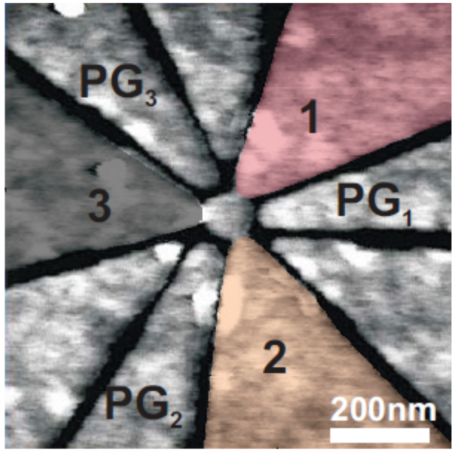
Three-terminal graphene quantum devices



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with
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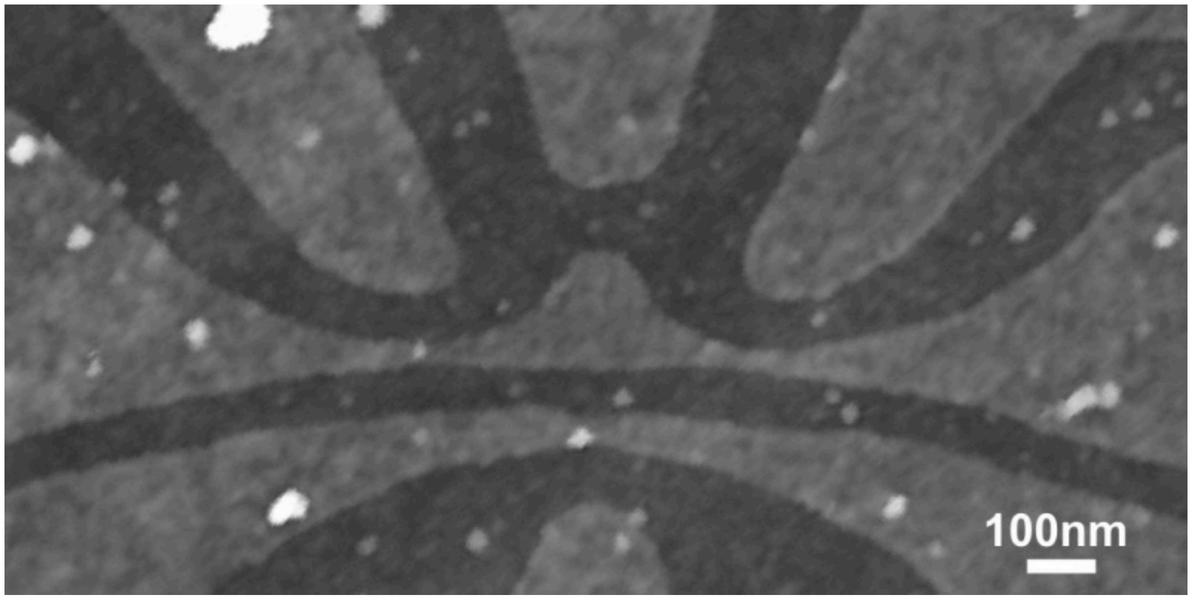
P. Simonet
S. Dröscher
C. Barraud
T. Ihn

- constrictions and dots
- 3-terminal dots
- bilayer quantum structures

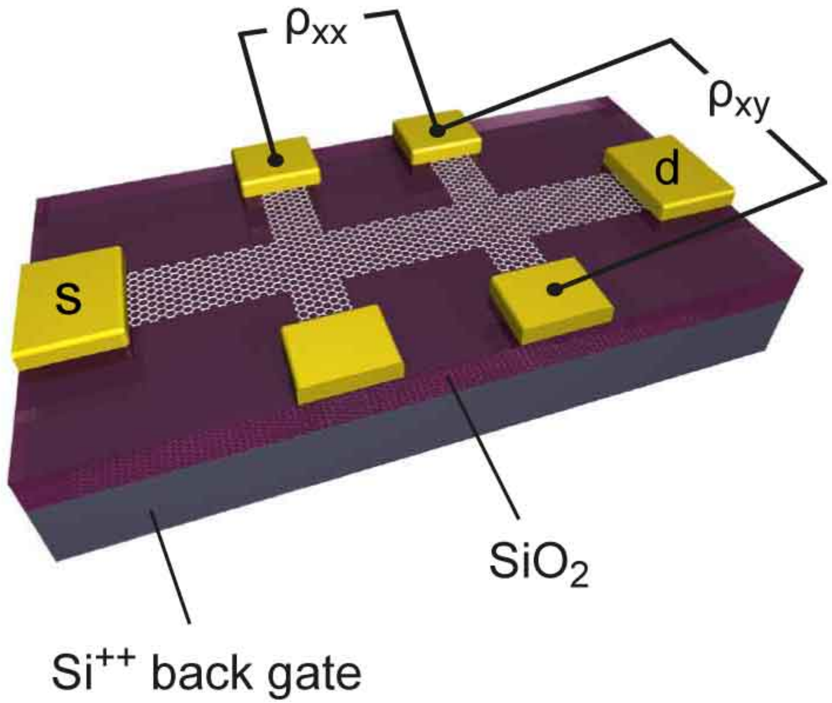
Why graphene quantum devices?

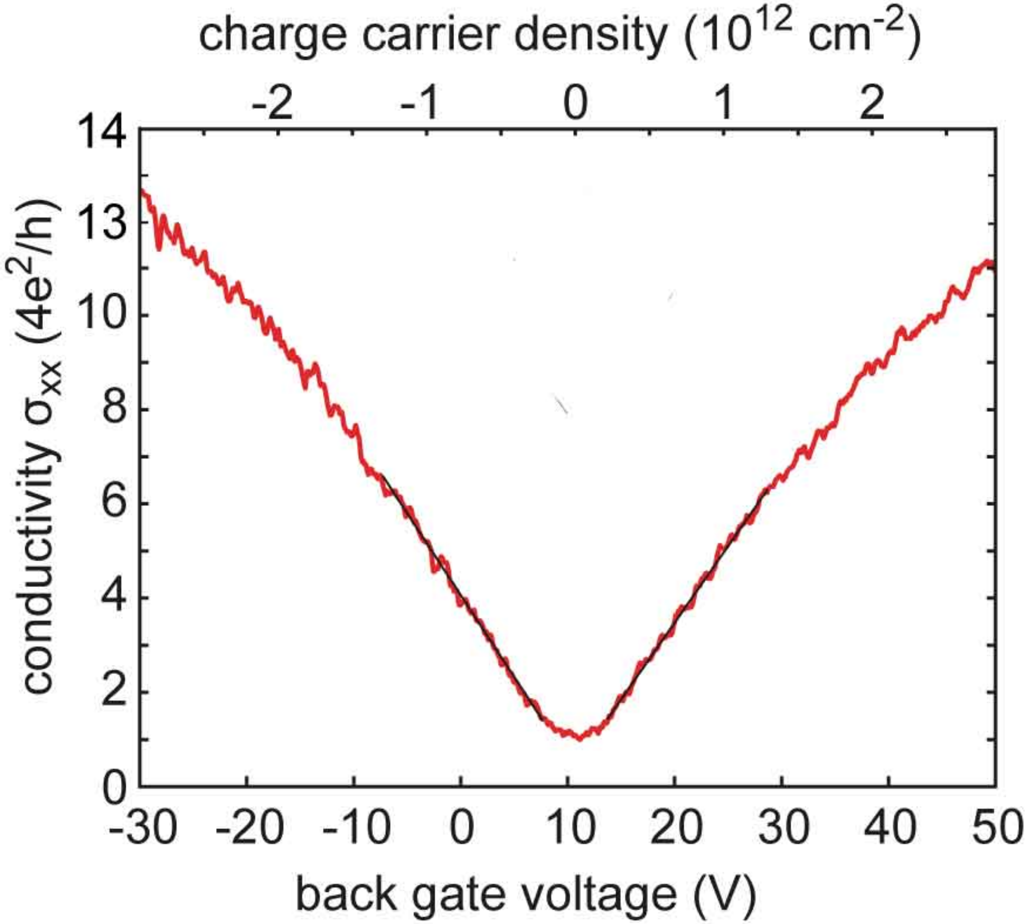
- Lateral patterning -> quantum structures
- Finite lateral size -> quantum confinement (?)
- Spin qubits -> long spin coherence times (?)

- What controls the confinement?
- What are the relevant energy scales?



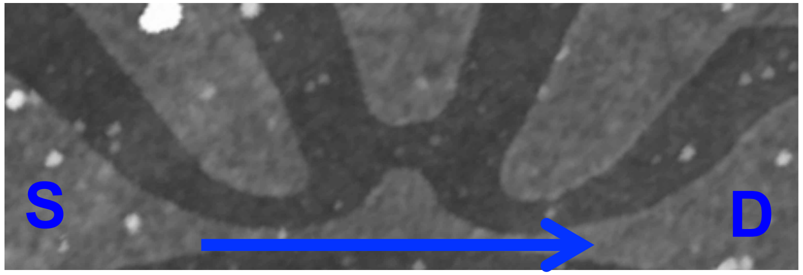
Graphene Hall bars

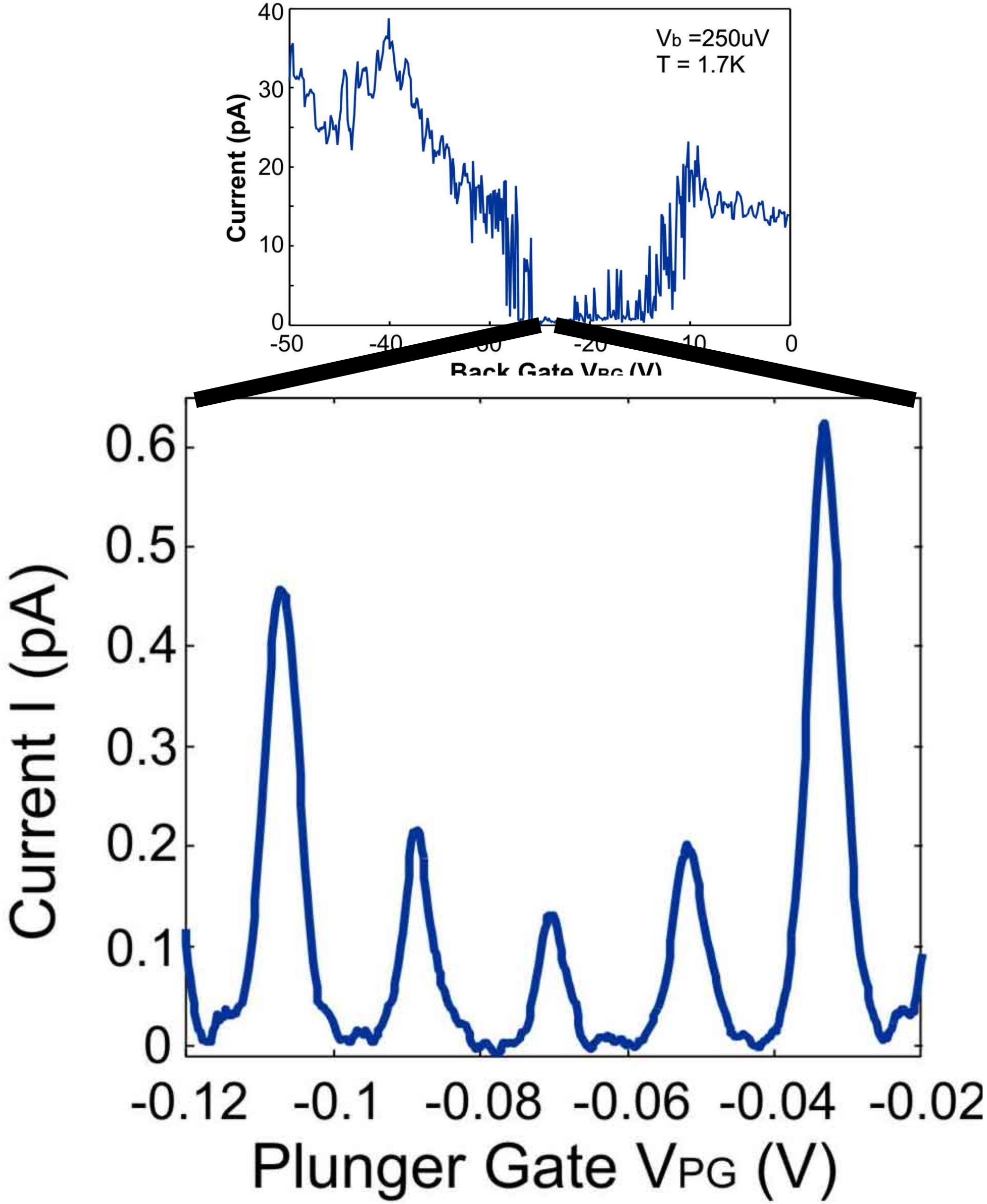


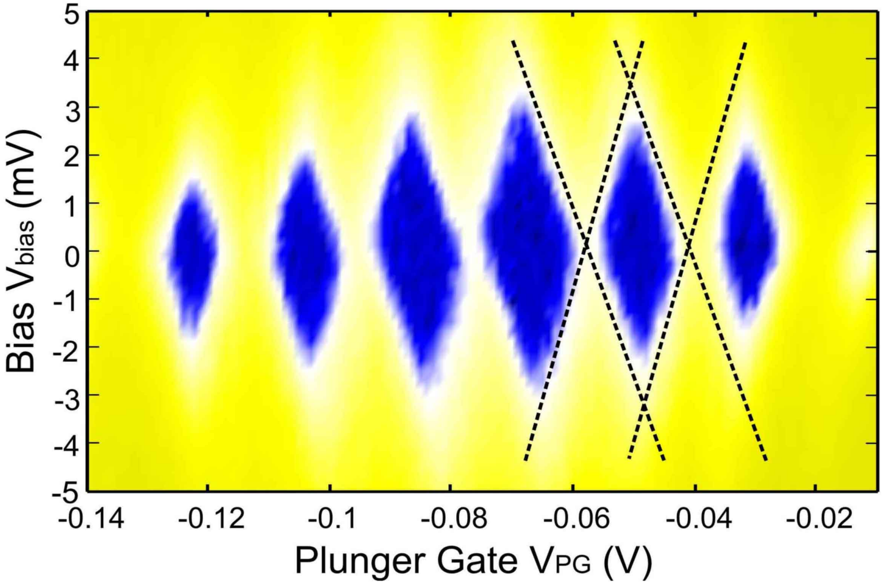


Conductivity is a ≈ linear function of gate voltage

Graphene quantum dots

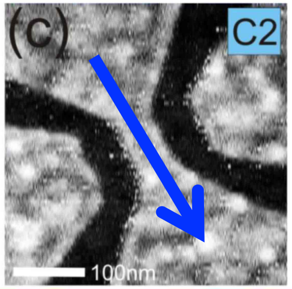


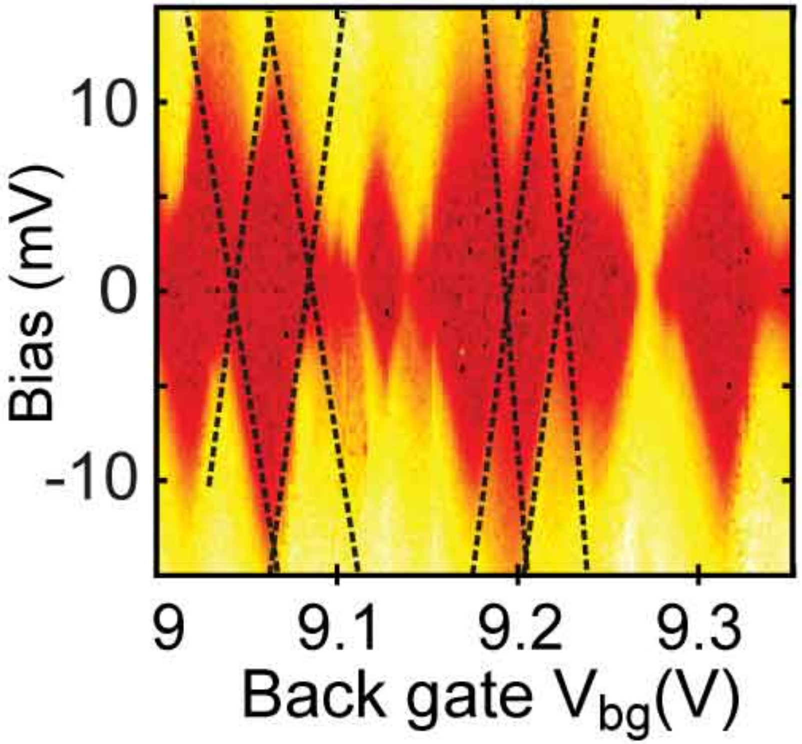




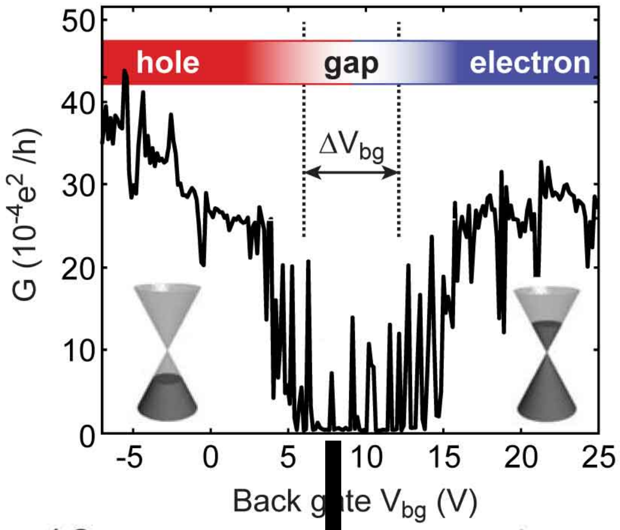
Coulomb blockade

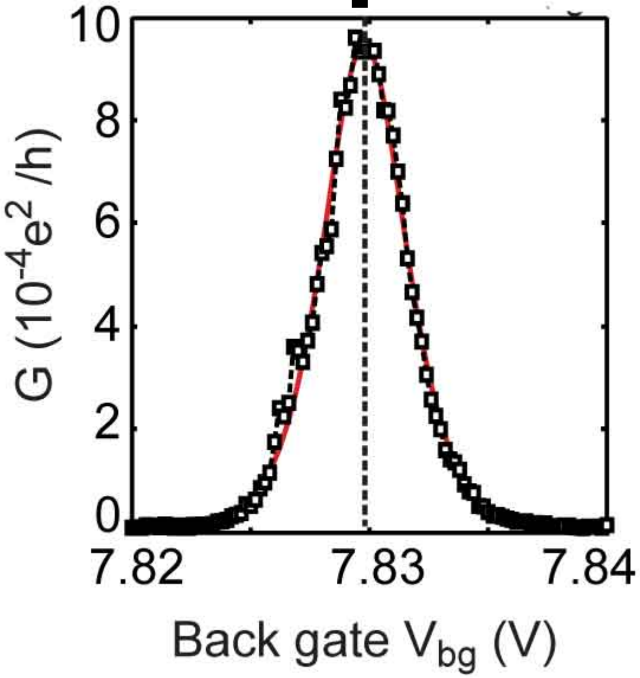
But: Graphene constrictions



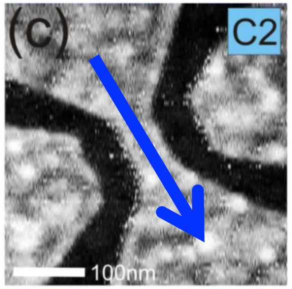


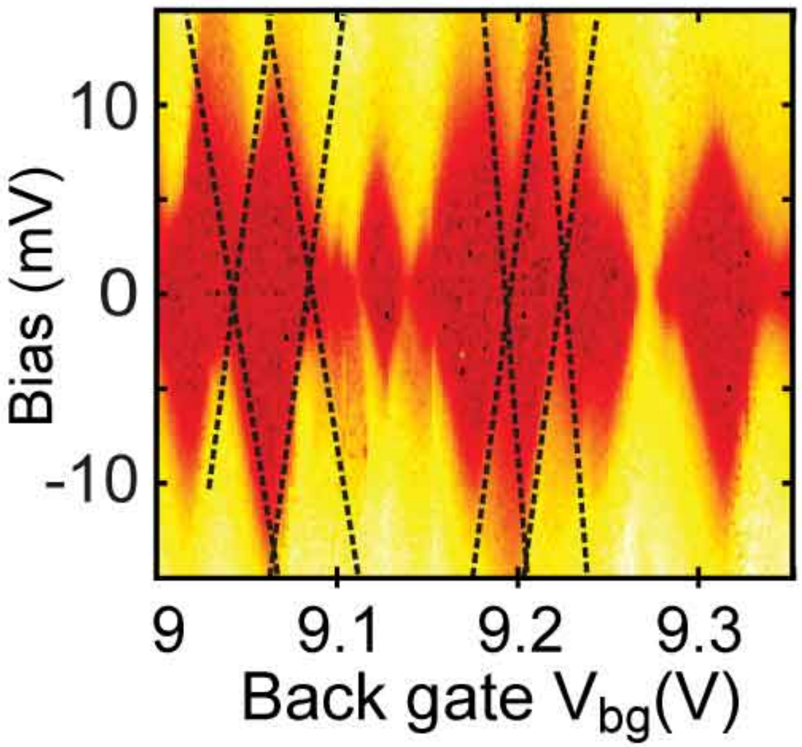
Coulomb blockade

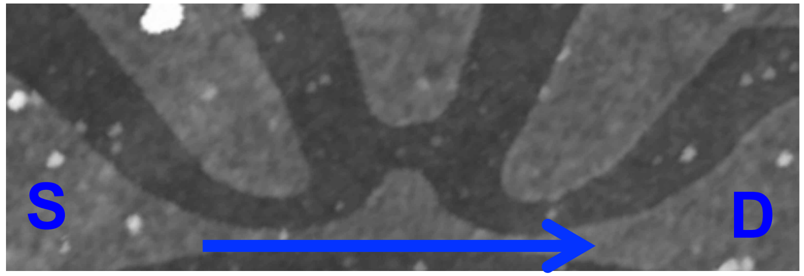


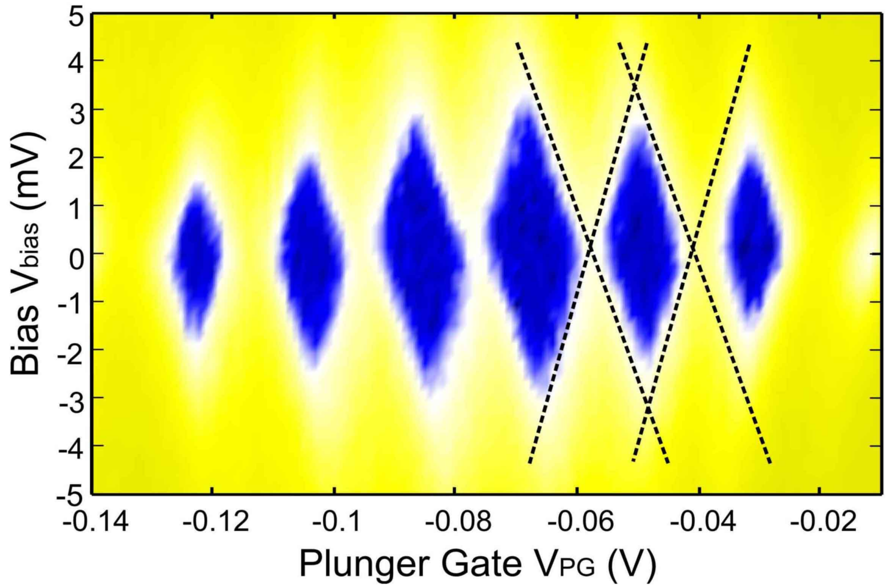


Constrictions and dots



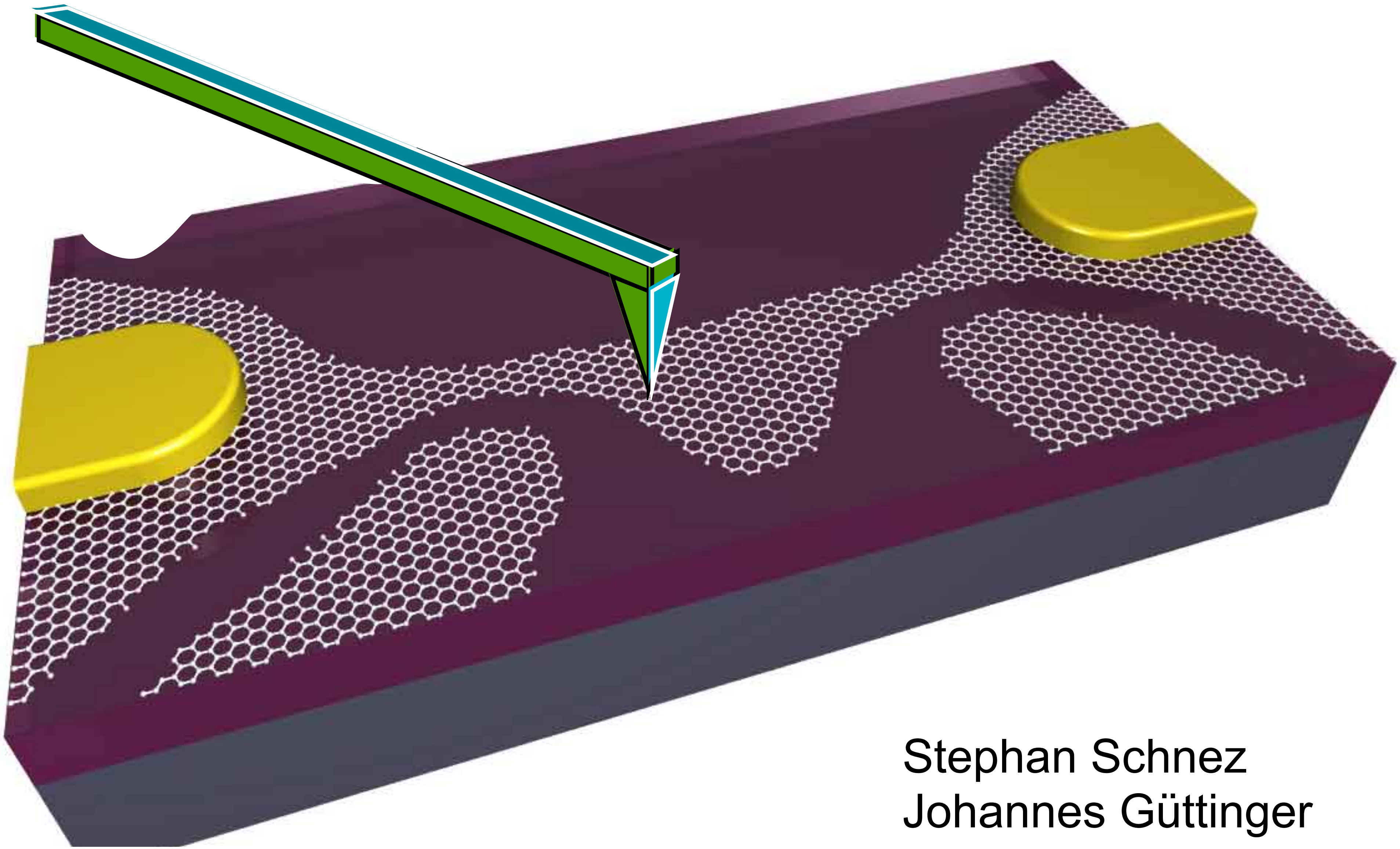






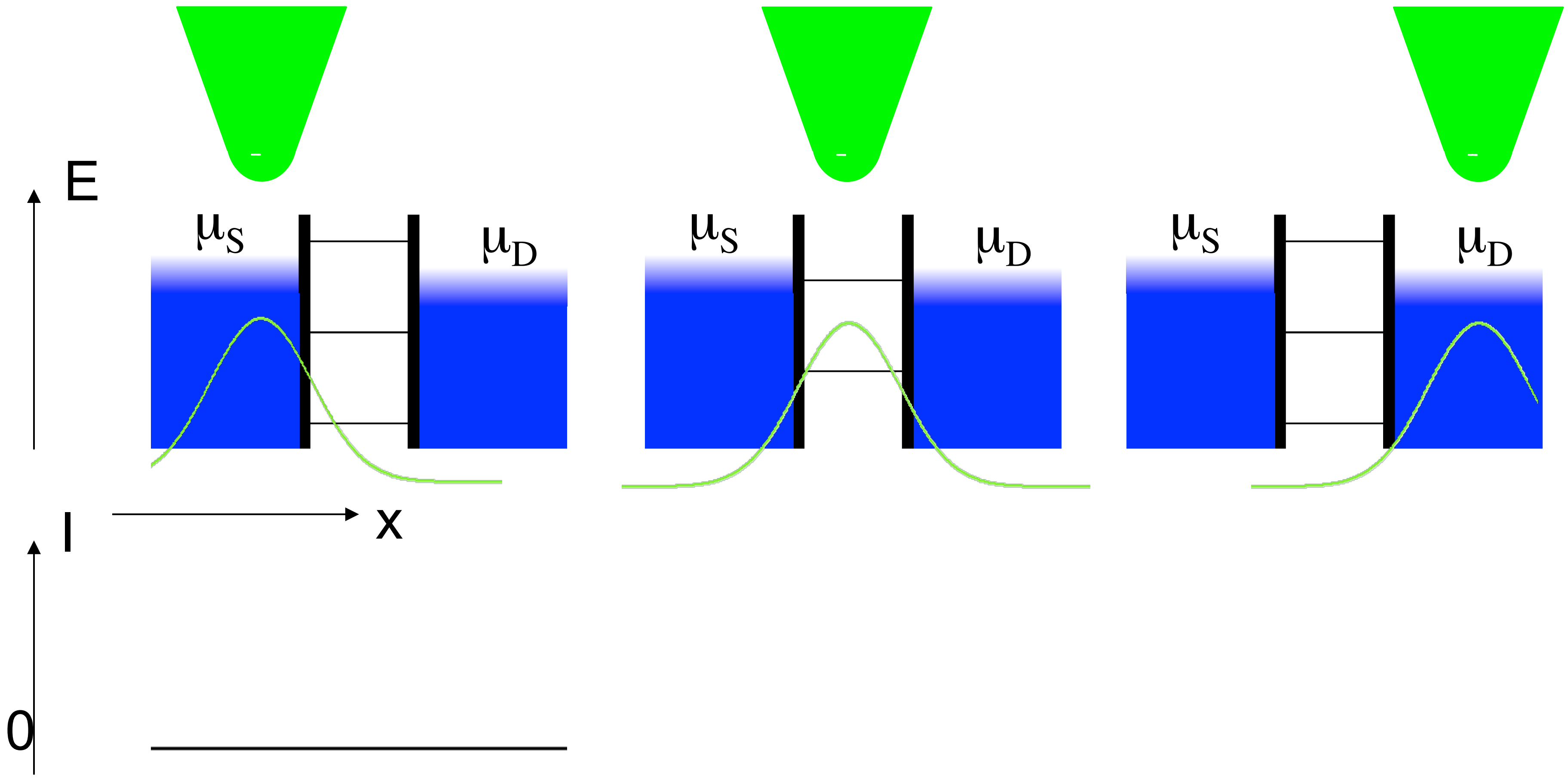
How to distinguish confined states in constrictions and dots?

Scanning gate experiments



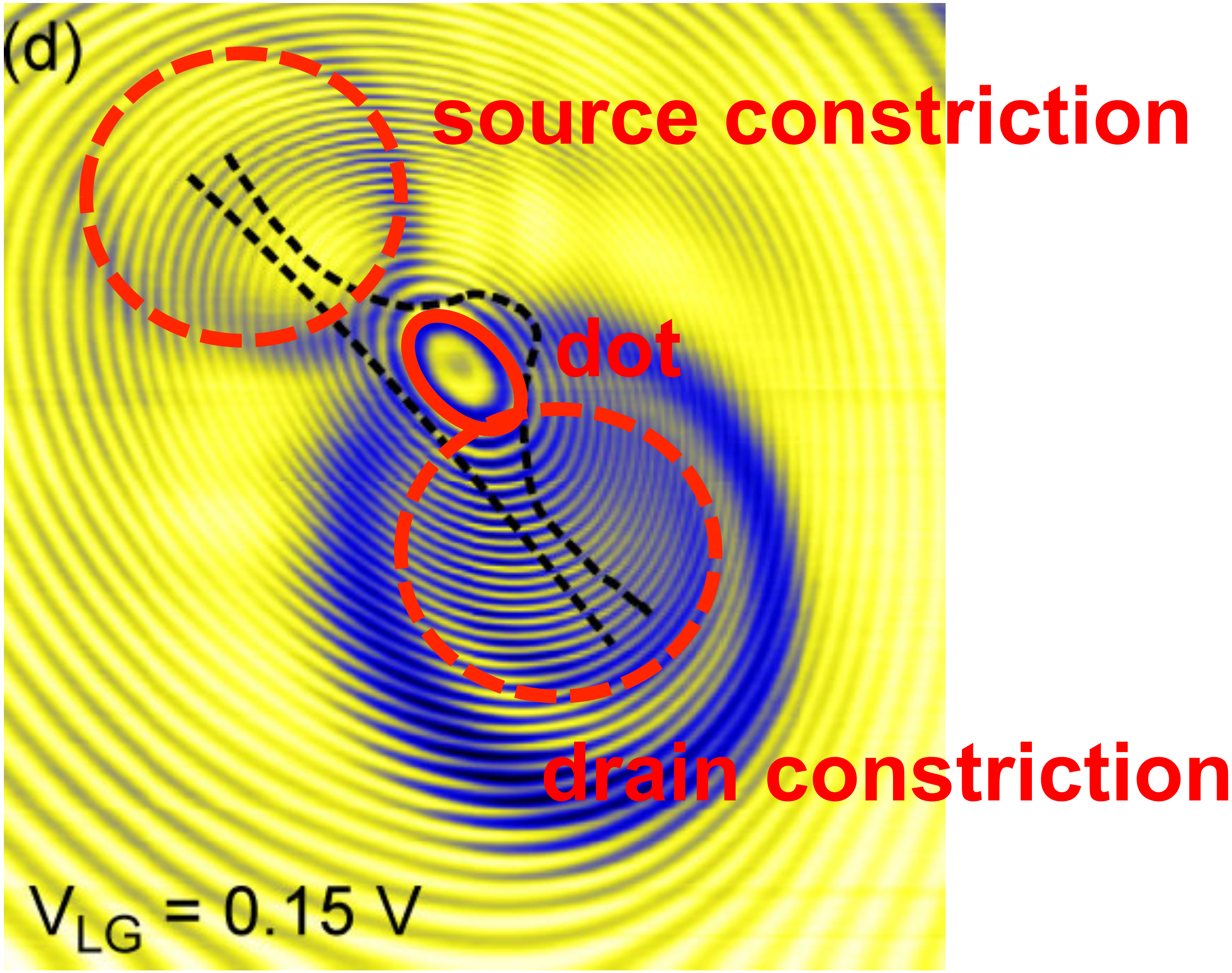
Stephan Schnez
Johannes Güttinger

Scanning the tip of an AFM across a quantum dot

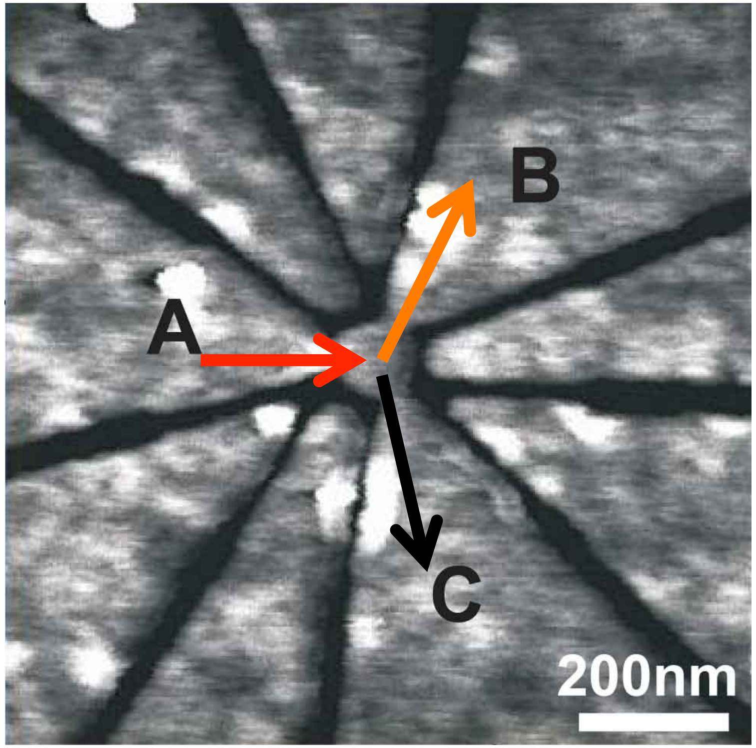


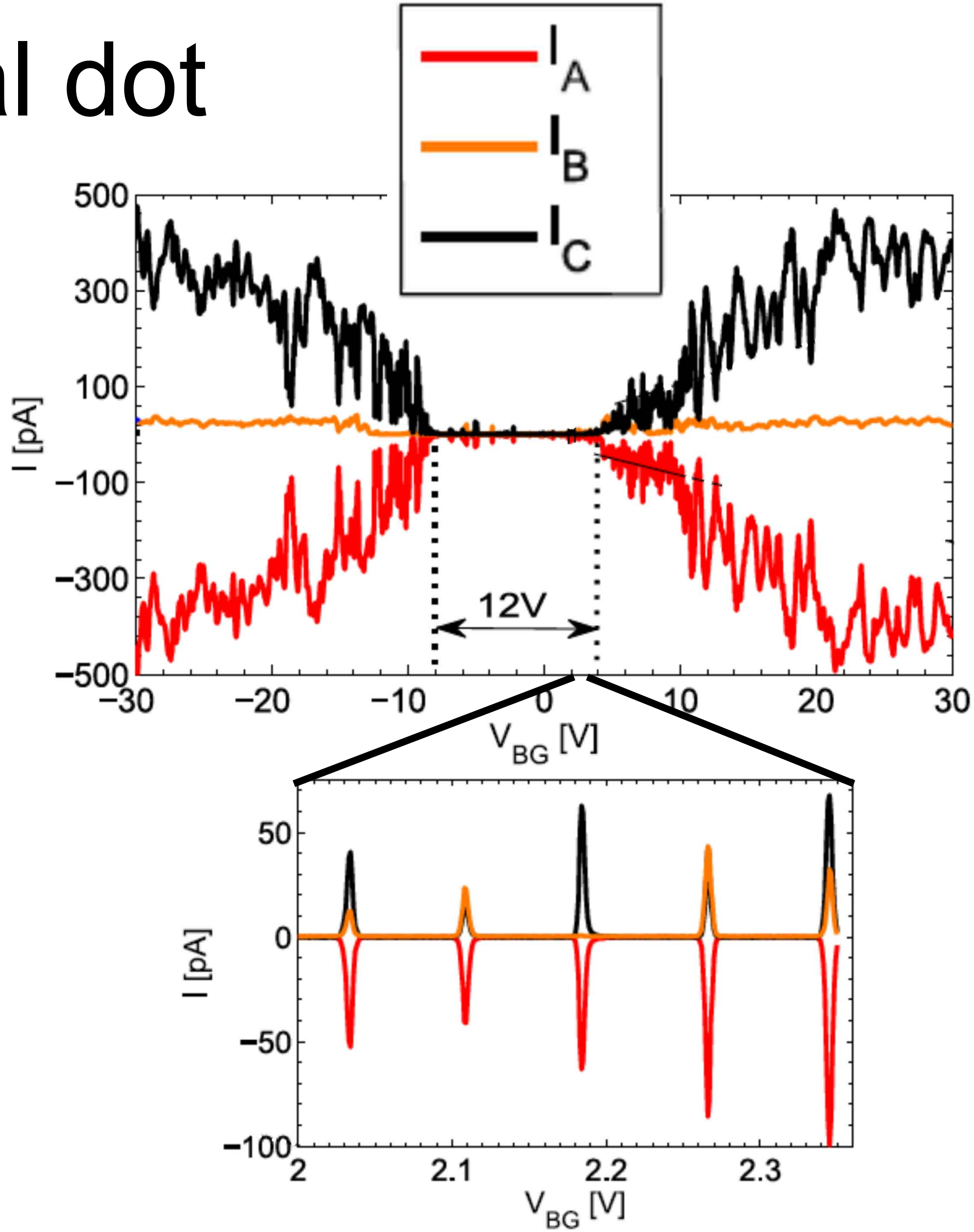
Coulomb blockade resonance Coulomb blockade

Scanning gate experiments



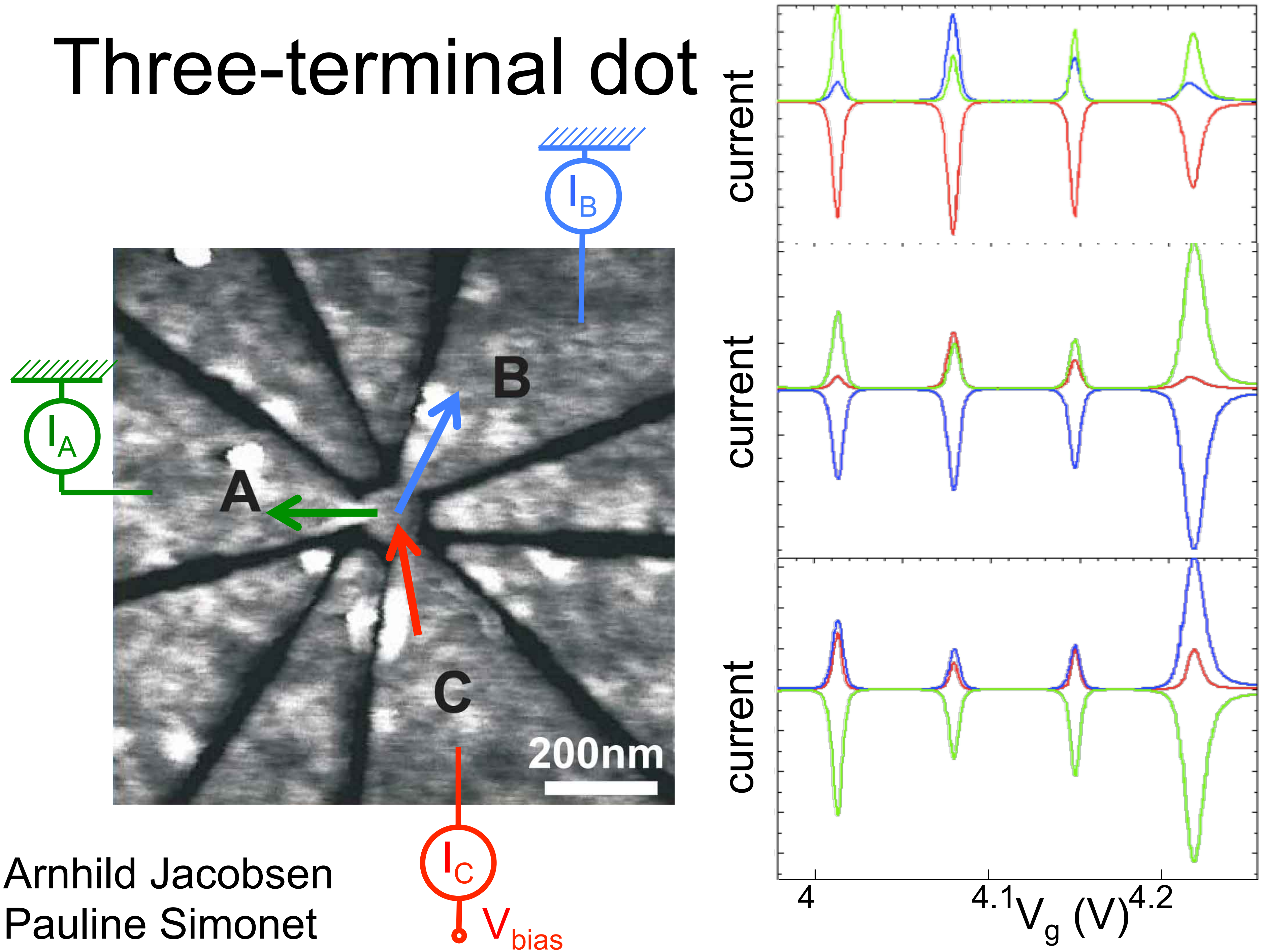
Three-terminal dot





Arnhild Jacobsen
Pauline Simonet

Three-terminal dot



Arnhild Jacobsen
Pauline Simonet

Three-terminal dot

conductance matrix

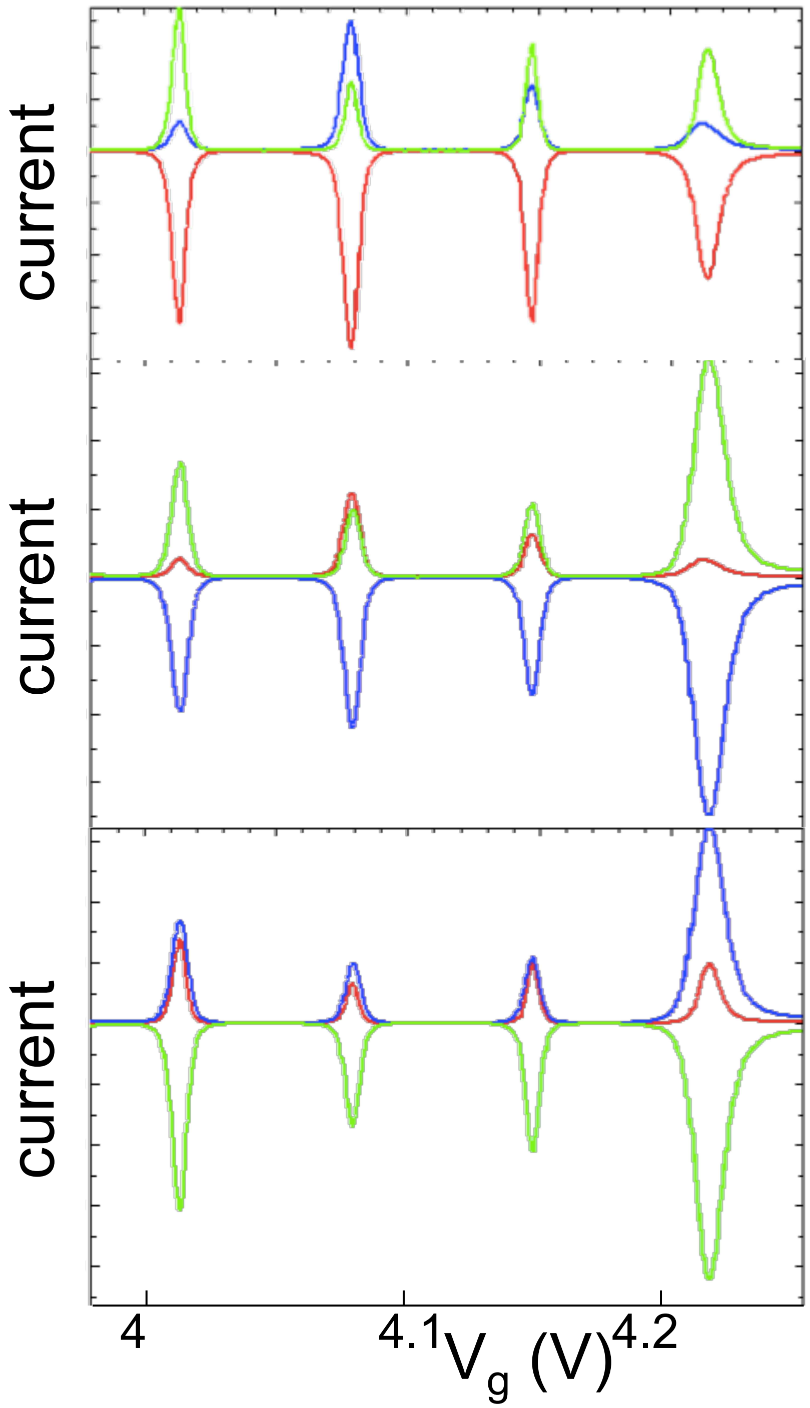
$$\begin{pmatrix} I_1 \\ I_2 \\ I_3 \end{pmatrix} = \begin{pmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \\ V_3 \end{pmatrix}$$

sum rules

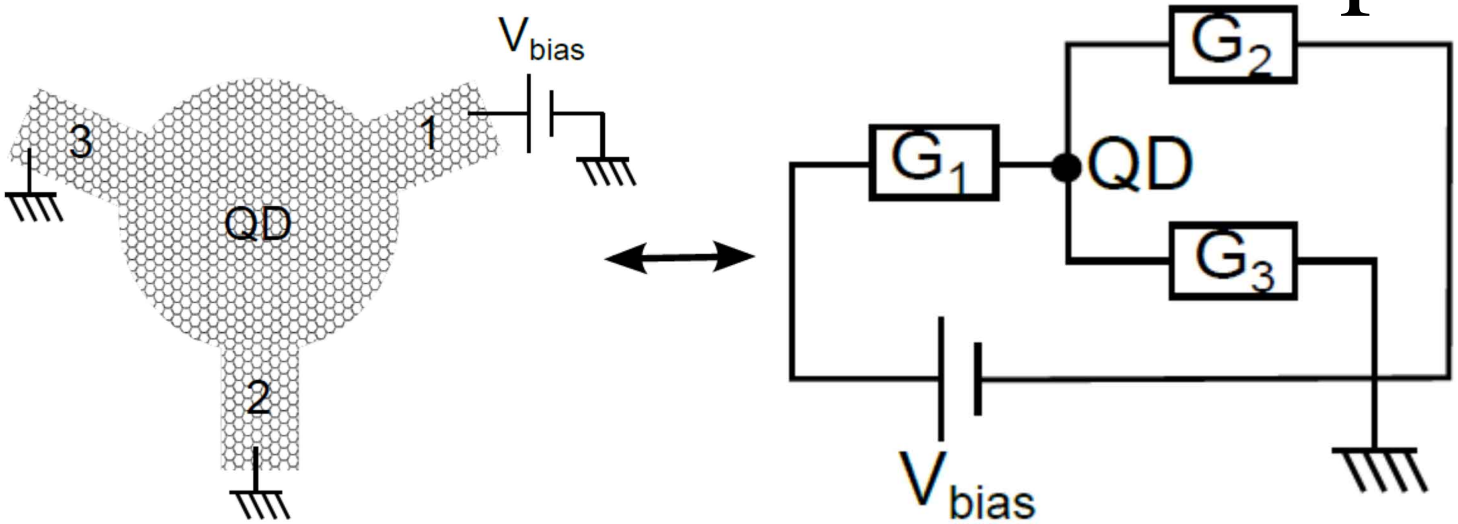
current conservation:

$$\sum I_i = 0 \rightarrow \sum_{i=1}^{3} G_{ij} = 0$$

$$V_1 = V_2 = V_3 \rightarrow \mathrm{I}_i = 0 \rightarrow \sum_{j=1}^{3} G_{ij} = 0$$



measurement set-up



Kirchhoff rules

apply voltage to one terminal
measure current in three terminals

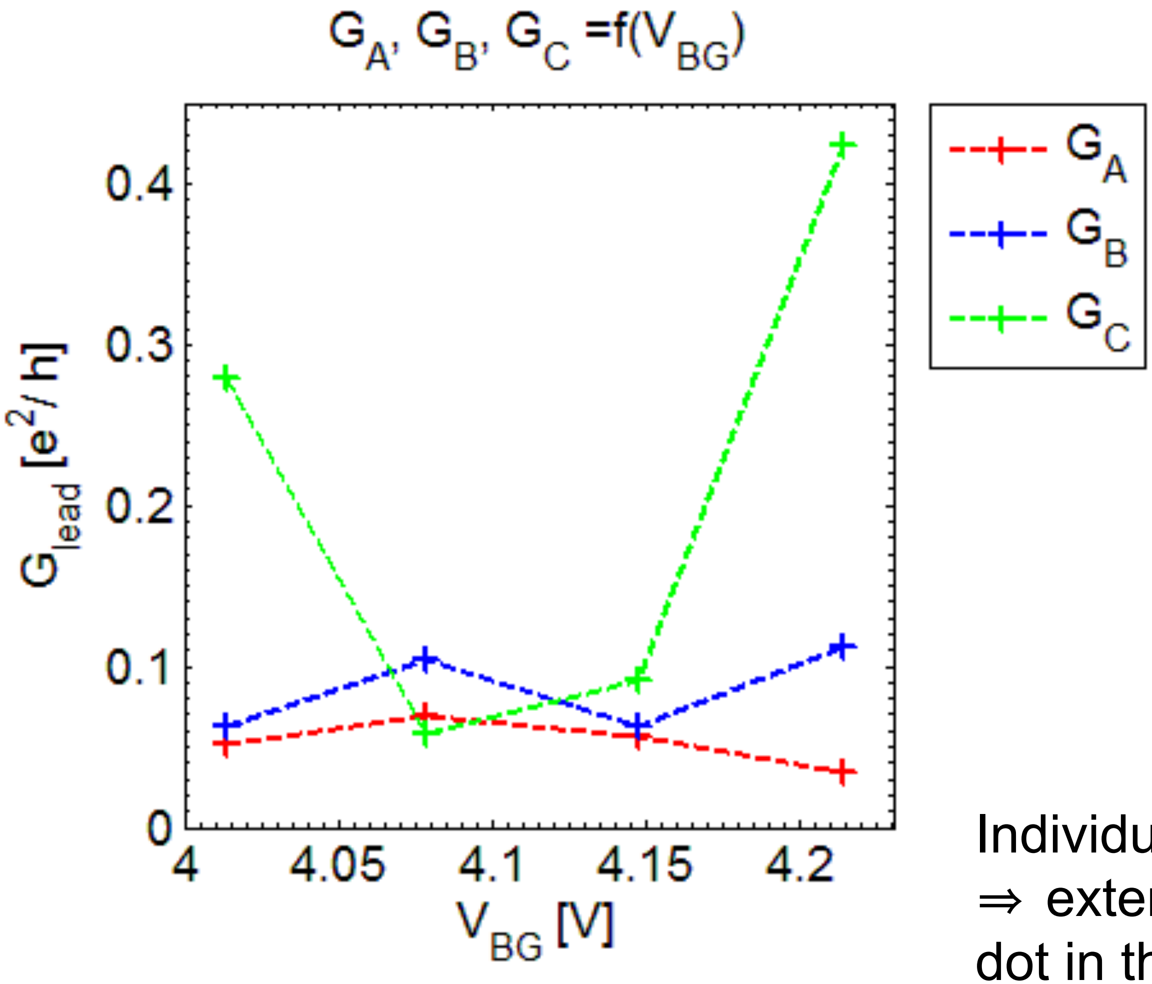
G_{ij}: three-terminal conductance
G_l: lead conductance

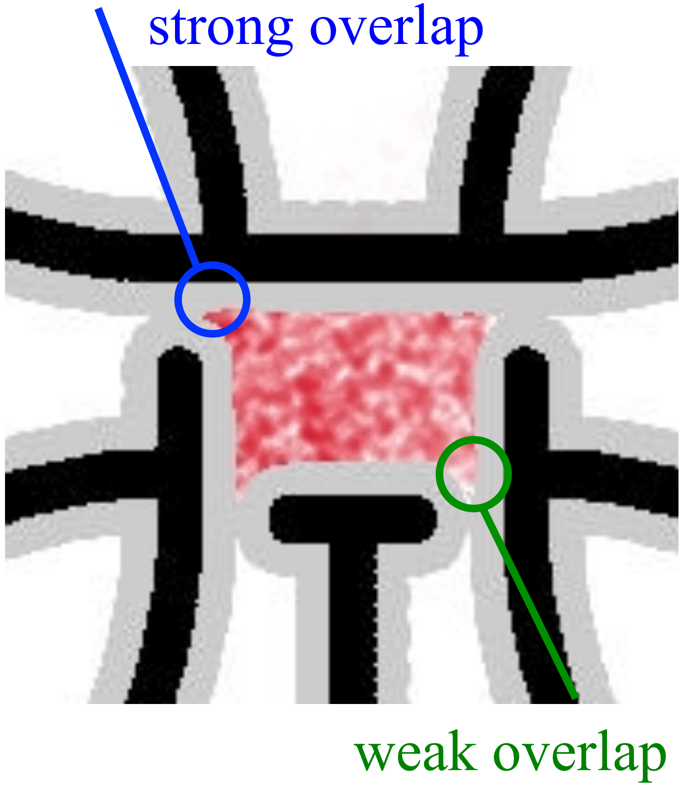
$$\begin{pmatrix} G_{11} & G_{12} & G_{13} \\ G_{21} & G_{22} & G_{23} \\ G_{31} & G_{32} & G_{33} \end{pmatrix} = \frac{1}{G_1 + G_2 + G_3} \begin{pmatrix} G_1(G_2+G_3) & -G_1G_2 & -G_1G_3 \\ -G_1G_2 & G_2(G_1+G_3) & -G_2G_3 \\ -G_3G_3 & -G_3G_2 & G_3(G_1+G_2) \end{pmatrix}$$

2-terminal sequential tunneling:

$$G_n = \frac{e^2}{h}\frac{1}{4kT}\left(\frac{1}{\Gamma_n^S} + \frac{1}{\Gamma_n^D}\right)^{-1} \cosh^{-2}\left(\frac{\alpha_G\left(V_G^n - V_G\right)}{2kT}\right)$$

Three-terminal dot:
-> lead conductances

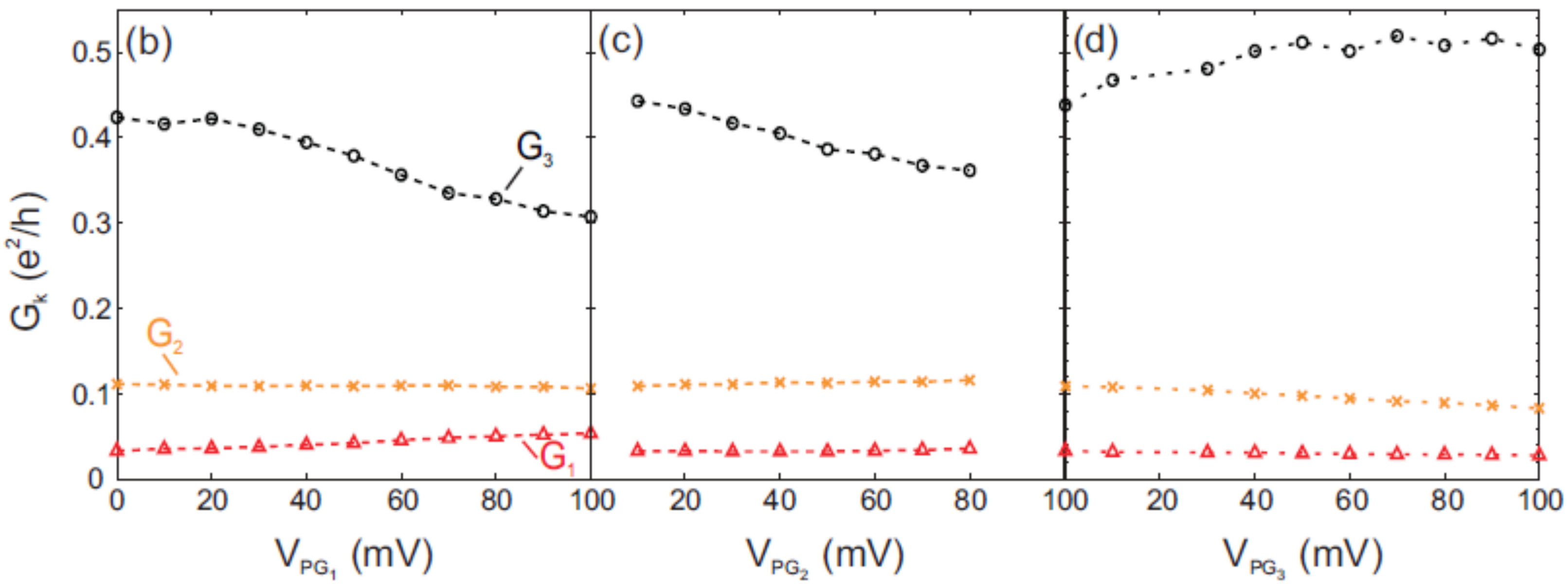




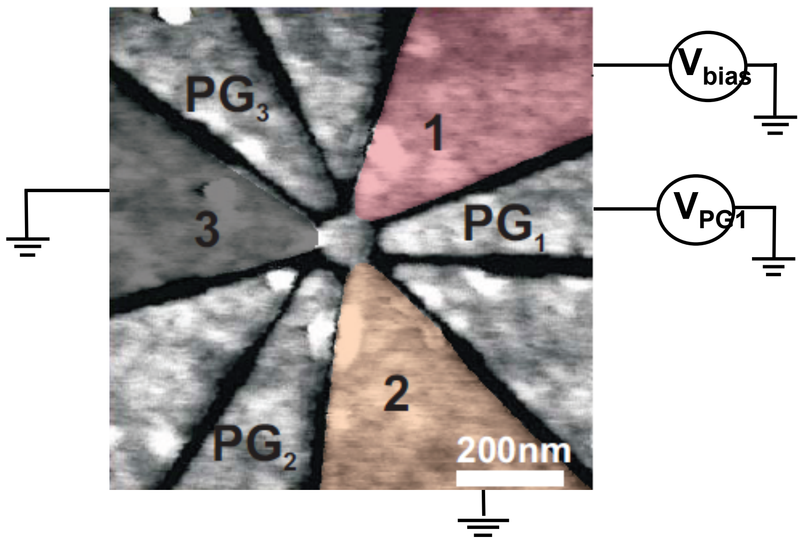
Individual coupling to the leads
⇒ extent of the wave function in the dot in the vicinity of the leads.

Arnhild Jacobsen, Pauline Simonet

Lateral gating

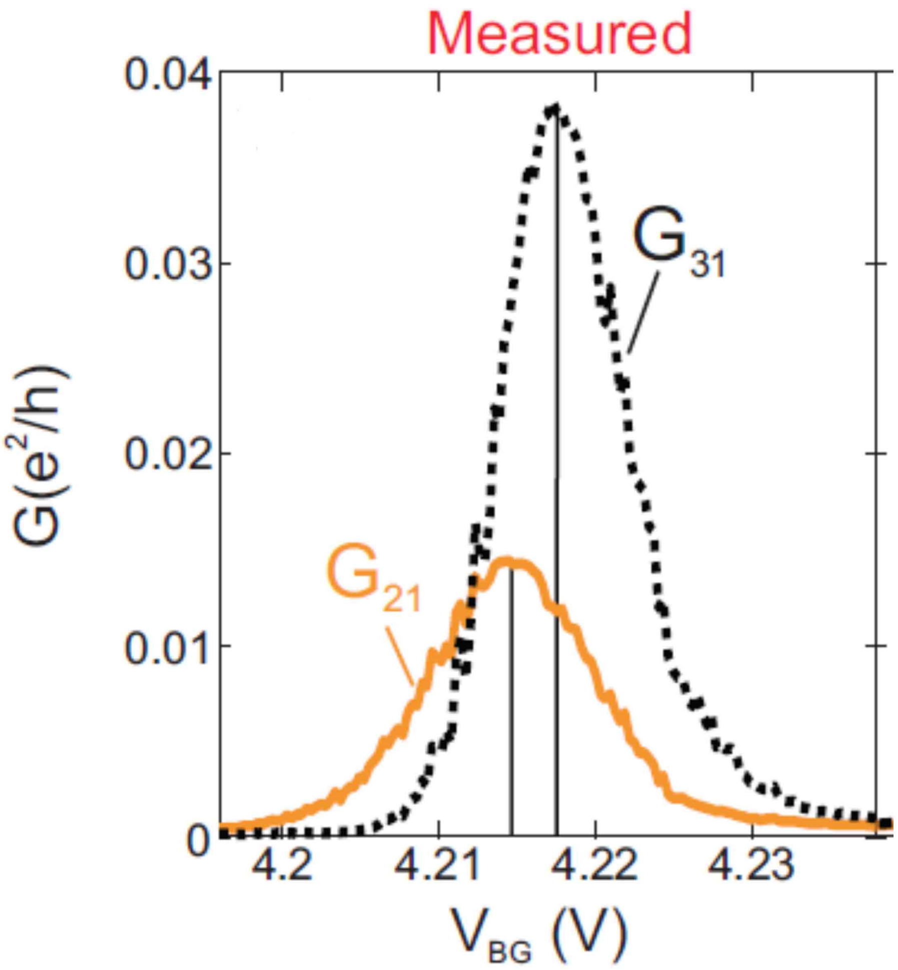


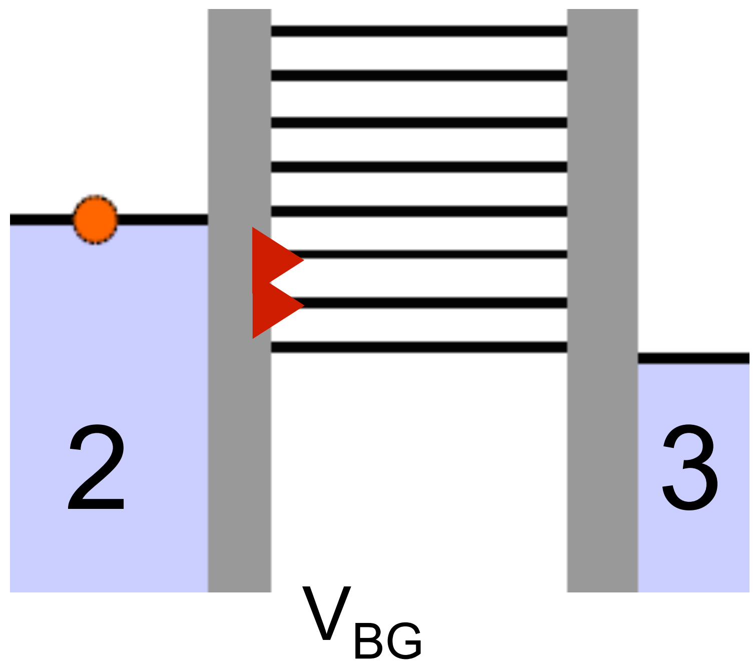
Points taken at $V_{BG} \approx$ Peak
* resonance



- Plunger gates seem to tune dominantly the dot.
- Homogeneous dot rather than puddles.

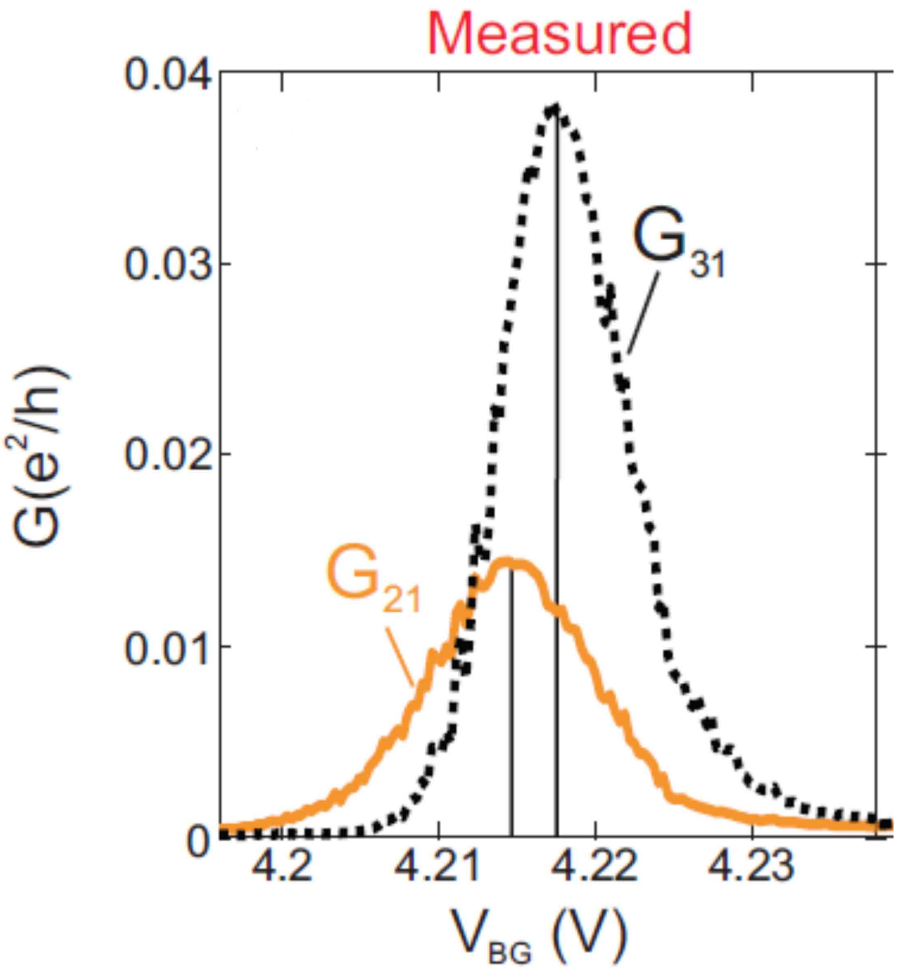
Multi-level transport





Resonances in two leads at slightly different energies

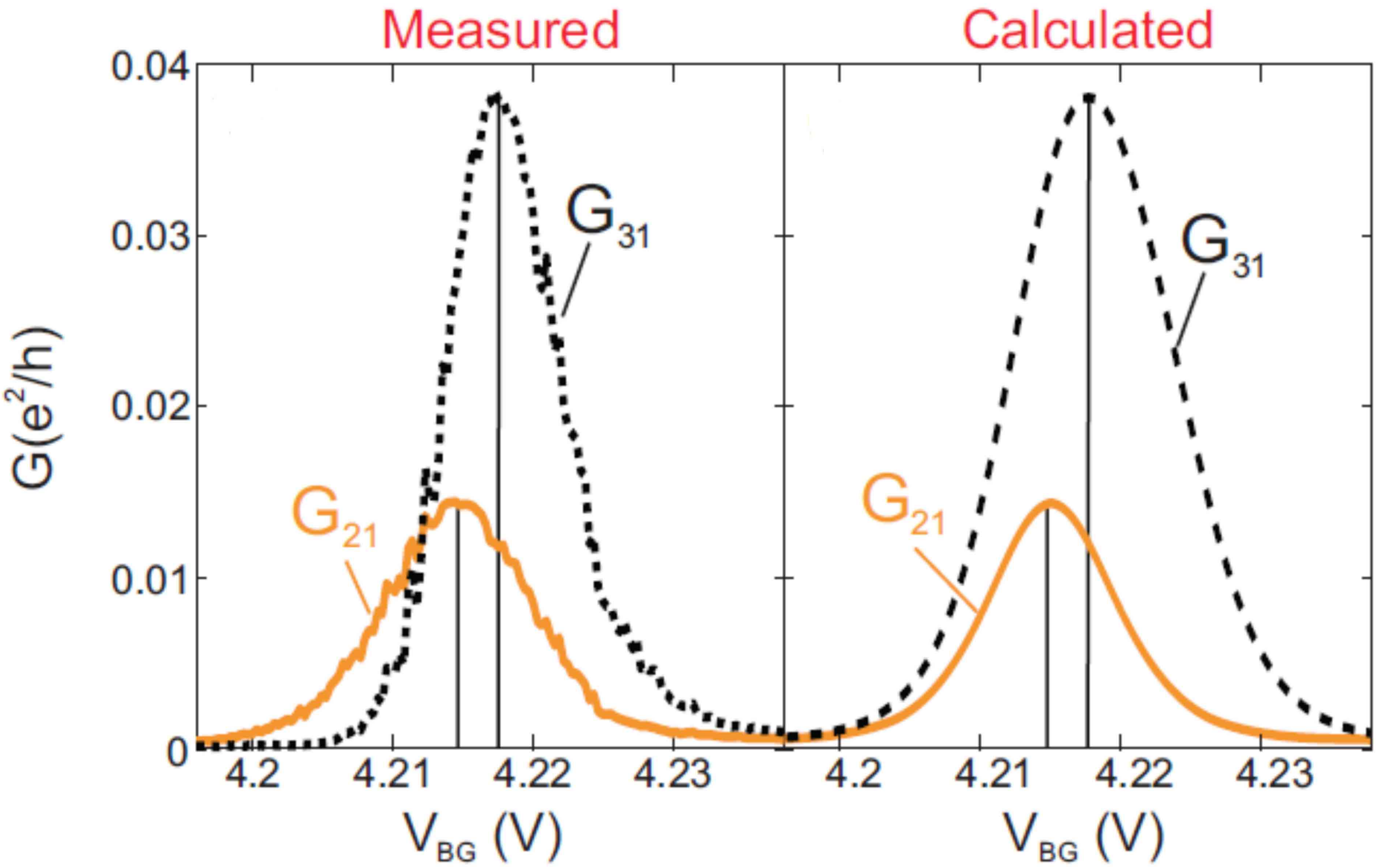
Multi-level transport



- Rate equations
- Linearization (Beenakker, 1991)
- 2 contributing currents from 2 levels
- Parameters:
  - single particle level spacing
  - peak height
  - distribution of current between two levels

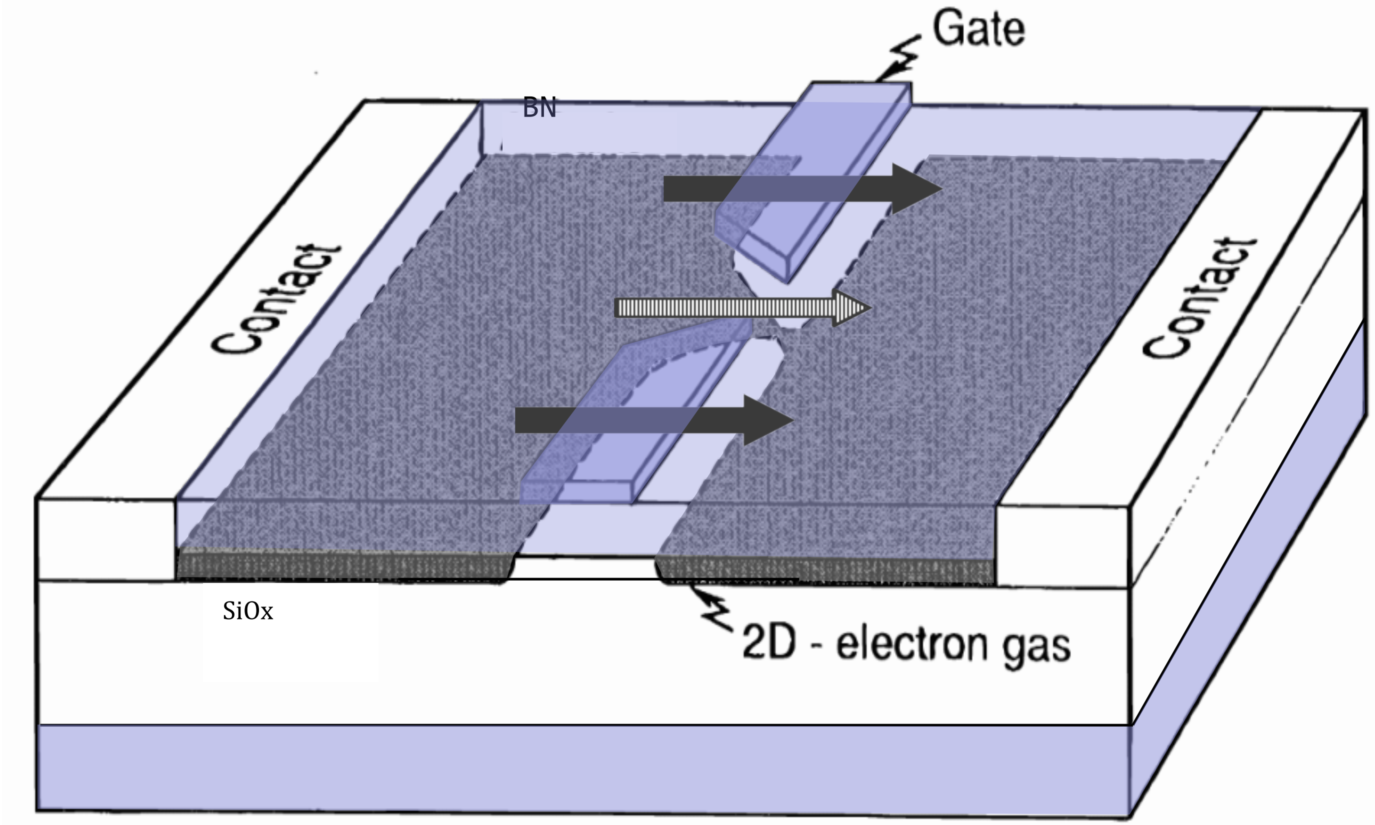
Resonances in two leads at slightly different energies

Multi-level transport



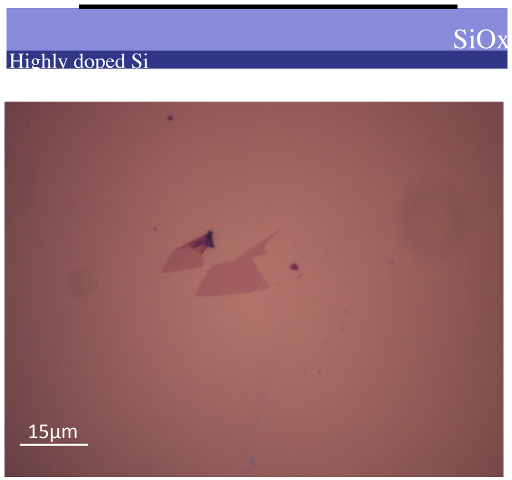
Resonances in two leads at slightly different energies

Split-gates on bilayer graphene

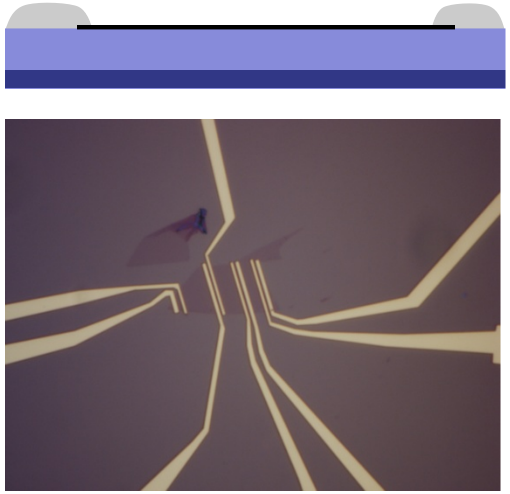


Quantum structures on bilayer graphene

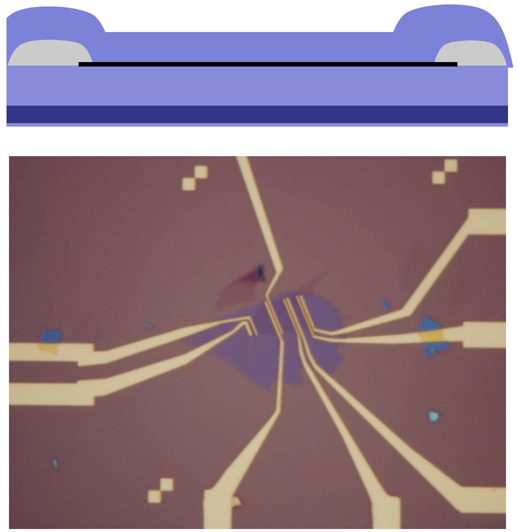
graphene deposition



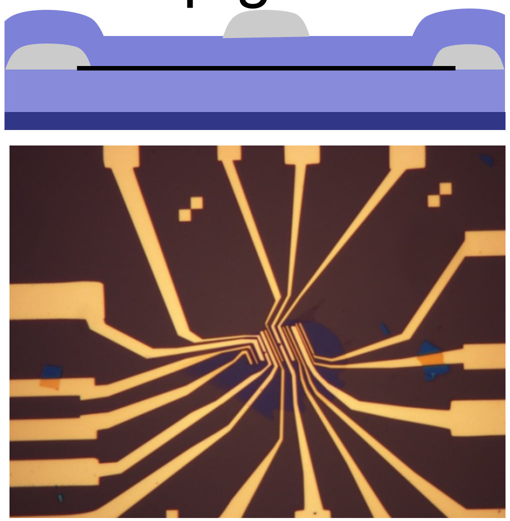
Ohmic contacts

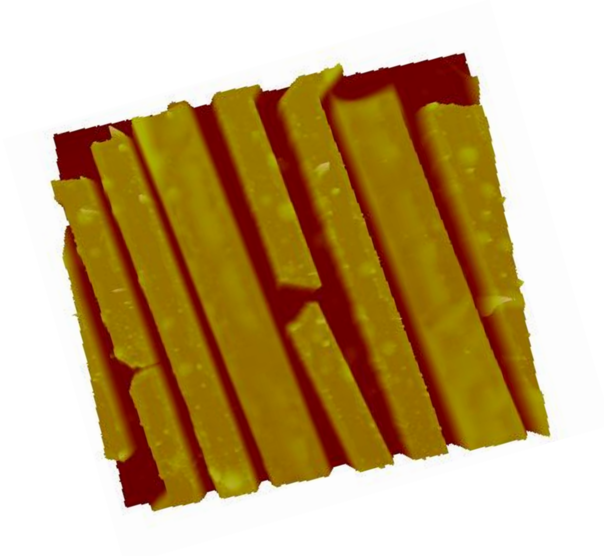


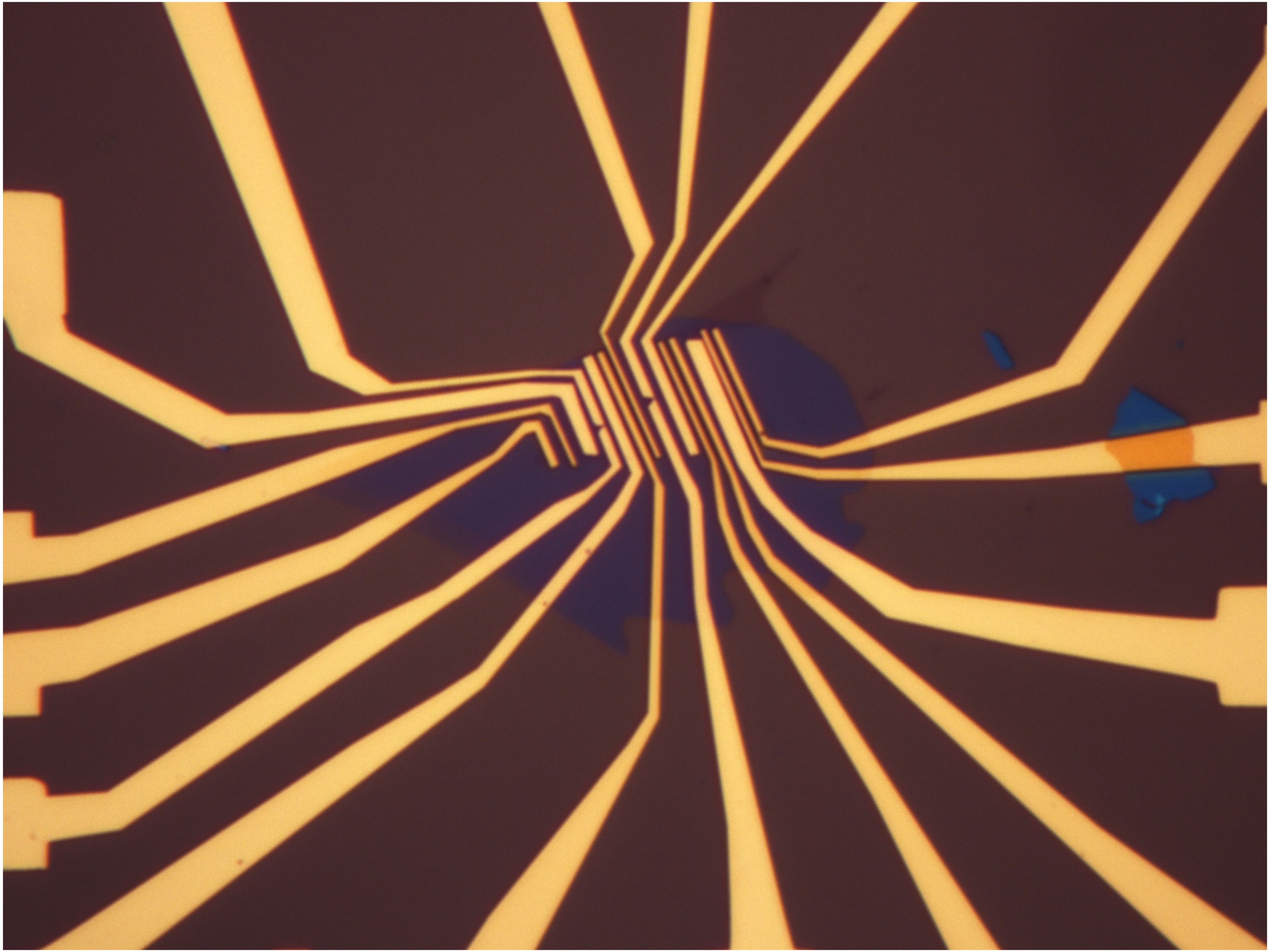
BN deposition



Top gate





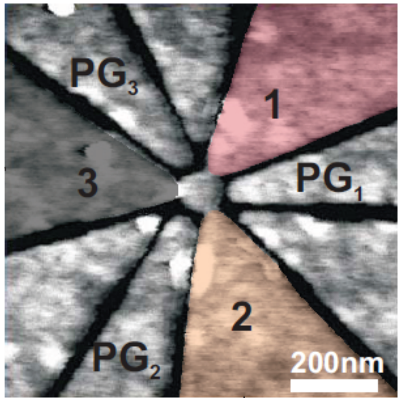


Thank you

Constrictions: Coulomb blockade
Multi-terminal quantum structures
Bilayer quantum structures

Susanne Dröscher

Clément Barraud



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