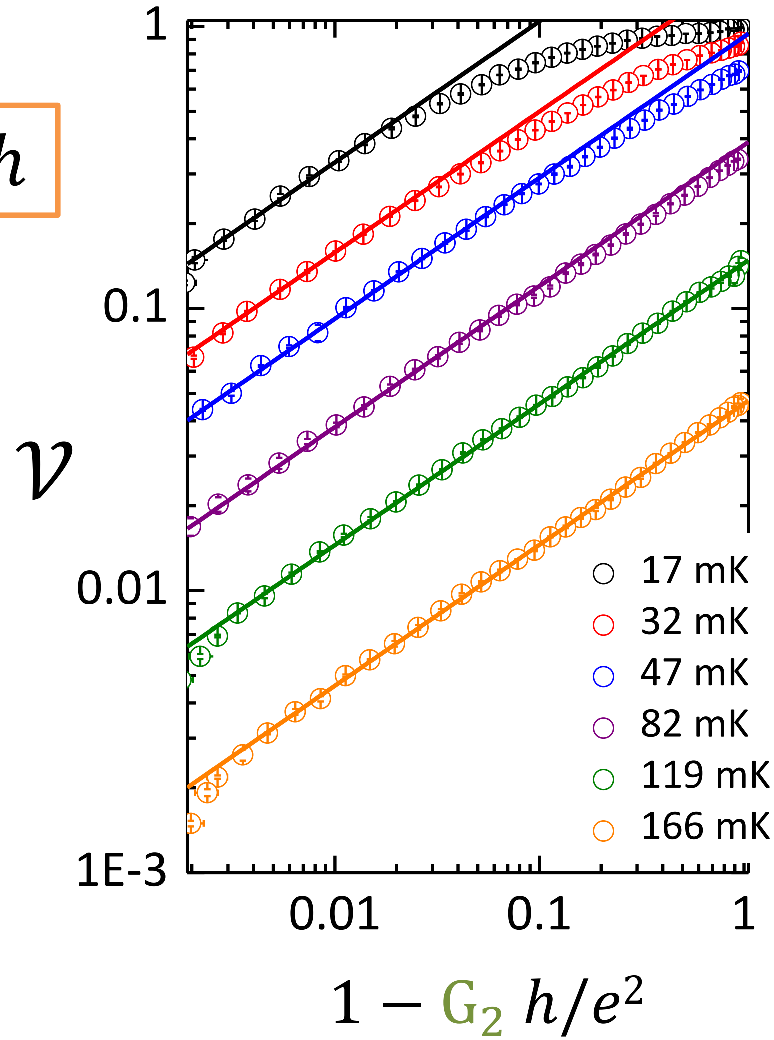
One fit parameter : T_{fit}=16.5 mK

$\mathcal{V} \propto \sqrt{1 - G_2 h/e^2}$ when $G_2 \longrightarrow e^2/h$

Temperature dependence

$G_1 = 0.75\, e^2/h$

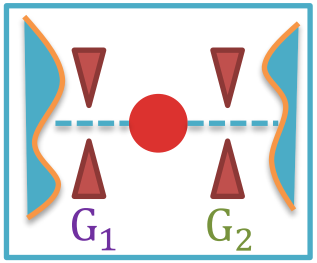


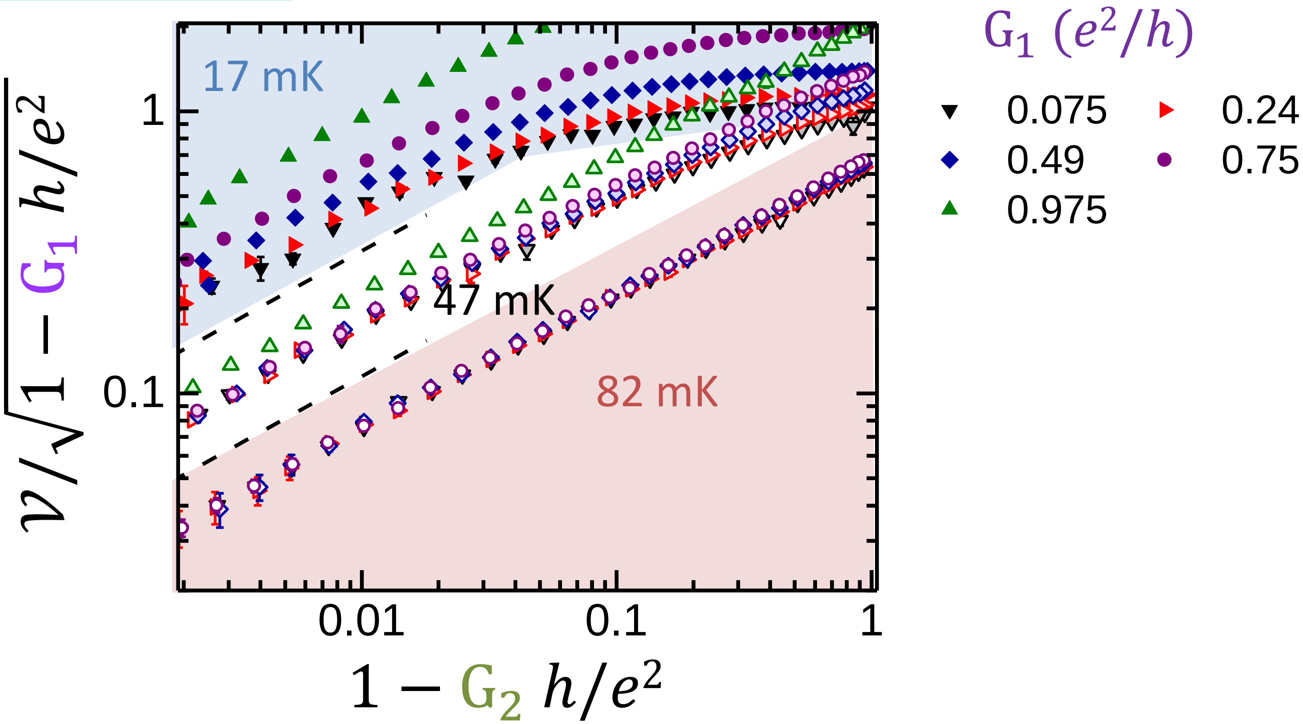


E_C=300 mK

$\mathcal{V} \propto \sqrt{1 - G_2 h/e^2}$ if $\nu < 0.3$

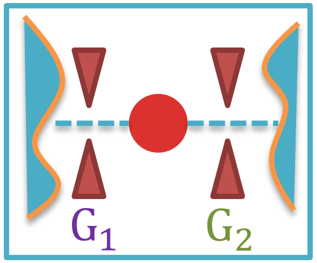
Temperature dependence

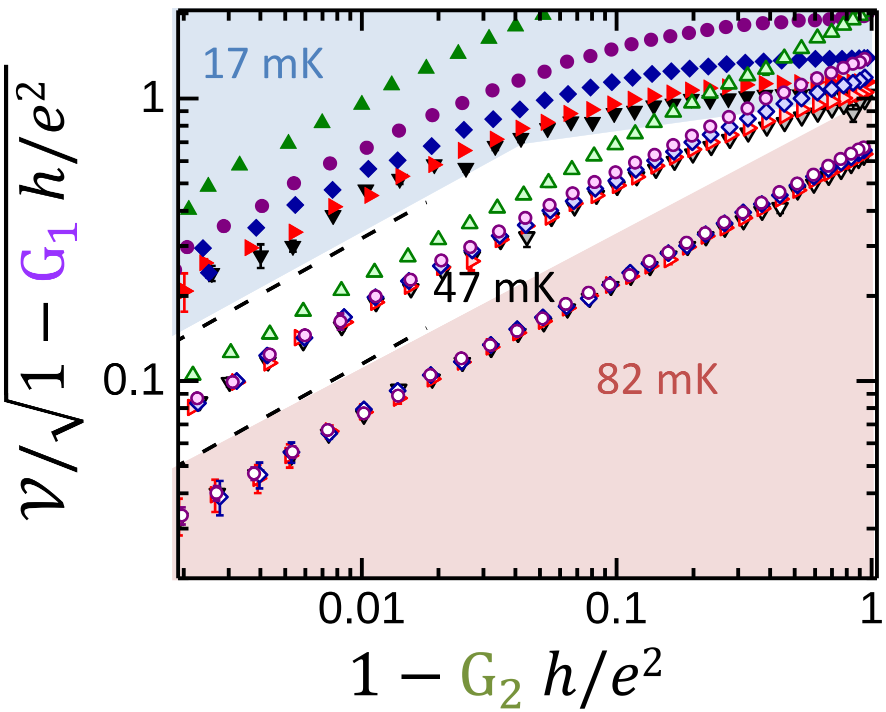




For T=80 mK , universal behavior

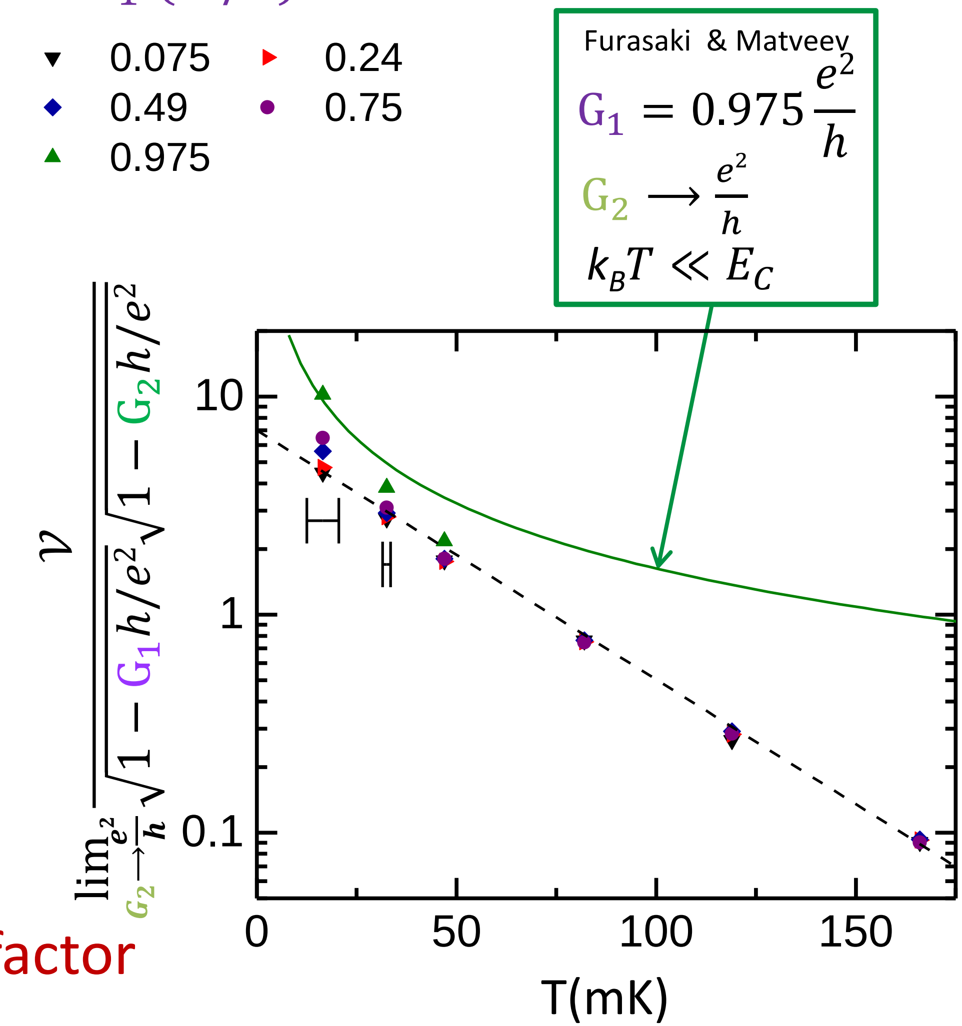
Temperature dependence





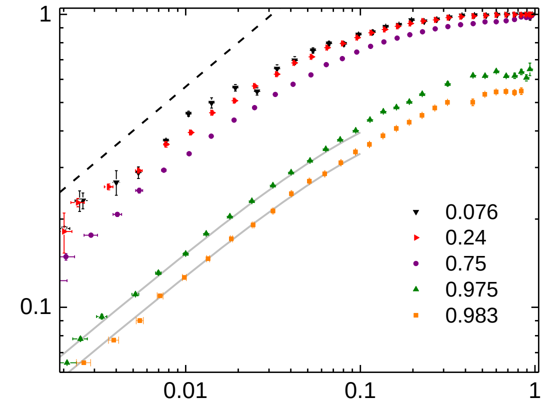
$G_1\ (e^2/h)$

▼ 0.075	▶ 0.24
◆ 0.49	● 0.75
▲ 0.975	



For T>80 mK , universal behavior and exponential decrease of ν prefactor with T

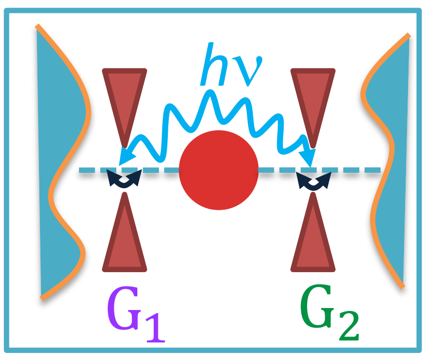
Conclusions and perspectives

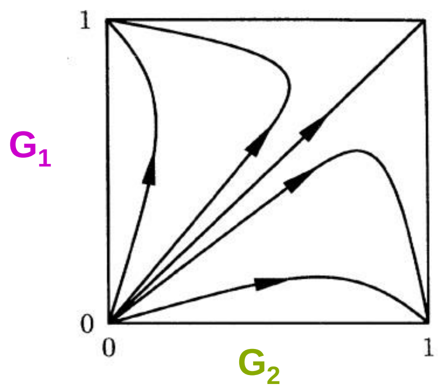


✓ <u>CHARGE QUANTIZATION</u>

No charge quantization with one ballistic channel in agreement with theoretical predictions and explored beyond

✓ Conductance modifications when both channels are non ballistic





Predictions :
A. Furasaki, K. A. Matveev PRB 1995

2-channel charge Kondo effect : cf Frédéric's talk

- Noise — Predictions : Kindermann *et al.* PRL 2003; PRB 2004, Safi & Saleur PRL 2004, etc….
- Heat transport and thermoelectricity
- Finite size — Predictions : Nazarov PRB 1991, Florens, Simon, Andergassen, Feinberg PRB 2007 Le Hur, Li, PRB 2005 etc…

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Ulf Gennser

Antonella Cavanna

Frédéric Pierre

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erc

Thanks:

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To the Quantronics group for having launched me in the research world