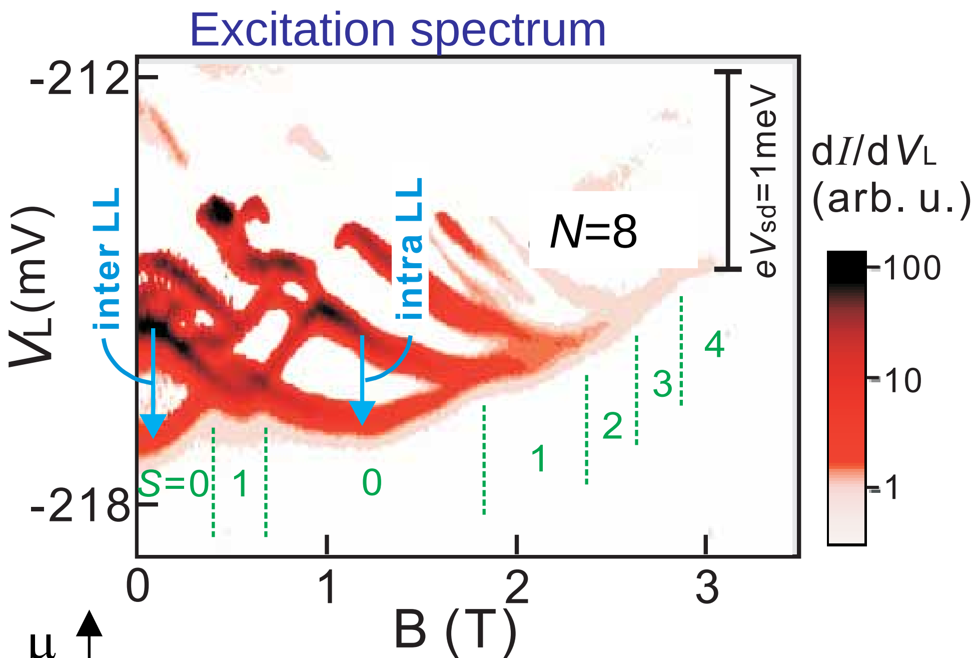
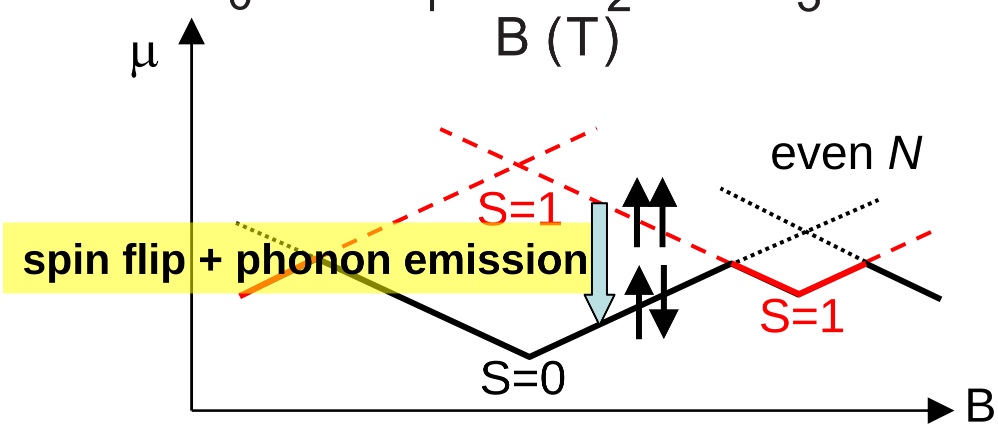
Singlet-triplet spin relaxation mechanism in a quantum dot studied by electrical pump-and-probe

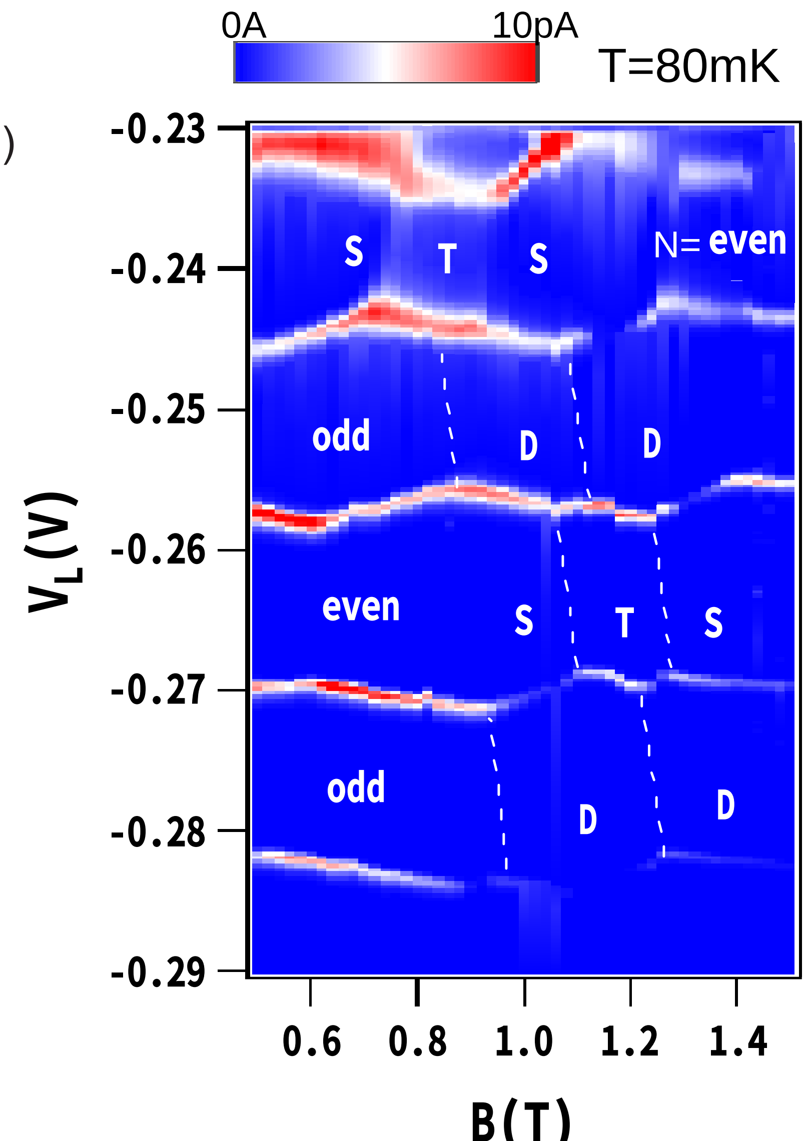
S. Sasaki[1], T. Fujisawa[1, 2], T. Hayashi[1] and Y. Hirayama[1,3]

[1]*NTT Basic Research Laboratories, NTT Corporation*
[2]*Tokyo Institute of Technology*
[3]*SORST-JST*

Singlet and triplet states in an even N quantum dot



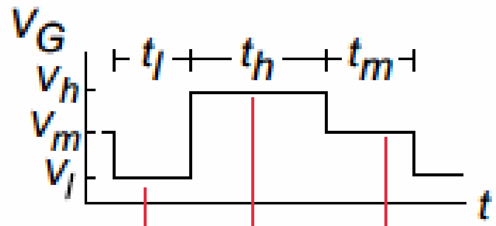




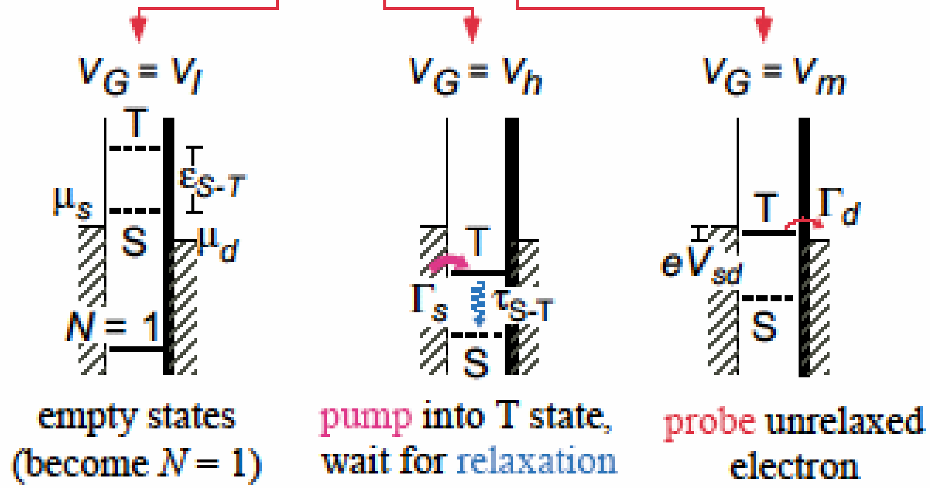
Long relaxation time is expected

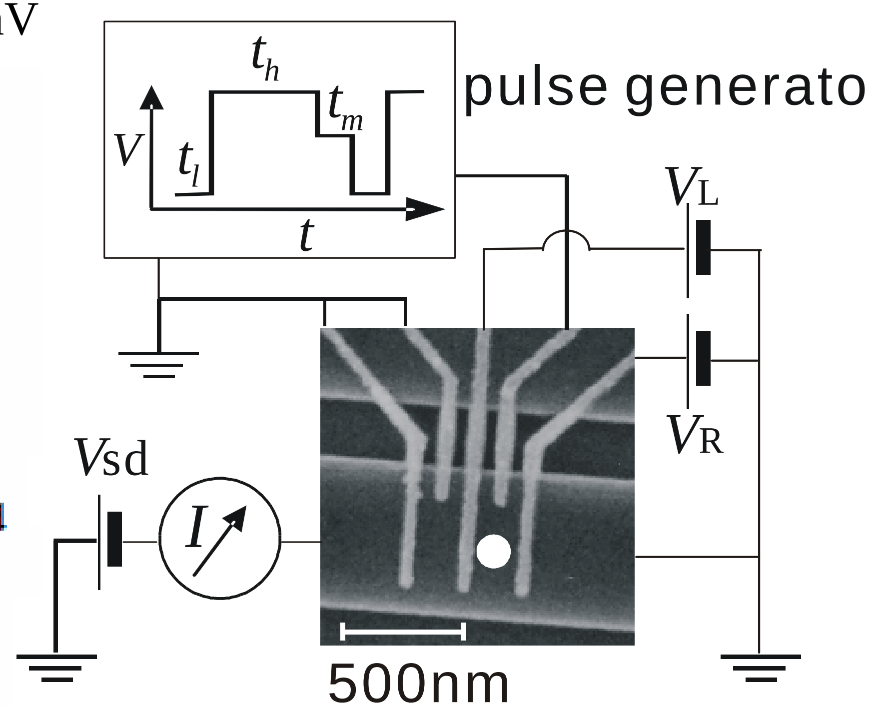
Electrical pump and probe method

T. Fujisawa *et al.*, Nature **419**, 278 (2002)



$t_l = t_m$ = 500ns
t_h = 1 μs ~ 300 μs
Vsd = 0.1 mV





used as a single dot

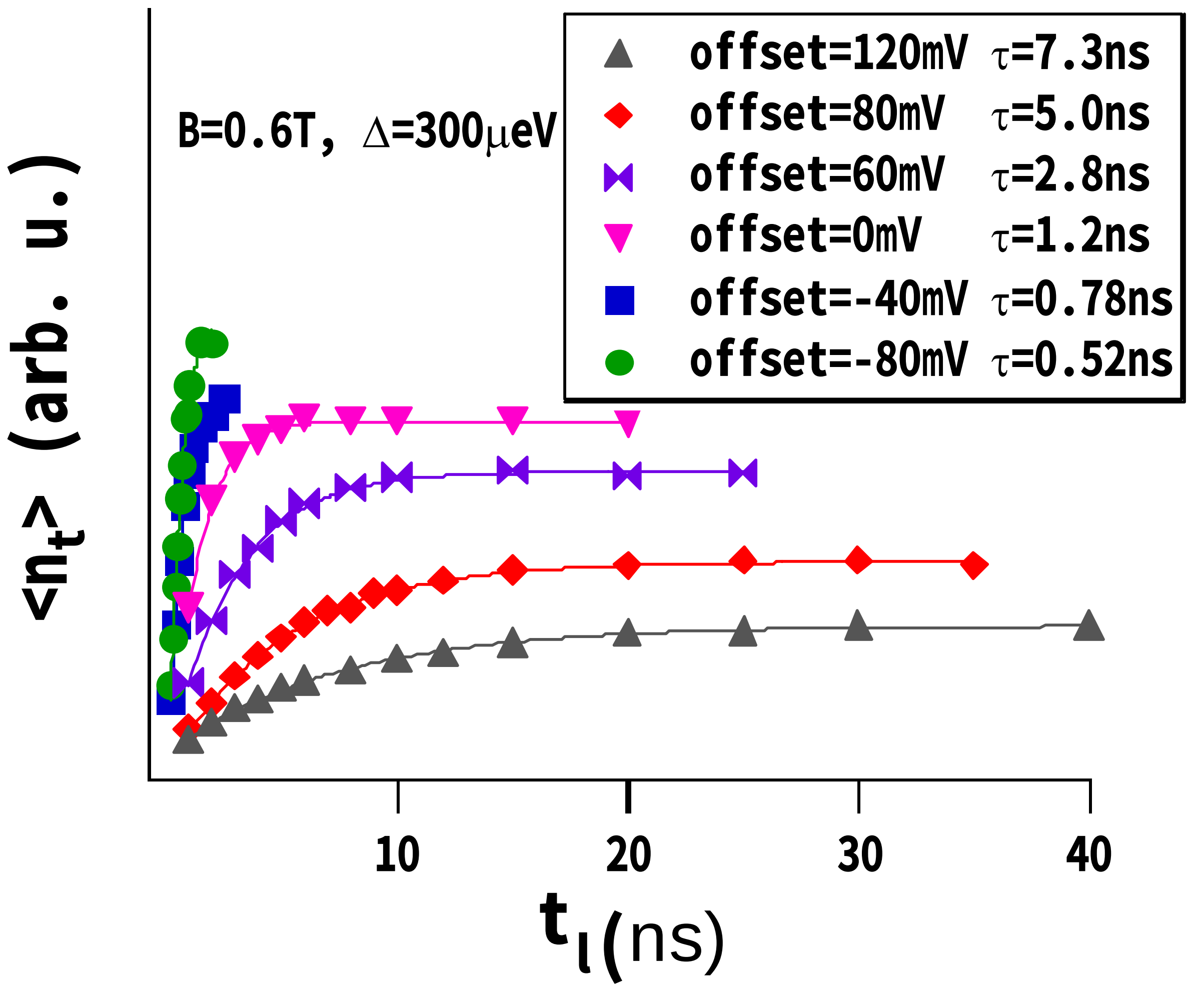
$$\langle n_t \rangle = A\exp(-t_h/\tau_{S\text{-}T})$$

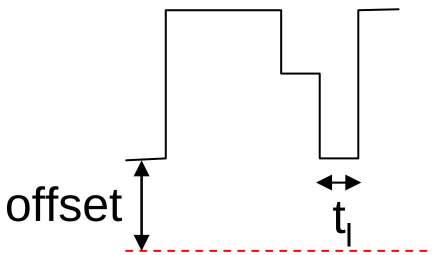
A~1: related to the injection efficiency

$\tau_{S\text{-}T}$: spin-flip energy relaxation time

Determination of Γ_{tot}

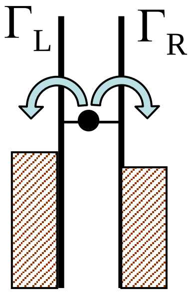
$\langle n_t \rangle \propto \{1 - \exp(-t_l / \tau)\}$





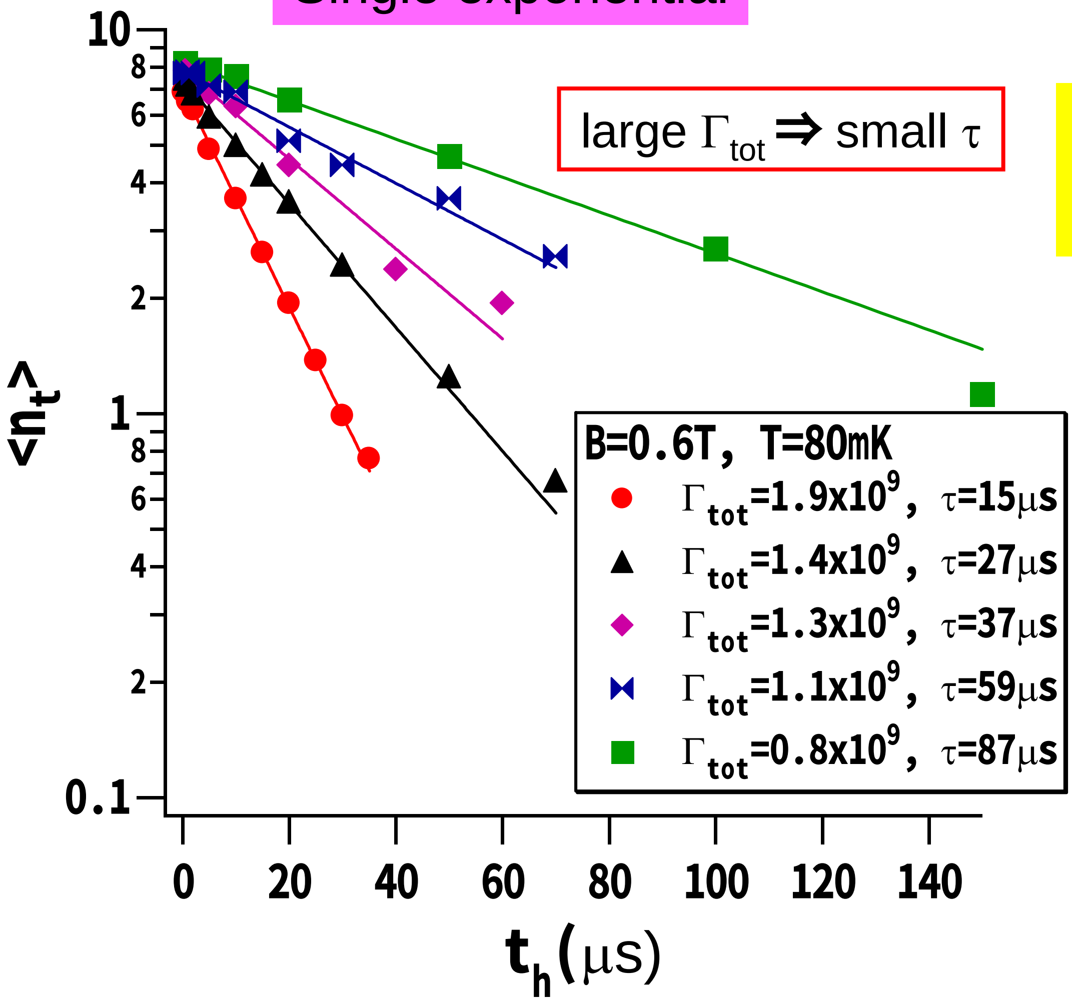
escape rate

$\Gamma_{tot} = \Gamma_L + \Gamma_R$

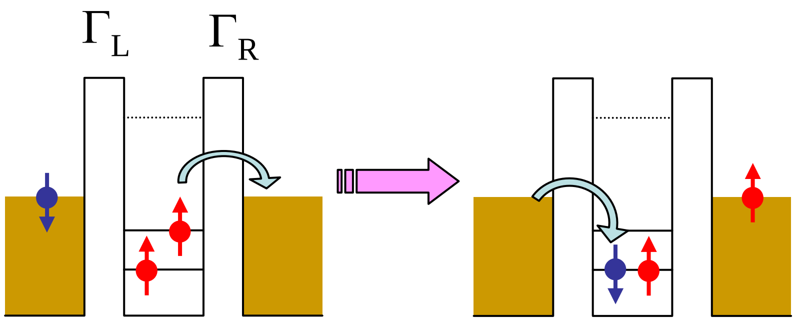


Spin relaxation by cotunneling

Single exponential



Second order tunneling process (cotunneling) induces spin relaxation by exchanging spin with electrodes.

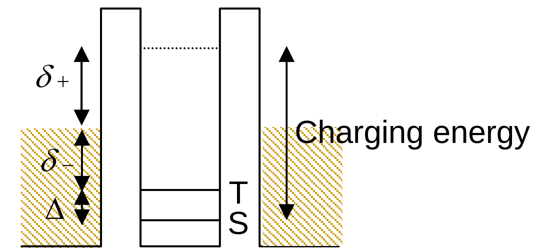


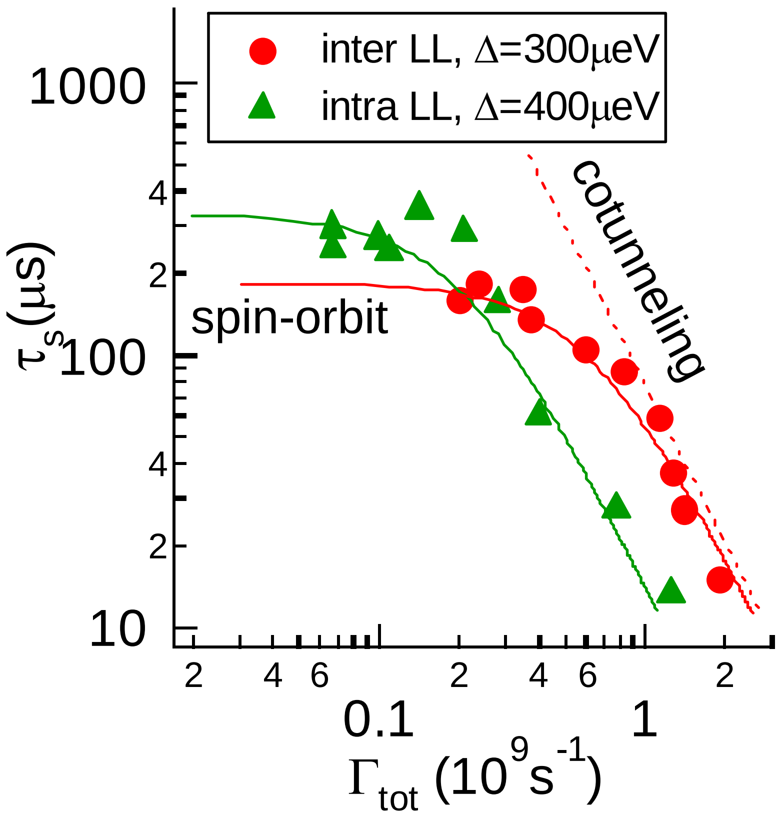
$$\Gamma_{tot} = \Gamma_L + \Gamma_R$$

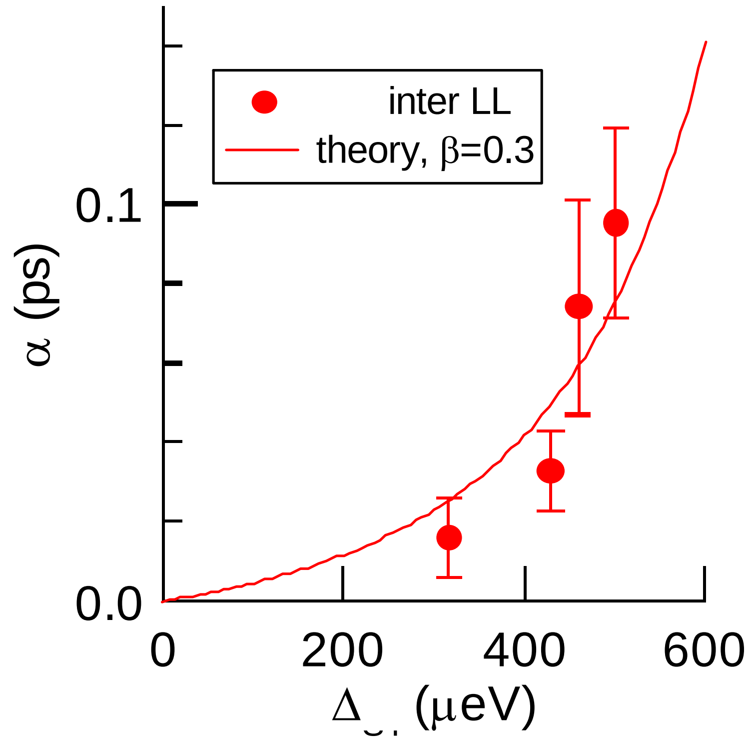
Analysis of the cotunneling effect

$$\tau_{\mathrm{cot}}^{-1} = \frac{\Delta(\hbar\Gamma^{*}_{tot})^2}{h}\left(\frac{1}{\delta_-}+\frac{1}{\delta_+}\right)^2 = \alpha\Gamma_{tot}^{\ 2}$$

Effective tunneling rate $\Gamma^{*}_{tot} = \beta\Gamma_{tot}$



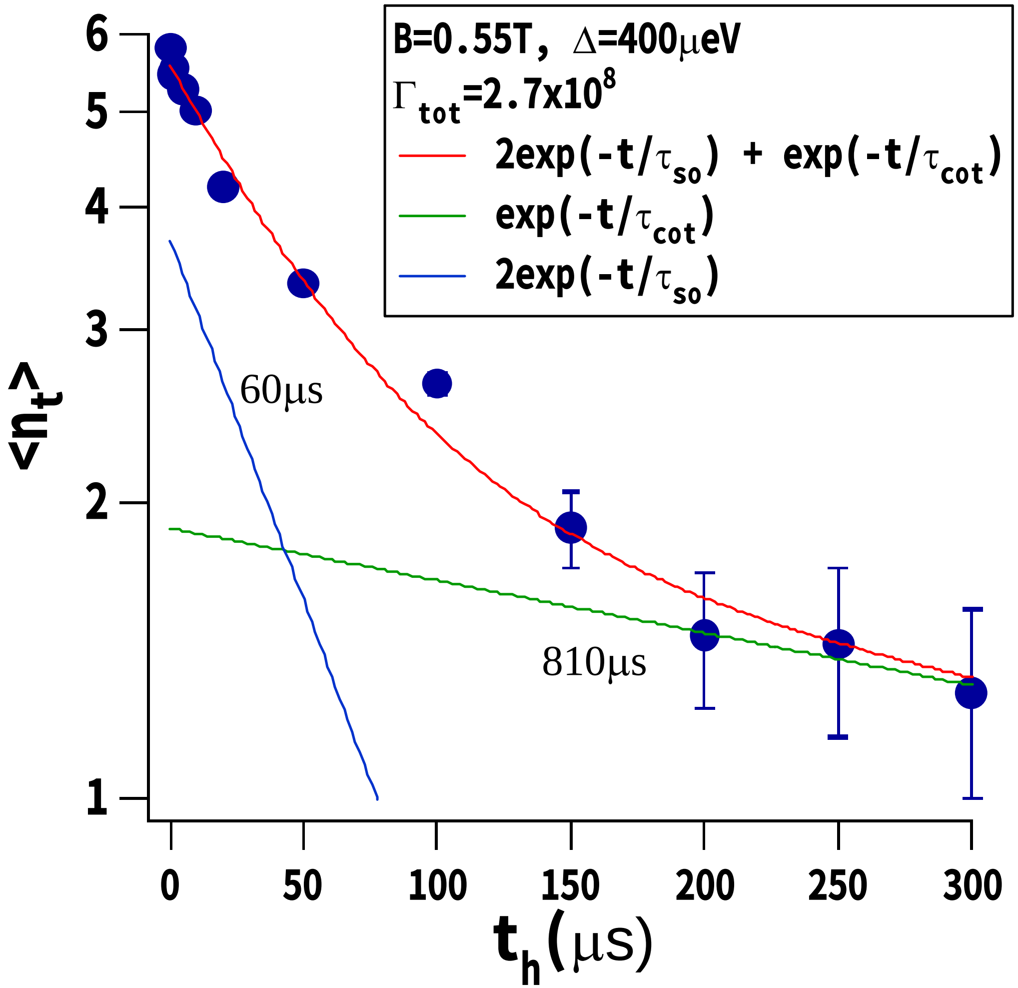




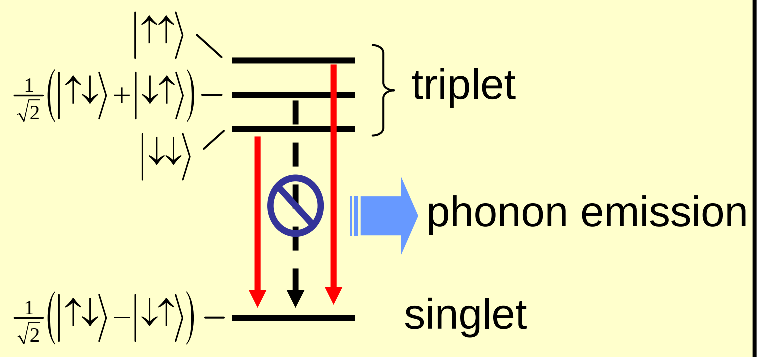
Allowed and forbidden transitions by spin-orbit interaction

Double exponential

small Γ regime

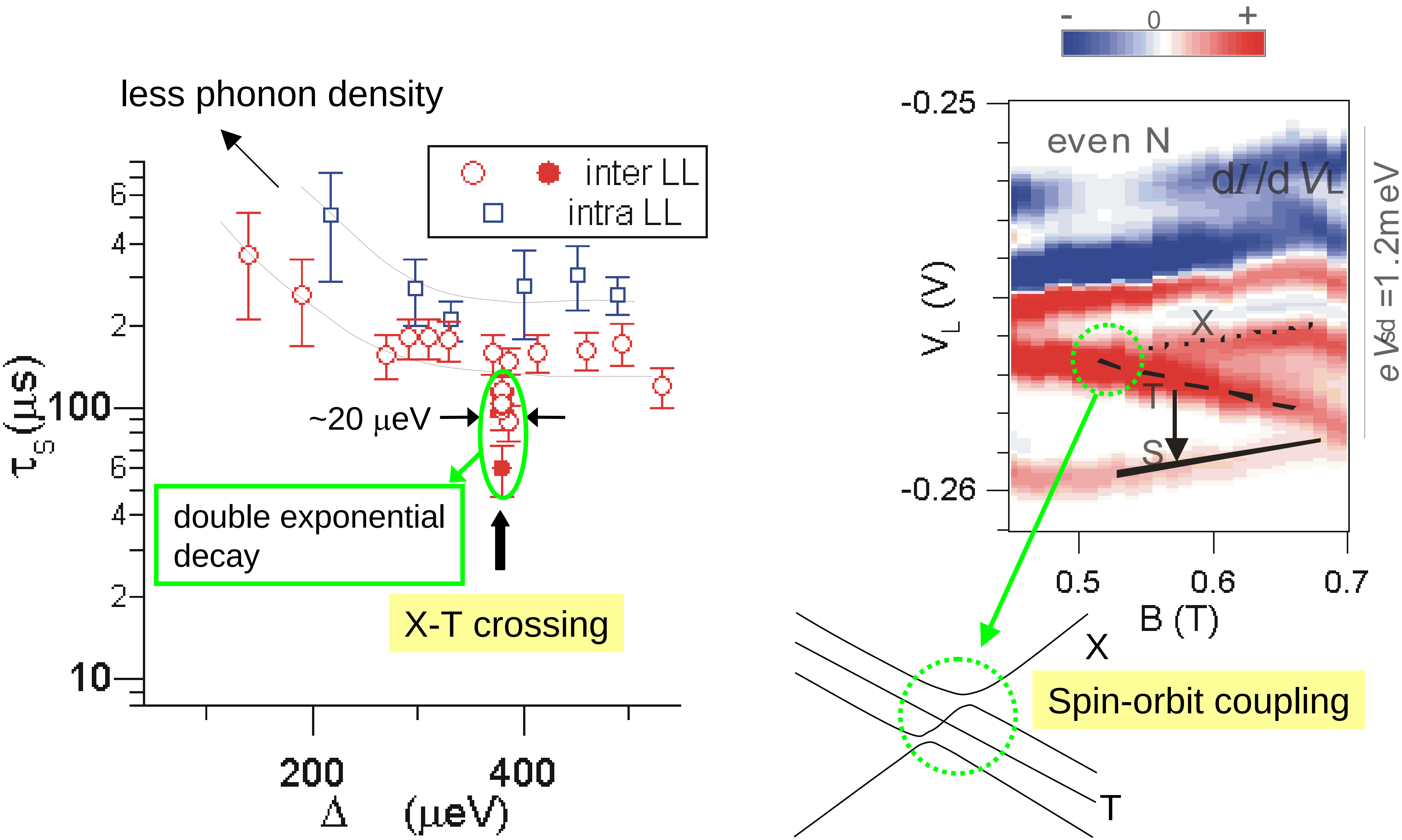


Phonon emission under spin-orbit effect



Spin-orbit coupling between singlet and triplet states allows phonon emission transition from the triplet to the singlet state. However, one of the triplet states should be long-lived due to the selection rule.

Singlet-triplet energy dependence of the relaxation time



Summary

Spin relaxation mechanism from triplet excited state to singlet ground state in a lateral quantum dot is studied by electrical pump-and-probe method.

Spin relaxation mechanism:

- large $\Gamma \Rightarrow$ cotunneling
- small $\Gamma \Rightarrow$ spin-orbit interaction

  Double exponential decay characteristic is observed consistent with the selection rule for spin-orbit coupling