Spin blockade lifting due to phonon mediated spin relaxation and electric dipole spin resonance in nanowire quantum dots

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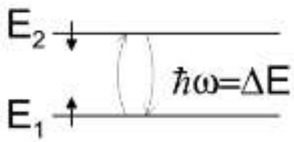
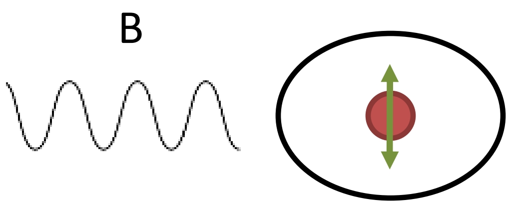
Electrical control over a single spin

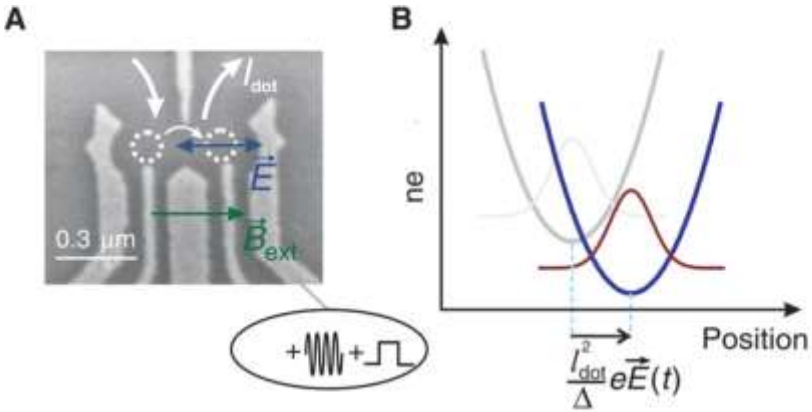
- quantum computation on spin qubits
- spins in quantum dots - quantum gates
- single gates require spin rotations



B > 0

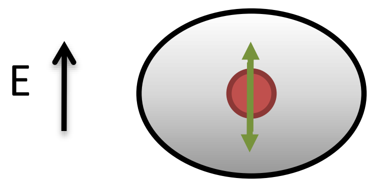
- Rabi oscillation in AC magnetic field – low scalability





K. C. Nowack, et al., Science **318**, 1430 (2007).

- spin-orbit interaction, spin oscillations in an effective magnetic field



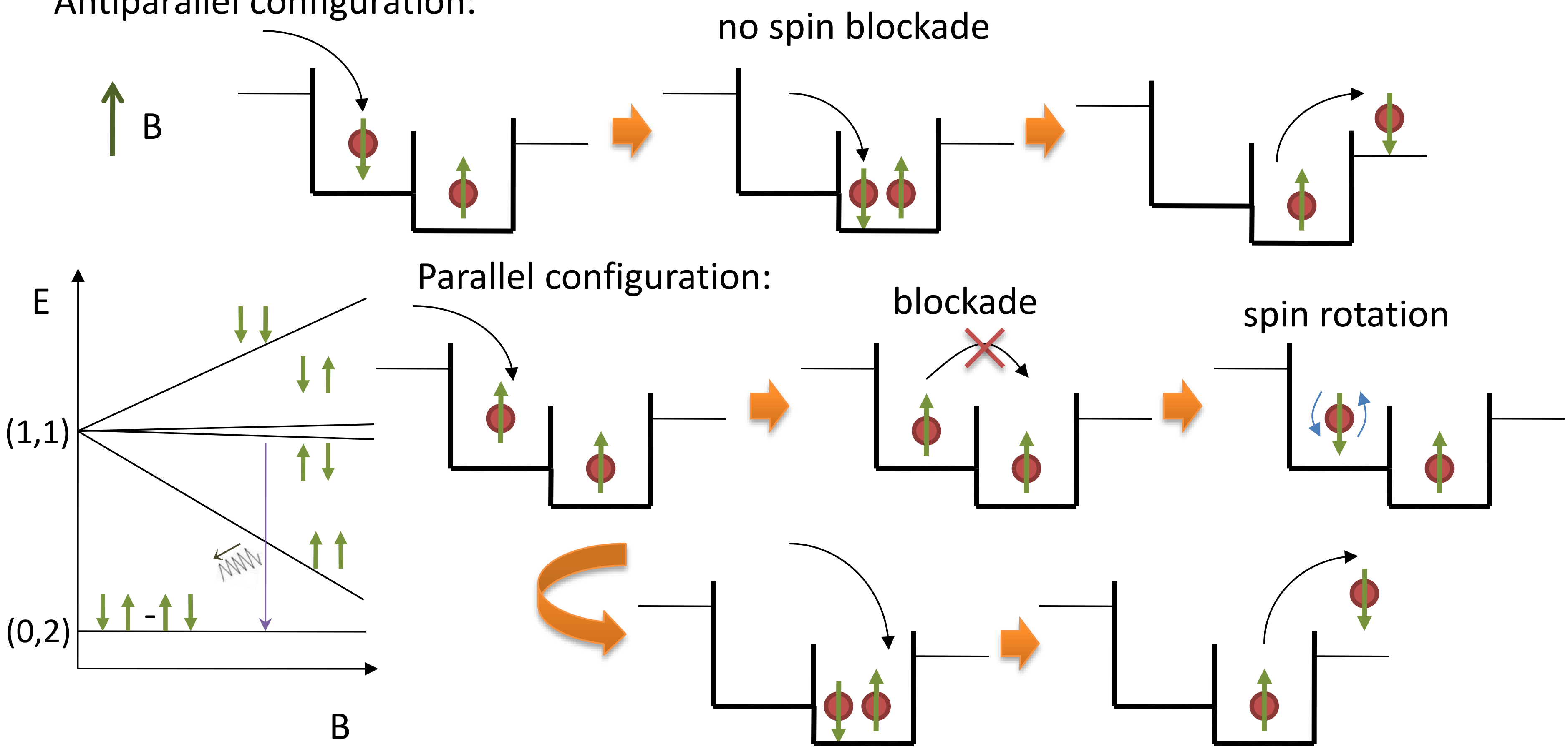
$$\hat{H}_{SO} = \frac{\hbar \nabla V}{4 m_0^2 c^2} \cdot (\boldsymbol{\sigma} \times \mathbf{p})$$

Electric Dipole Spin Resonance (**EDSR**)

Spin to charge conversion

Spin blockade in double dots allows for the measurement of the spin state

Antiparallel configuration:



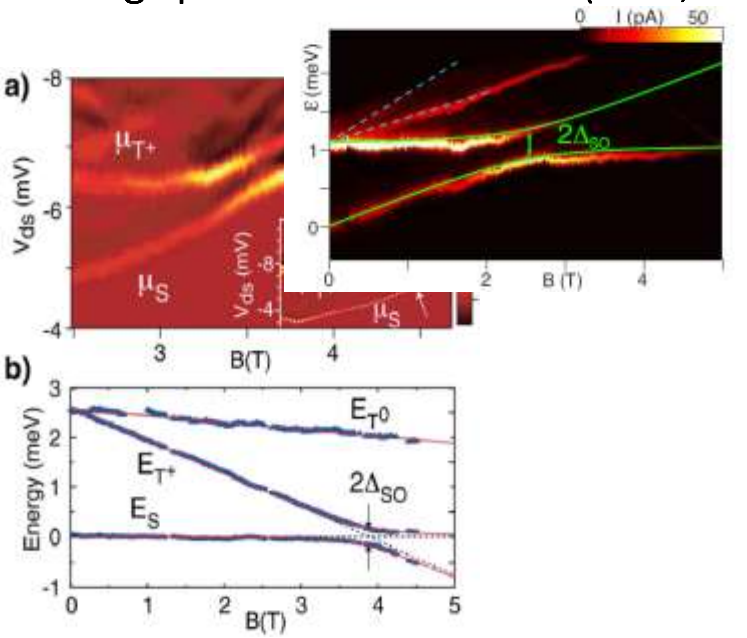
Energy dissipated by phonons

Sequential events - current increases when the spin is rotated
At the resonances

Nanowire quantum dots

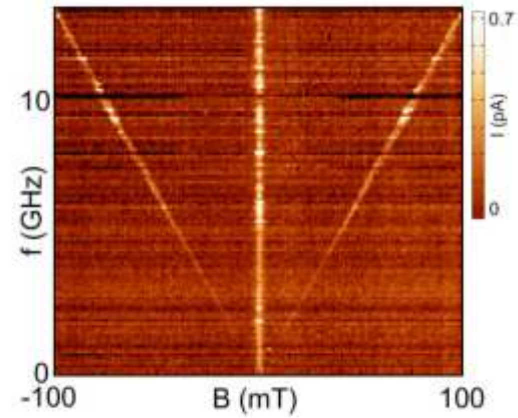
Measured map of the current due to spin blockade lifting.

Strong spin-orbit interaction (InSb, InAs)



C. Fasth et al., Phys. Rev. Lett., **98**, 266801 (2007)

A. Pfund et al., Phys. Rev. B **76**, 161308(R) (2007)

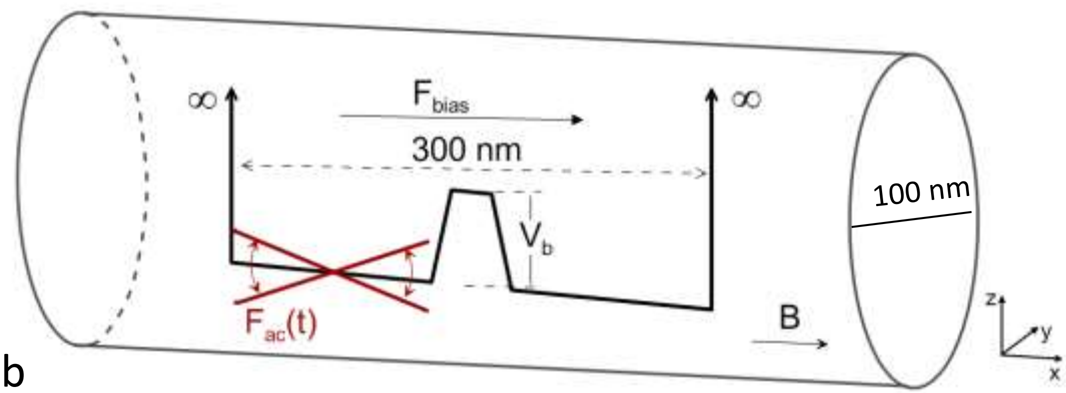


S. Nadj-Perge, et al., Nature (London) **468**, 1084 (2010).

Strong SOI -> spin relaxation

How does this affects EDSR observed due to spin blockade lifting?

Theory – model system



InSb

$$H_{1D}(t) = h^1_{1D}(t) + h^2_{1D}(t) + \frac{\sqrt{\pi/2}}{4\pi\varepsilon_0\varepsilon l}\mathrm{erfcx}\left[\frac{|x_1 - x_2|}{\sqrt{2}l}\right]$$

$$h_{1D}(t) = \frac{\hbar^2 k_x^2}{2m^*} + V(x,t) - \alpha\sigma_y k_x + \frac{1}{2}\mu_B g(x) B\sigma_x$$

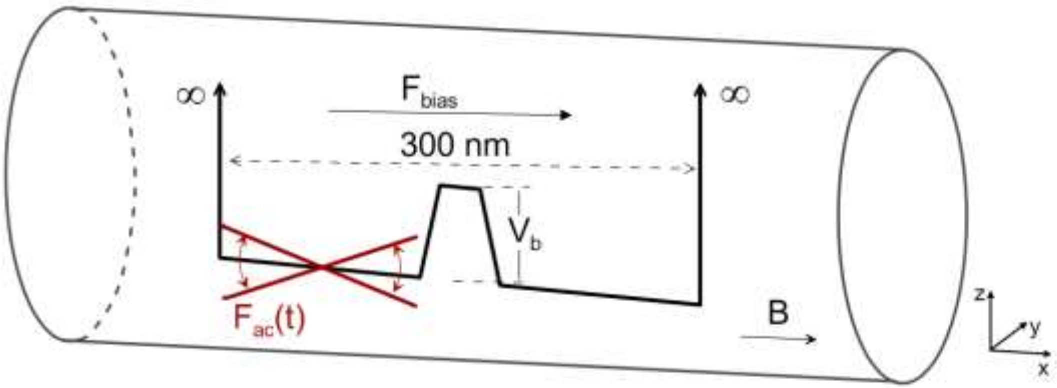
- Coupled QDs in a nanowire
- Quasi one-dimensional
- Two electrons
- Electric field present in one of the dots
- Magnetic field along the structure
- Different g-factors in the dots
- Bias voltage

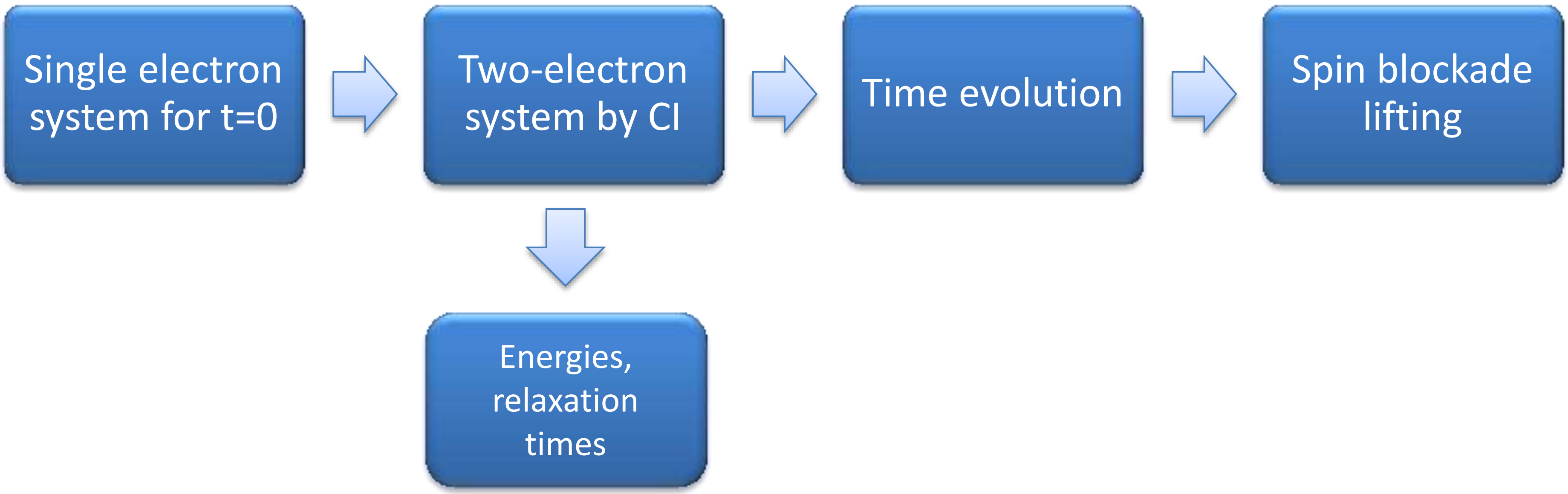
$$\tau_{if}^{-1} = \frac{2\pi}{\hbar}\sum_{\nu,i=1,2}\int_{\mathbf{q}} dq|M_\nu(\mathbf{q})|^2 \times |\langle\Psi^f|e^{-i\mathbf{q}\mathbf{r}_i}|\Psi^i\rangle|^2\delta(|E^f - E^i| - E_q)$$

$$E_q = \hbar c_\nu|\mathbf{q}|$$

Electron scattering on piezoelectric and deformation potentials

Theory – model system

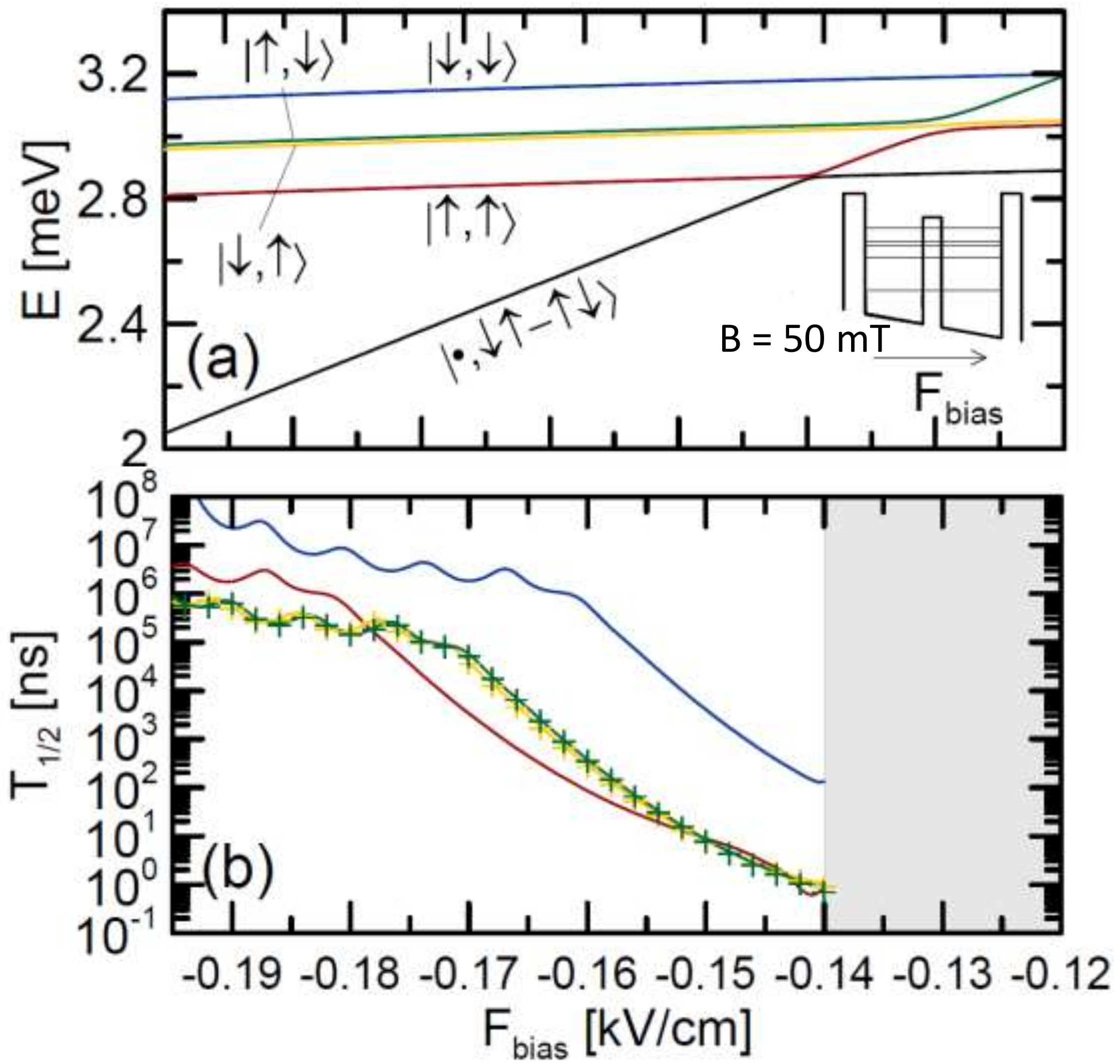




Relaxation time

Without oscillating electric field, $F_{AC} = 0$

How relaxation times change as function of F_{bias}?



Half life due to relaxation to the groundstate:

$$T_{1/2} = \ln(2)/\tau_{if}$$

$|\uparrow,\uparrow\rangle$ relaxes in nanosecond,

$|\downarrow,\downarrow\rangle$ relaxes in microseconds

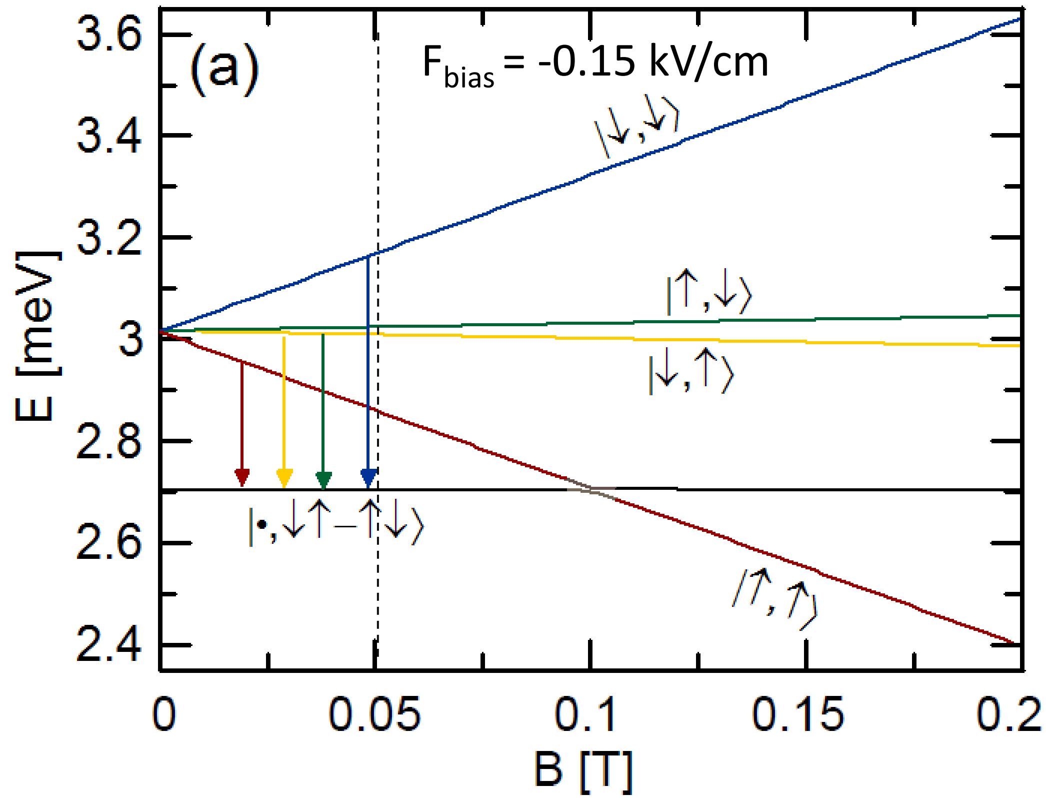
Relaxation time

Zeeman splitting

B < 100 mT relaxation time of spin positive triplet comparable to S = 0 states

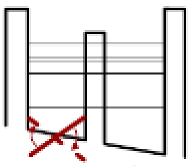
B = 100 mT singlet triplet anticrossing

B > 100 mT spin positive triplet blocked again



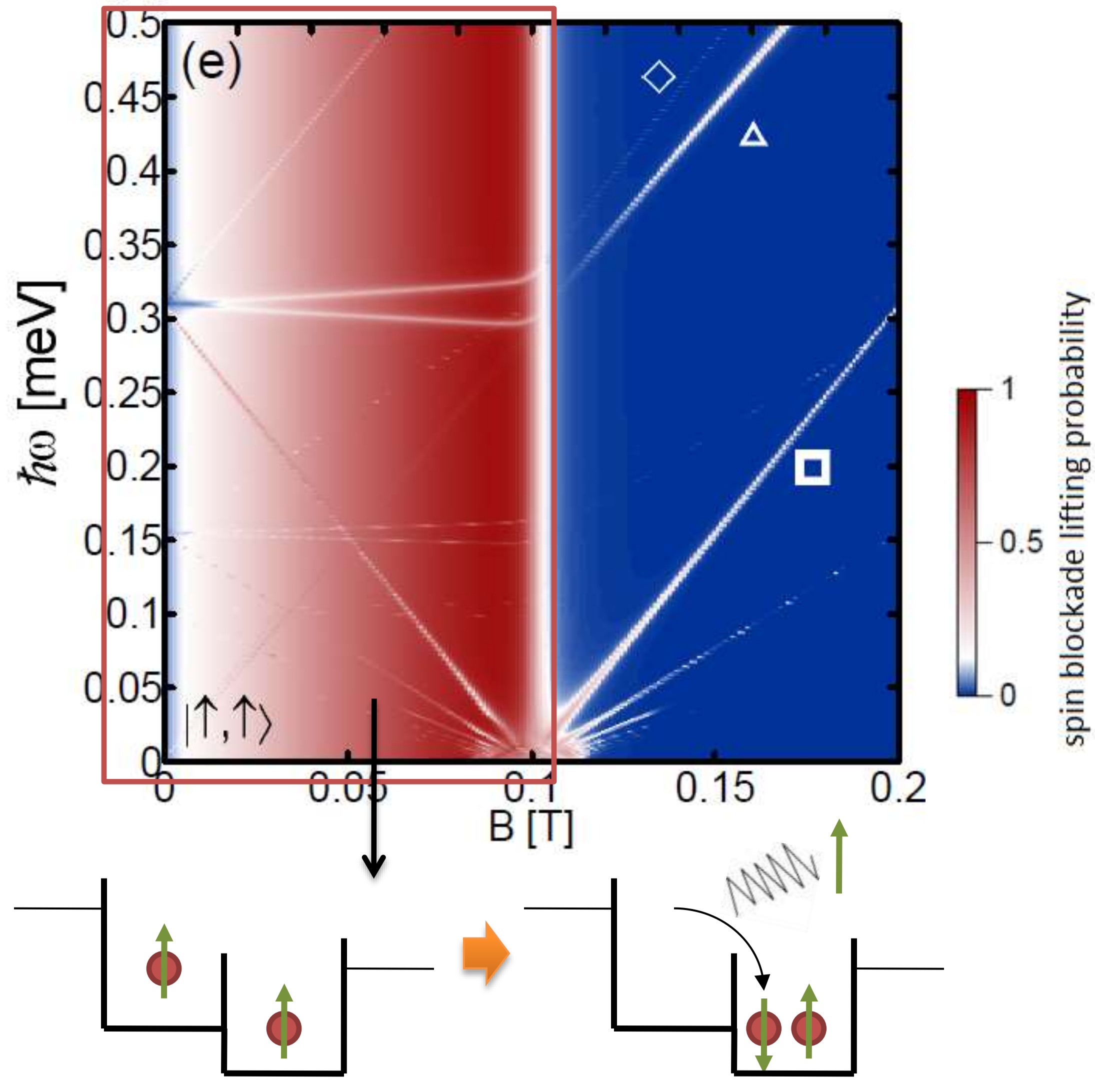
Time evolution

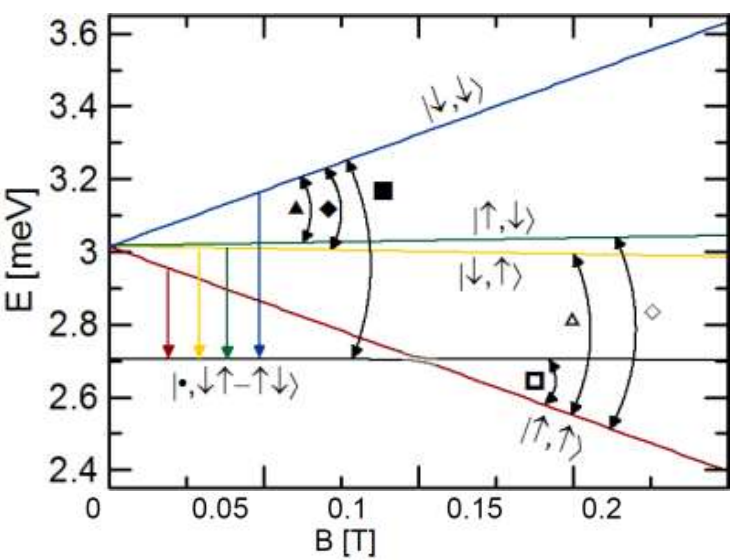
after 30 ns:



Nonzero driving field F_{AC}

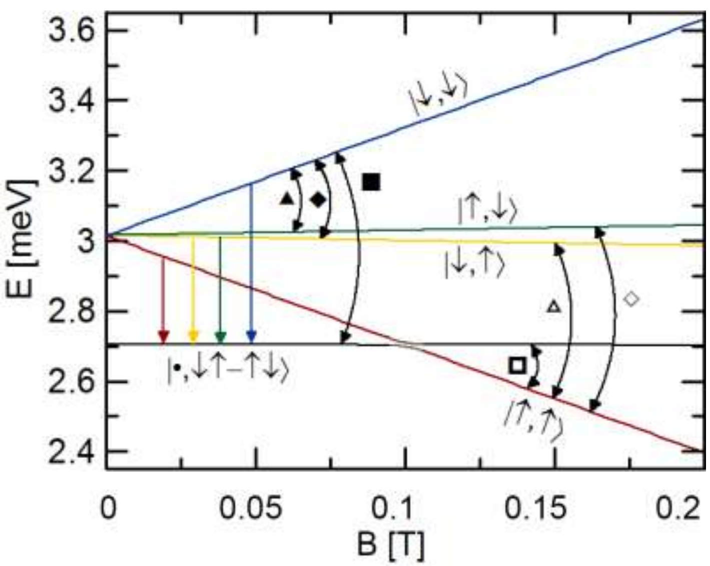
$|\uparrow,\uparrow\rangle$ As an initial condition

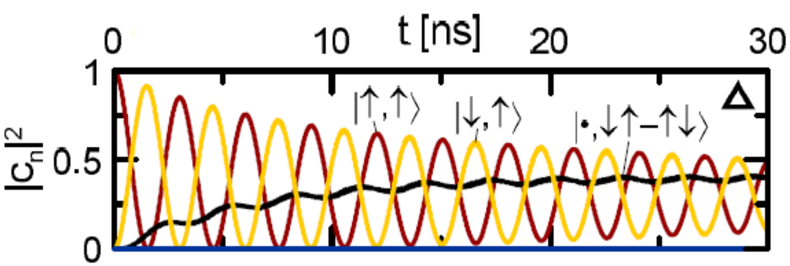


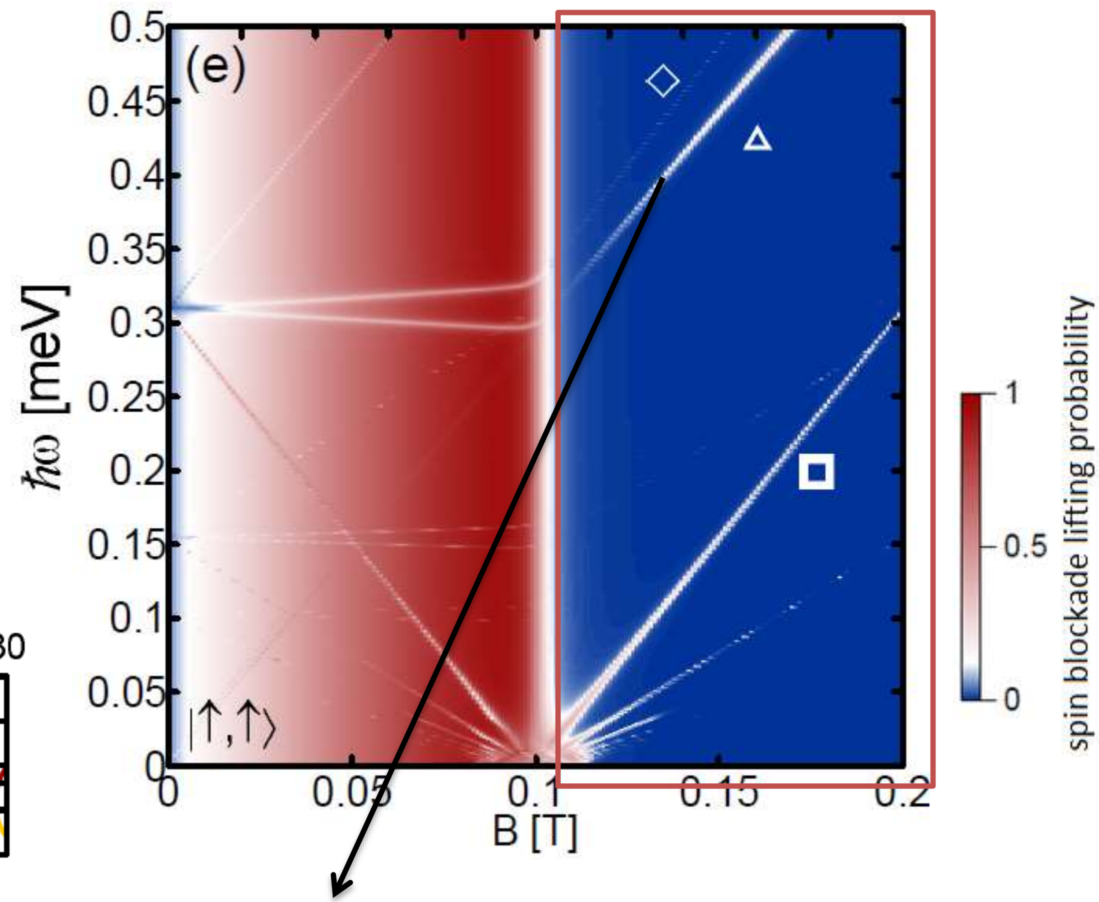


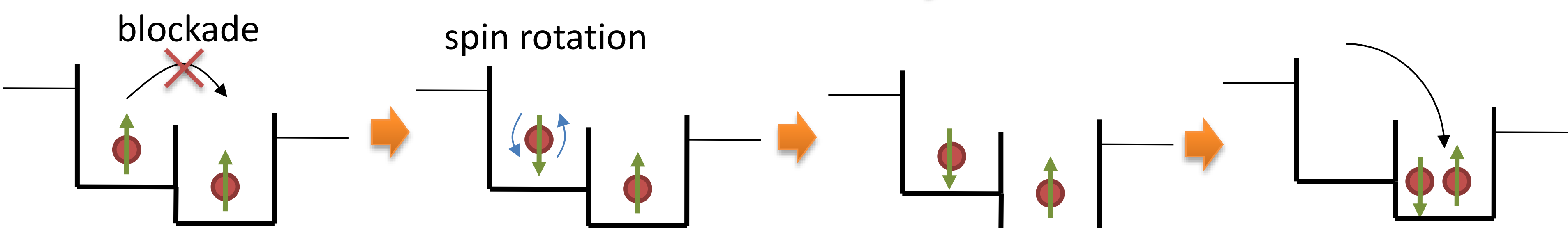
No blockade, no EDSR observed

Time evolution

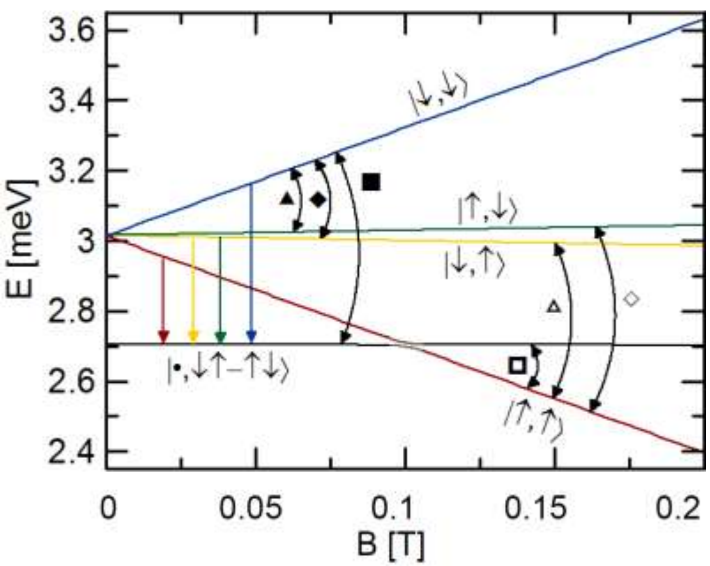


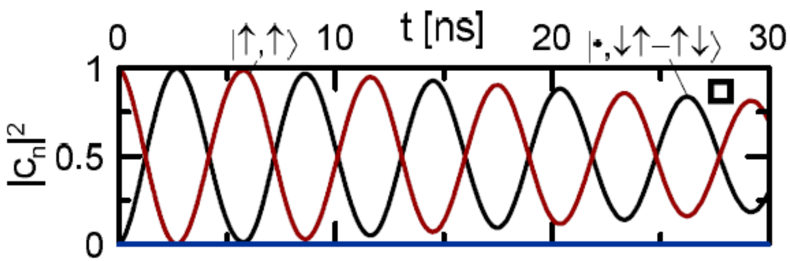


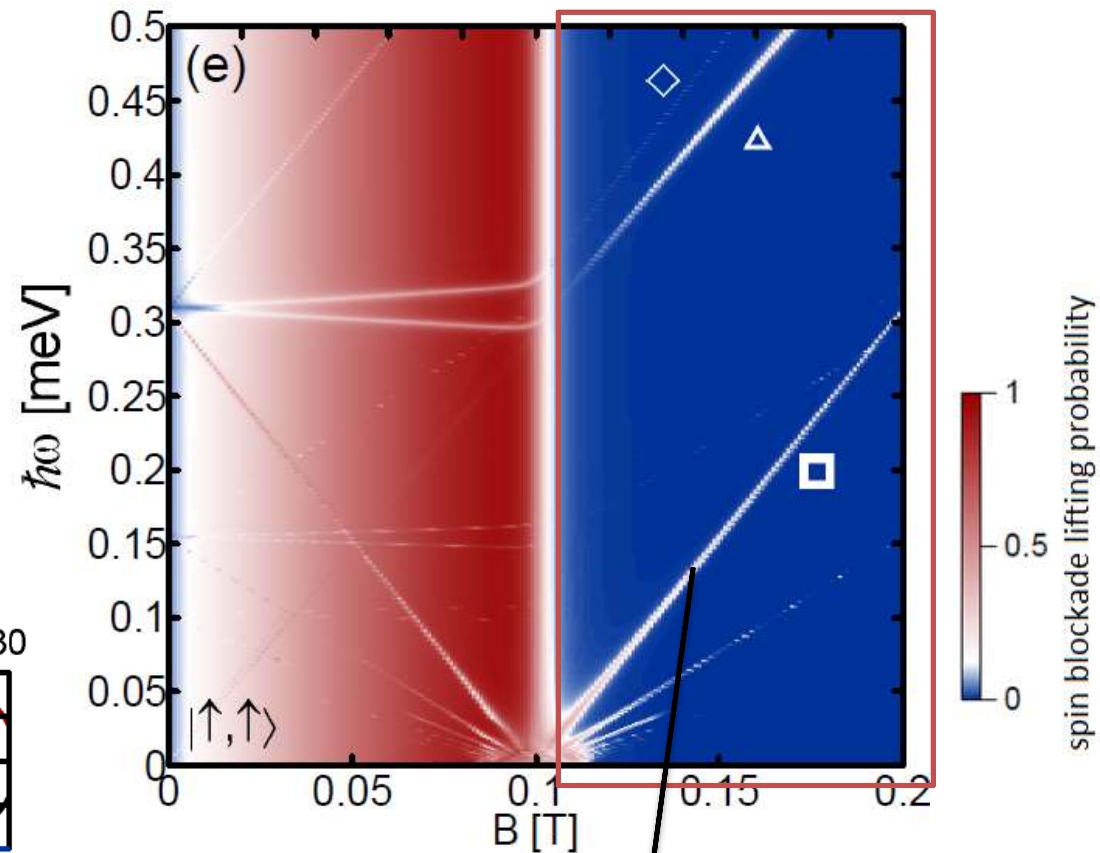




Time evolution

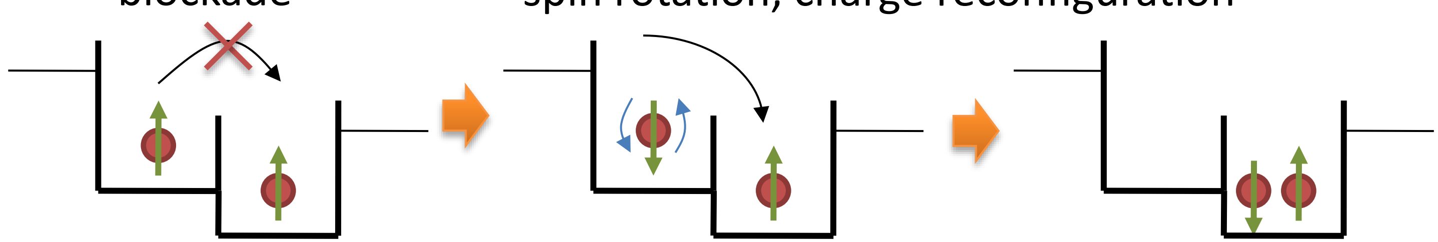




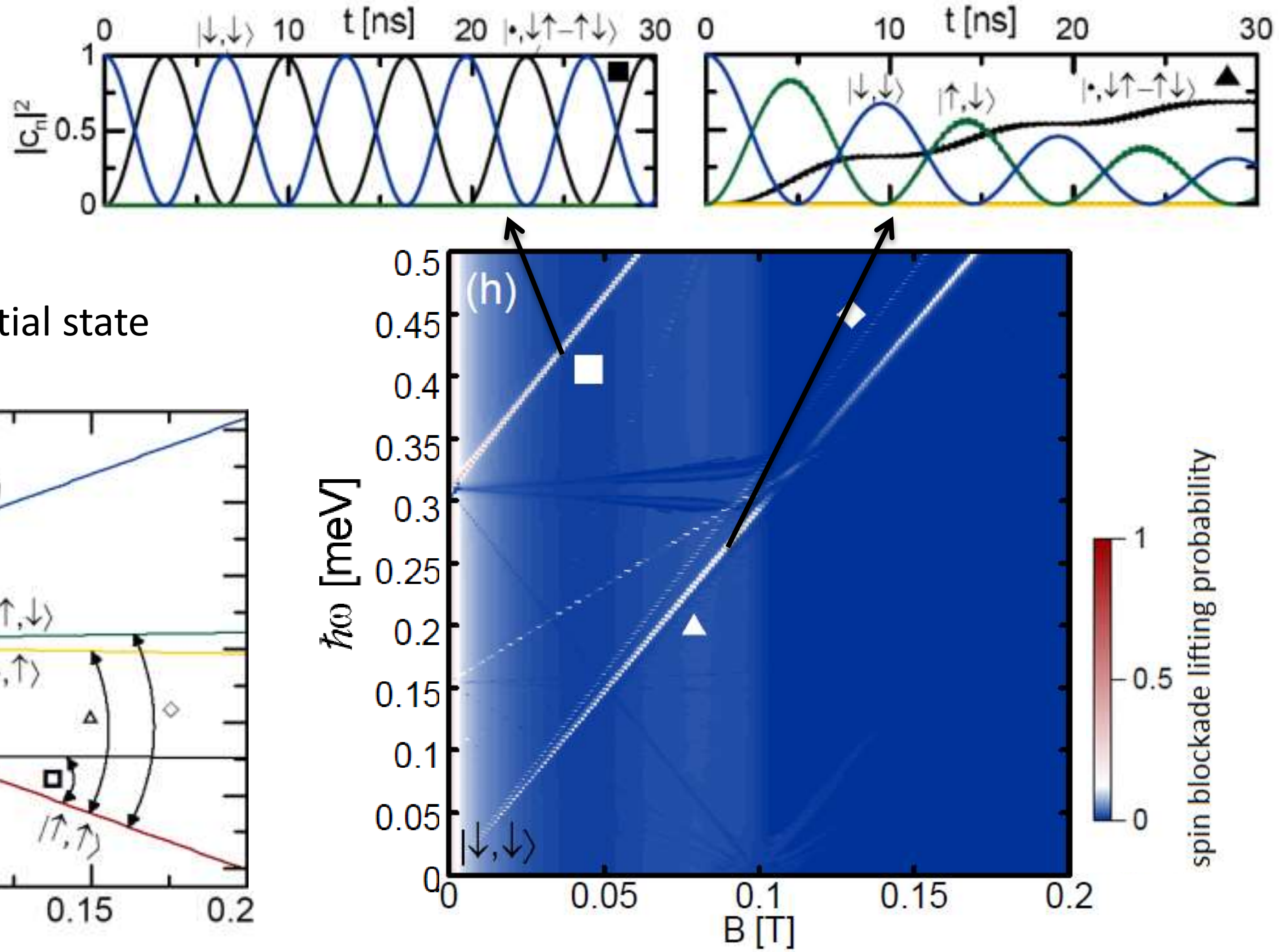


blockade

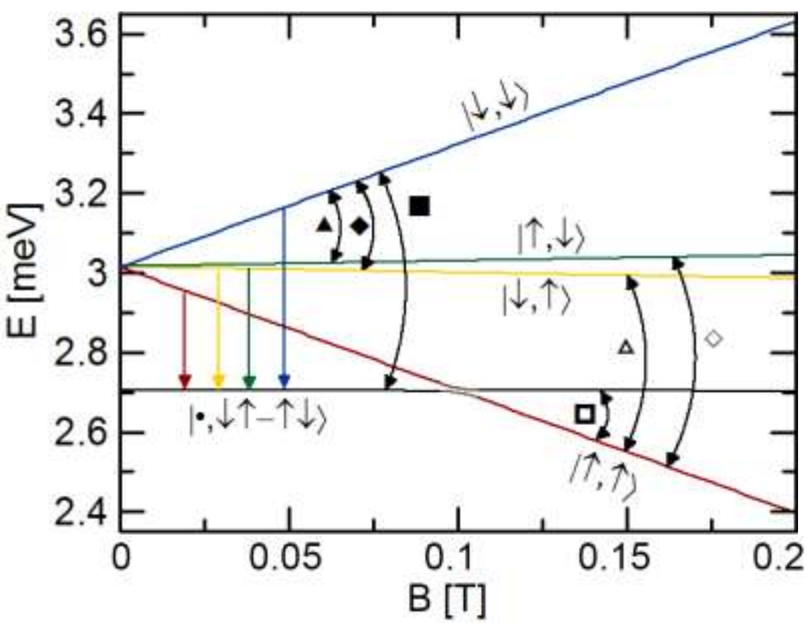
spin rotation, charge reconfiguration



Time evolution



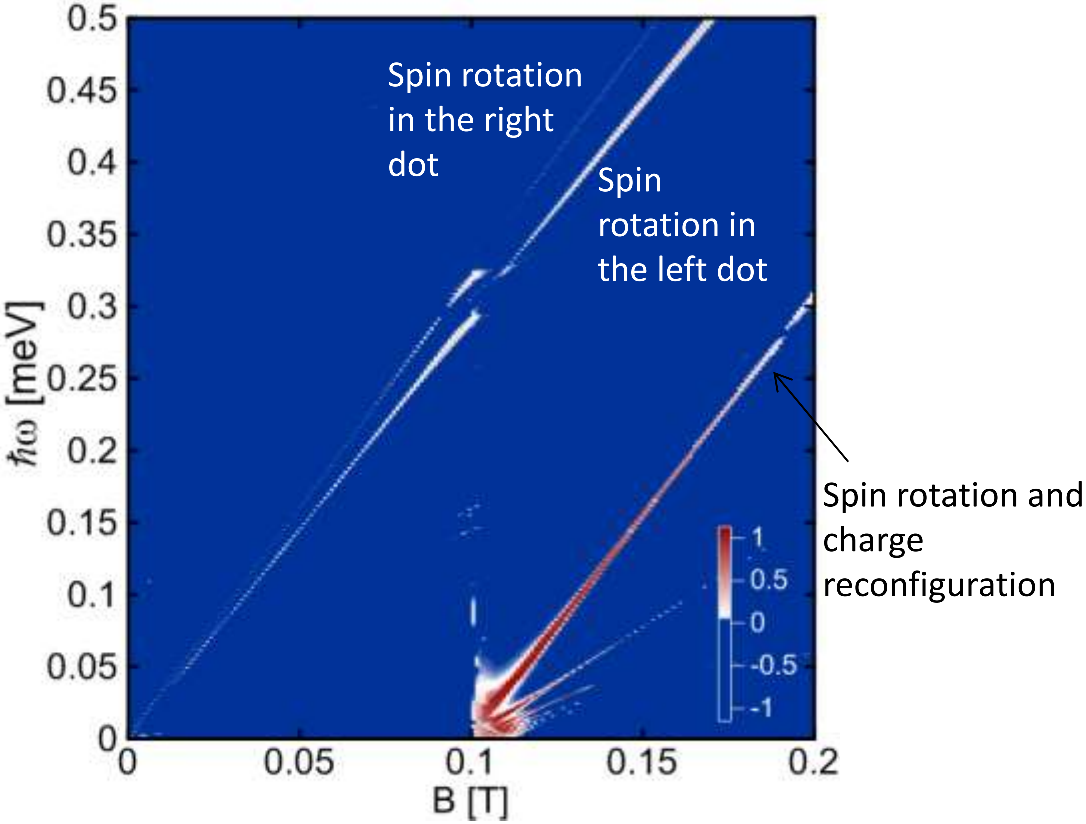
$|\downarrow,\downarrow\rangle$ as an initial state



Comparison with the experiment

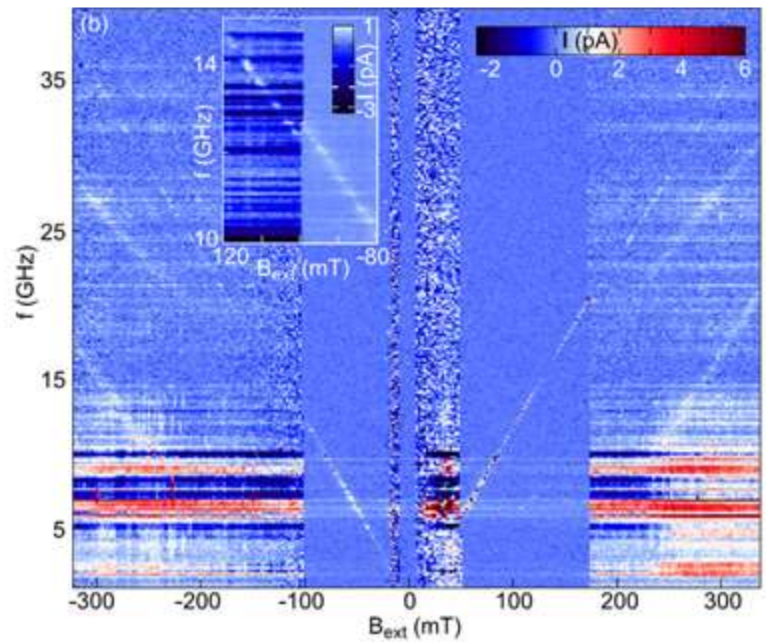
In real system all the 4 states are initialized

Total probability of spin blockade lifting with removed background for $F_{AC} = 0$.



M.P. Nowak, B. Szafran arXiv: 1303.0211 (2013)

Similar set of lines observed in the experimental maps of the current:



S. M. Frolov, et al., Phys. Rev. Lett. **109**, 236805 (2012).

Conclusions

- In a nanowire QDs the relaxation rate governed mainly by the energy difference not the spin polarization
- Strong spin-orbit interaction results in deblocking the spin positive triplet before the anticrossing
- EDSR can produce two kind of resonance lines
  - Direct transitions with charge reconfiguration (1,1) -> (0,2) observed after singlet-triplet acticrossing
  - Indirect transitions with the (1,1) -> (0,2) transition mediated by phonons.

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