All electrical spin preparation in a triple dot I-SET

Andrea Donarini

Georg Begemann, and Milena Grifoni

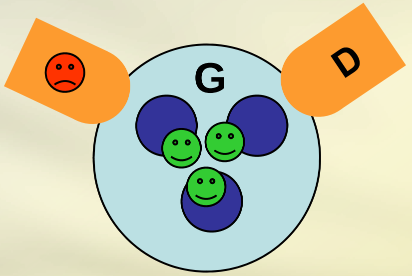
University of Regensburg, Germany

SFB 689 meeting - Niederalteich - 30.09.2010

Interference SET…

- **Weak coupling**
- **Coulomb** interaction
- Nanometer **scale**
- **Low** temperature

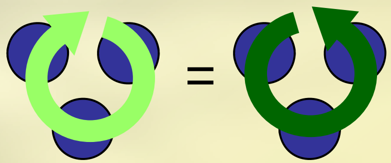
⇒ **Coulomb blockade**



$$\hbar\Gamma \ll k_{\mathrm{B}}T \ll \Delta E_{\mathrm{ex}}$$

- **Rotational** symmetry

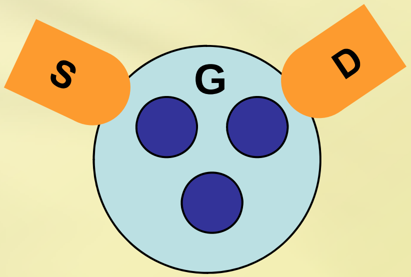
⇒ **Orbitally degenerate states**



$$E_1 = E_2$$

- Contact **geometry**

⇒ **Contact symmetry breaking**

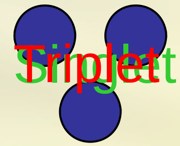


$$\frac{\gamma_{1L}}{\gamma_{2L}} \neq \frac{\gamma_{1R}}{\gamma_{2R}}$$

… with a magnetic flavour

- **Coulomb** interaction
- Nanometer **scale**

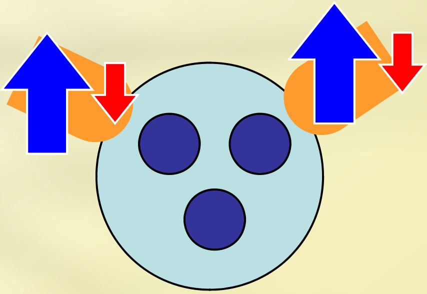
⇨ **Exchange splitting**



$E_{\text{triplet}} \neq E_{\text{singlet}}$

- Parallel **ferromagnetic** leads

⇨ **Spin symmetry breaking**



$\Gamma_{\alpha\uparrow} \neq \Gamma_{\alpha\downarrow}$

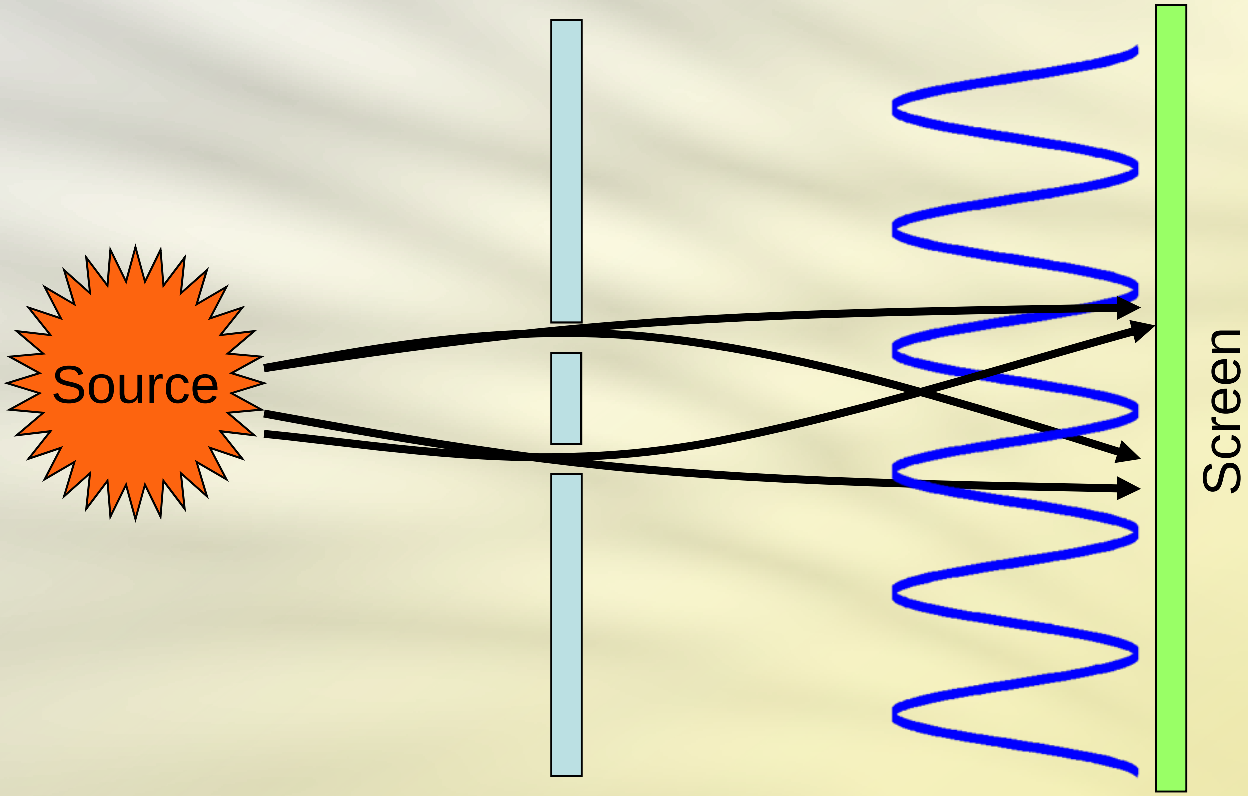
The interplay between orbital and spin degree of freedom

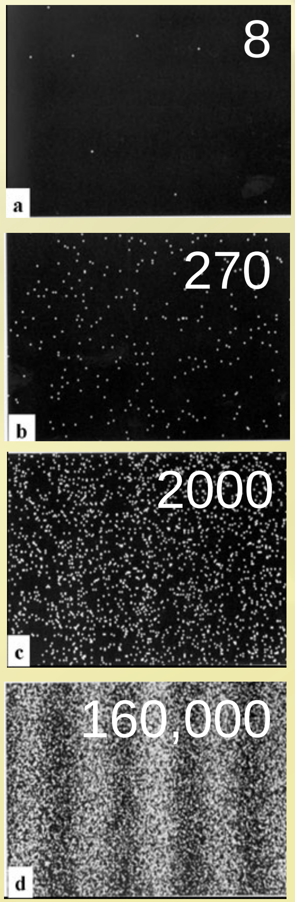
⇩

excited state blocking and all-electrical spin control on the system.

Macroscopic interference

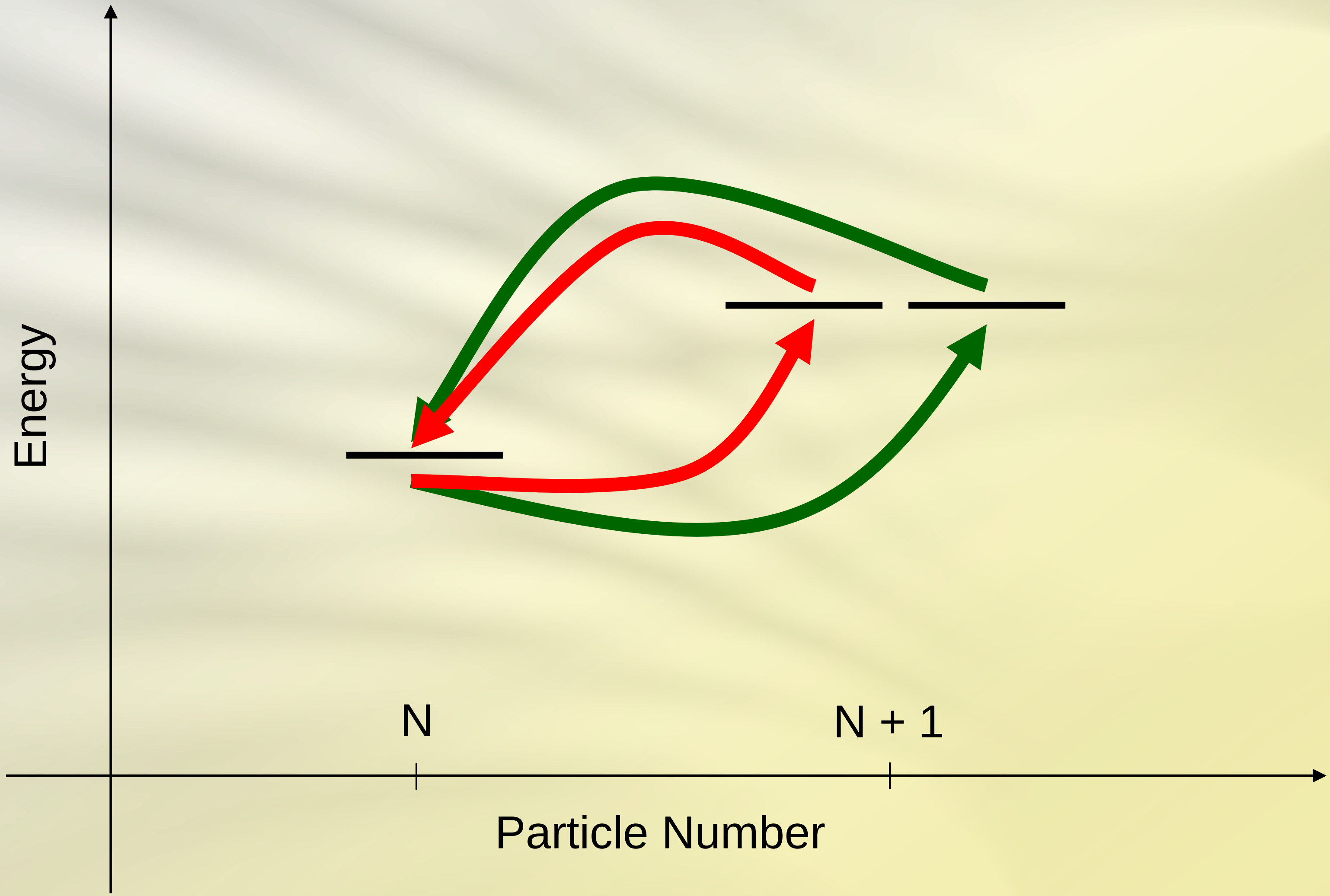
Young's light-interference experiment (1801)



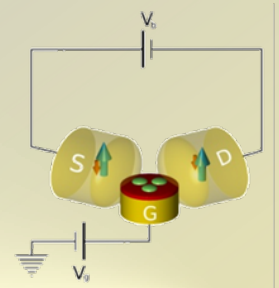


Double-slit experiment with interference
of single electrons (1961)

The “two paths” in the ISET

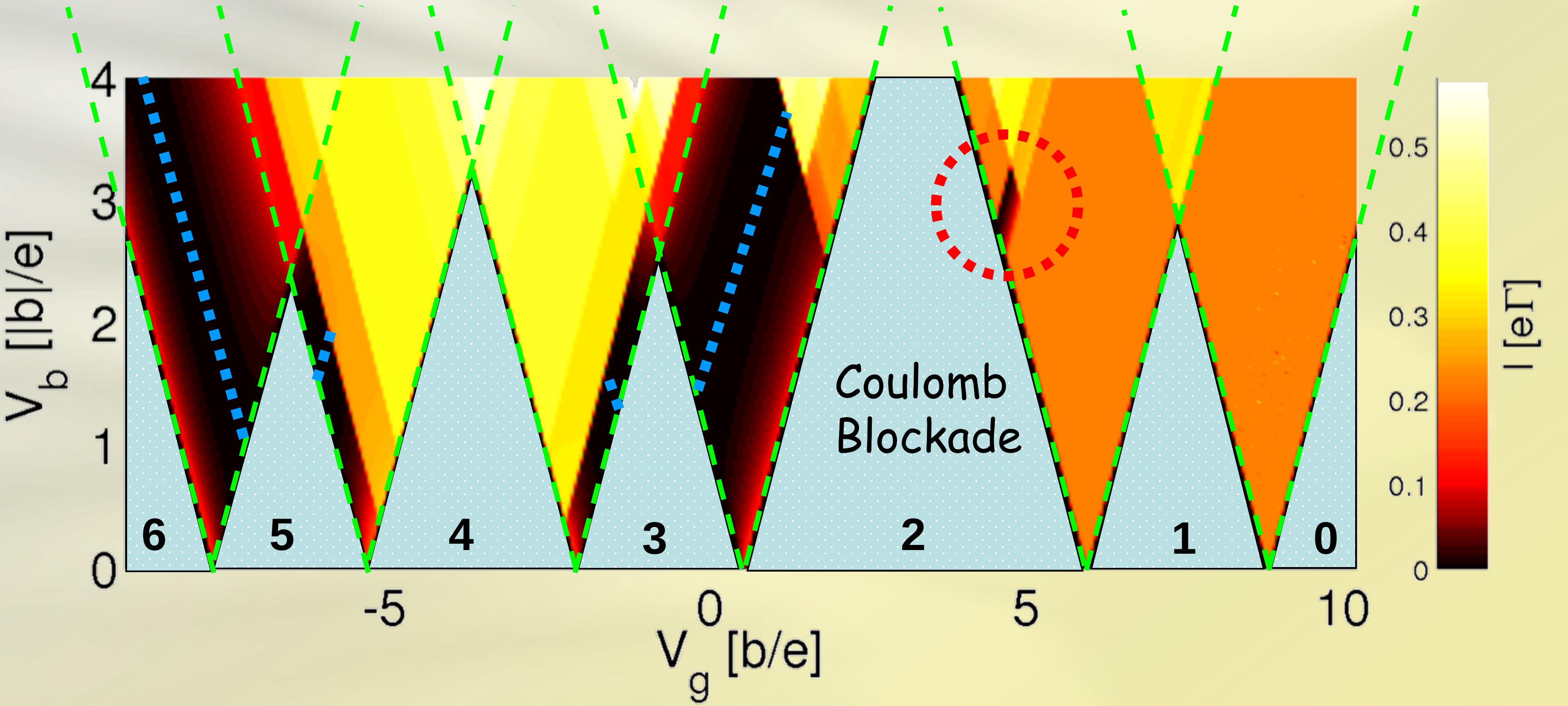


Current blocking

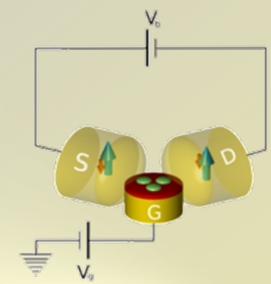


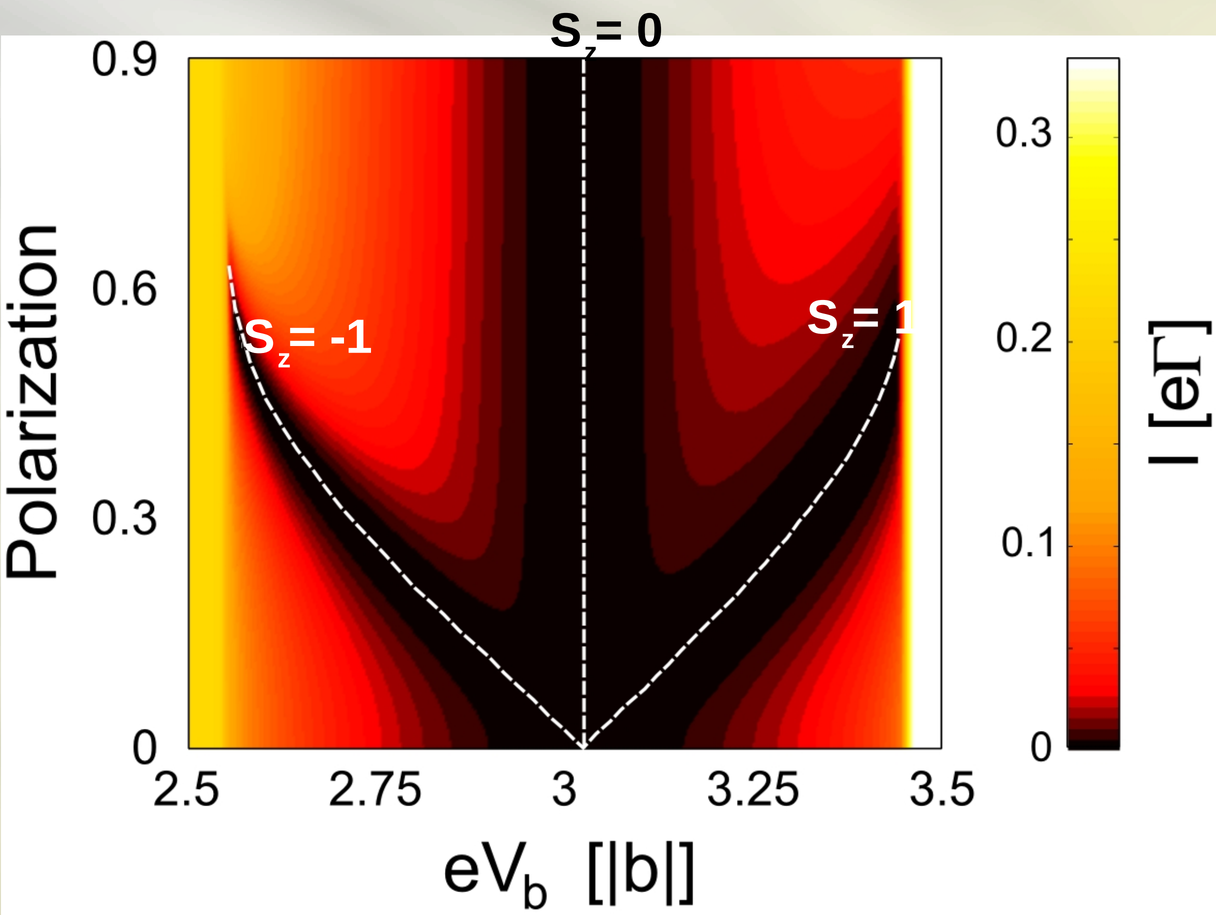
Interference Blockade
--**ground** states--

Interference Blockade
--**excited** state--



Polarized leads





Parallel polarized leads

[**No magnetic field on the system**]

All-electric spin control

The Hamiltonian

$$H = H_{\text{sys}} + H_{\text{leads}} + H_{\text{tun}}$$

$$H_{\text{sys}} = \xi_0 \sum_{i\sigma} d^\dagger_{i\sigma} d_{i\sigma} + b \sum_{i\sigma} \left(d^\dagger_{i\sigma} d_{i+1\sigma} + d^\dagger_{i+1\sigma} d_{i\sigma} \right)$$
$$+U \sum_i \left(n_{i\uparrow} - \tfrac{1}{2}\right)\left(n_{i\downarrow} - \tfrac{1}{2}\right)$$
$$+V \sum_i \left(n_{i\uparrow} + n_{i\downarrow} - 1\right)\left(n_{i+1\uparrow} + n_{i+1\downarrow} - 1\right)$$

Extended Hubbard Hamiltonian with on-site and nearest neighbors **Coulomb interaction**

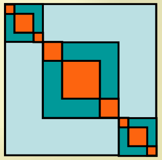
$$H_{\text{tun}} = t \sum_{\alpha k \sigma} (c^\dagger_{\alpha k \sigma} d_{\alpha\sigma} + d^\dagger_{\alpha\sigma} c_{\alpha k \sigma})$$

← Tunnelling restricted to the dot closest to the corresponding lead

H_{leads} Ferromagnetic leads with equal parallel polarization

Generalized Master Equation

- We start with the **Liouville** equation: $\dot{\rho} = -\frac{i}{\hbar}[\mathcal{H}, \rho]$



- We consider a reduced density matrix block-diagonal in spin, energy and particle number. We keep coherencies between orbitally degenerate states.

- The **Generalized Master Equation** is an equation of motion for the reduced density matrix. We calculate it in the lowest non-vanishing order in the coupling to the leads and in the Markov approximation. It reads:

$$\dot{\sigma} = \underbrace{-\frac{i}{\hbar}[H_{\mathrm{sys}}, \sigma]}_{\text{Coherent dynamics}} \underbrace{- \frac{i}{\hbar}[H_{\mathrm{eff}}, \sigma]}_{\text{Effective internal dynamics}} + \underbrace{\mathcal{L}_{\mathrm{tun}}\sigma}_{\text{Tunnelling dynamics}}$$

Coherent dynamics

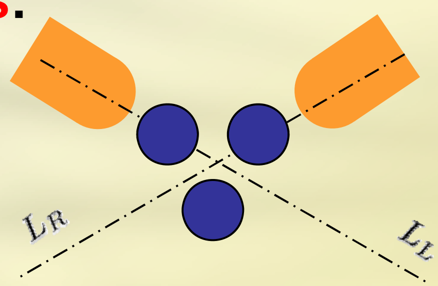
Effective **internal** dynamics

Tunnelling dynamics

The effective Hamiltonian

The effective Hamiltonian is expressed in terms of **angular momentum** operators and **renormalization frequencies**:

$$H_{\text{eff}} = \sum_{\alpha S_z} \omega_{\alpha S_z} L_\alpha,$$



In particular in the Hilbert space of the 2 particle first excited states

$$L_\alpha = \frac{\hbar}{2}\begin{pmatrix} 1 & e^{i2|\ell|\phi_\alpha} \\ e^{-i2|\ell|\phi_\alpha} & 1 \end{pmatrix}$$

$$\omega_{\alpha S_z} = \frac{1}{\pi}\sum_{\sigma'\{E\}} \Gamma^0_{\alpha\sigma'}\Big[\langle 2_1 \ell S_z|d_{M\sigma'}|3\{E\}\rangle\langle 3\{E\}|d^\dagger_{M\sigma'}|2_1 \; -\ell\, S_z\rangle p_\alpha(E-E_{2_1})+ \langle 2_1\ell S_z|d^\dagger_{M\sigma'}|1\{E\}\rangle\langle 1\{E\}|d_{M\sigma'}|2_1 \; -\ell\, S_z\rangle p_\alpha(E_{2_1}- E)\Big]$$

Bias and gate dependent

Blocking conditions

The interference blocking state:

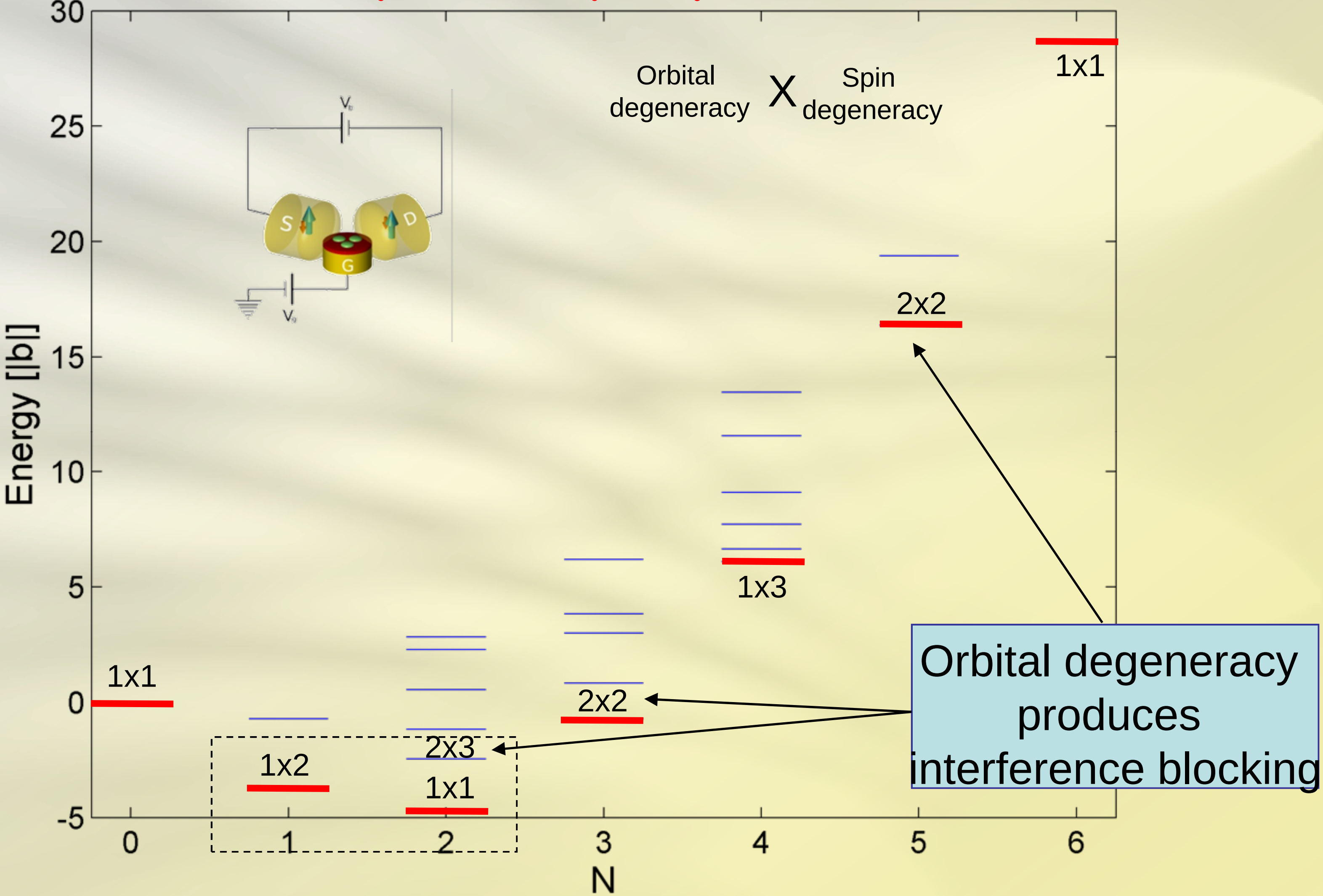
- is a linear combination of degenerate system eigenstates
- is achievable from the global minimum via a finite number of allowed transitions
- has vanishing tunnelling amplitudes for all energetically allowed outgoing transitions

$$\mathcal{L}_{\mathrm{tun}}\sigma_{\mathrm{B}} = 0$$

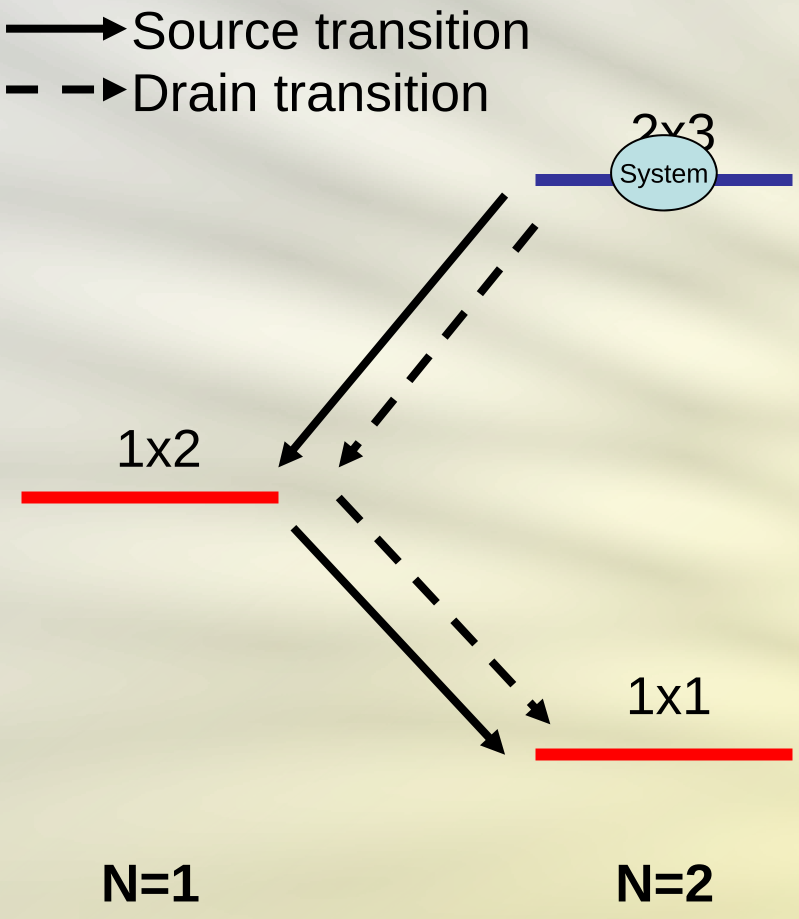
- is an eigenstate of the effective Hamiltonian

$$[H_{\mathrm{eff}}, \sigma_{\mathrm{B}}] = 0$$

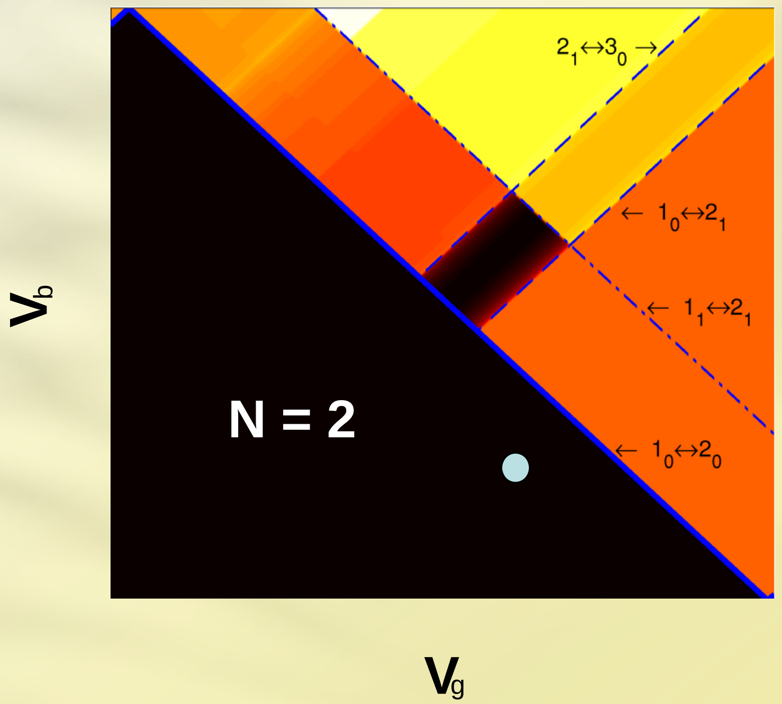
Many-body spectrum



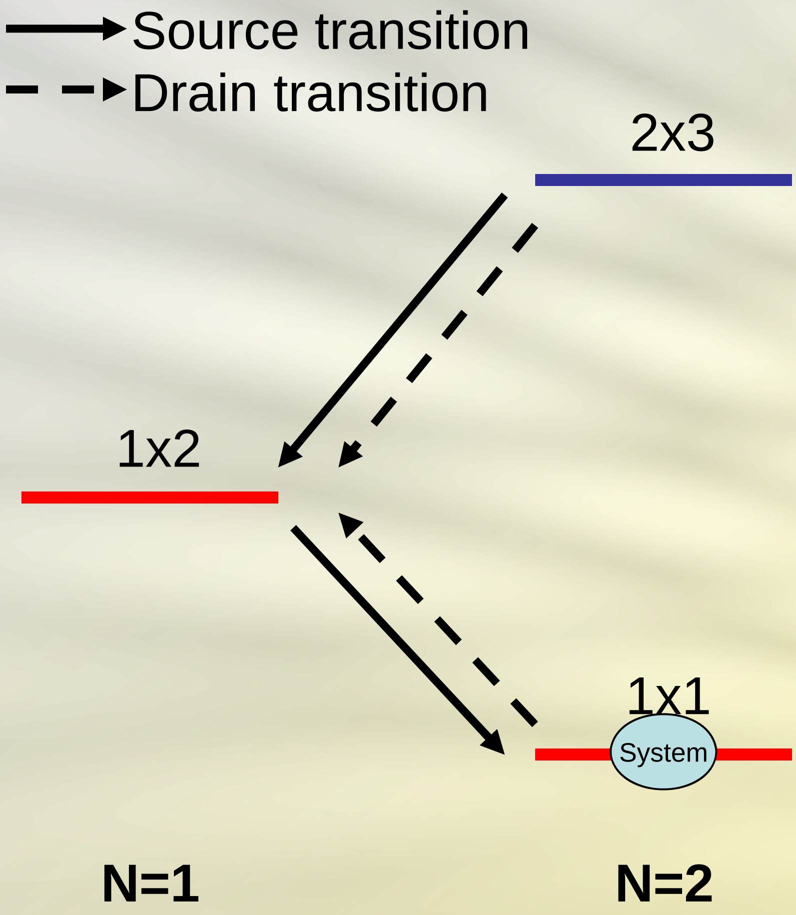
Excited state blocking

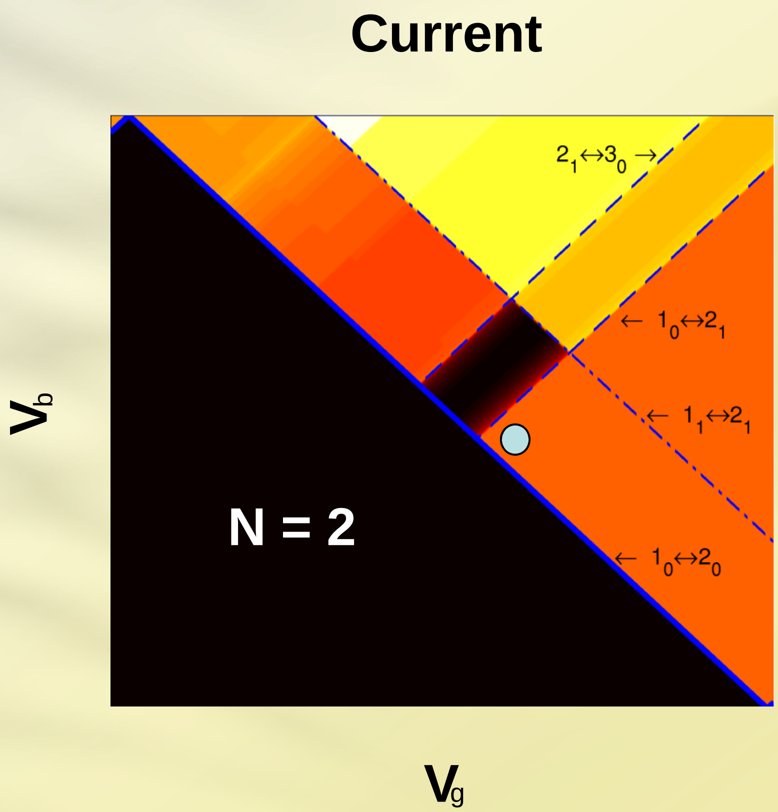


Coulomb Blockade

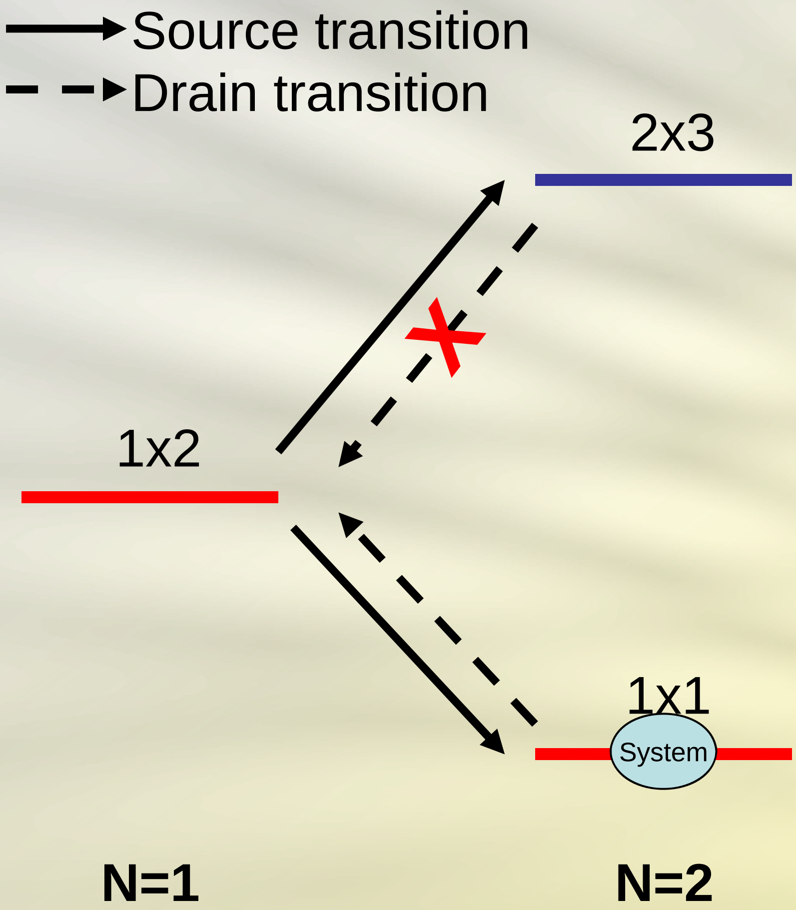


Excited state blocking

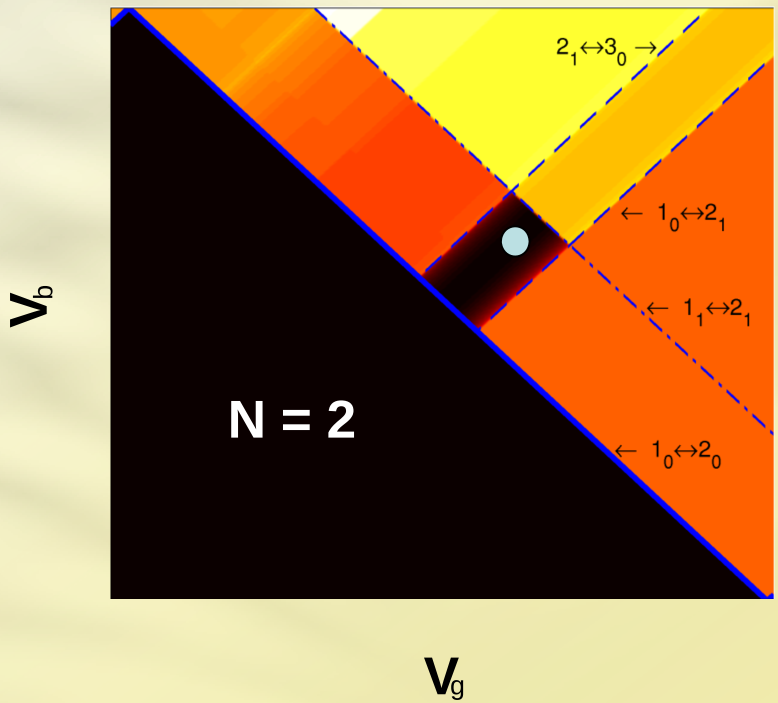




Excited state blocking



Interference Blockade

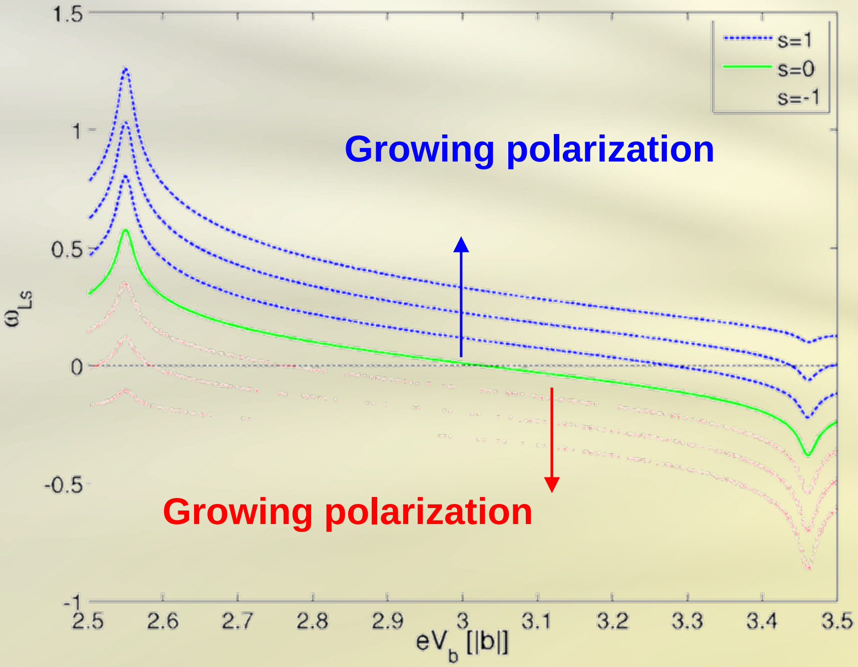


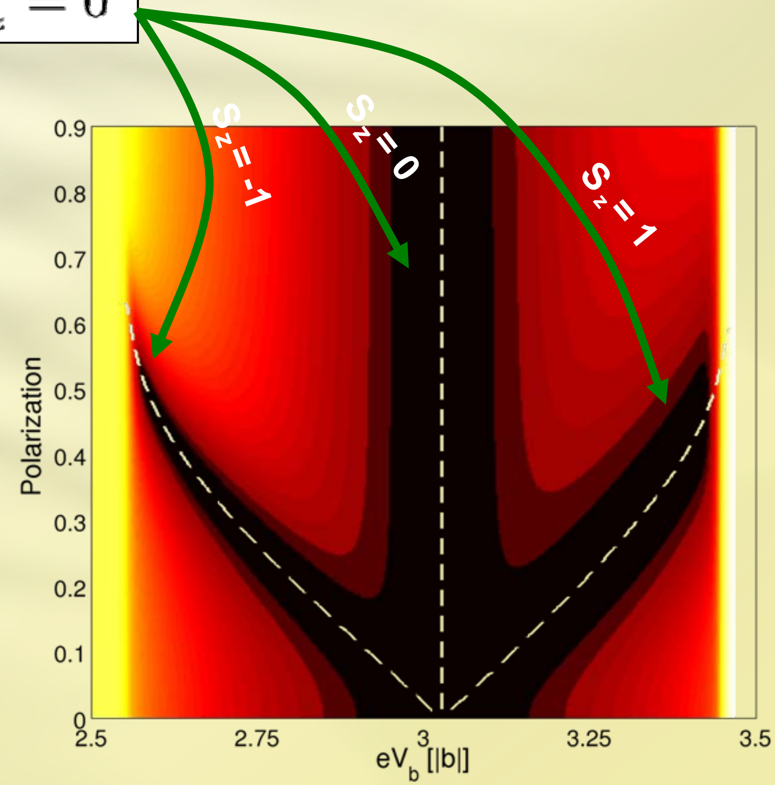
Three linear combinations of 2-particle excited states are coupled **ONLY to the source**.

Triplet splitting

The states decoupled from the right lead are eigenstates of L_R. They are eigenstates of H_{eff} only if

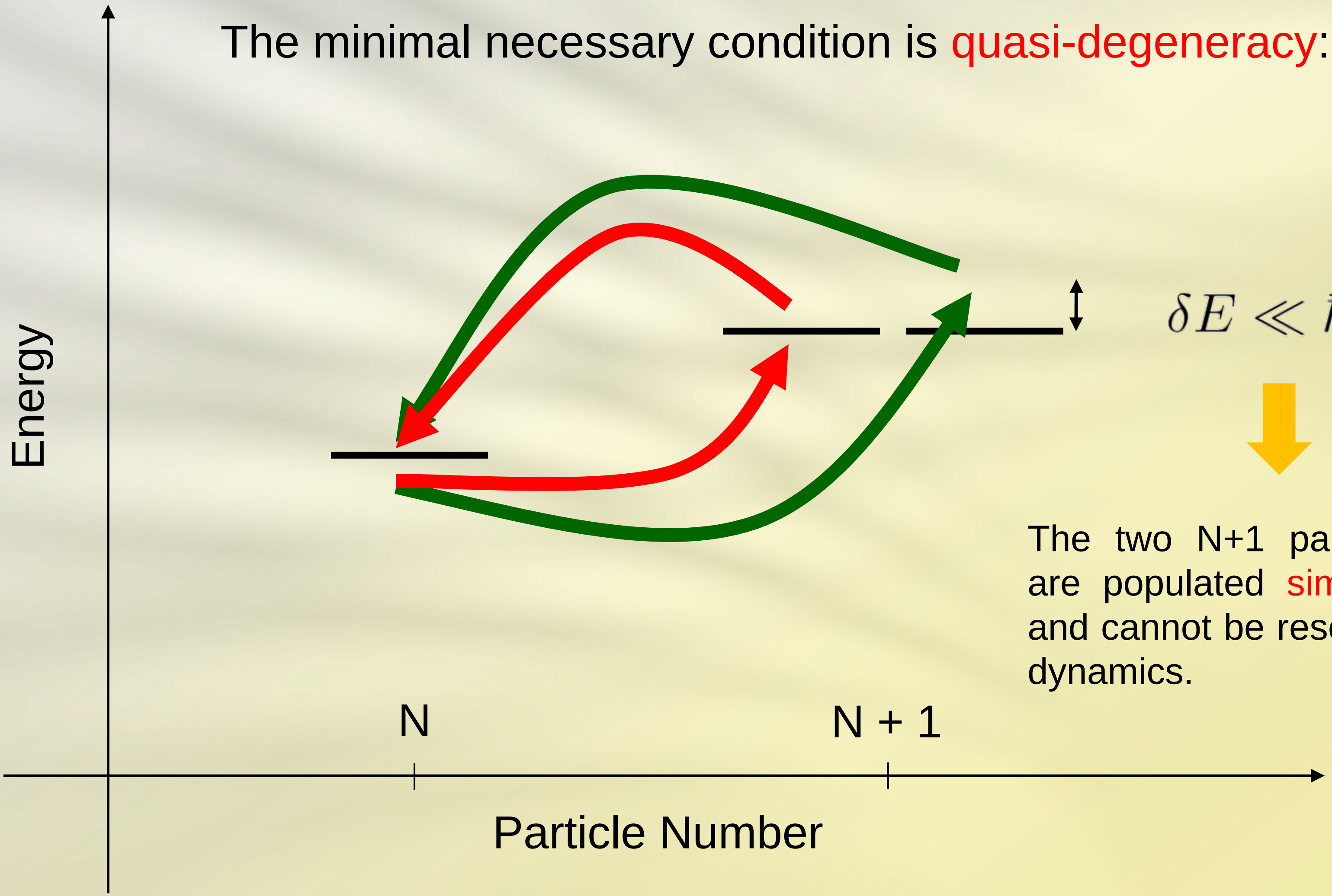
$$\omega_{L\,S_z} = 0$$





Quasi-degeneracy

The minimal necessary condition is quasi-degeneracy:



$$\delta E \ll \hbar\Gamma$$

The two N+1 particle states are populated simultaneously and cannot be resolved by the dynamics.

Conclusions

• Symmetric nanojunctions have an **orbitally degenerate many-body spectrum**

• Destructive interference between orbitally degenerate states leads to the formation of ground- as well as **excited- interference blocking states**

• Exploiting the interplay of interference blocking and Coulomb interaction we could achieve **all-electrical spin control of a triple dot junction**

References:

G. Begemann, D. Darau, **AD**, and M. Grifoni *PRB* **77**, 201406(R) (2008)

D. Darau, G. Begemann, **AD**, and M. Grifoni *PRB* **79**, 235404 (2009)

AD, G. Begemann, and M. Grifoni *Nano Lett.* **9**, 2897 (2009)

AD, G. Begemann, and M. Grifoni PRB in press (2010) **arXiv:1007.0639**

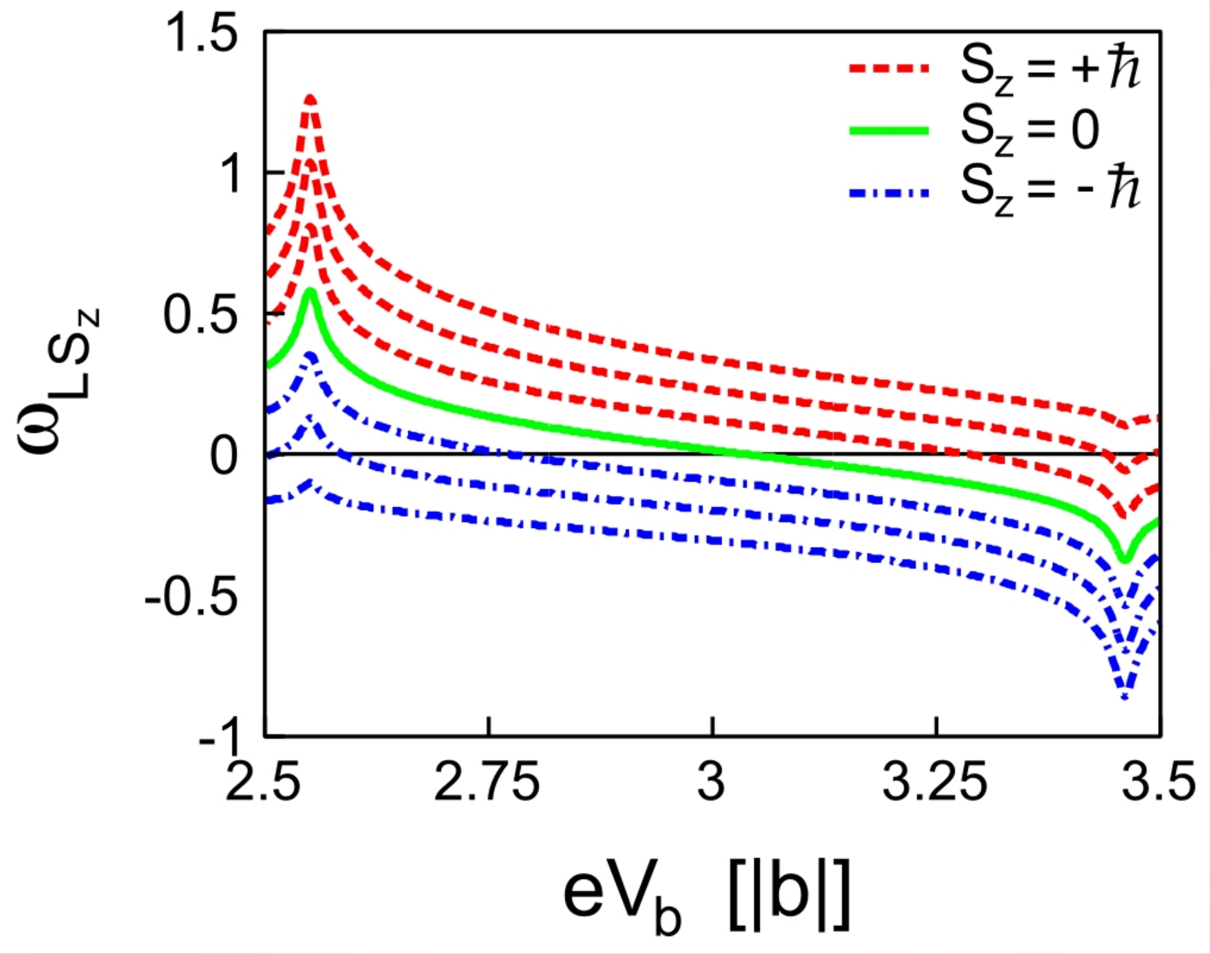
Thanks

Georg Begemann

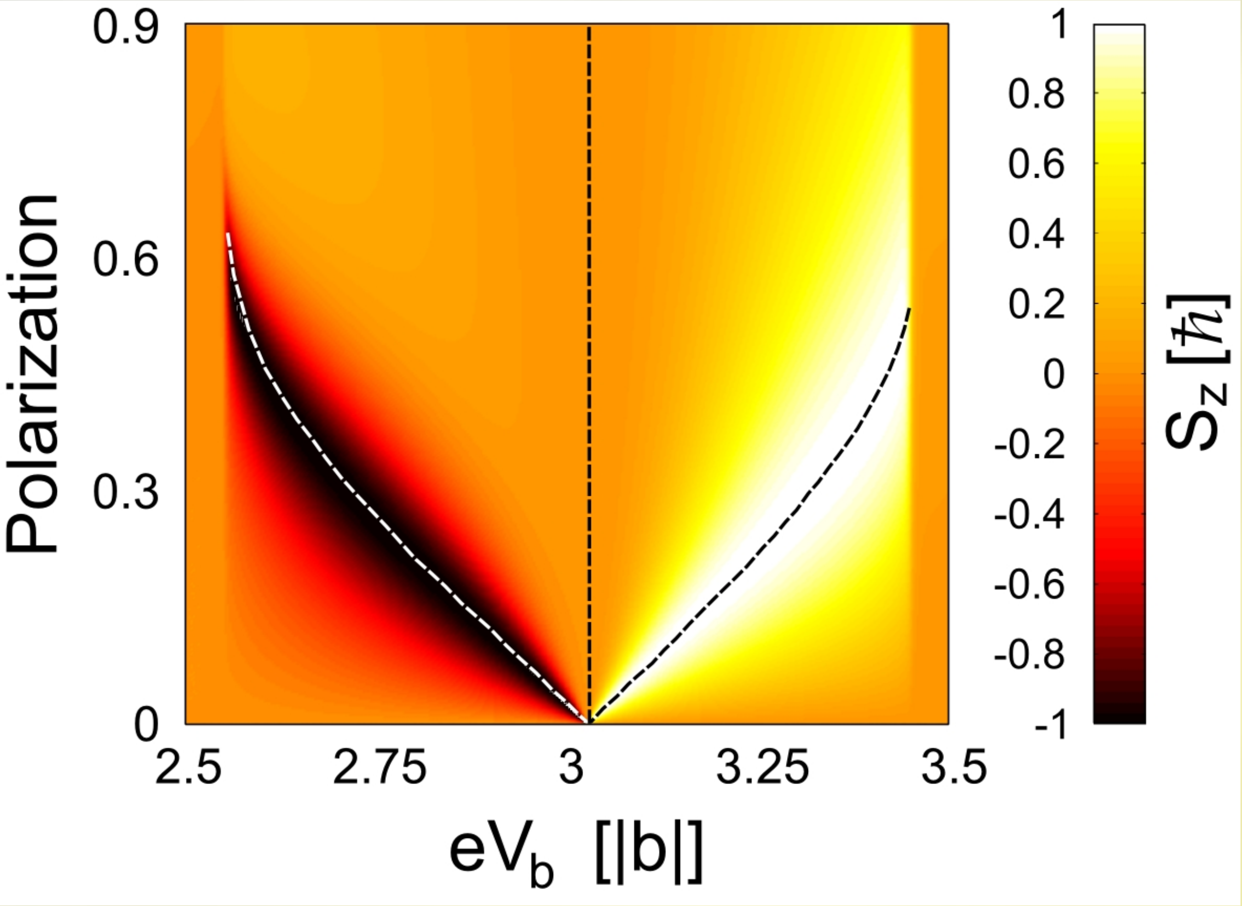
Milena Grifoni

Dana Darau

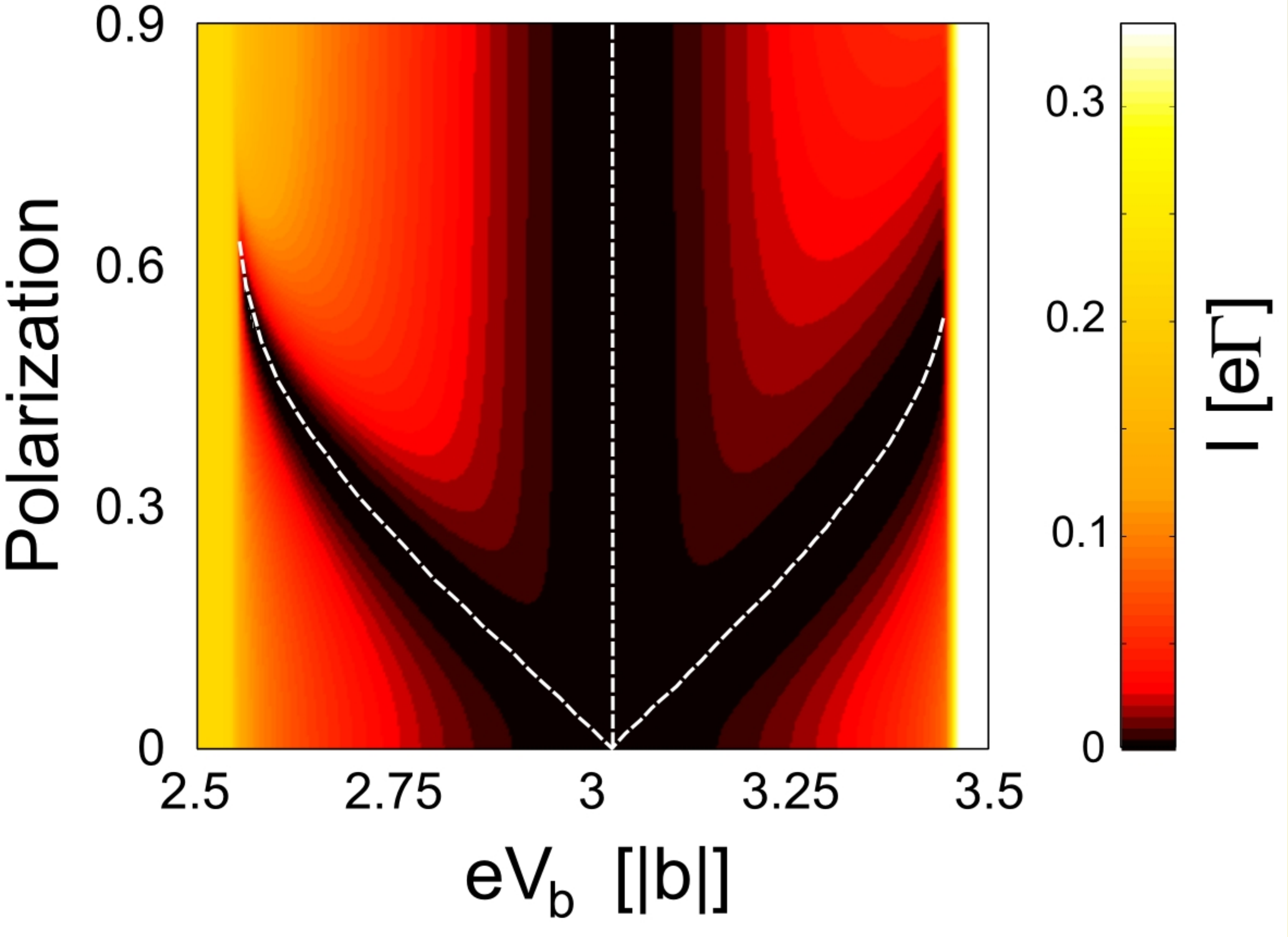
...and you for your attention!

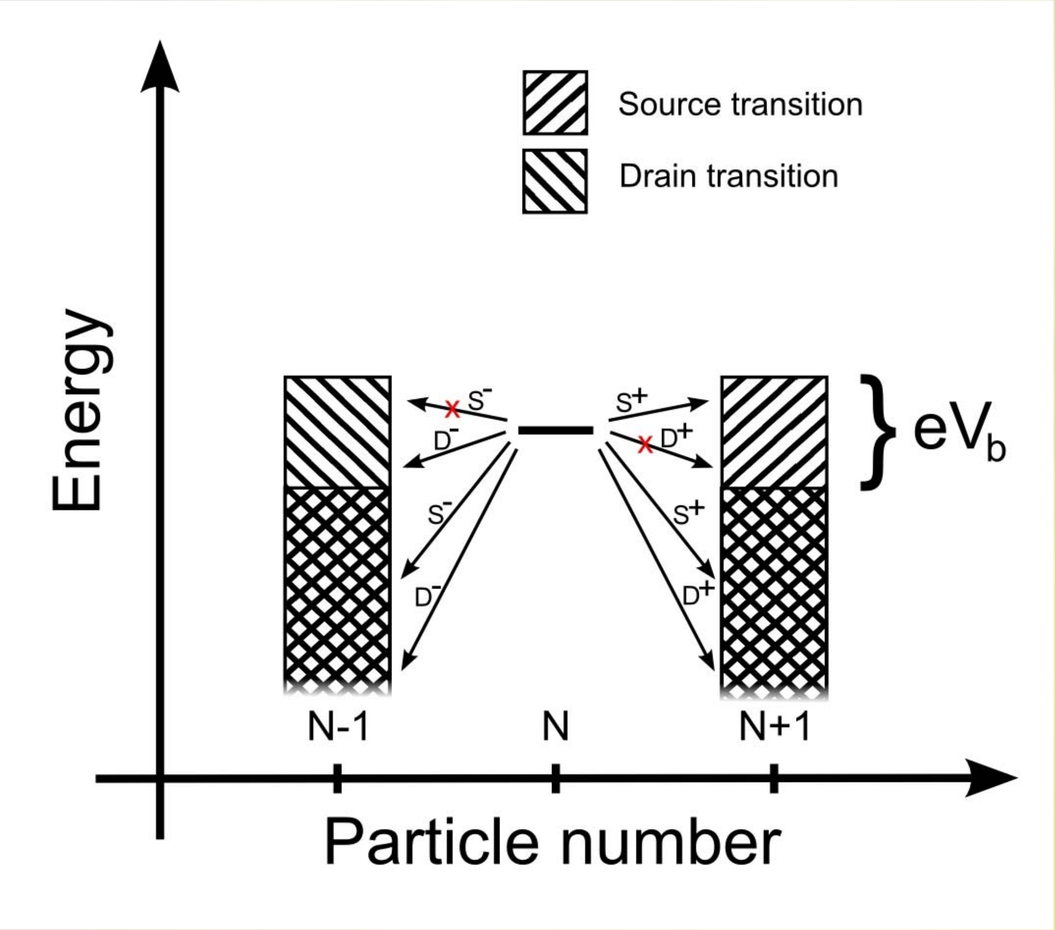


1.5
1
0.5
0
-0.5
-1
2.5
2.75
3
3.25
3.5
ω_{LS_z}
eV_b [|b|]
$S_z = +\hbar$
$S_z = 0$
$S_z = -\hbar$



0.9
0.6
0.3
0
Polarization
2.5
2.75
3
3.25
3.5
eV_b [|b|]
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
S_z [ħ]


0.9
0.6
0.3
0
Polarization
2.5
2.75
3
3.25
3.5
eV_b [|b|]
0.3
0.2
0.1
0
I [eΓ]


Source transition
Drain transition
Energy
S-
D-
S-
D-
S+
D+
S+
D+
eV_b
N-1
N
N+1
Particle number