Molecular states in a one–electron double quantum dot

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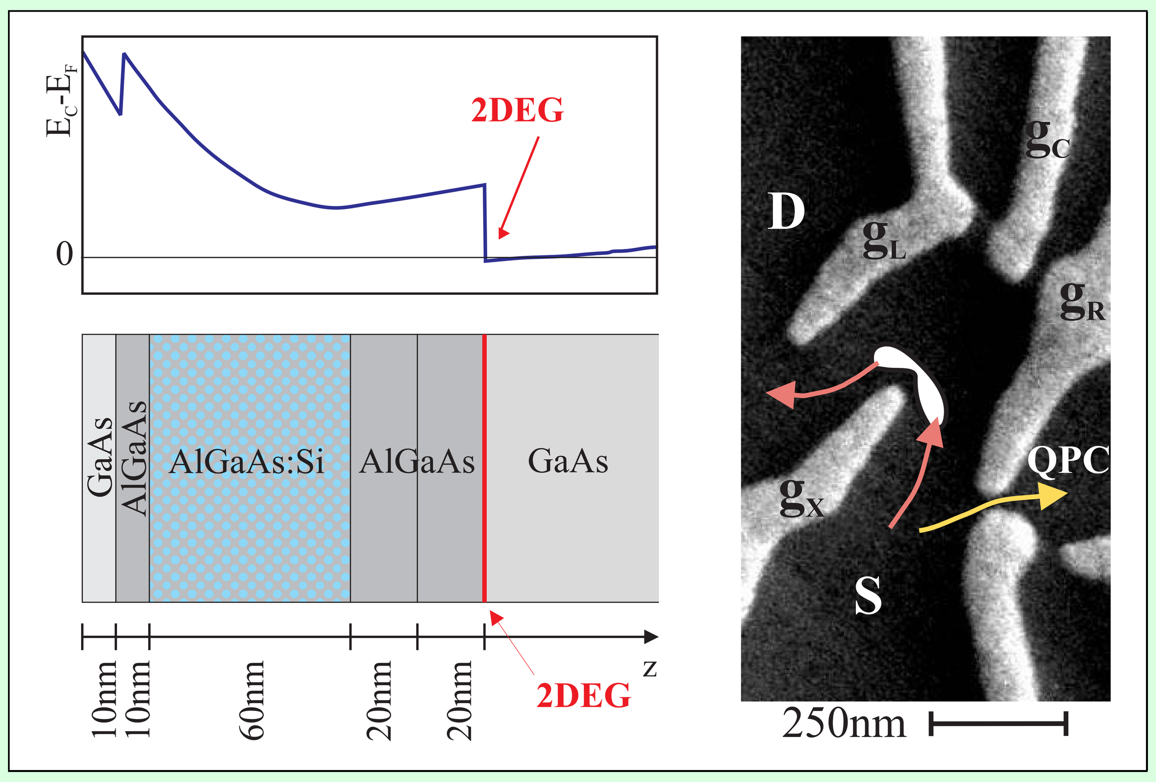
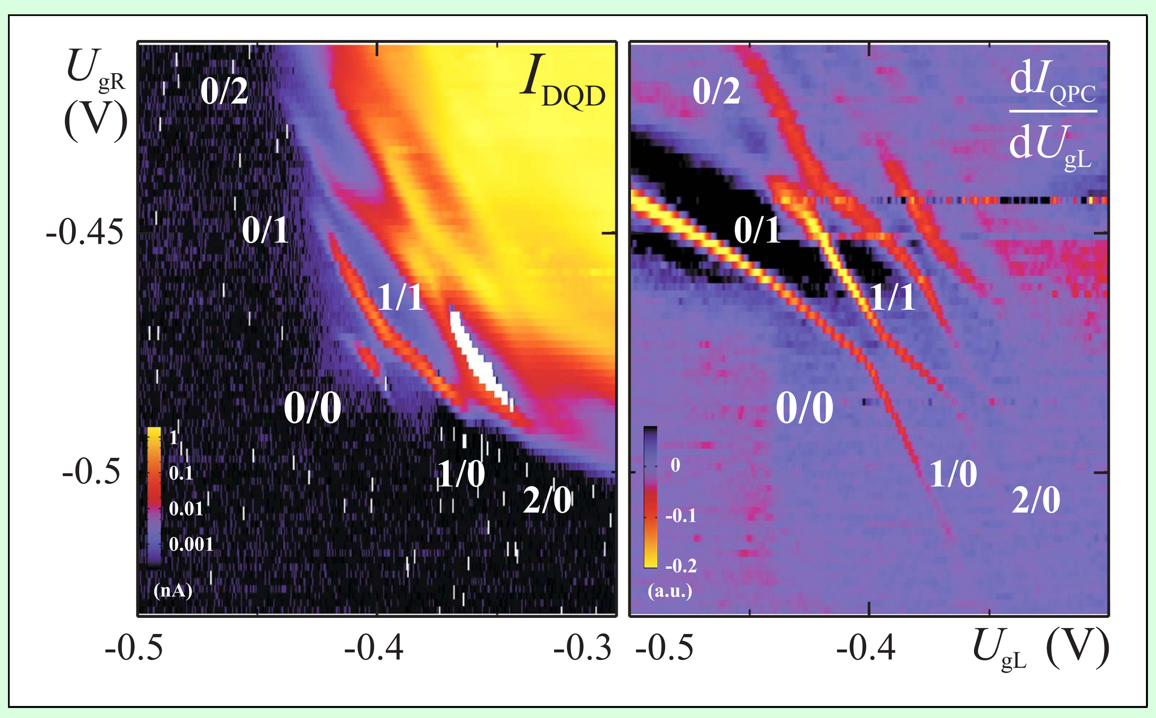
Material system



- GaAs/AlGaAs heterostructure
- Top gates written by SEM lithography
- Triangular geometry for low electron numbers [1]
- Quantum point contact (QPC) for electrostatic charge detection [2,3]

Double dot charging diagram



- Sweep of right versus left side gate
- Direct dc-current measurement (left plot)

$\rightarrow$ Strong interdot coupling, delocalization

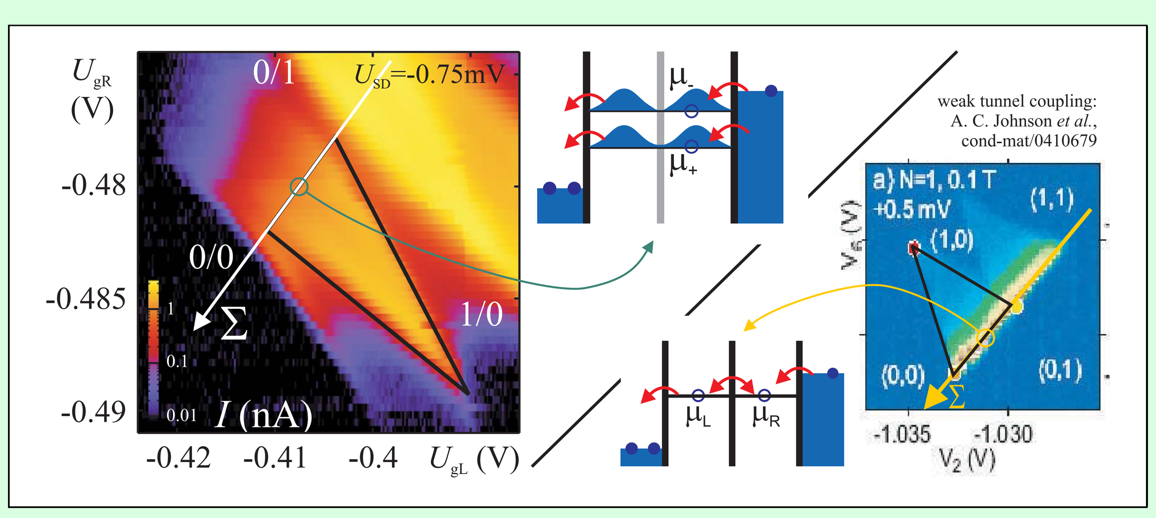
- Quantum point contact charge detection (right plot)

$\rightarrow$ Double quantum dot can be emptied completely

$\rightarrow$ Delocalization, continuous charge redistribution between dots at the symmetry line $0/1 \leftrightarrow 1/0$

$\rightarrow$ No maximum in $\left|\frac{dI_{QPC}}{dU_{gL}}\right|$ at this line [4]

Transport window at finite U_{SD}



- $U_{SD} = -0.75\,\mathrm{mV} \rightarrow$ transport window
- Weak coupling case: triangle expected
- Here: **strong tunnel coupling**
- Edges of current onset follow **molecular states**

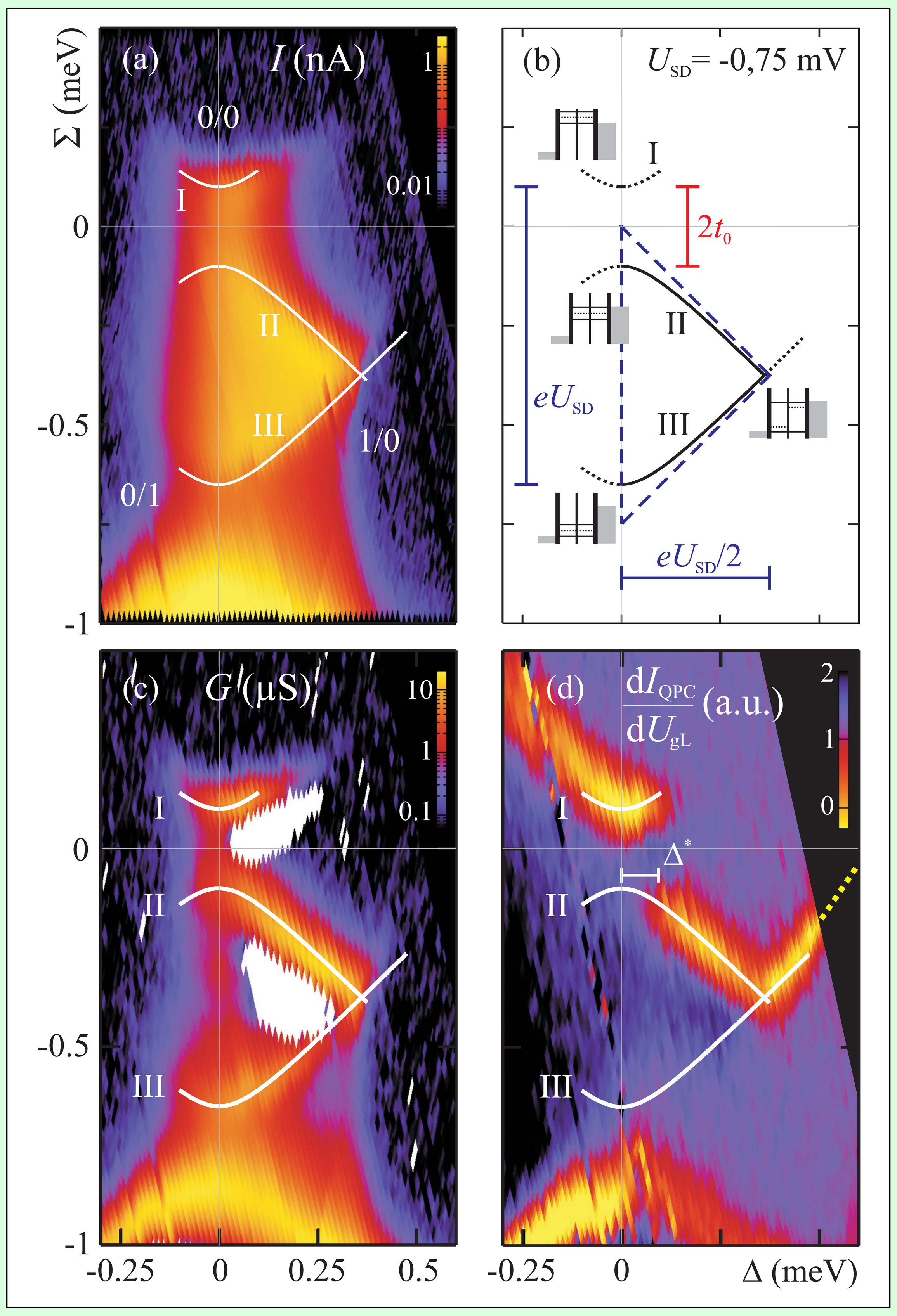
$$H \doteq \begin{pmatrix} \Delta & -t_0 \\ -t_0 & -\Delta \end{pmatrix}, \quad \mu_\pm(\Delta) = \mp\sqrt{\Delta^2 + t_0^2}$$

(see model lines, next plot)

Anticrossing at finite U_{SD}, $N \leq 1$

Coordinate transformation $U_{gL}, U_{gR} \rightarrow \Sigma, \Delta$

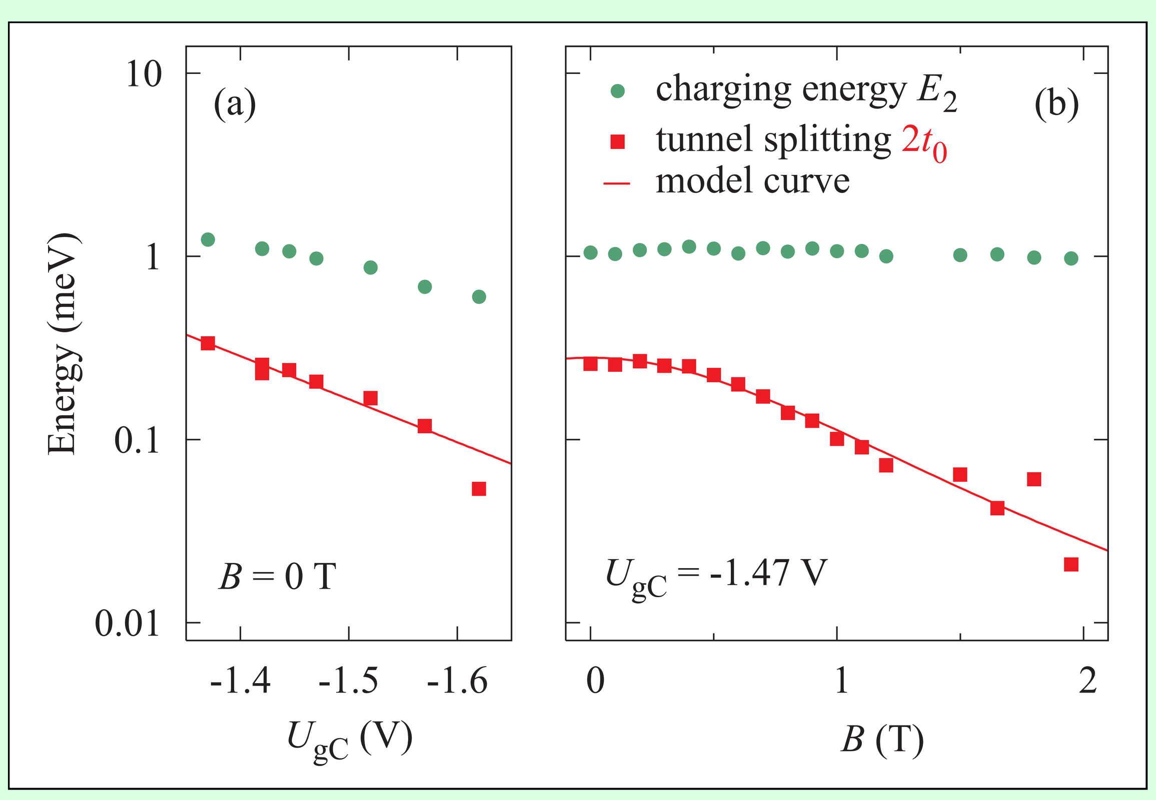
$$\Sigma = \frac{\mu_R + \mu_L}{2}, \qquad \Delta = \frac{\mu_R - \mu_L}{2}$$



- Tunnel splitting $2t_0$ clearly visible and easily quantified (via comparison to eU_{SD})
- Bottom of plot: onset of two-electron charging
- White areas (lhs plot): negative conductance G
- Discontinuity of charging line at $\Delta^* > 0$ (rhs plot)

$\rightarrow$ tunnel rates to *source* vs. *drain*: $t_S/t_D \sim 5$

Controlling the tunnel splitting



- E_2: charging energy for the second electron
- Larger $|U_{gC}|$ pushes the two dots apart

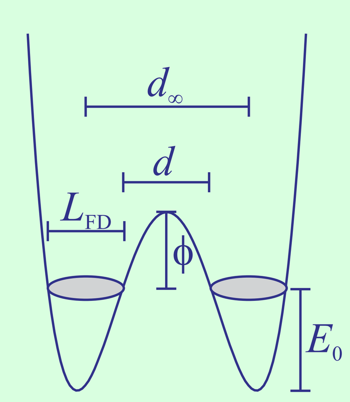
$\rightarrow$ smaller $2t_0$, smaller E_2

- $B_\perp$ compresses the quantum dot states

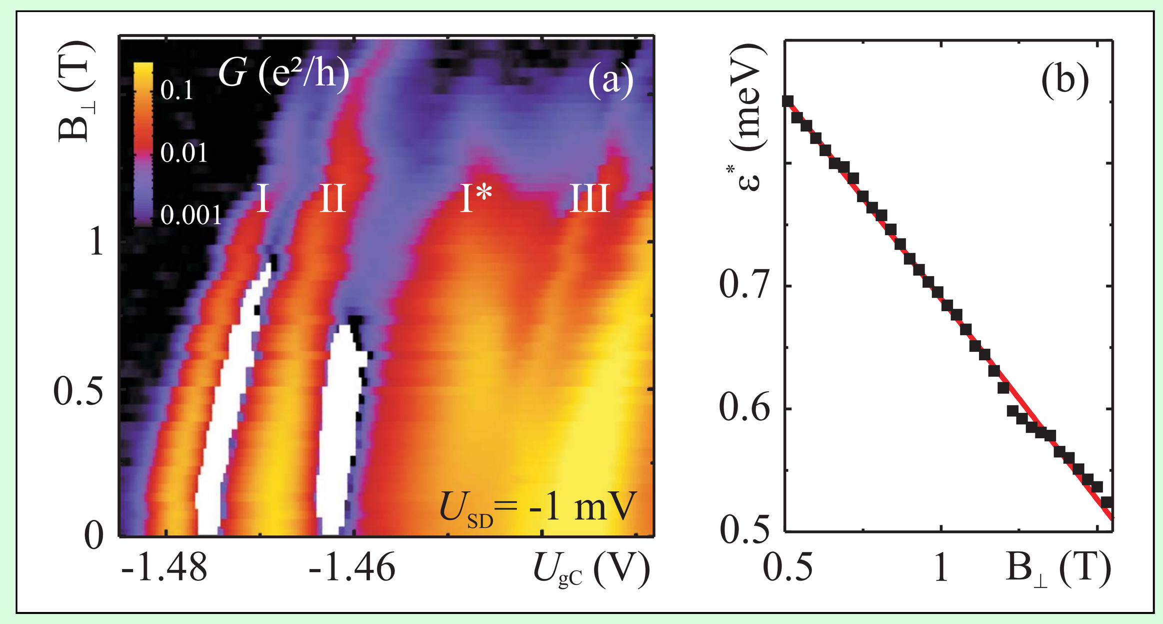
$\rightarrow$ smaller $2t_0$, constant E_2

- Model (WKB & Fock-Darwin)

$$2t_0 \simeq 2E_0/\pi \exp\left(-\sqrt{2m^*\phi}\,d/2\hbar\right),$$
$$d(B) = d_\infty - L_{FD}(B),$$
$$L_{FD}(B) = \sqrt{\frac{\hbar}{\omega_c m^*}}\left(1 + \frac{4\omega_0^2}{\omega_c^2}\right)^{-\frac{1}{4}}$$

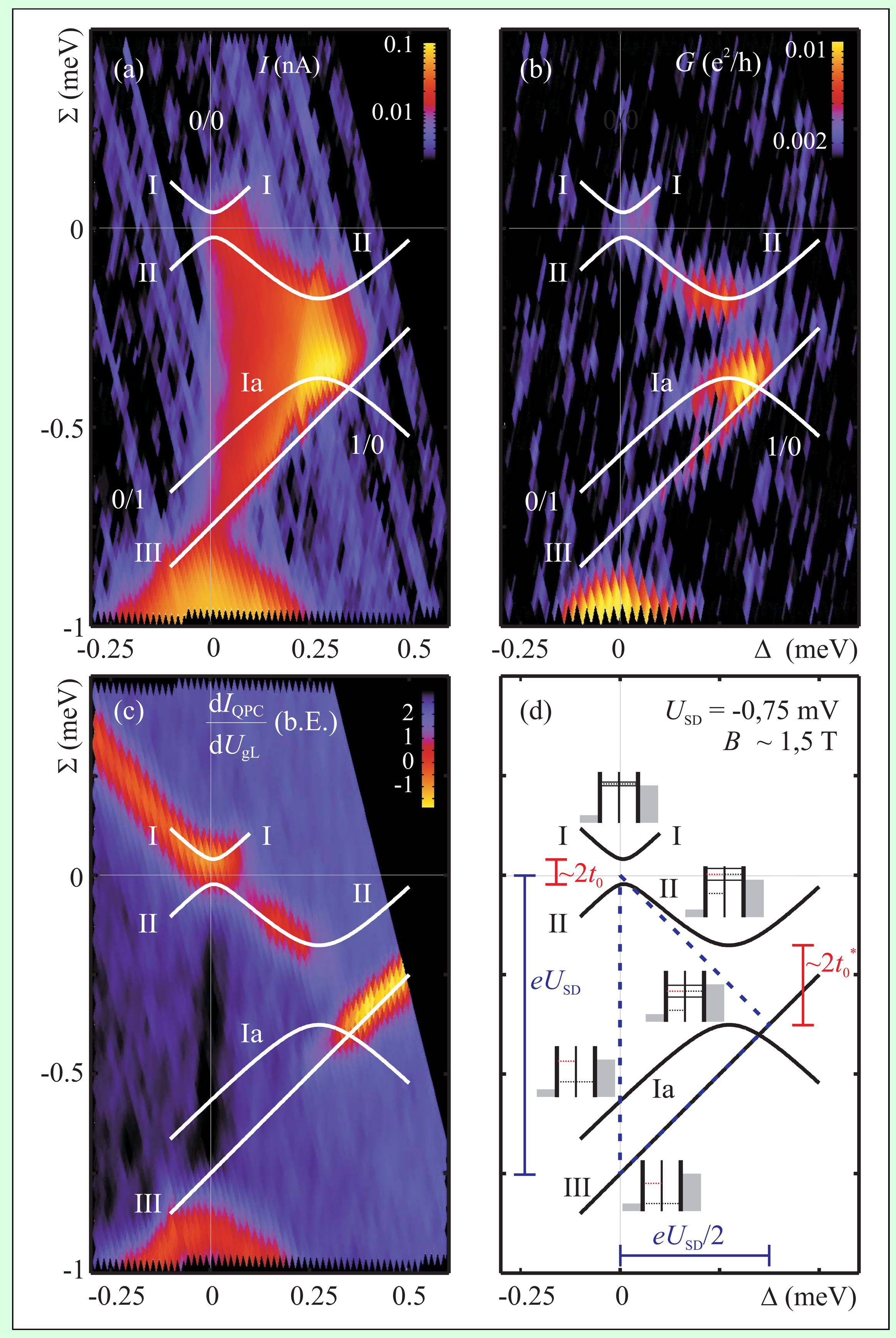


$B_\perp > 0 \longrightarrow$ additional excited state



- Excited single-dot state enters transport window at finite $B_\perp$ (additional line I* of finite G)
- Excitation energy $\varepsilon^*(B_\perp) \sim$ linear in $B_\perp$

Second anticrossing at $\Delta, B_\perp > 0$



- Hybridization of localized ground state (right dot) and excited state (left dot) for $eU_{SD} > 2\Delta = \varepsilon^*(B_\perp)$
- Model lines: $$H \doteq \begin{pmatrix} \Delta & -t_0 & -t_0^* \\ -t_0 & -\Delta & 0 \\ -t_0^* & 0 & -\Delta + \varepsilon^* \end{pmatrix}$$

References

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[2] M. Field *et al.*, PRL **70**, 1311 (1992).
[3] J. M. Elzerman *et al.*, PRB **67**, 161308 (2003).
[4] J. R. Petta *et al.*, PRL **93**, 186802 (2004).

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