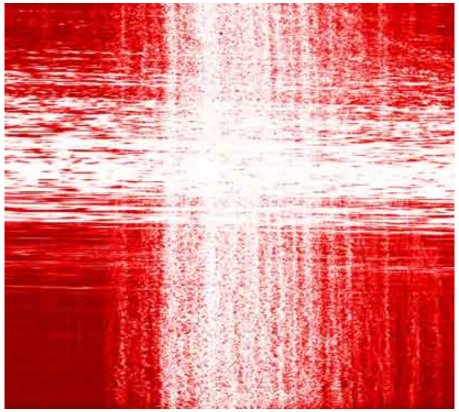
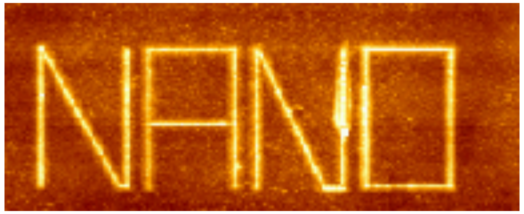
Charges, spins (and phonons) in graphene quantum dots



Klaus Ensslin



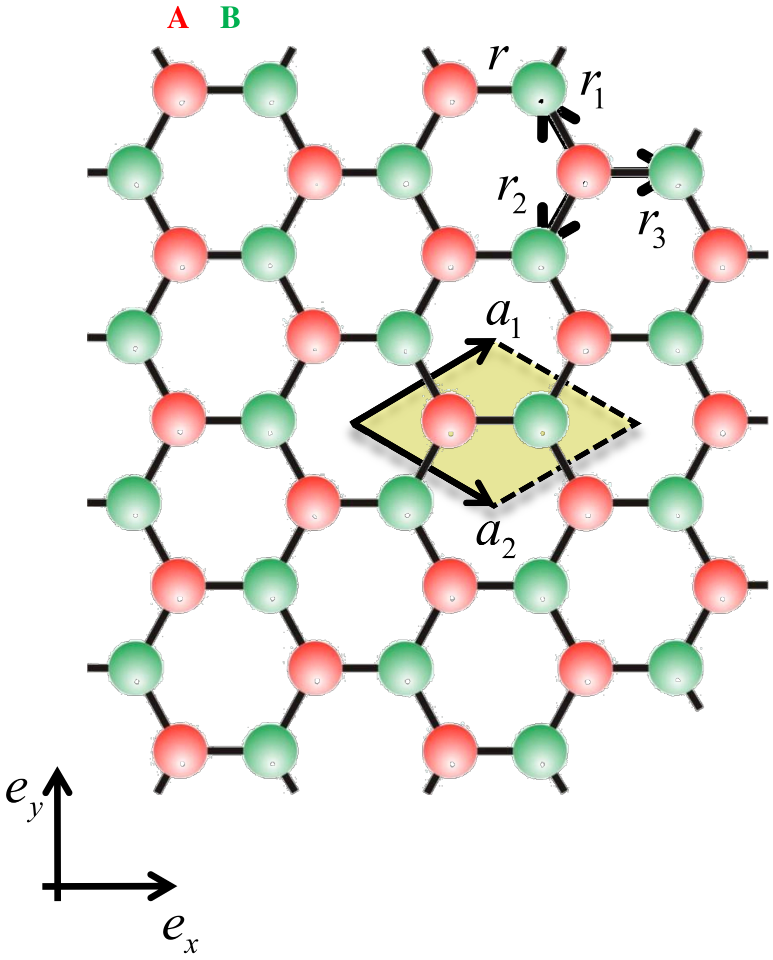
Solid State Physics ETH Zürich

With
F. Molitor
J. Güttinger
S. Schnez
S. Dröscher
A. Jacobsen
C. Stampfer
T. Ihn

- graphene quantum dots
- orbital and spin effects
- double dots and excited states

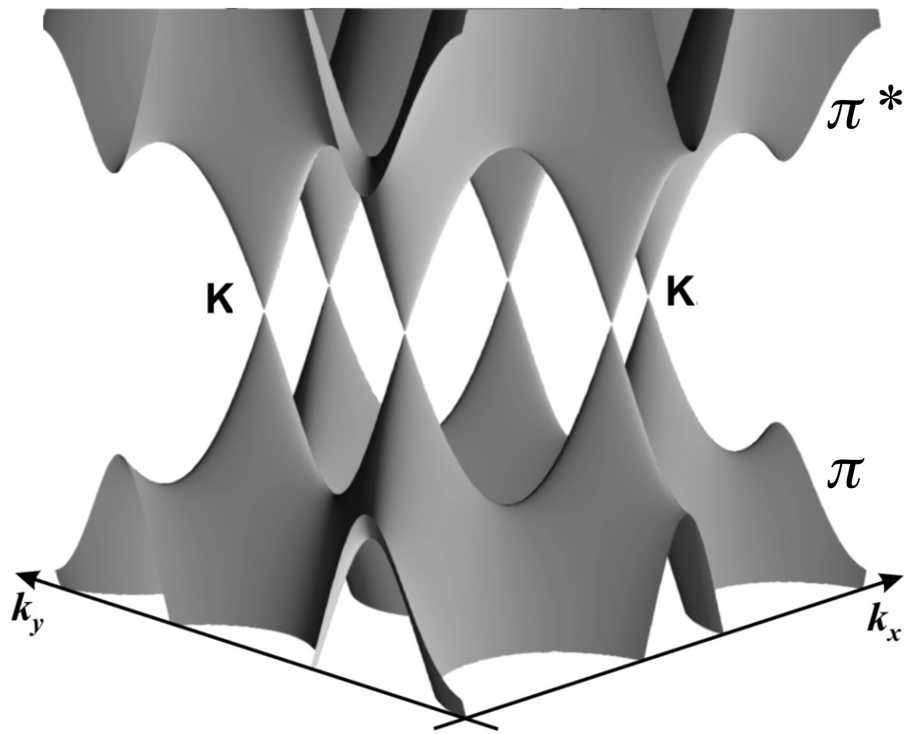
Electronic properties of Graphene

P. R. Wallace, Phys. Review **71**, 9, (1947)



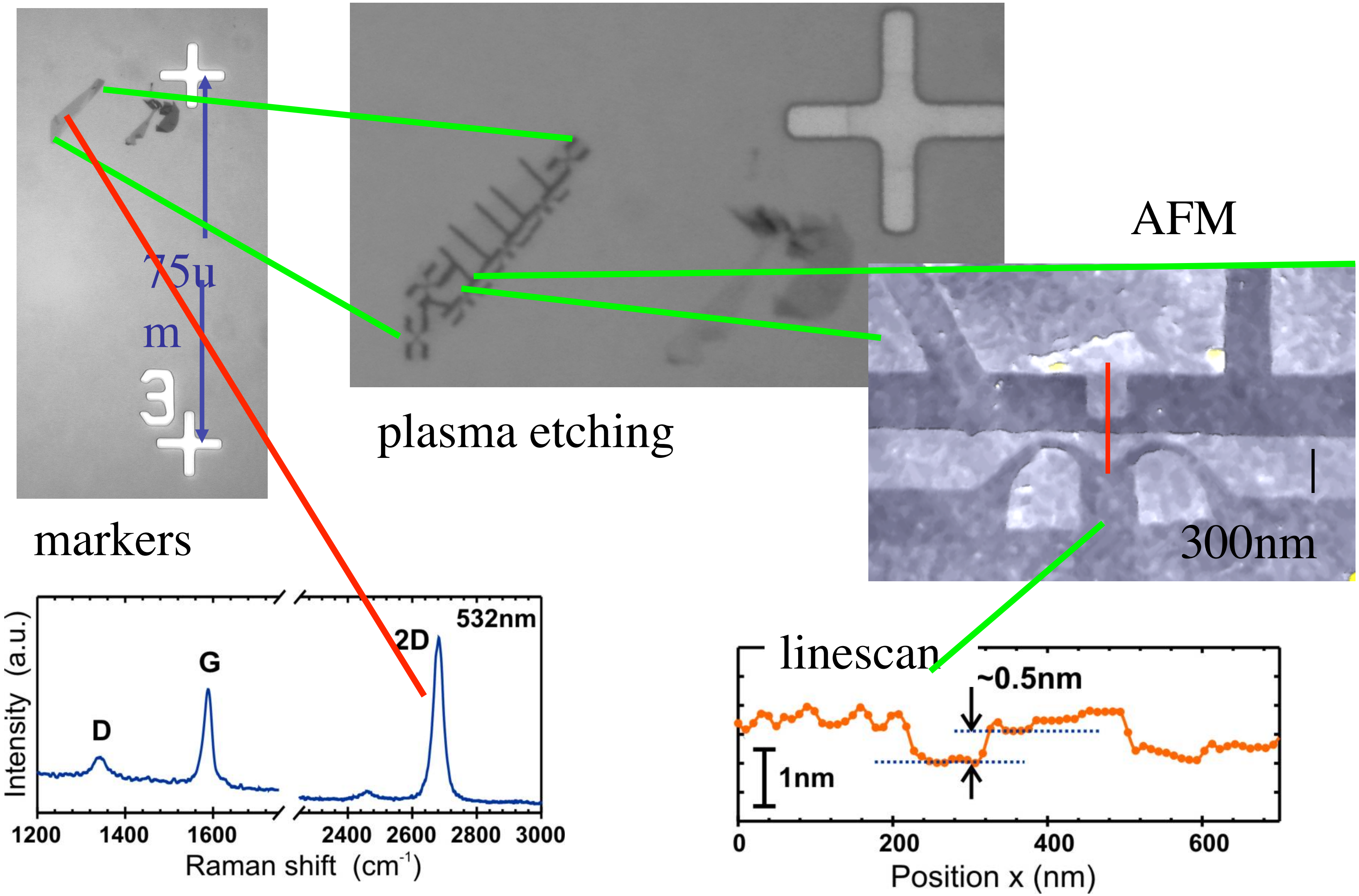
$$E_{2D}(\vec{k}) = E_0 \pm \left| \sum_{i=1}^{3} t \exp\left(\vec{k} \cdot \vec{r}_i\right) \right|$$

$t \simeq 2.6\, eV$

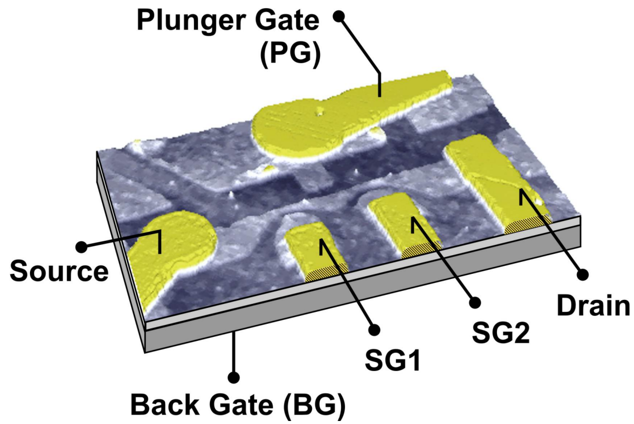


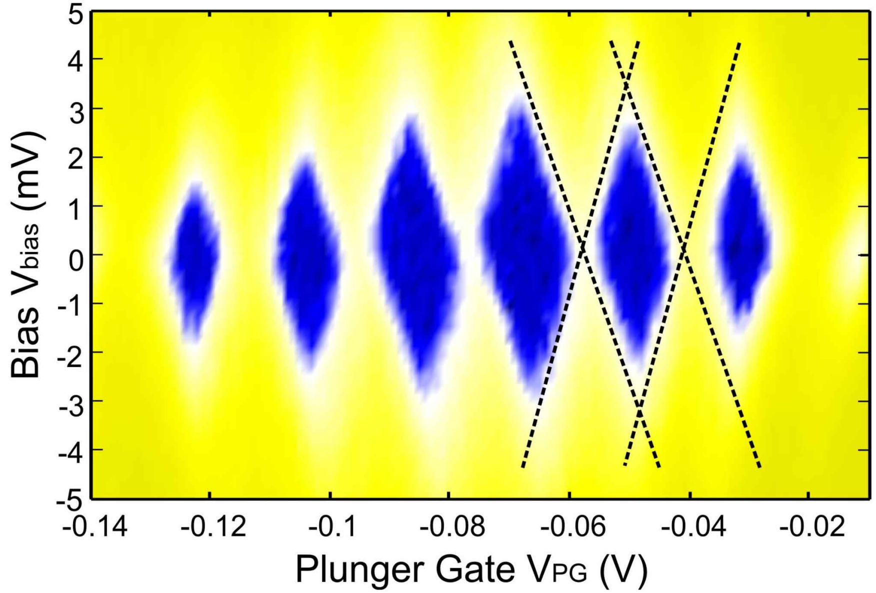
tight binding calculation

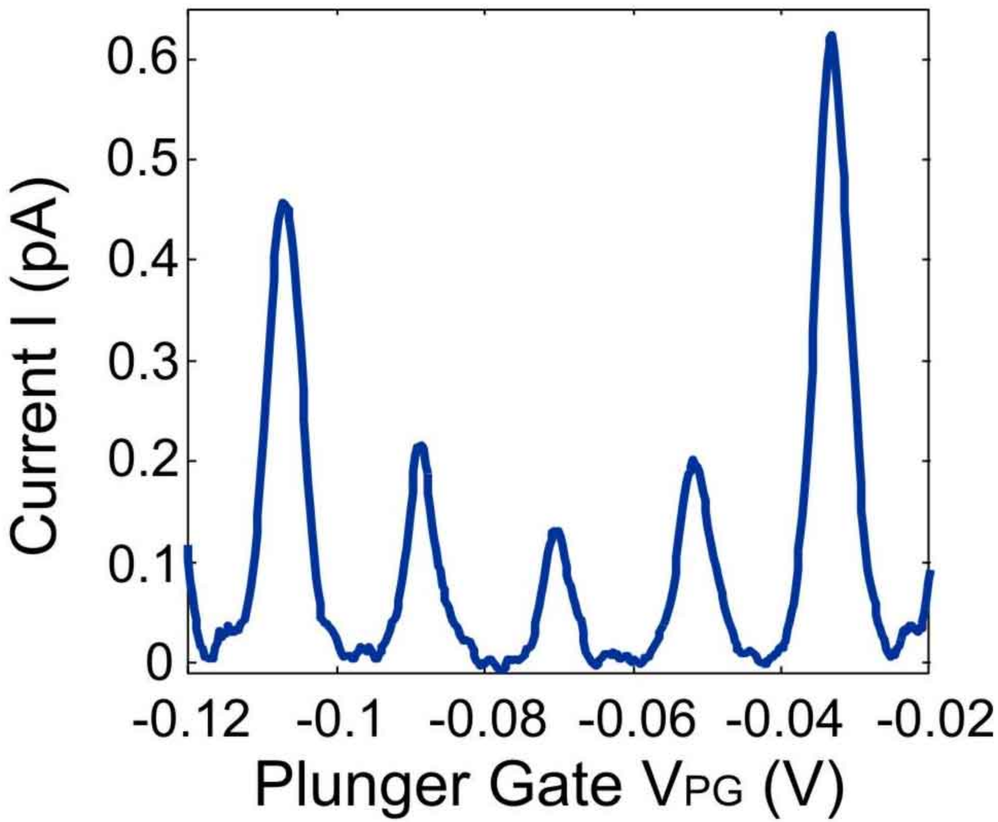
Fabrication of nanostructures



Coulomb blockade



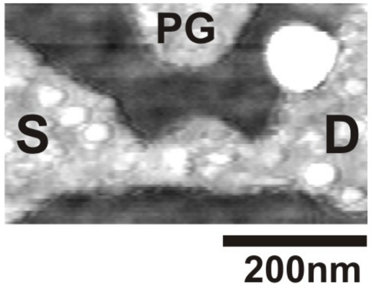


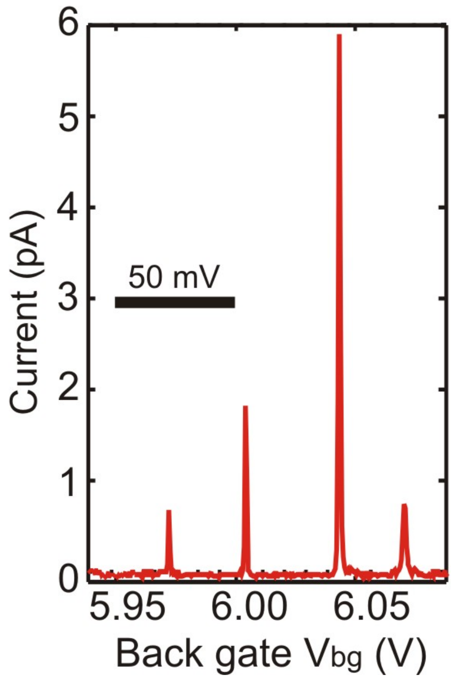


Stampfer et al. APL **92**, 012102 (2008)
Ponomarenko et al, Science **320**, 356 (2008)

Excited States in a Graphene Quantum Dot

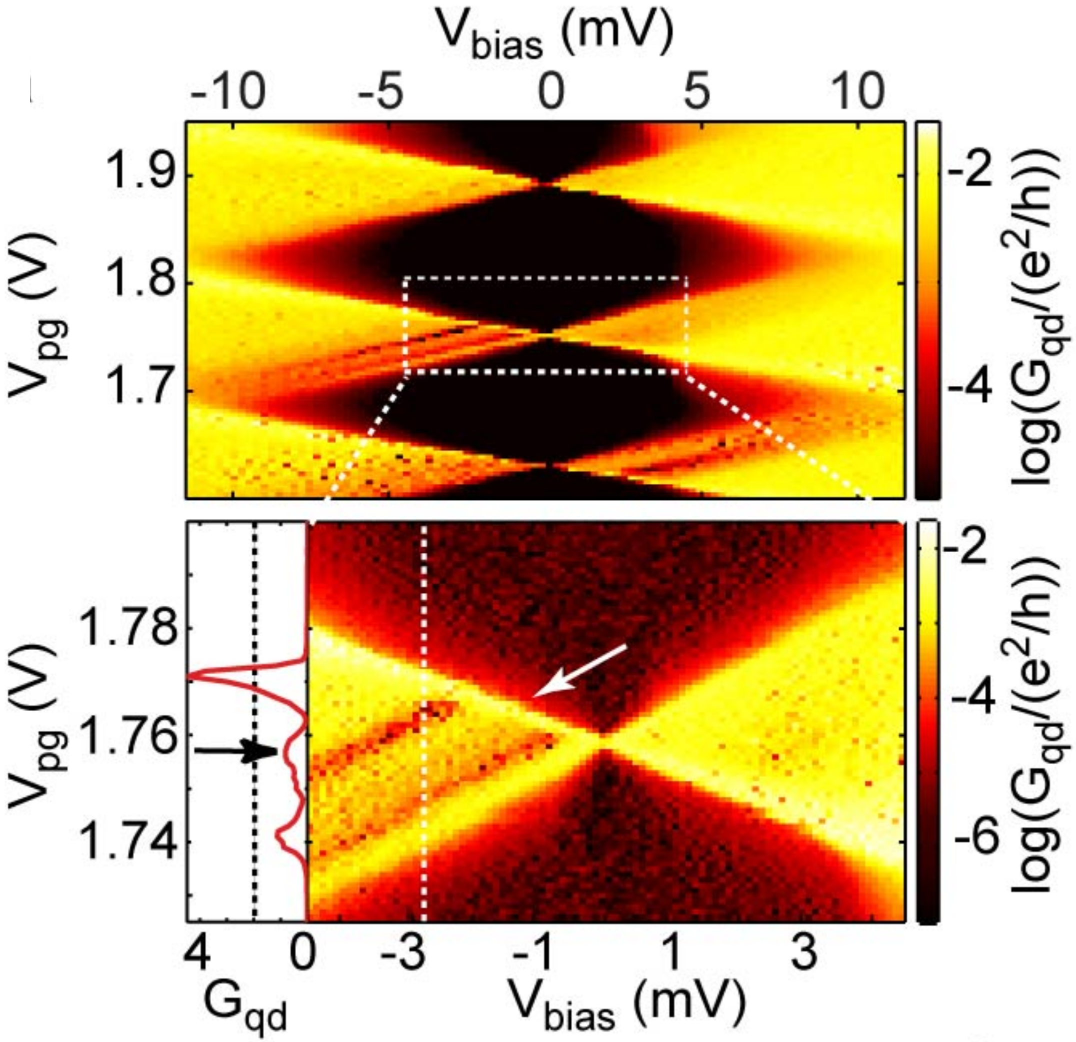
Scanning force micrograph



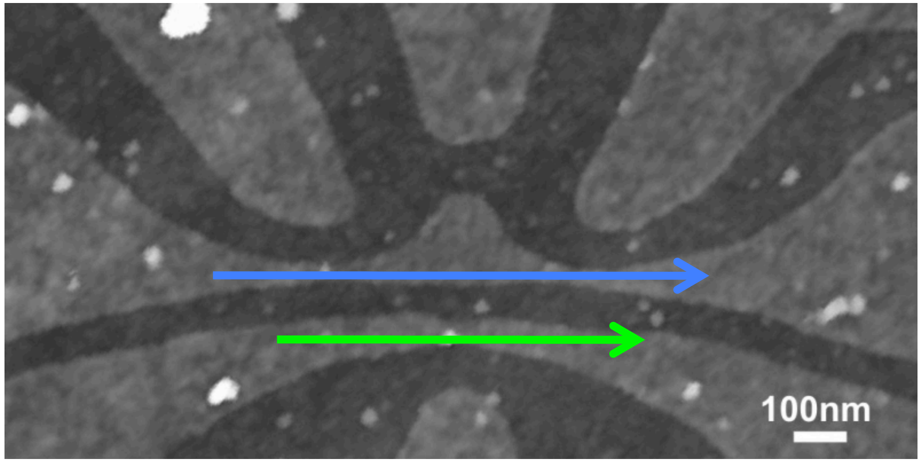


T=200mK

Vb=16μV



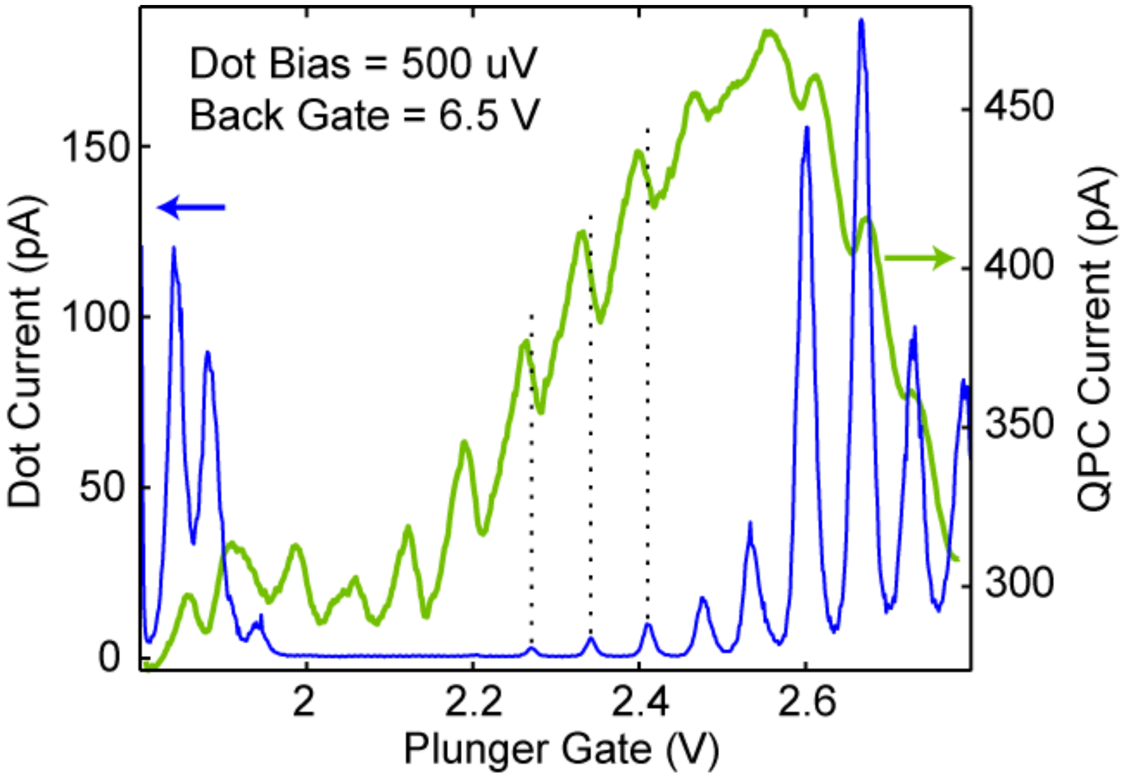
Graphene dot with charge detector



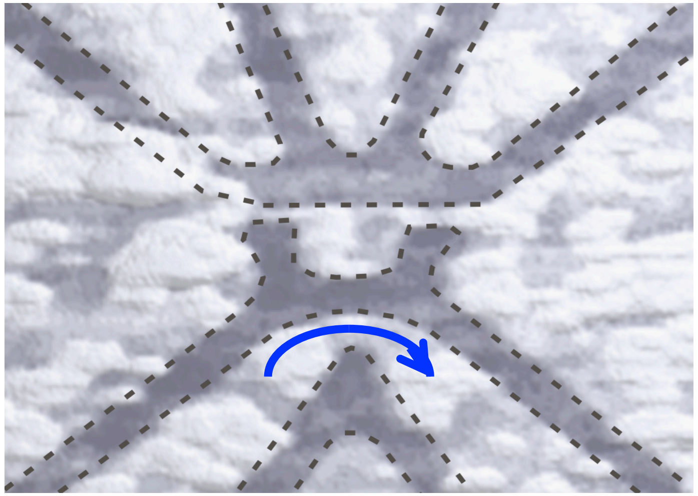
dot

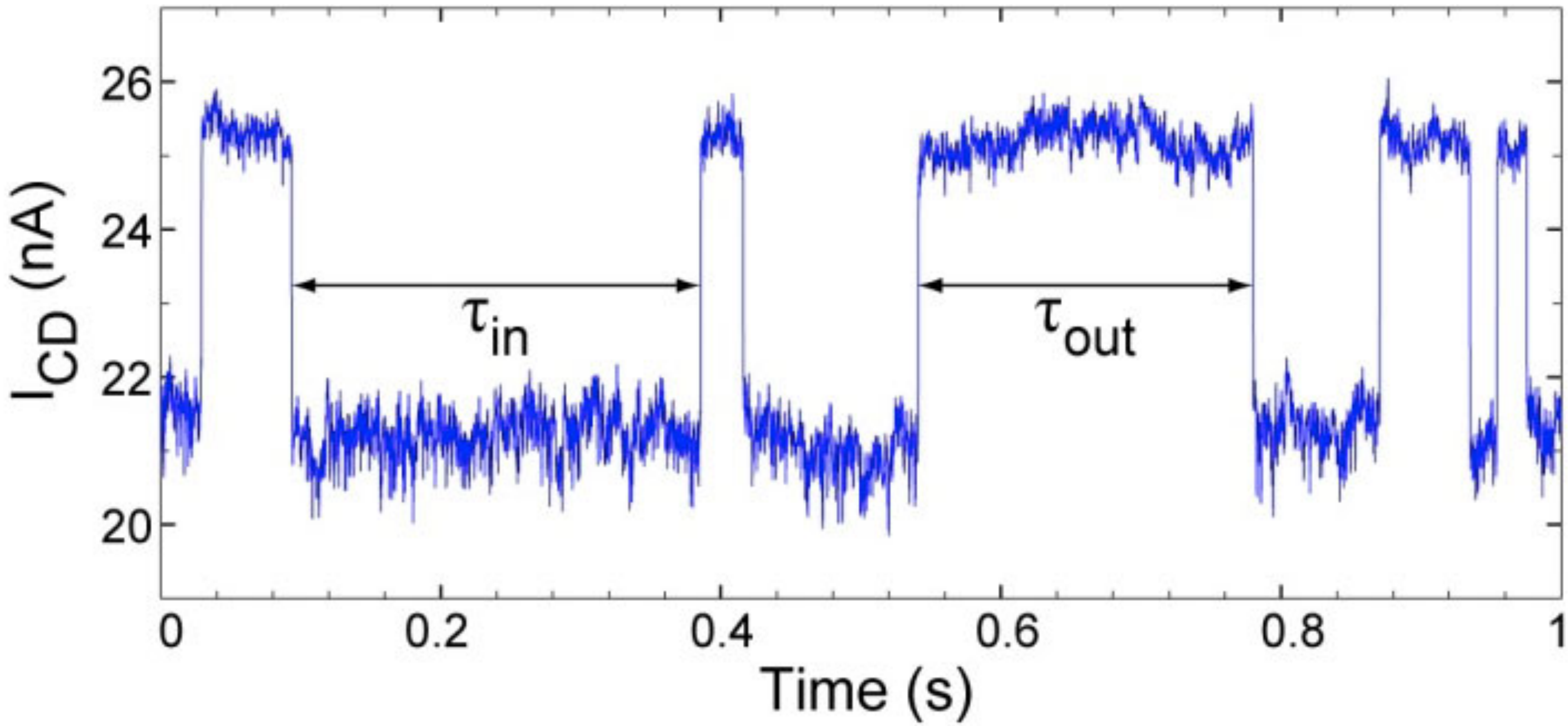
constriction

C. Stampfer,
S. Hellmüller,
J. Güttinger,
F. Molitor,
T. Ihn



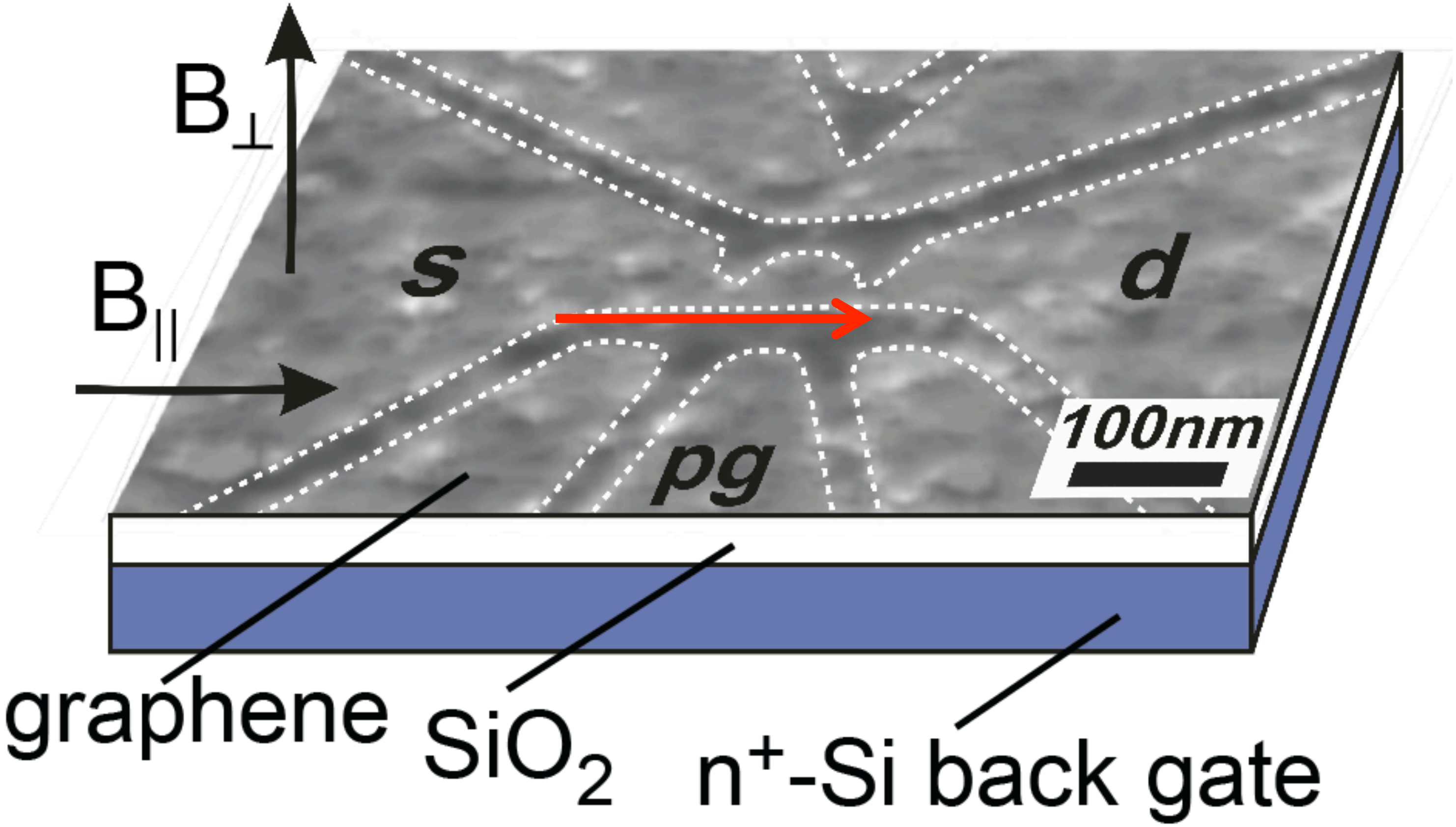
Electron counting in graphene





J. Güttinger, C. Achille, C. Stampfer

Graphene quantum dots: orbital and spin effects



QD area: 50 nm x 80 nm

Quantum dot states in magnetic fields

QD energy levels in a magnetic field:

$$\mu_N(B) = E_N(B) - E_{N-1}(B)$$

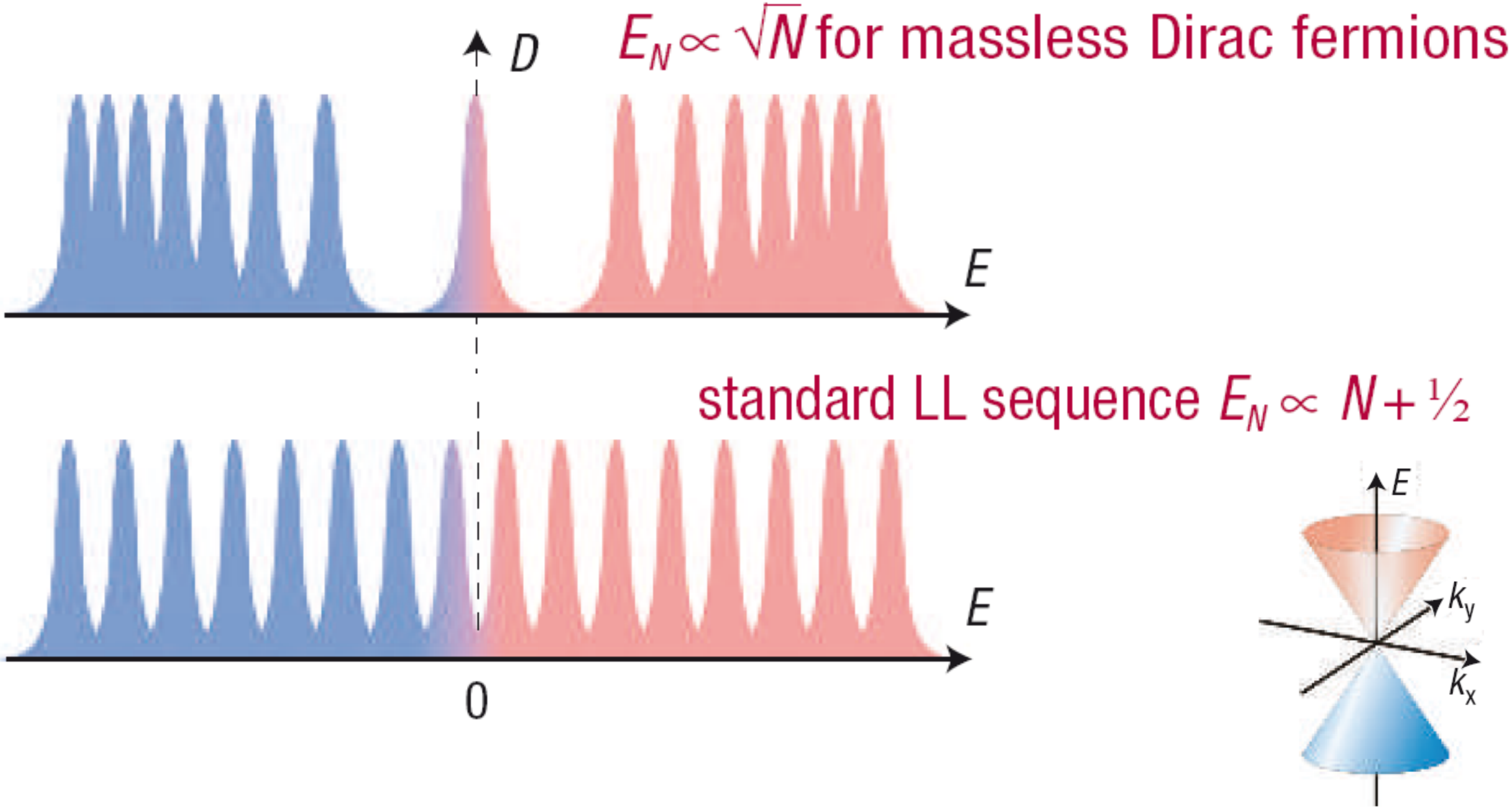
$B_\perp$ orbital effects dominate

$B_\parallel$ orbital effects suppressed, Zeeman splitting observable

Strategy: 1. use $B_\perp$ for identifying few-electron regime

2. use $B_\parallel$ for identifying spin states

Landau levels in graphene



taken from A. Geim & K. Novoselov, Nat. Mat. 6 183 - 191 (2007)

Landau levels in graphene quantum dots

8

140 nm

circular dot

6

B (T) 4

2

0

-200 -100 0 100

Energy (meV)

S. Schnez et al. PRB **78** (2008)

Landau levels in graphene quantum dots

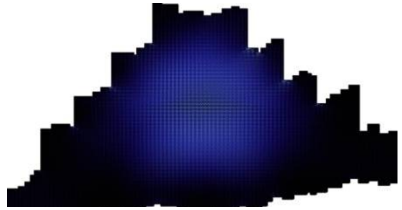
140 nm

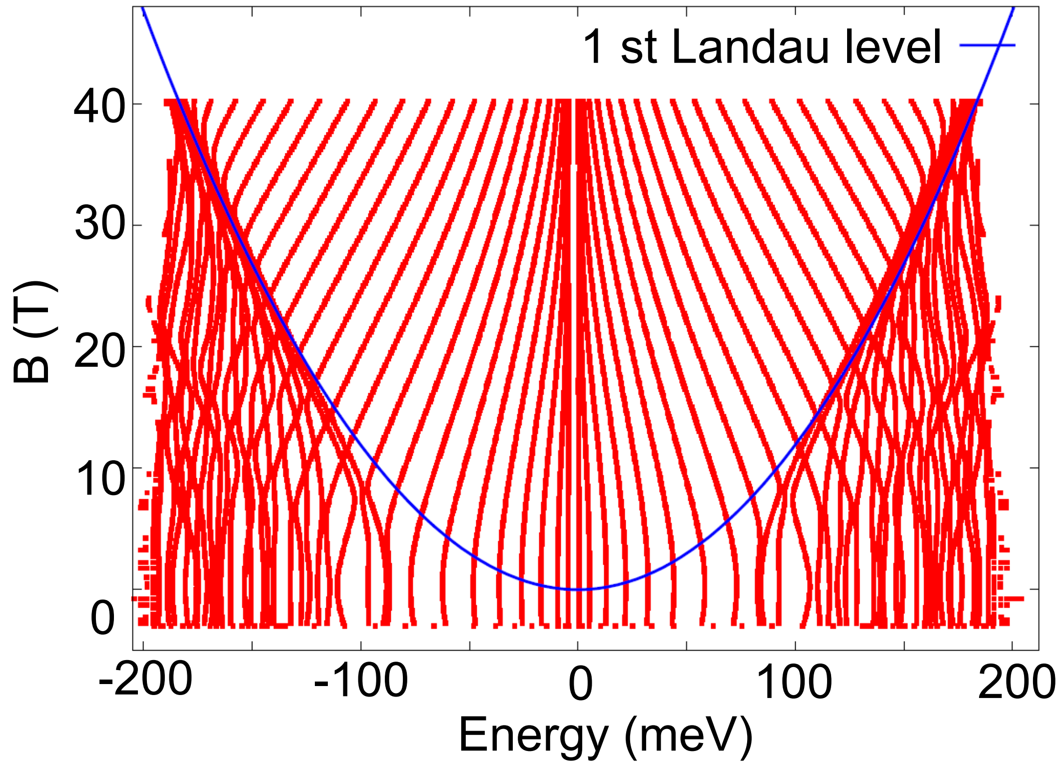
circular dot

B (T): 8, 6, 4, 2, 0

Energy (meV): -200, -100, 0, 100

45 nm dot



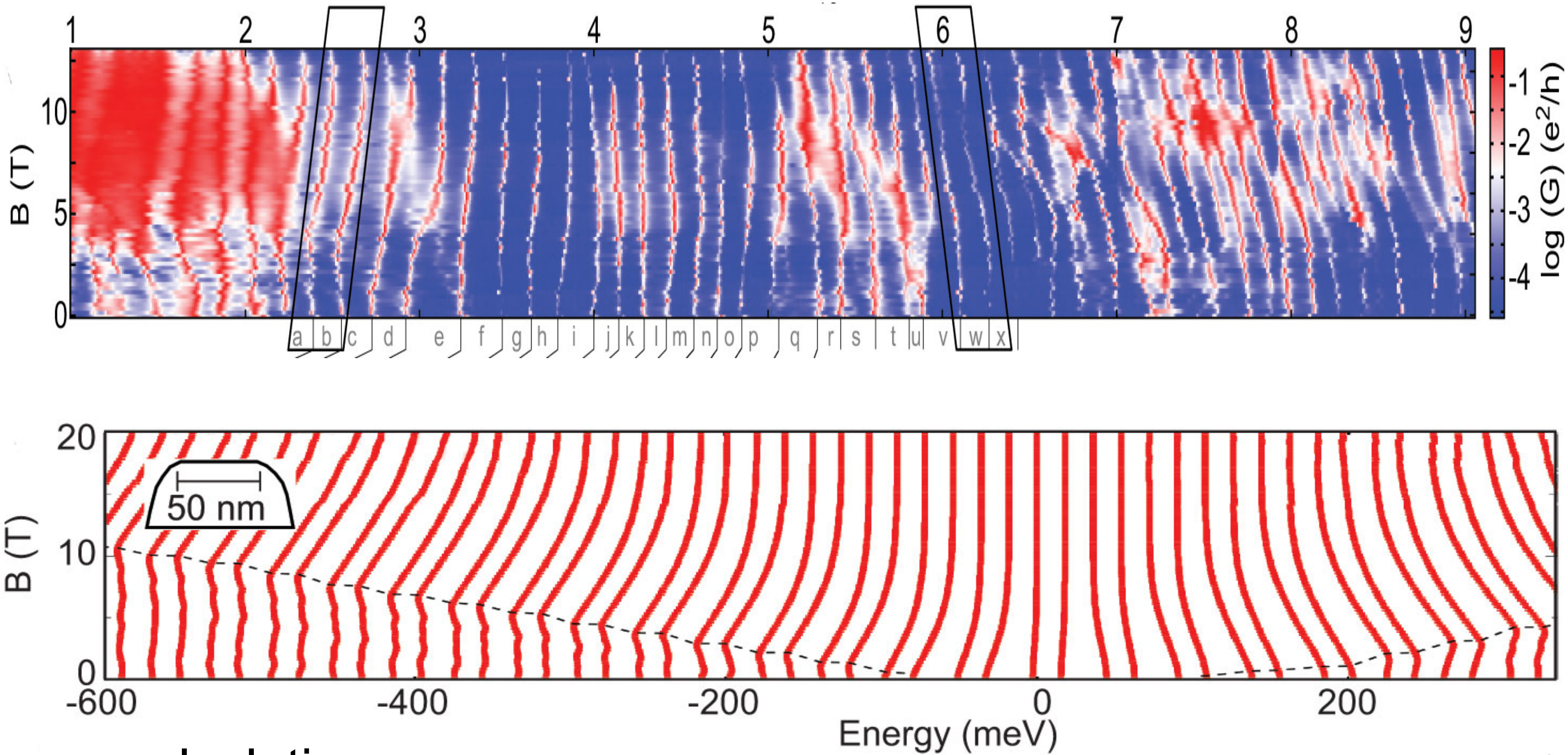


S. Schnez et al. PRB **78** (2008)

calculations by F. Libisch

Electron-hole crossover

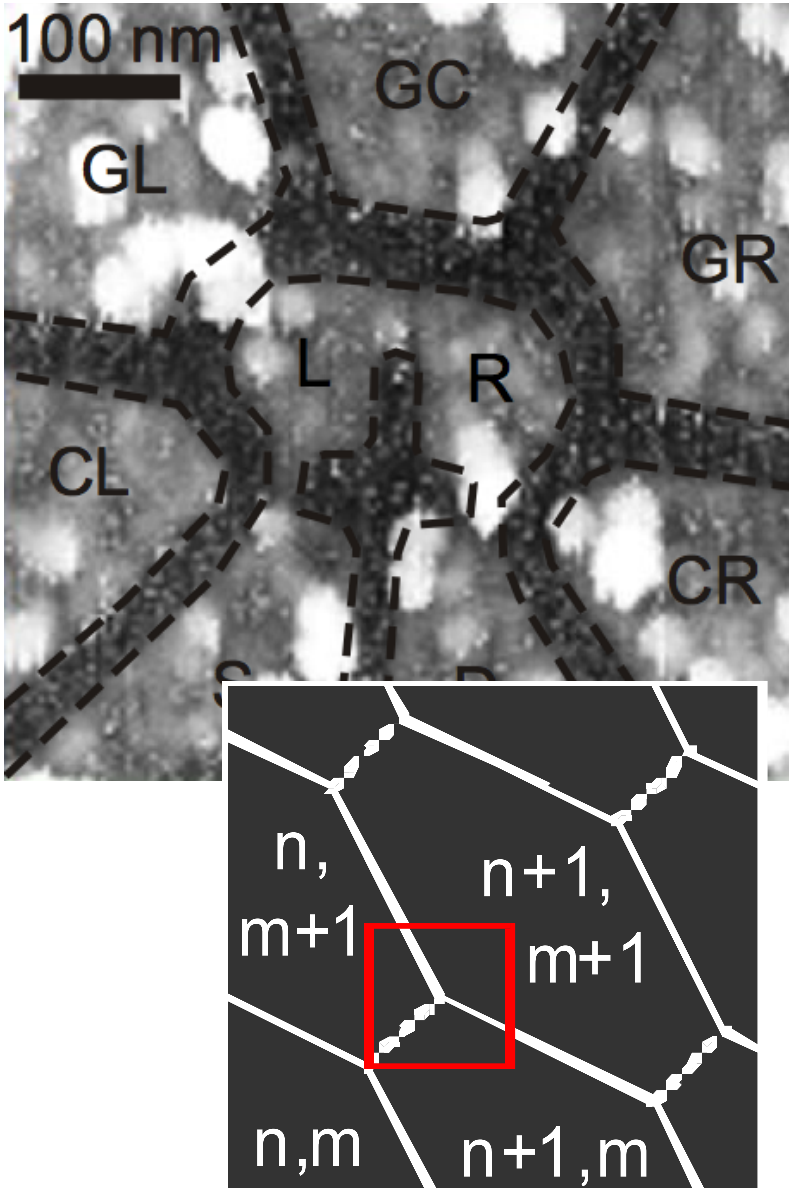
experiment

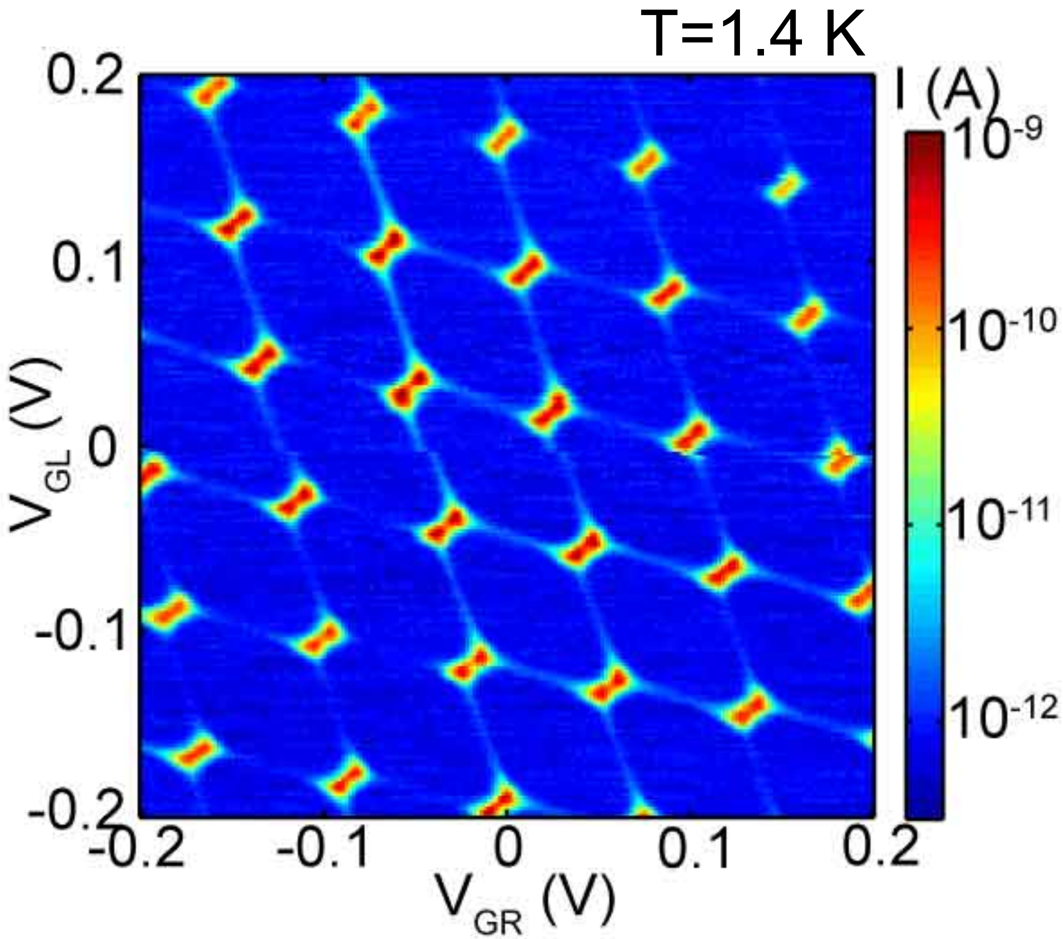


calculation

J. Güttinger, T. Frey, C. Stampfer

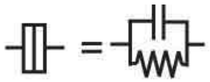
Graphene double dots

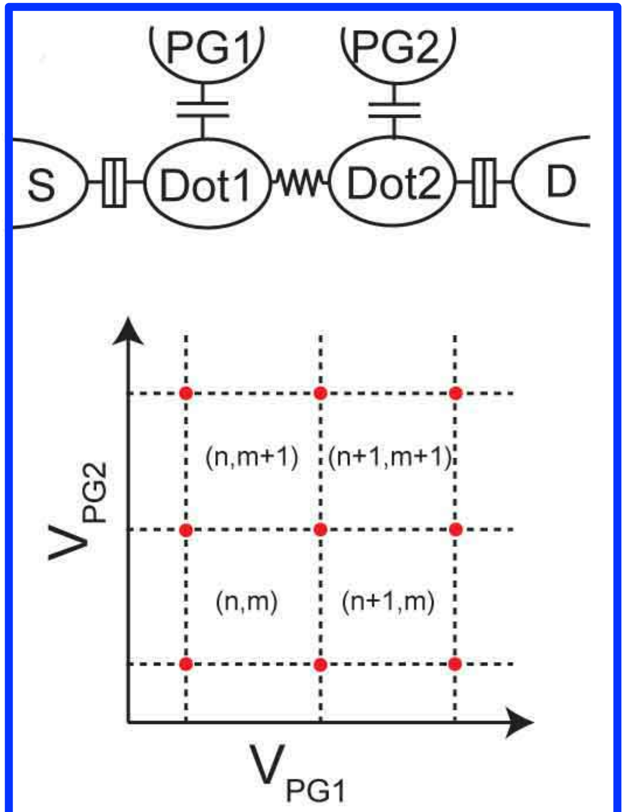




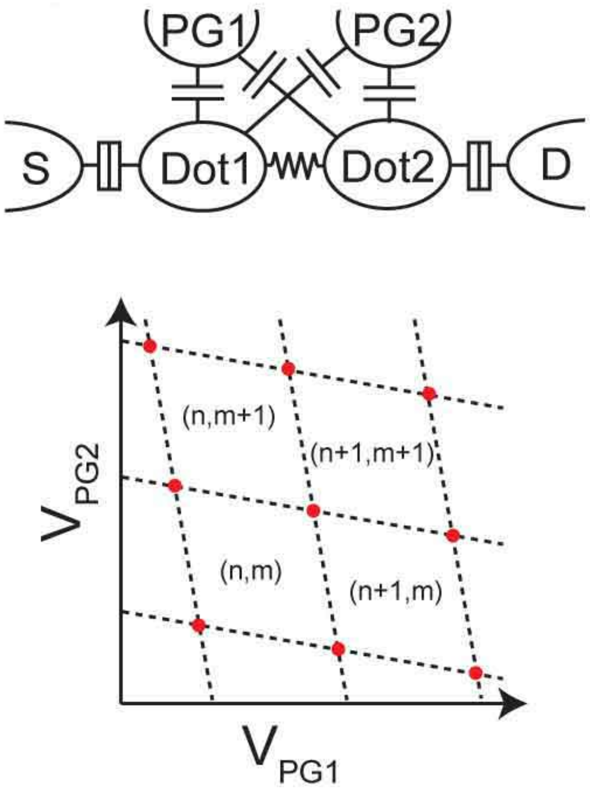
Francoise Molitor
Susanne Dröscher

Charge stability diagram: double dot

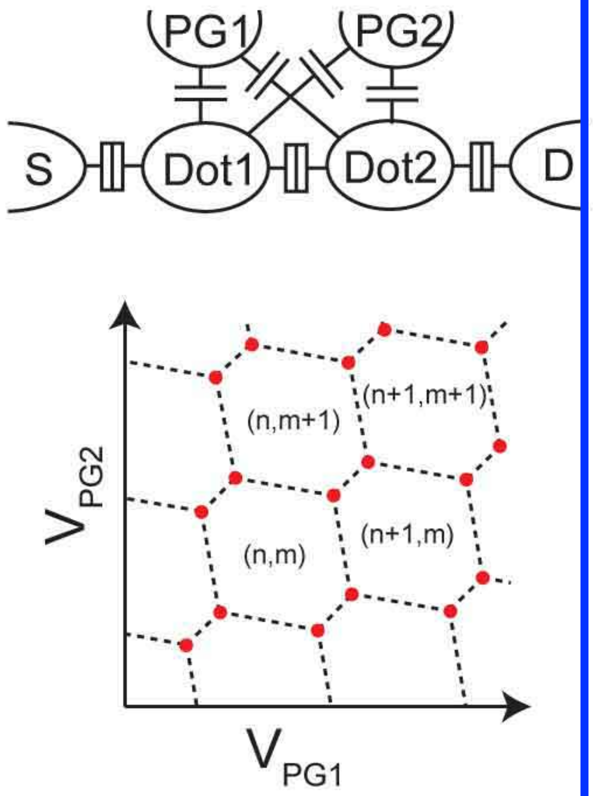




each dot coupled **only** to its gate

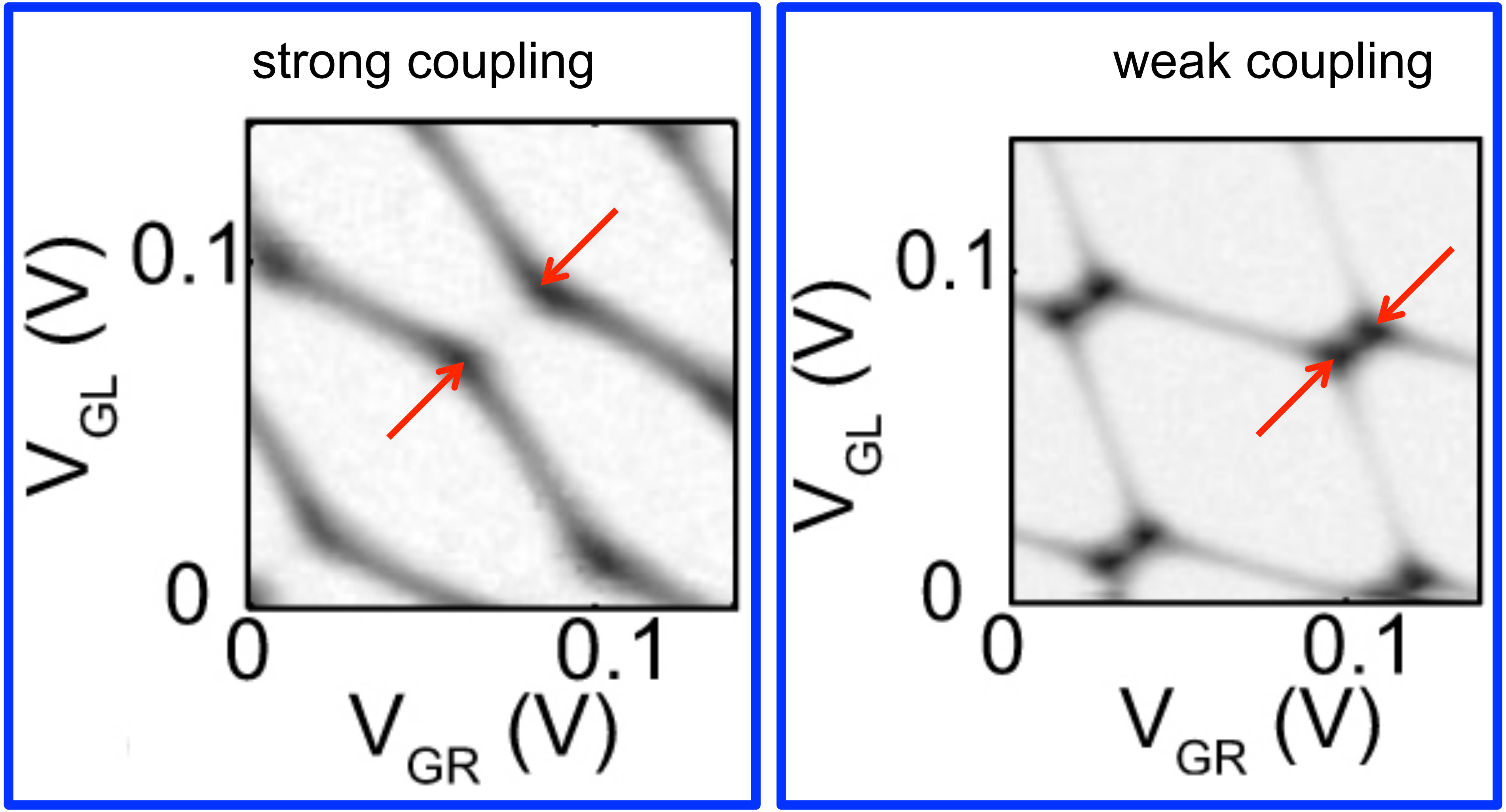


each dot coupled to **both gates**

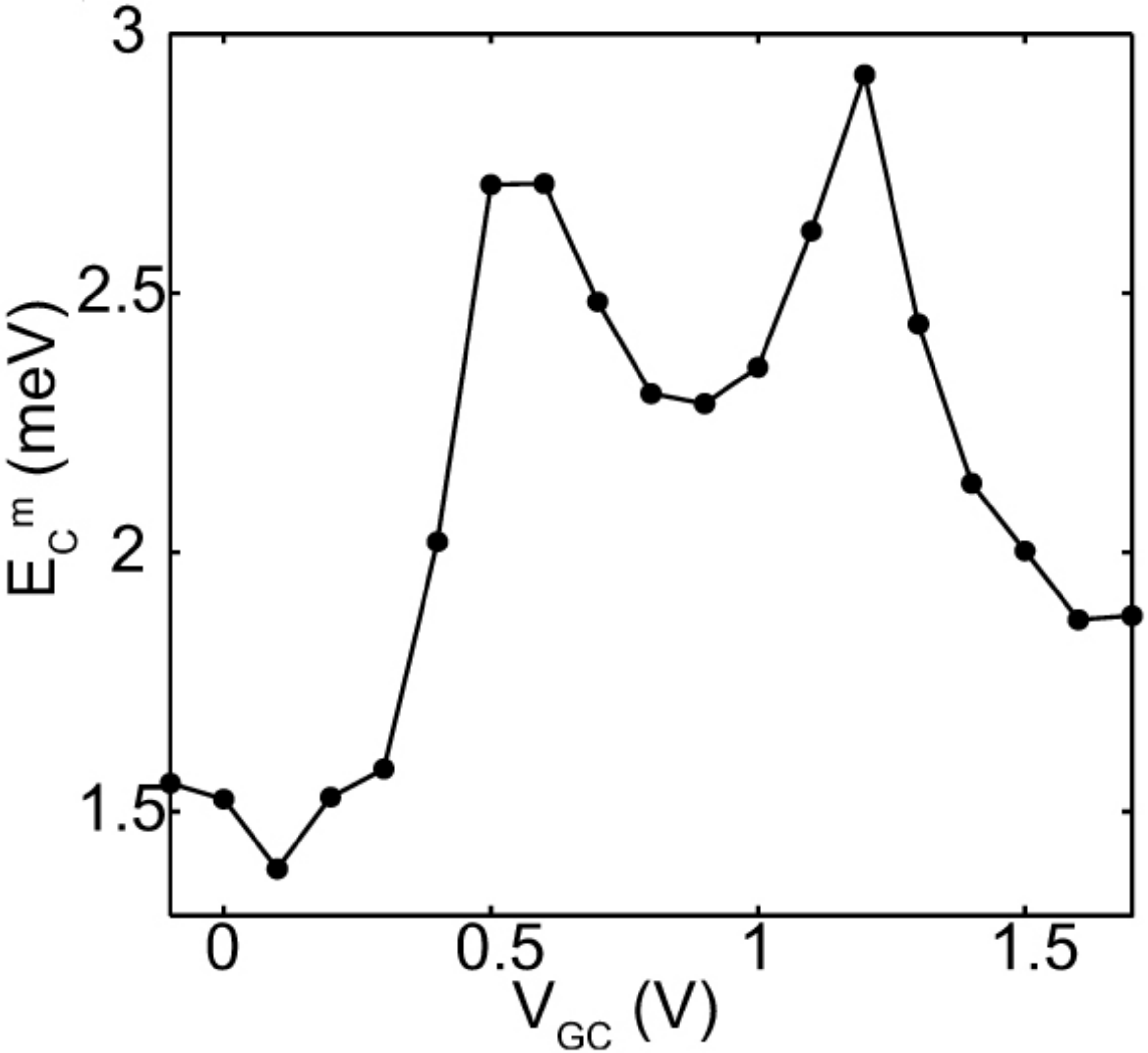


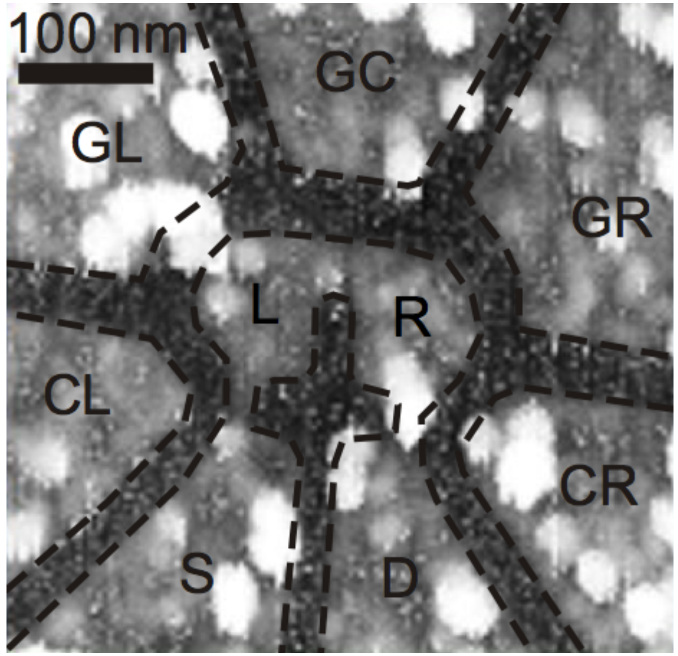
both dots coupled to each other

Graphene double dots: tuning the coupling



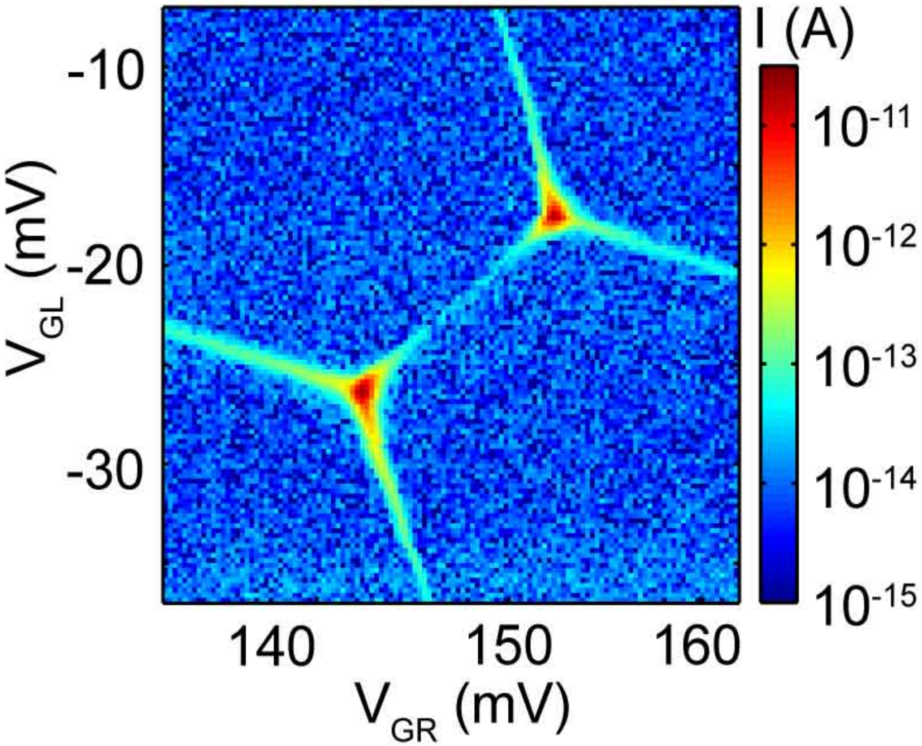
Graphene double dots: tuning the inter-dot coupling



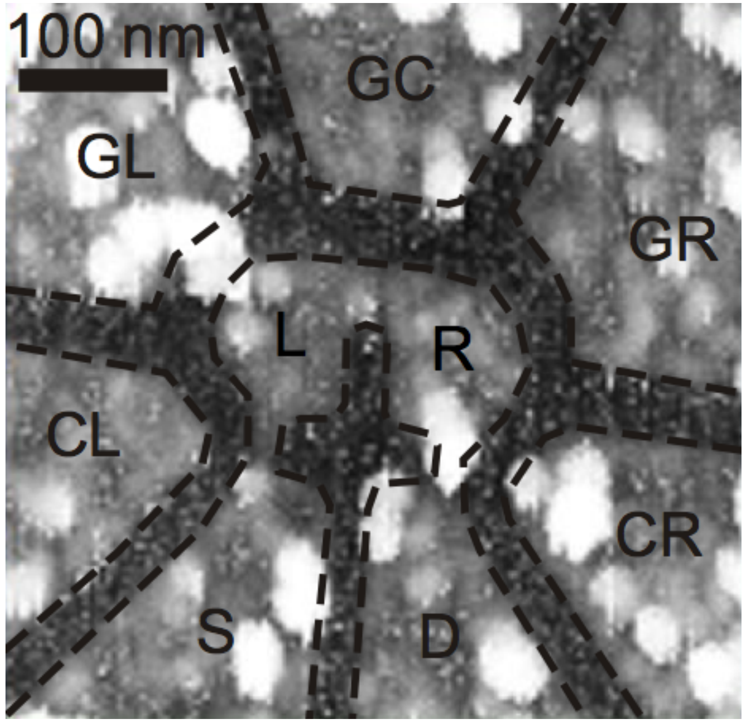


center gate tuning

tunnel/capacitive coupling

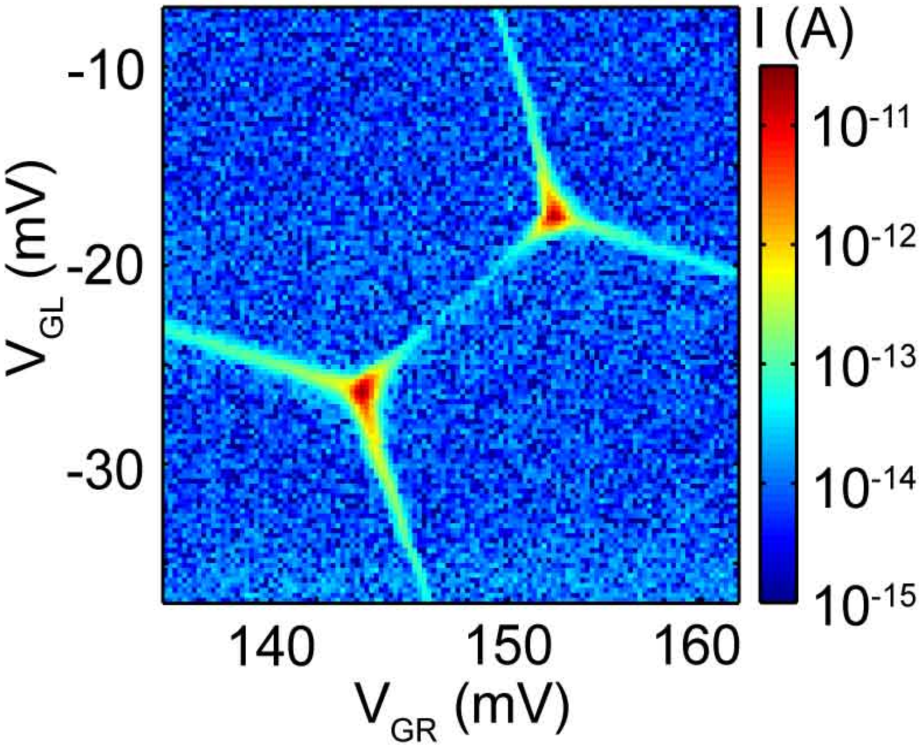


transport data: V_{bias} = 15 μV

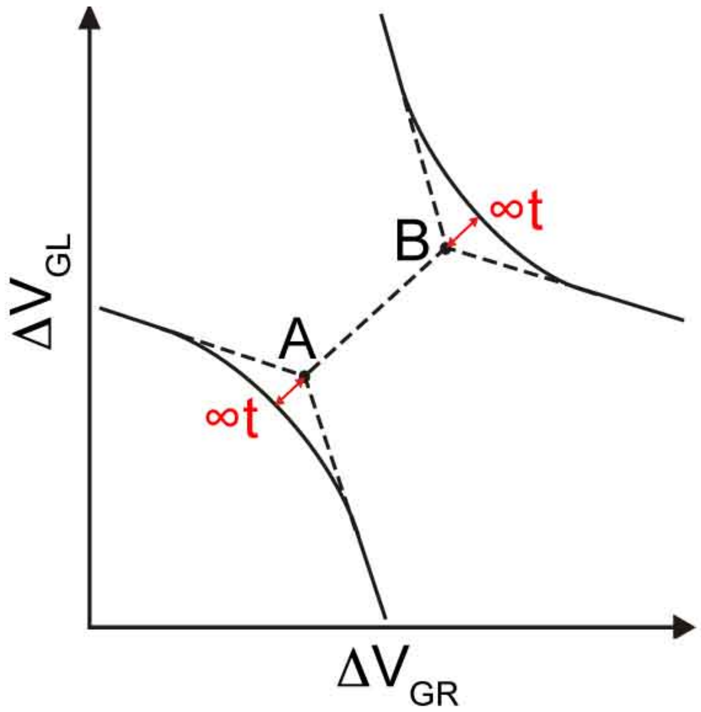


sample

tunnel/capacitive coupling

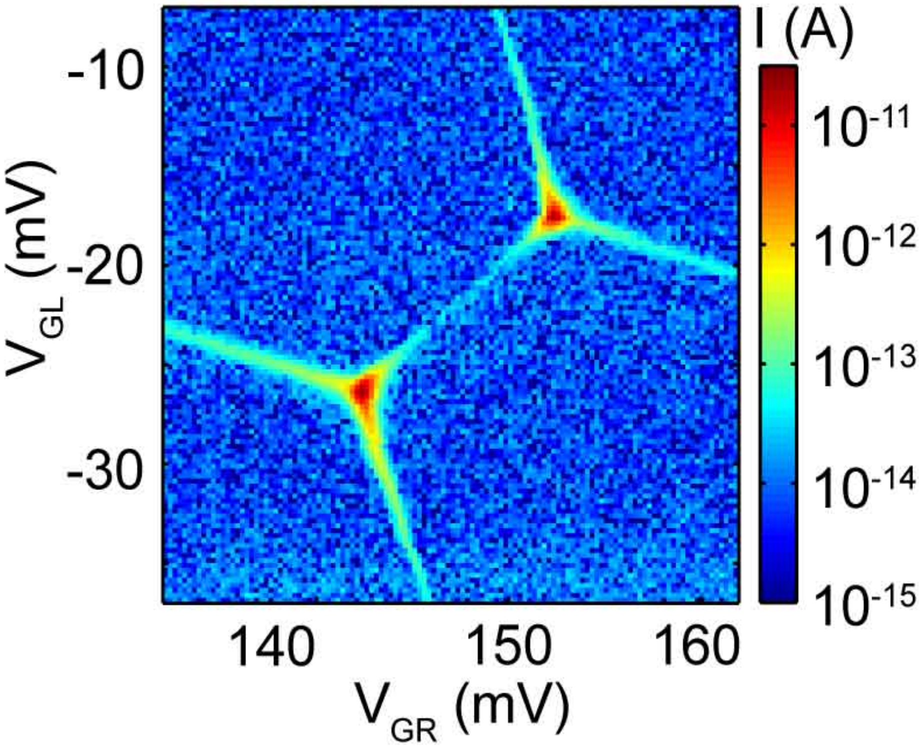


transport data: V_{bias} = 15 μV

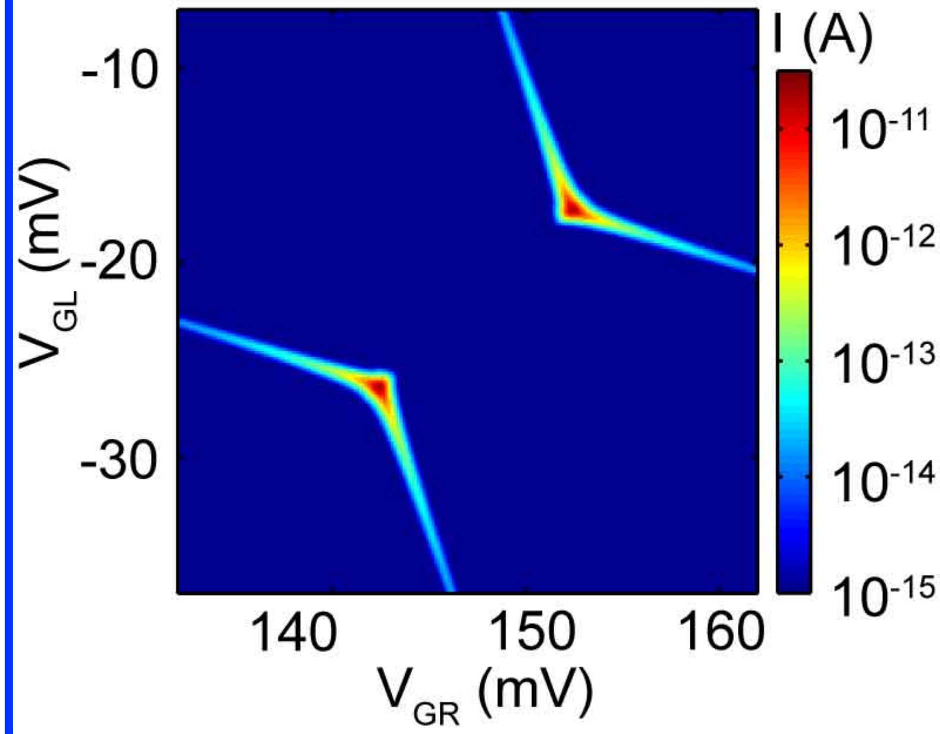


finite tunnel coupling
-> rounding of edges

tunnel/capacitive coupling

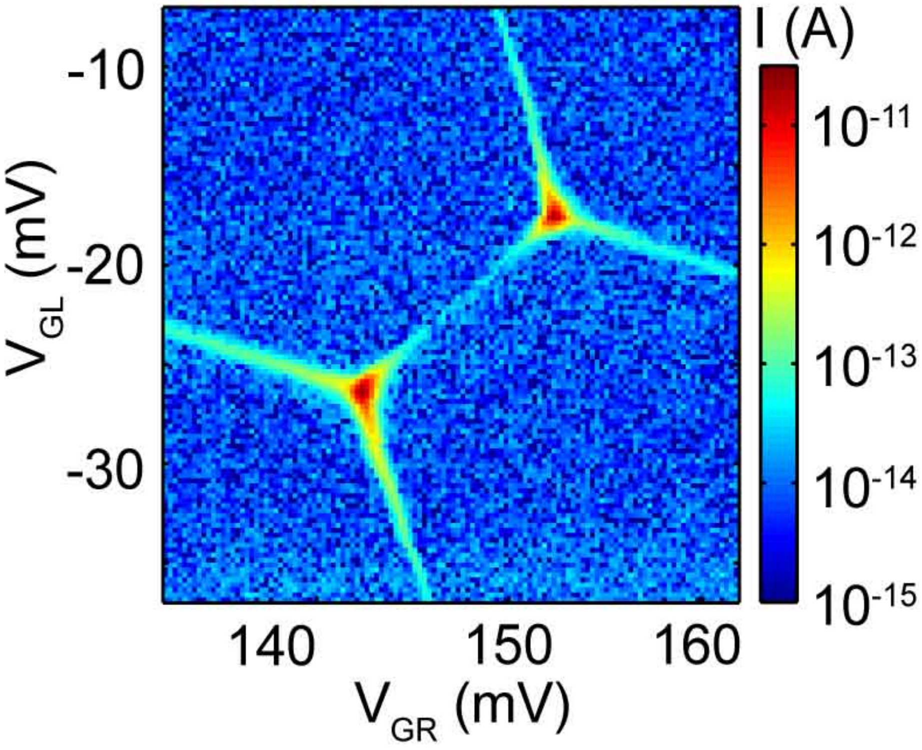


transport data: V_{bias} = 15 μV

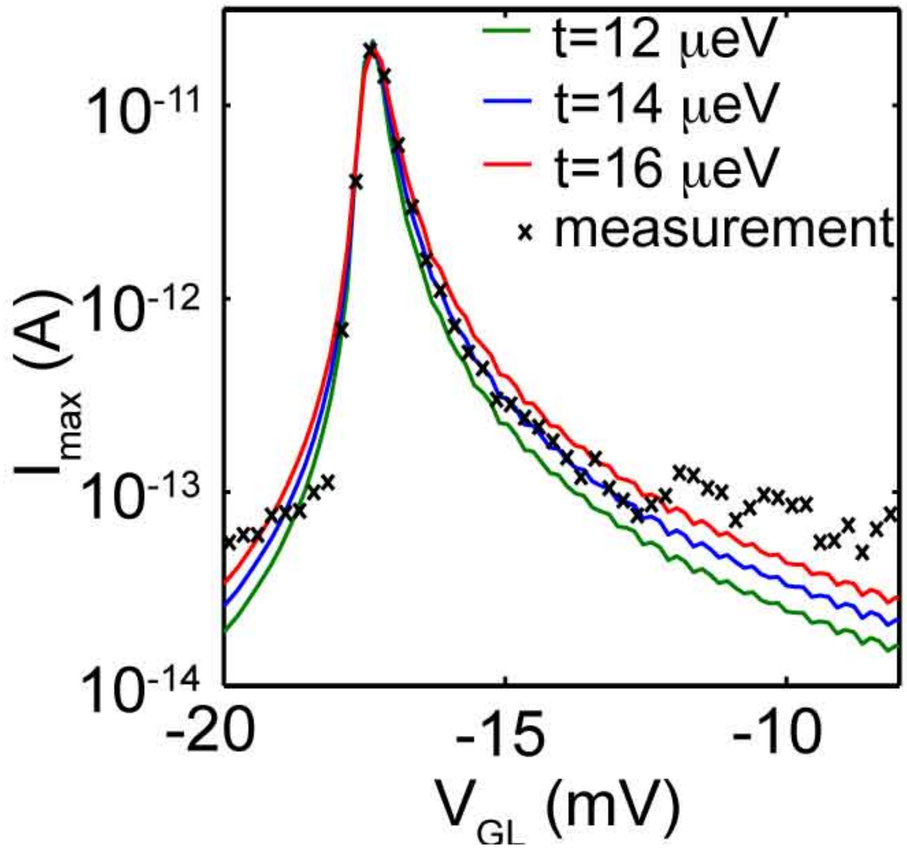


simulation

tunnel/capacitive coupling



transport data: V_{bias} = 15 μV



simulation: t ≈ kT

Thank you

Francoise Molitor

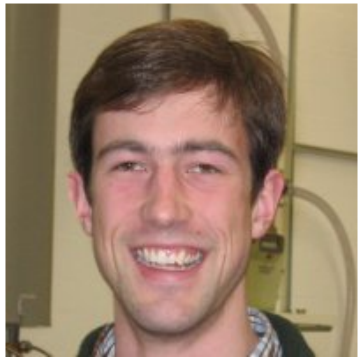
Christoph Stampfer

Arnhild Jacobsen

Thomas Ihn

Johannes Güttinger

Stephan Schnez



Susanne Dröscher

Preden Roulleau

Theo Choi