Implementing gates in quantum dot spin qubits

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QSIT student presentation

28th november 2011

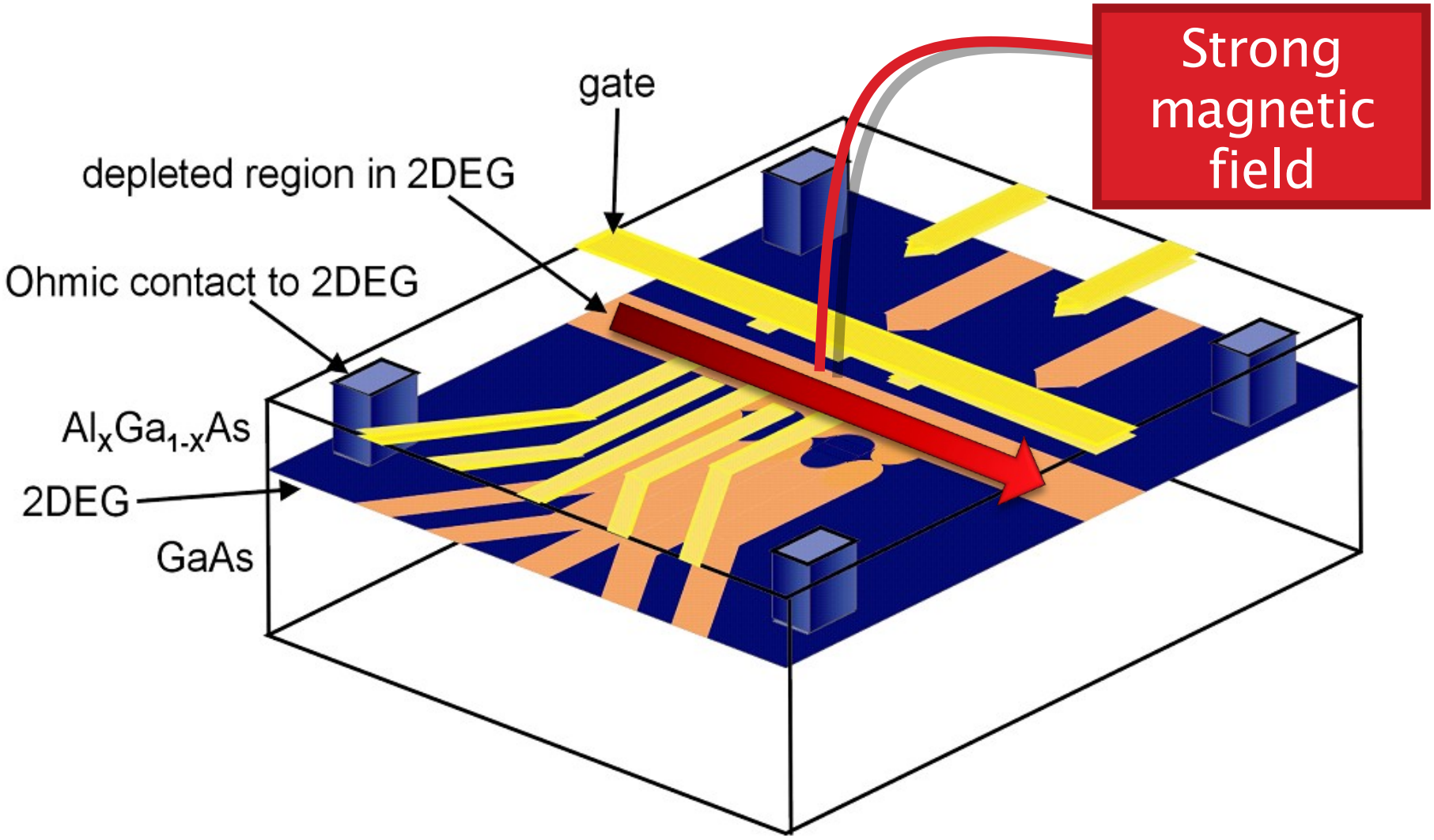
Outline

- Reminder
  - What is a (double) quantum dot?
  - What was discussed on the lecture?
- The talk itself
  - Energy diagram of DQD.
  - Dephasing of a qubit
  - SWAP operation
  - Spin Echo

What was discussed on the lecture?

- (a rather long reminder)

Double quantum dot

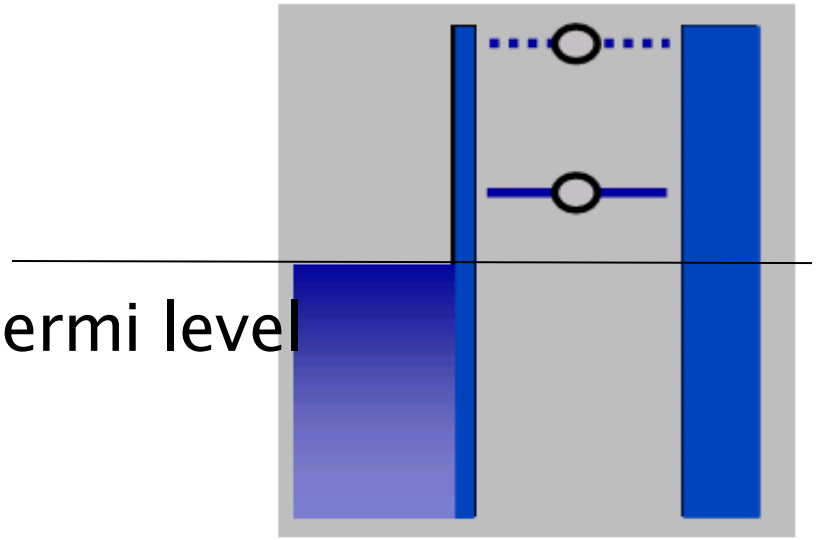


Lecture outline

Initialization	1-electron, low T, high B_0 $H_0 \sim \sum \omega_i \, \sigma_{zi}$
Read-out	convert spin to charge then measure charge
ESR	pulsed microwave magnetic field $H_{RF} \sim \sum A_i(t) \cos(\omega_i t) \; \sigma_{xi}$
SWAP	exchange interaction $H_J \sim \sum J_{ij}(t) \; \sigma_i \cdot \sigma_j$
Coherence	long relaxation time T_1 long coherence time T_2

Initialization 1-electron, low T, high B_0

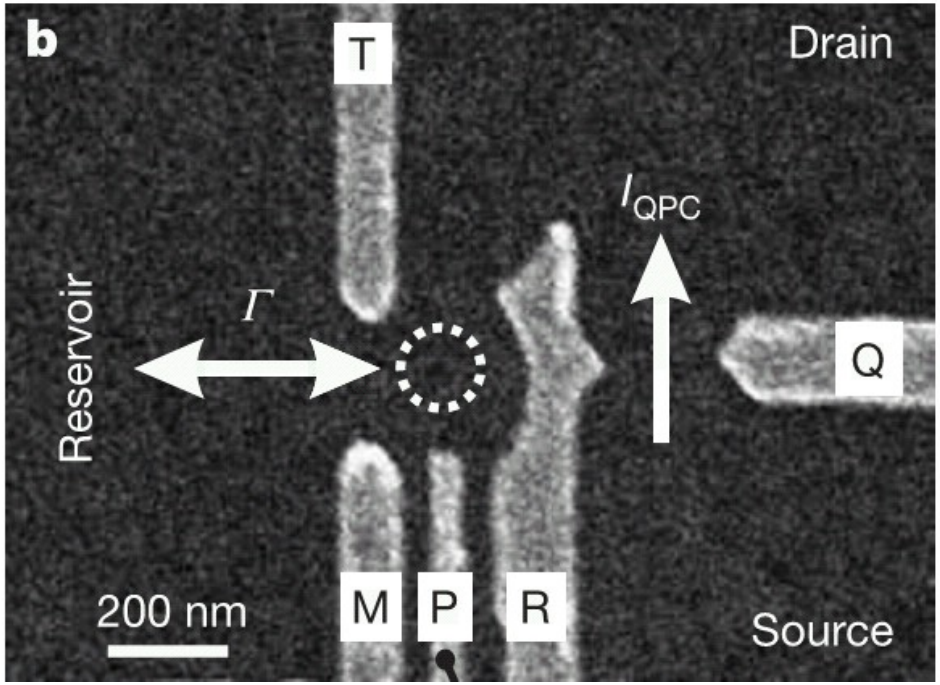
$$H_0 \sim \Sigma\, \omega_i\, \sigma_{zi}$$

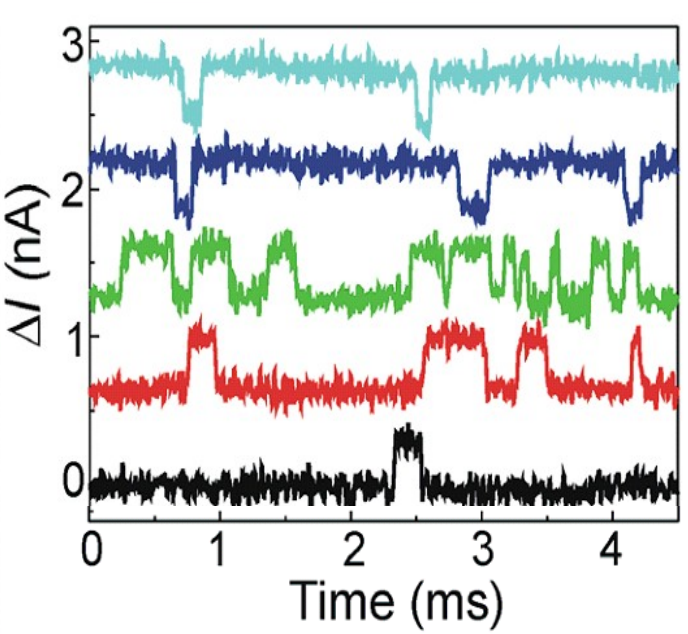


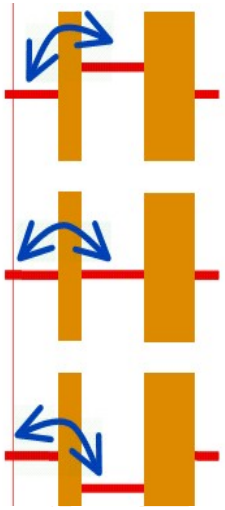
Read-out convert spin to charge

then measure charge

Read-out done using quantum point contact (QPC)

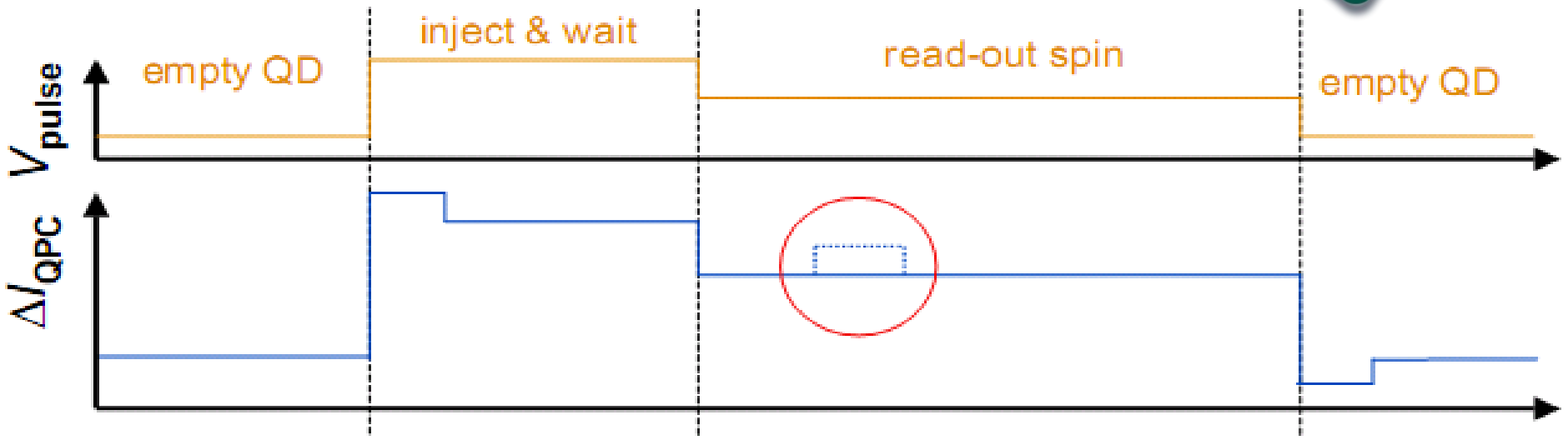


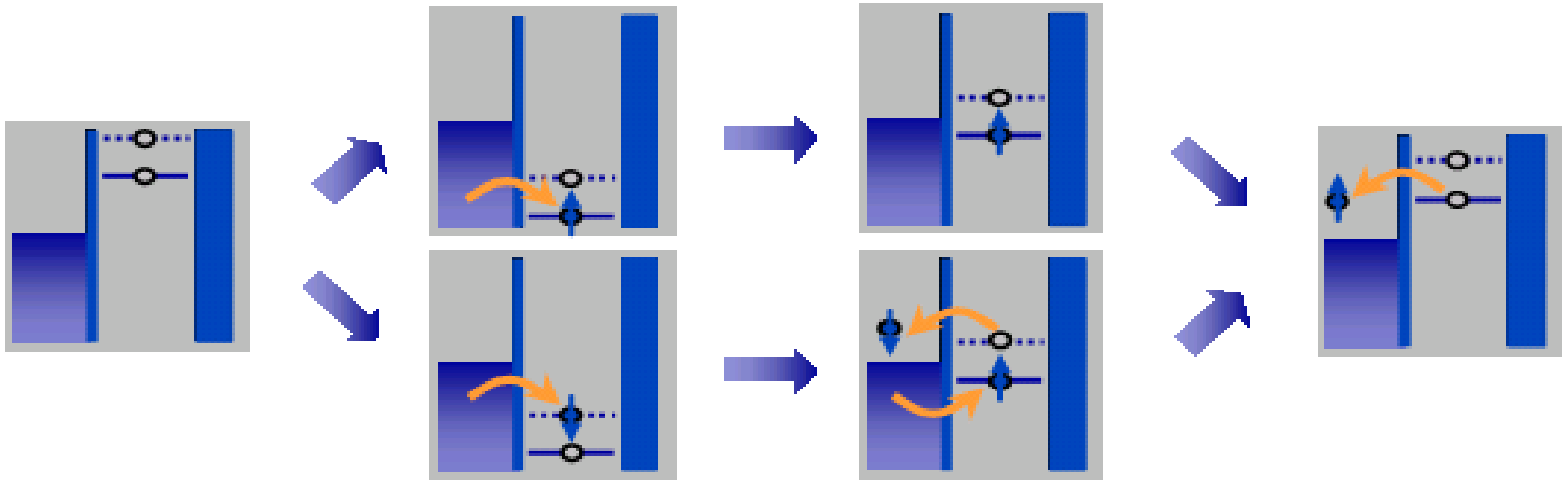




Read-out convert spin to charge

then measure charge





Lecture overview

Initialization — 1-electron, low T, high B_0

$$H_0 \sim \Sigma\ \omega_i\ \sigma_{zi}$$

Read-out — convert spin to charge

then measure charge

ESR — pulsed microwave magnetic field

$$H_{RF} \sim \Sigma\ A_i(t)\ \cos(\omega_i t)\ \ \sigma_{xi}$$

SWAP — exchange interaction

$$H_J \sim \Sigma\ J_{ij}(t)\ \ \sigma_i \cdot \sigma_j$$

Coherence — long relaxation time T_1

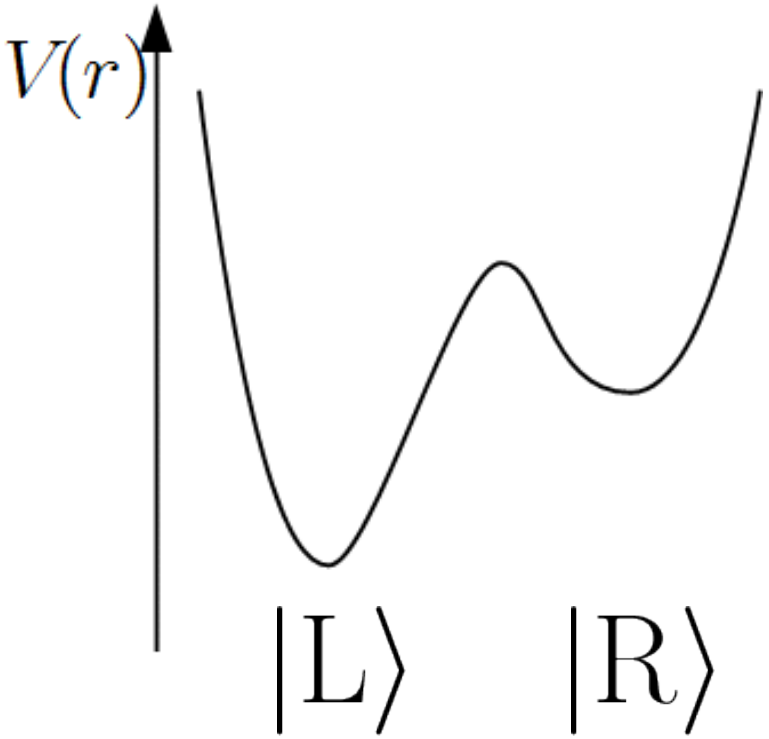
long coherence time T_2

My talk heeere!

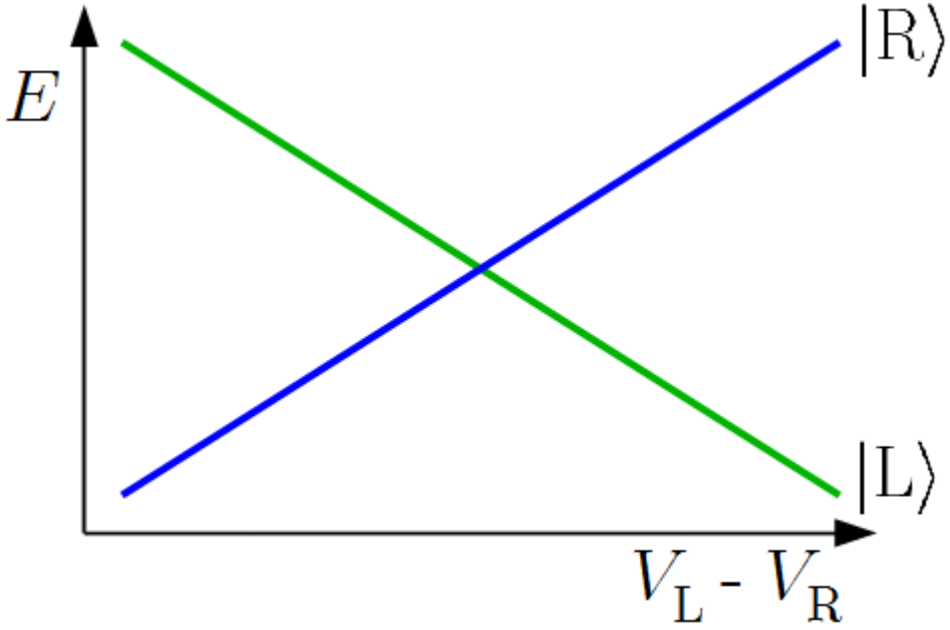
Energy Diagram of a Double Quantum Dot

- It brings some general ideas.

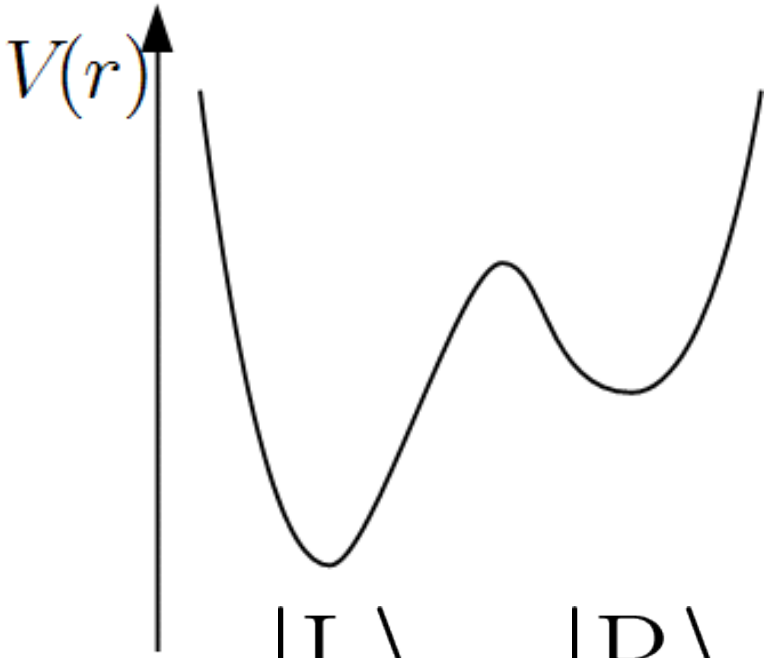
Spin-less particle in double well



$$\widehat{H} = \begin{pmatrix} E_{\mathrm{L}} & 0 \\ 0 & E_{\mathrm{R}} \end{pmatrix}$$



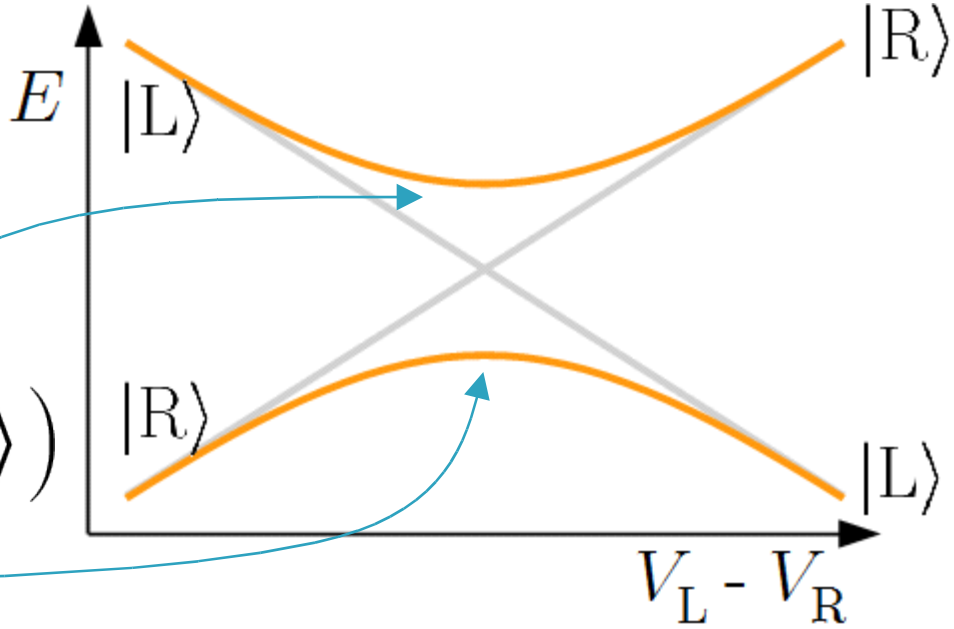
Spin-less particle in double well



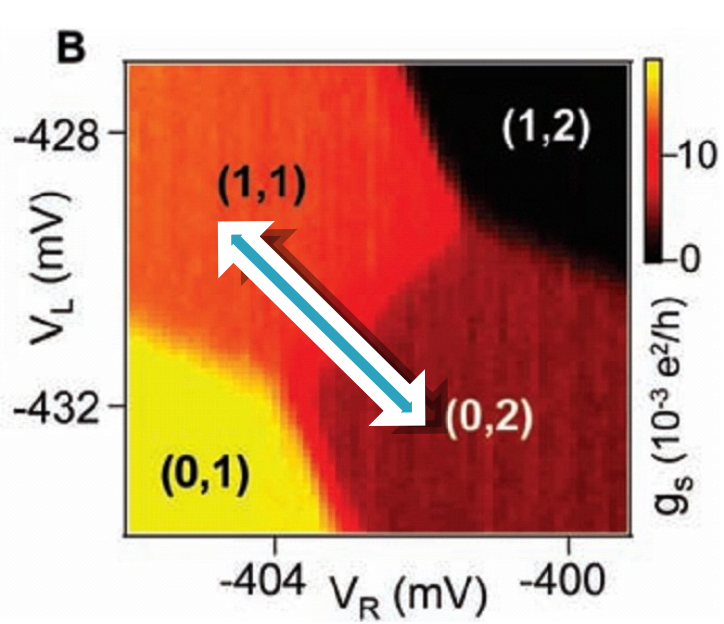
$$\hat{H} = \begin{pmatrix} E_{\mathrm{L}} & \theta \\ \theta & E_{\mathrm{R}} \end{pmatrix}$$

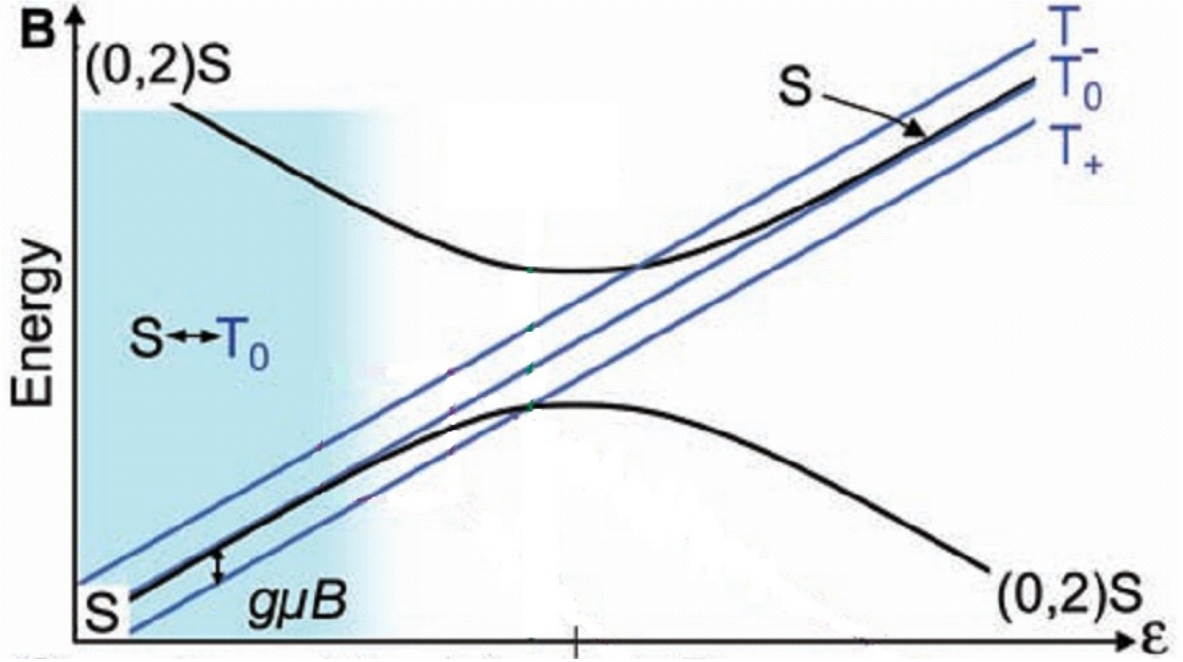
$|\mathrm{L}\rangle \quad |\mathrm{R}\rangle$

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|\mathrm{L}\rangle \pm |\mathrm{R}\rangle\right)$$

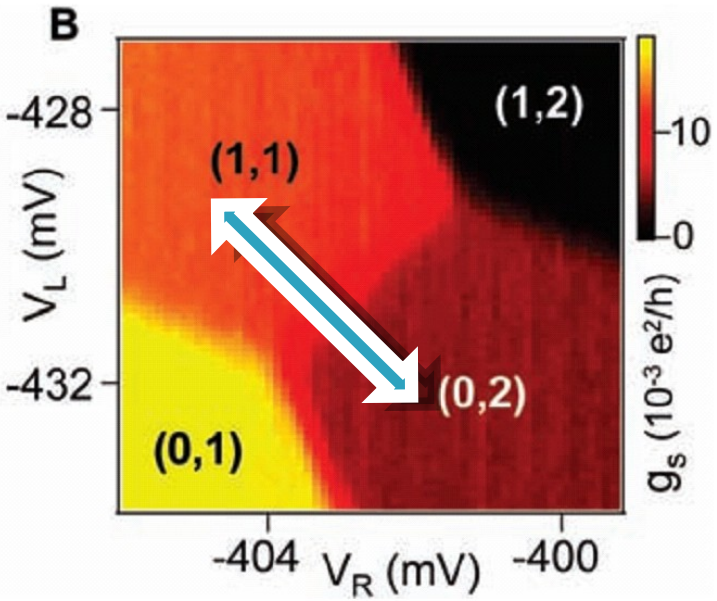


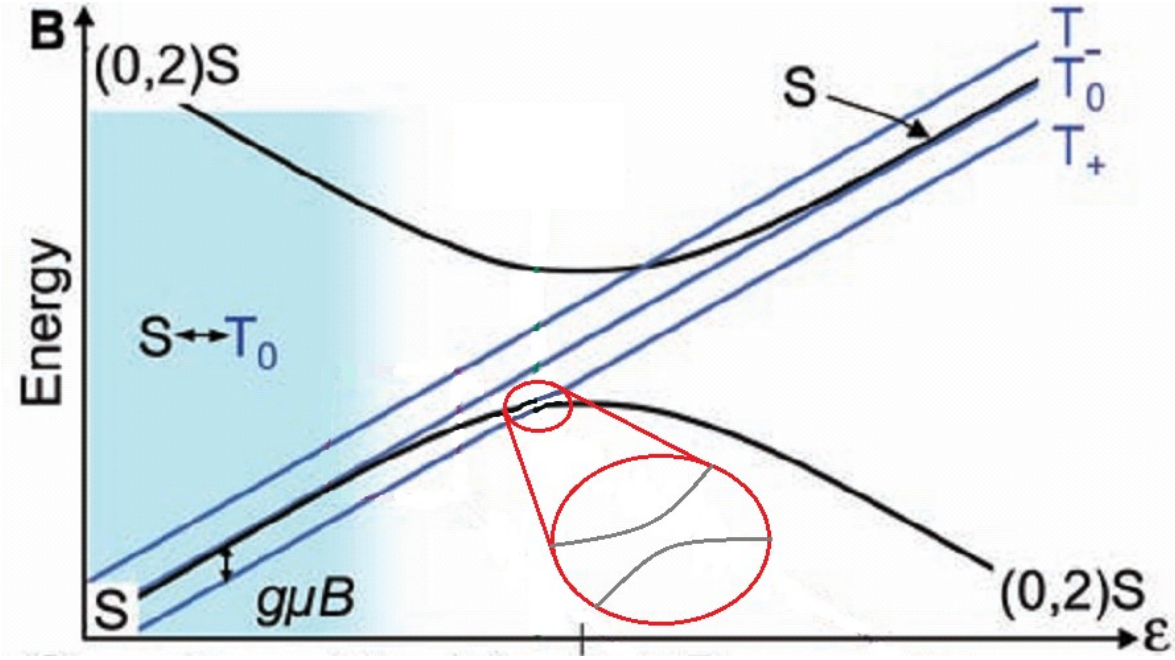
Energy diagram of a double quantum dot (1)





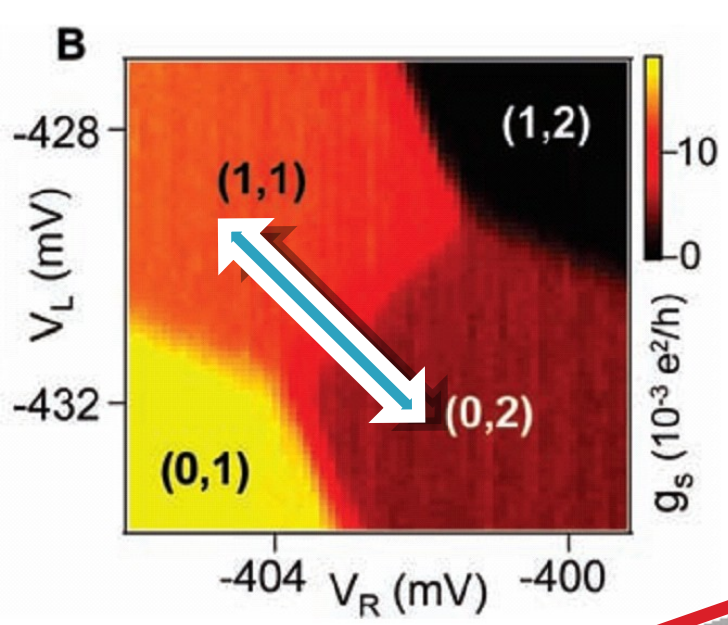
Energy diagram of a double quantum dot (2)

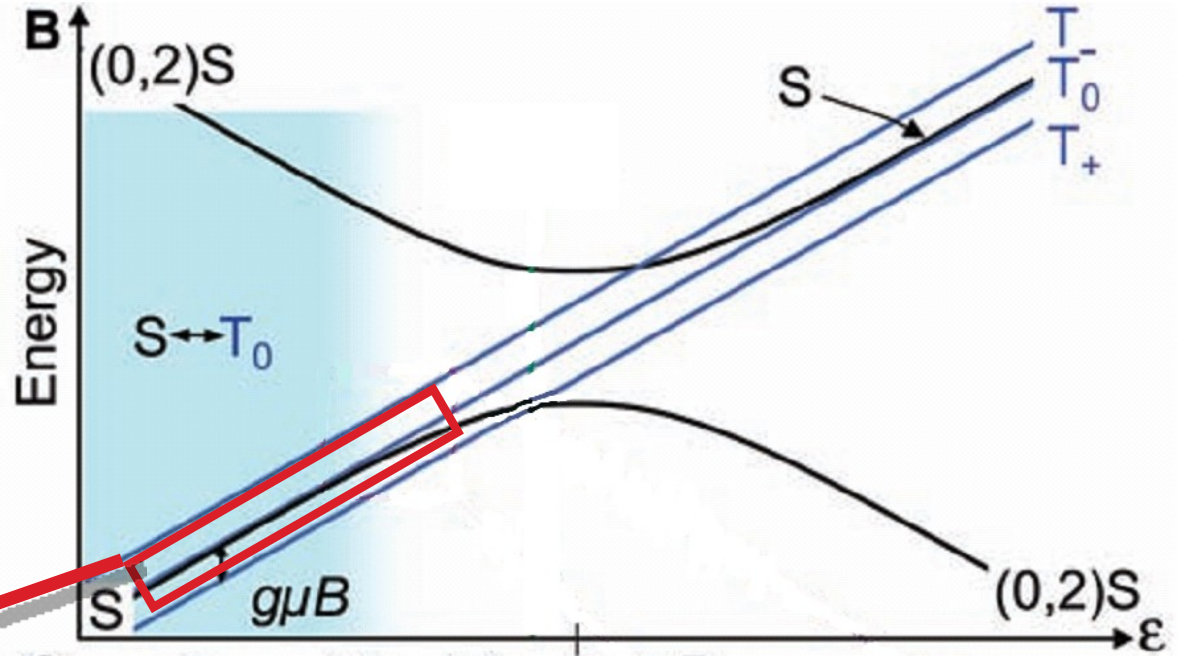




- Weak coupling between (0,2)S and (1,1)T_+.

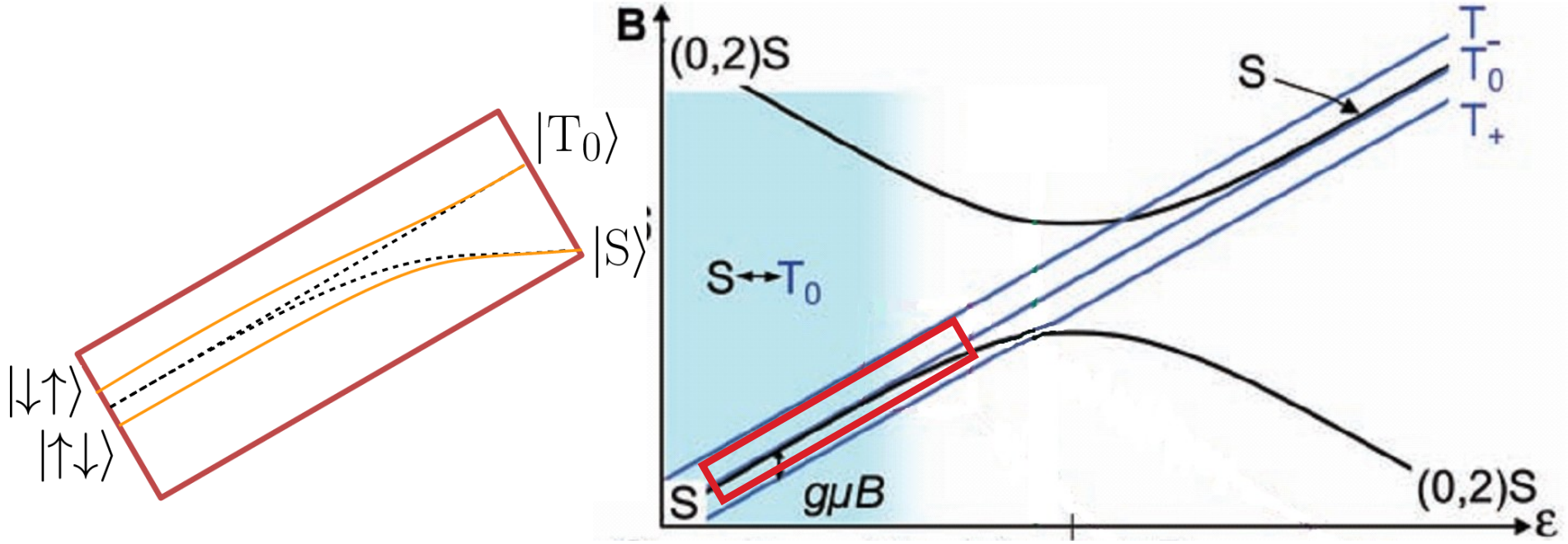
Energy diagram of a double quantum dot (3)





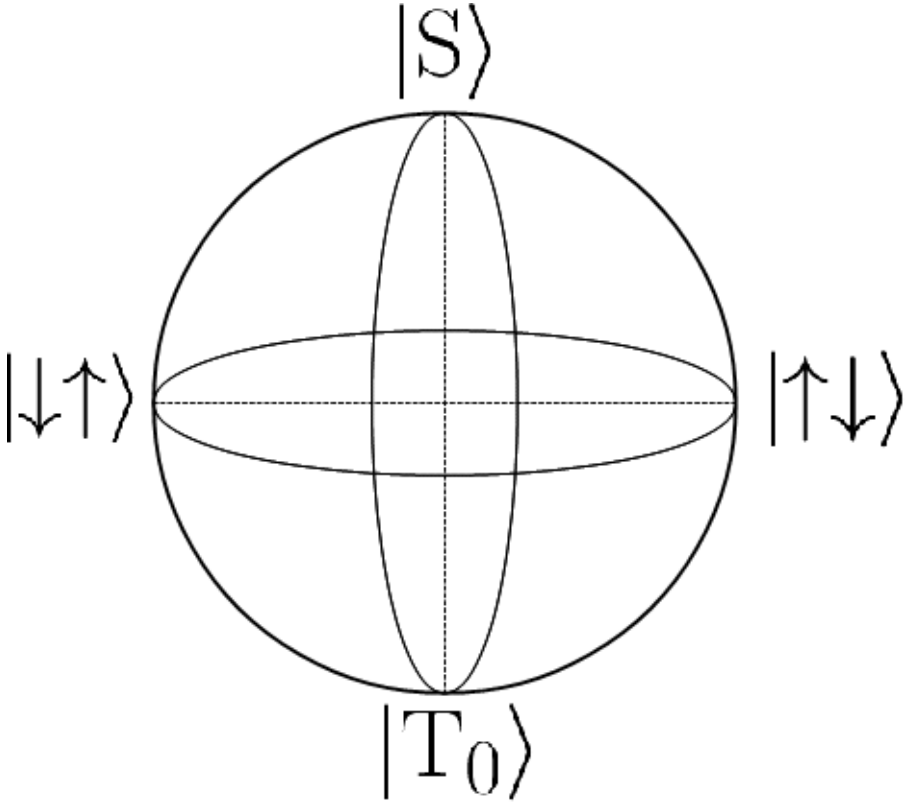
- In this region, the state effectively described in S – T_0 subspace,
- Effective hamiltonian: $\widehat{H} = \begin{pmatrix} J(\varepsilon) & \Delta B_{\text{nucl.}} \\ \Delta B_{\text{nucl.}} & 0 \end{pmatrix}$

Energy diagram of a double quantum dot (3)



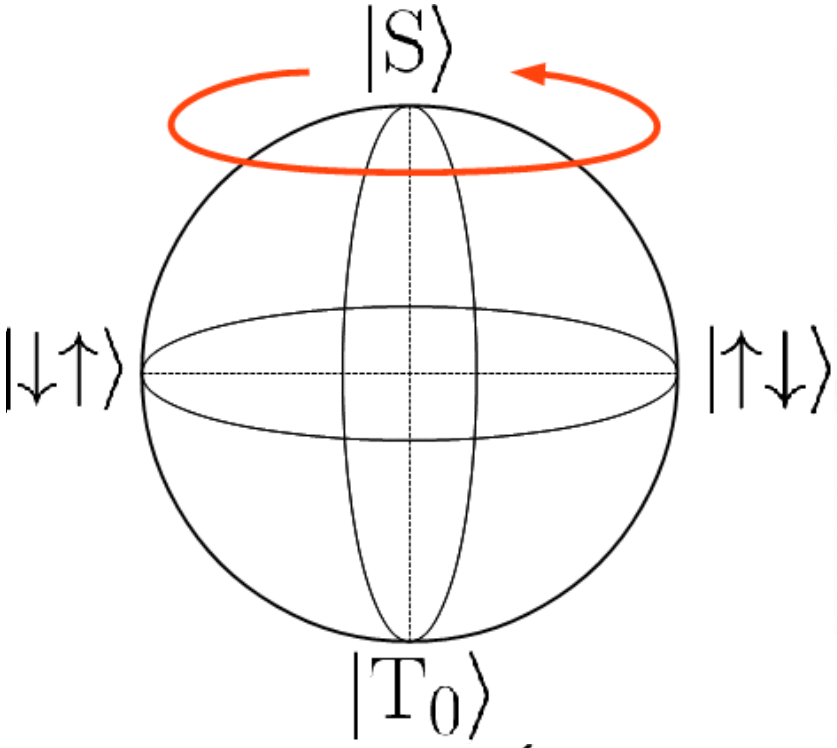
- Far left = deep in (1,1) region, $J(\varepsilon) \approx 0$.
  → Eigenstates of subspace are $|\uparrow\downarrow\rangle$ and $|\downarrow\uparrow\rangle$!

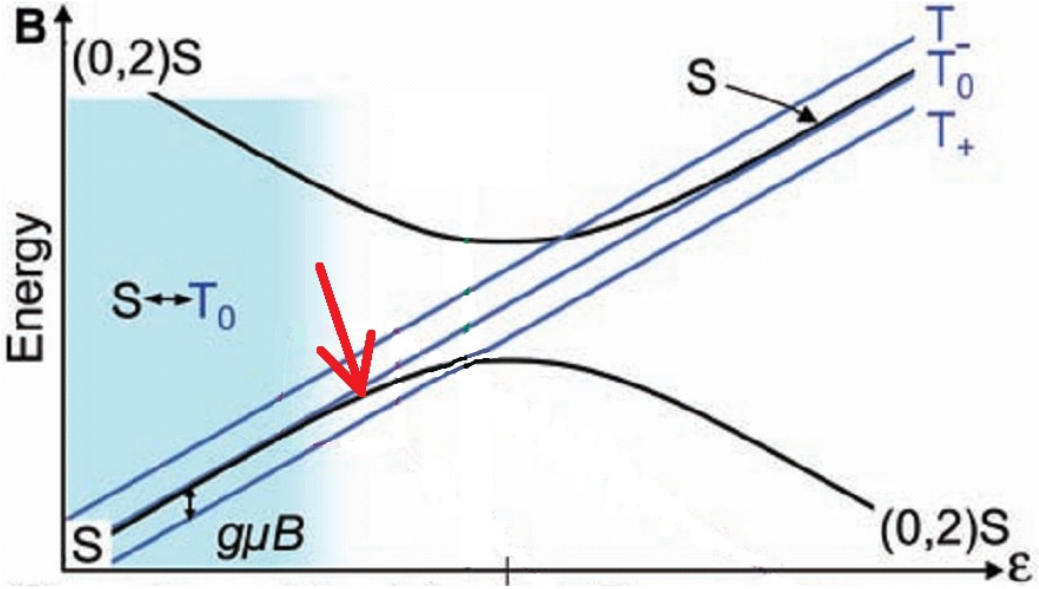
The logical qubit



$$\widehat{H} = \begin{pmatrix} J(\varepsilon) & \Delta B_{\mathrm{nucl.}} \\ \Delta B_{\mathrm{nucl.}} & 0 \end{pmatrix}$$

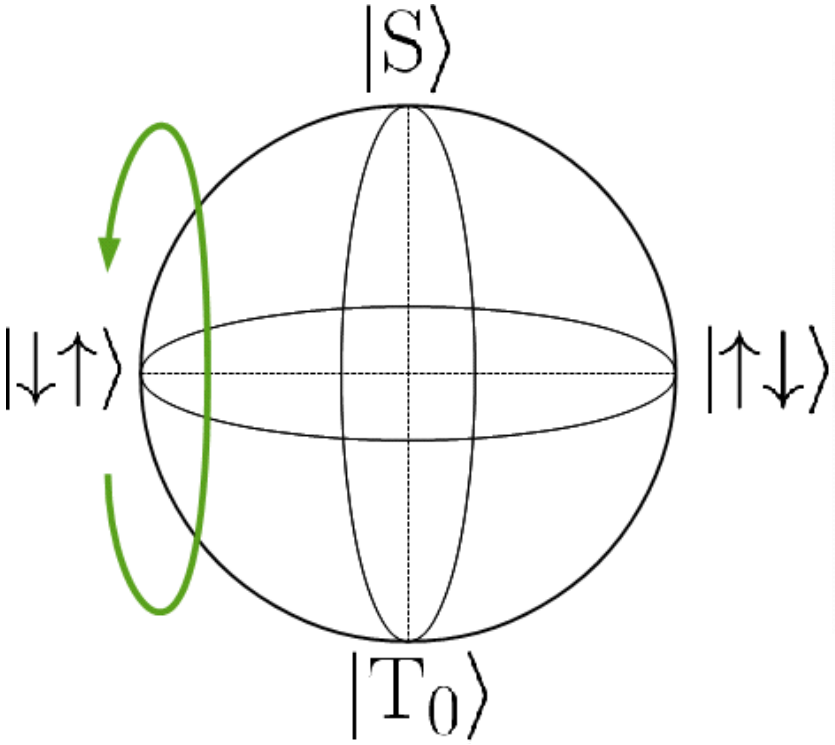
Qubit manipulation

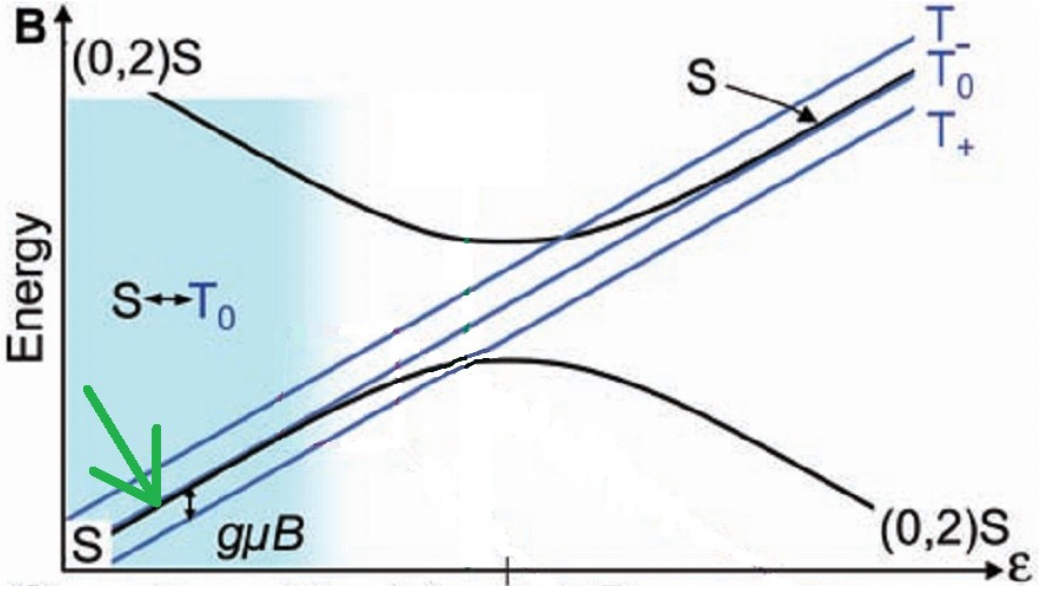




$$\hat{H} \approx \begin{pmatrix} J(\varepsilon)/2 & 0 \\ 0 & -J(\varepsilon)/2 \end{pmatrix} \propto \sigma_z$$

Qubit manipulation



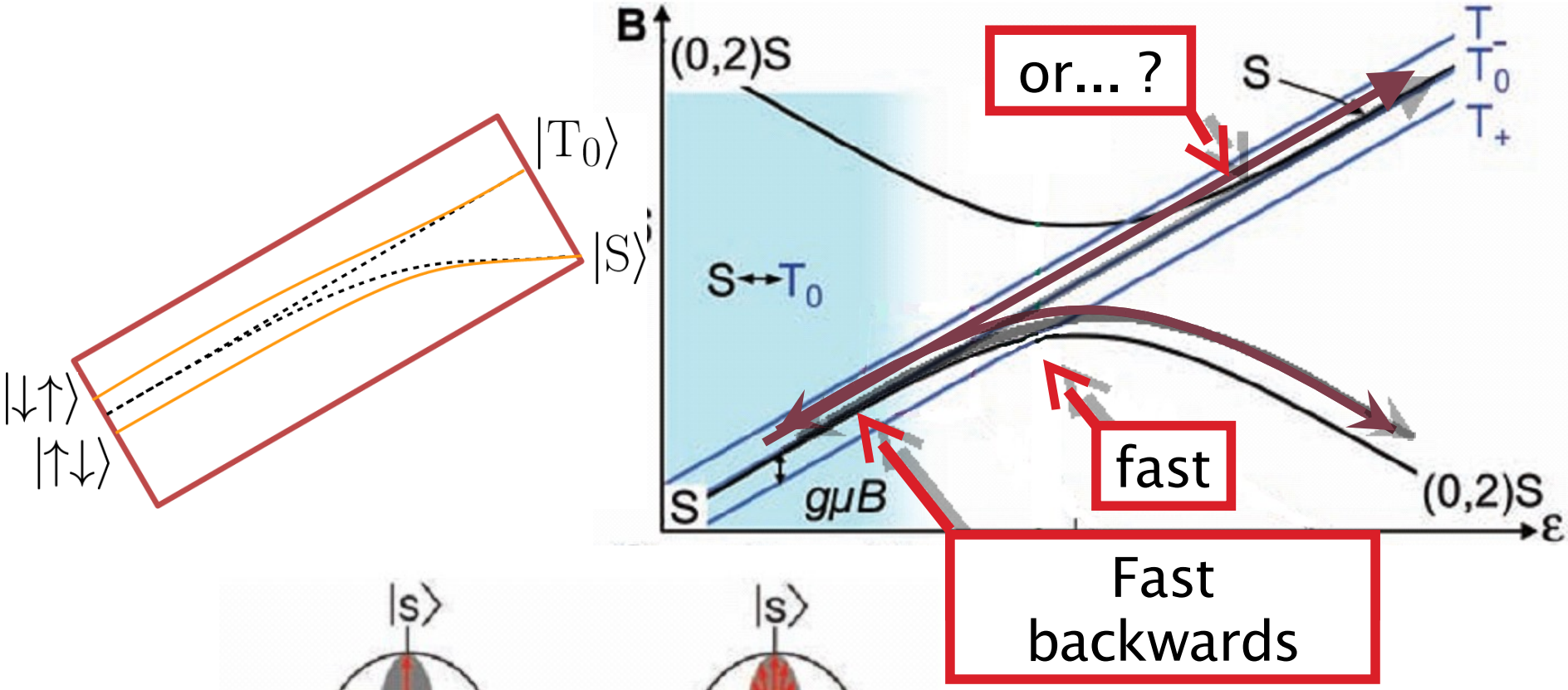


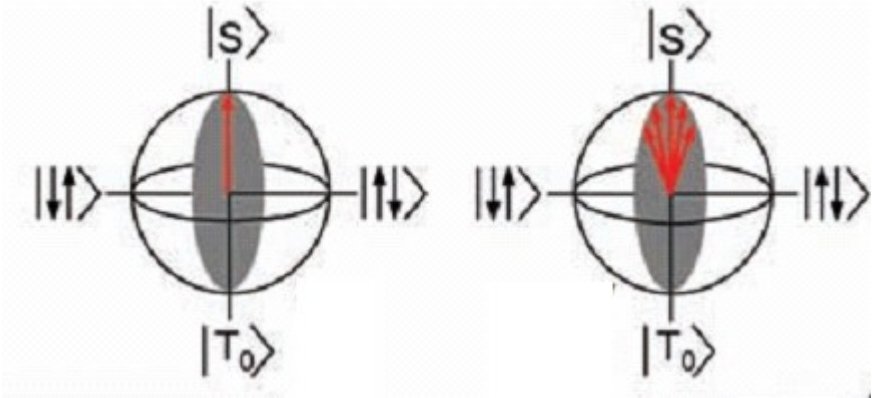
$$\hat{H} \approx \begin{pmatrix} 0 & \Delta B_{\text{nucl.}} \\ \Delta B_{\text{nucl.}} & 0 \end{pmatrix} \propto \sigma_x$$

Dephasing Time

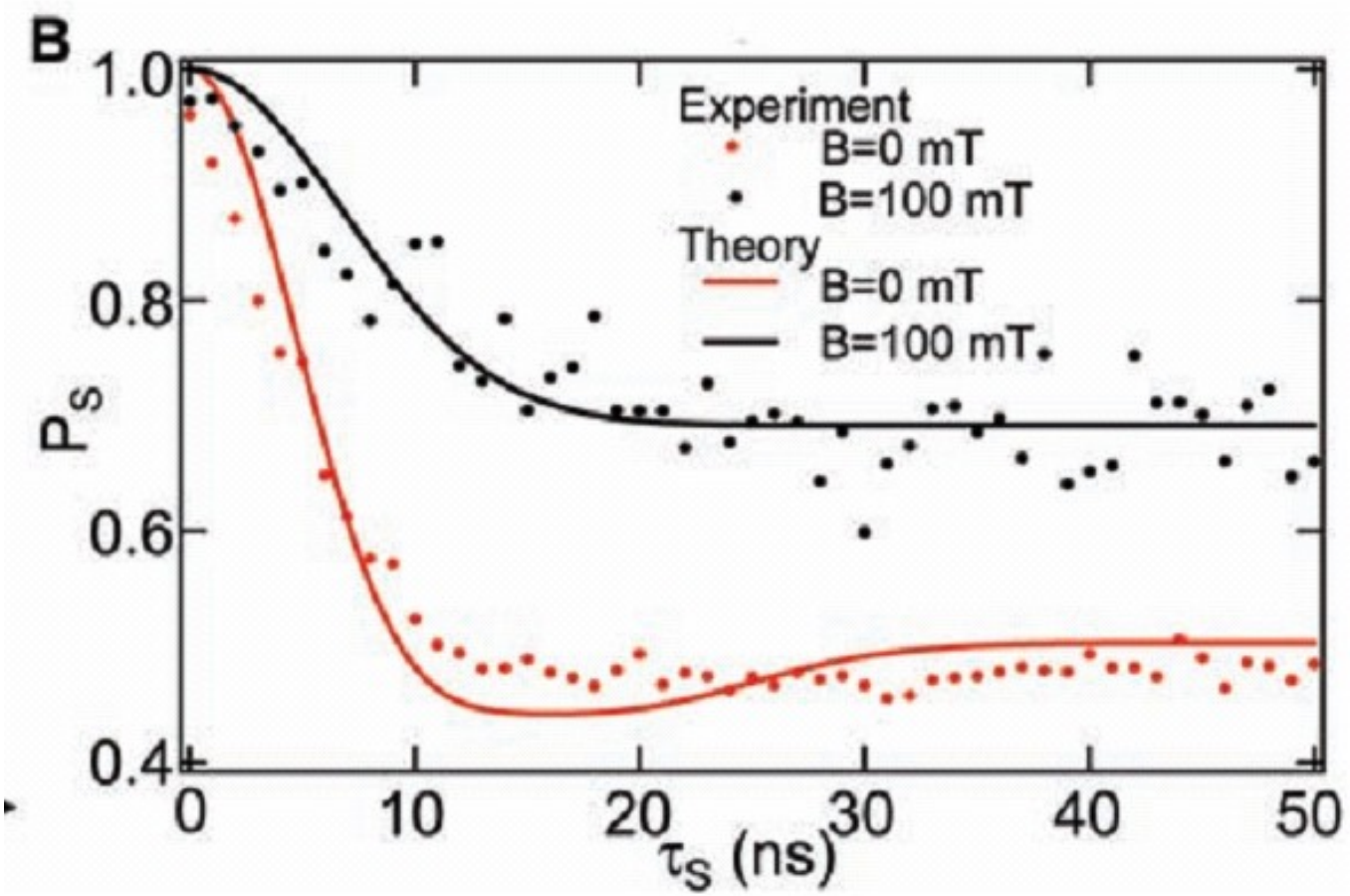
- Experiment #1

Measuring dephasing time





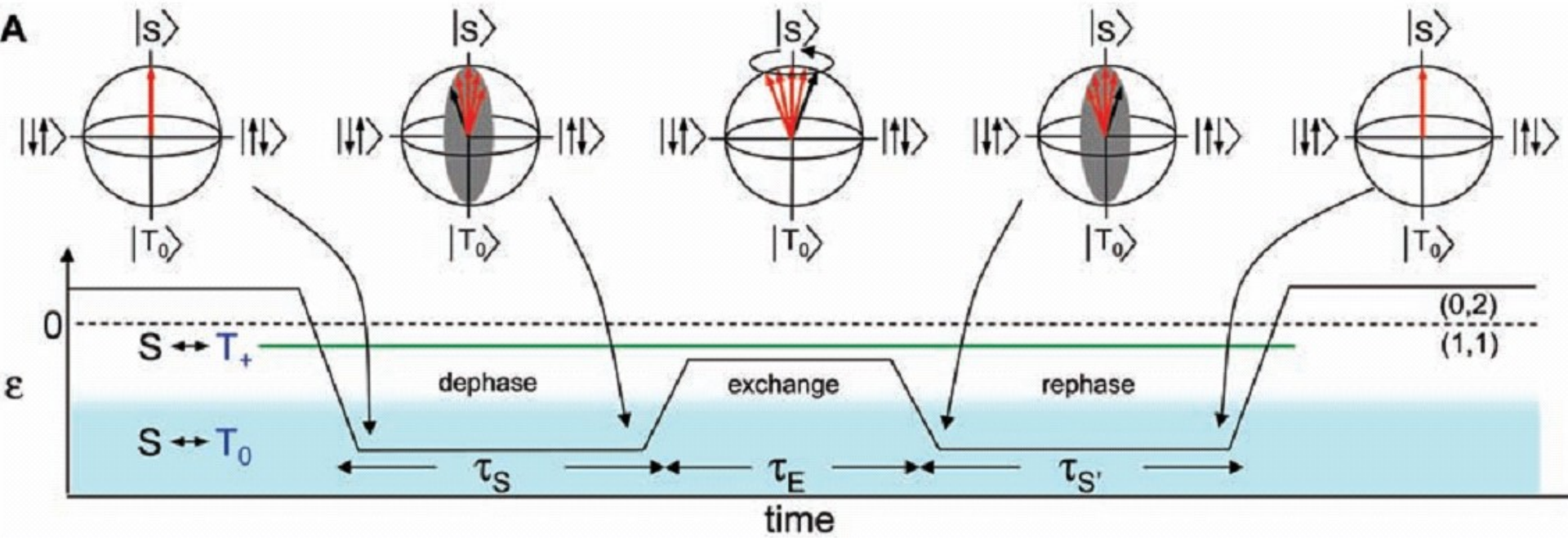
Dephasing time – Results



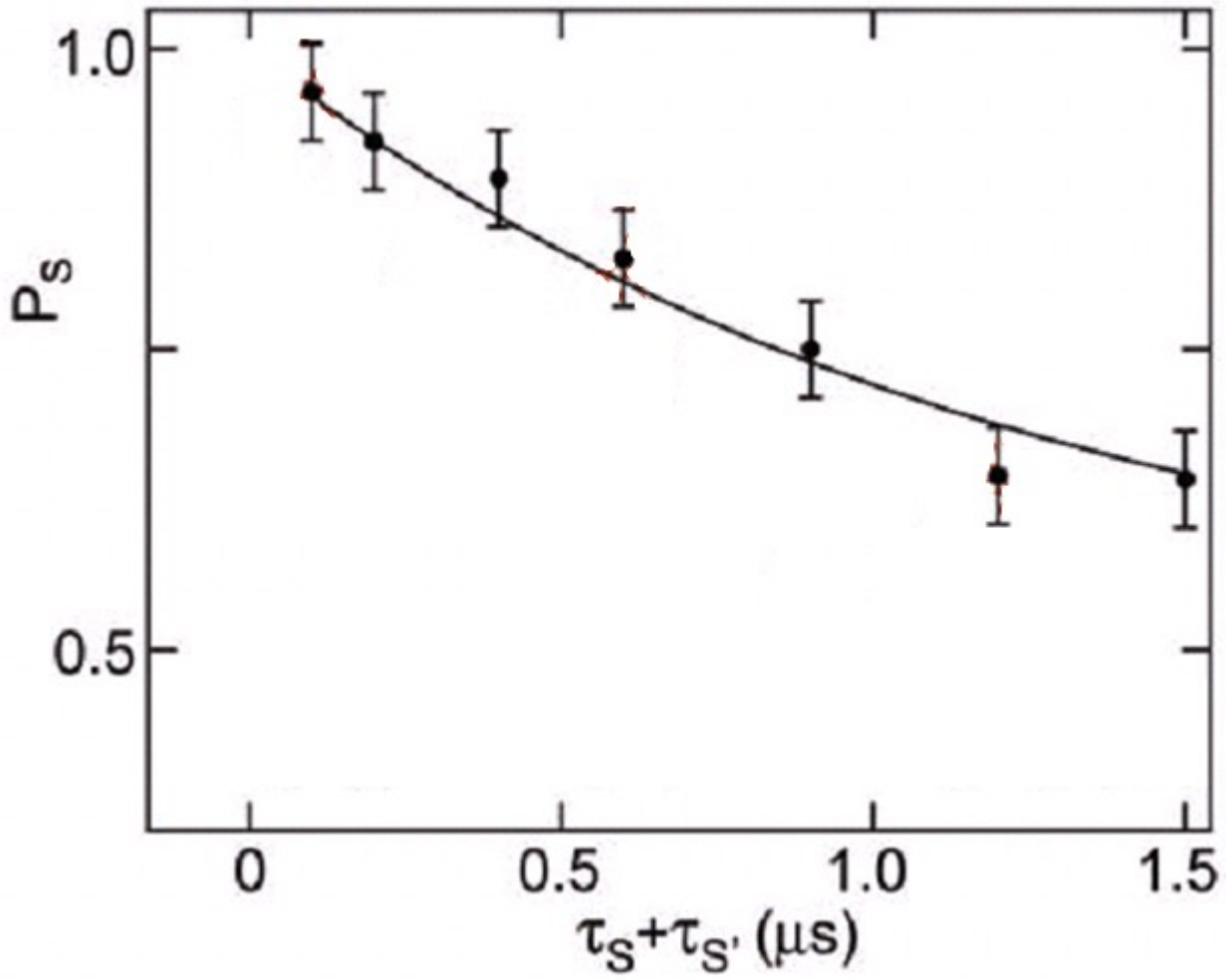
Spin Echo

- Experiment #2

Spin Echo: State manipulation



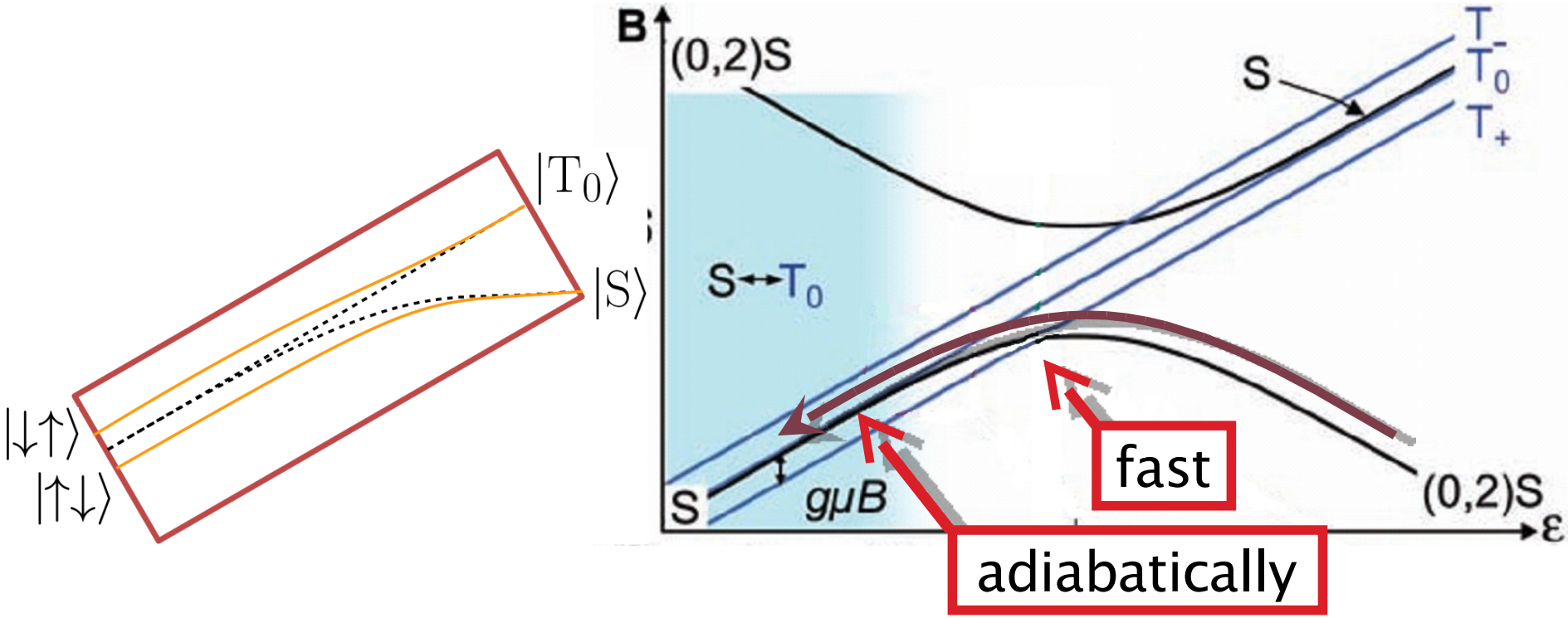
Spin Echo: Theory vs. Experiment

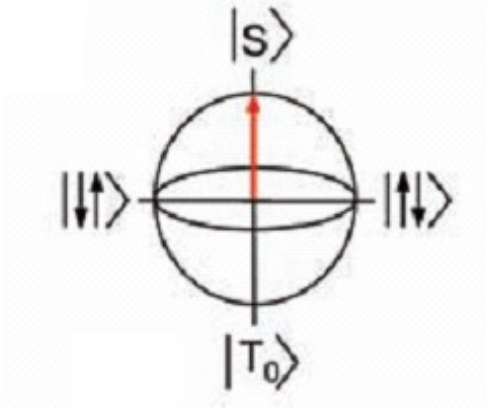


SWAP Operation

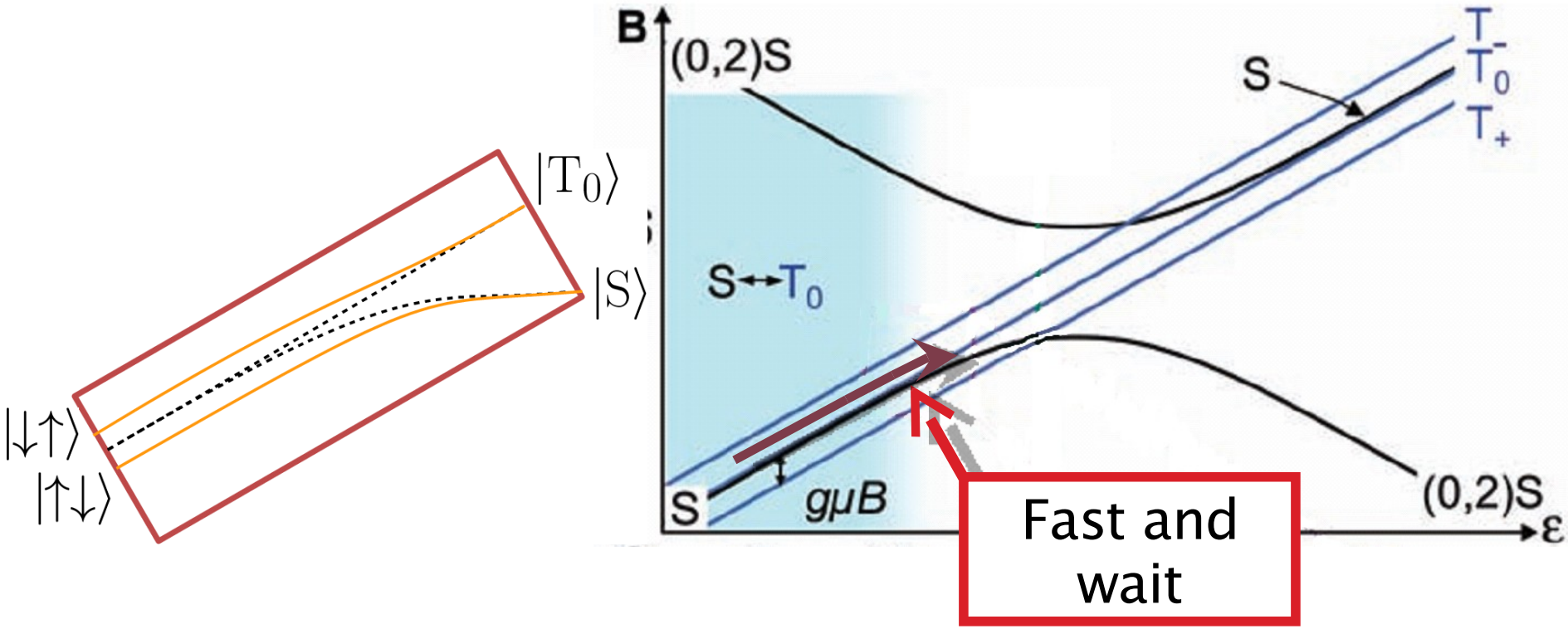
- Experiment #3

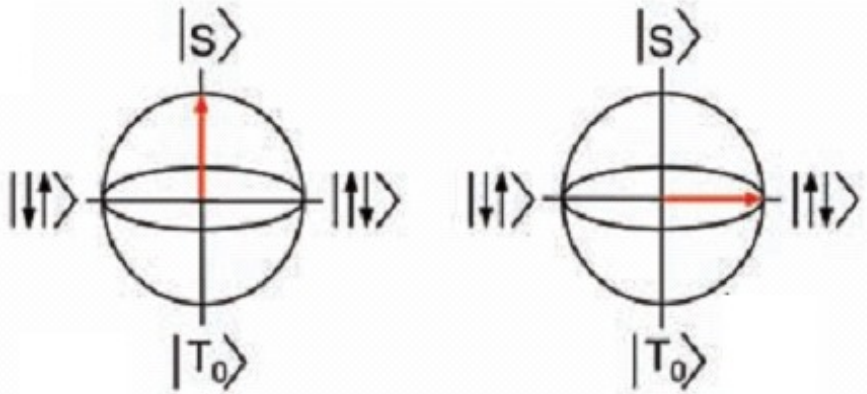
SWAP operation



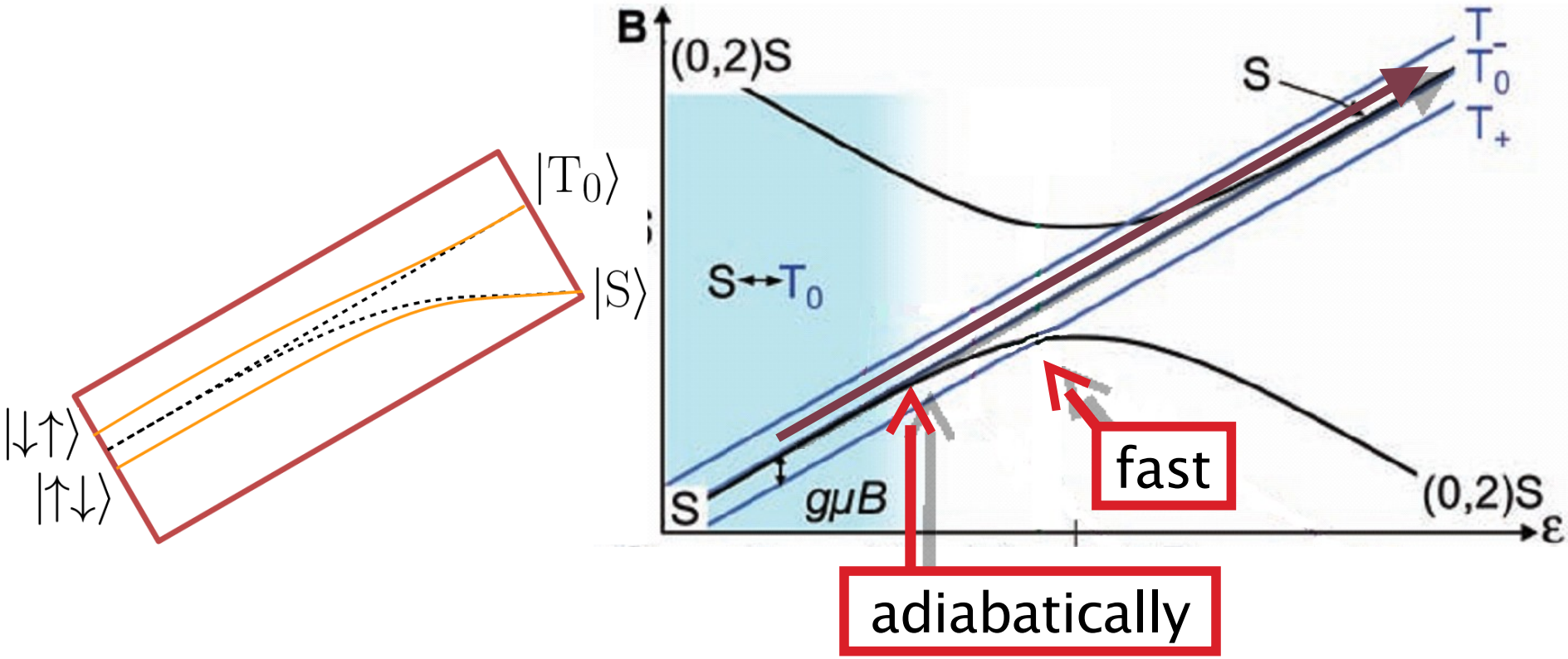


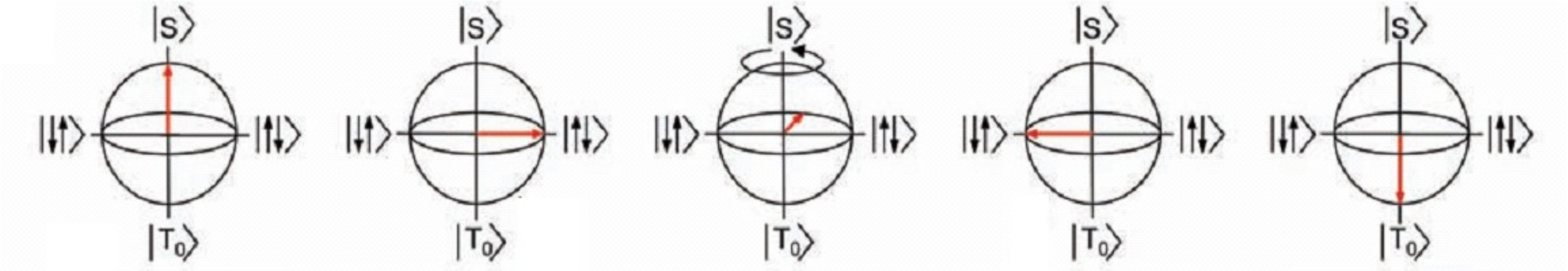
SWAP operation



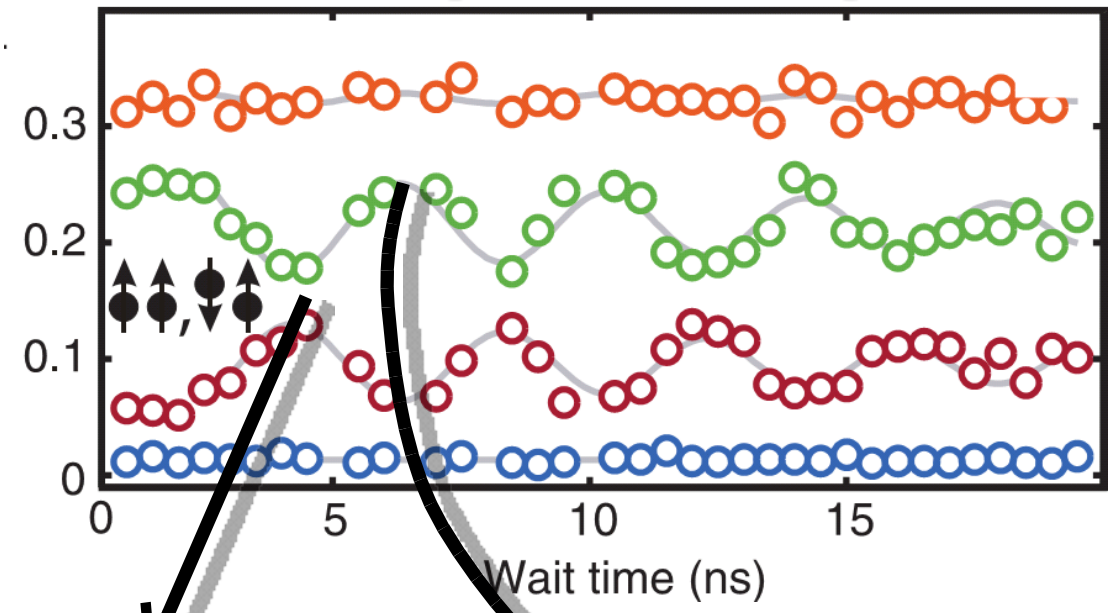


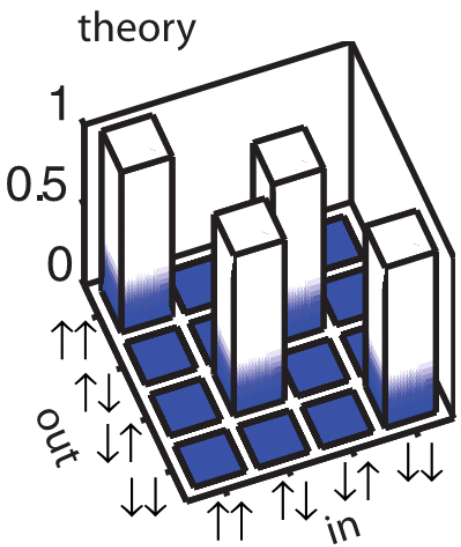
SWAP operation

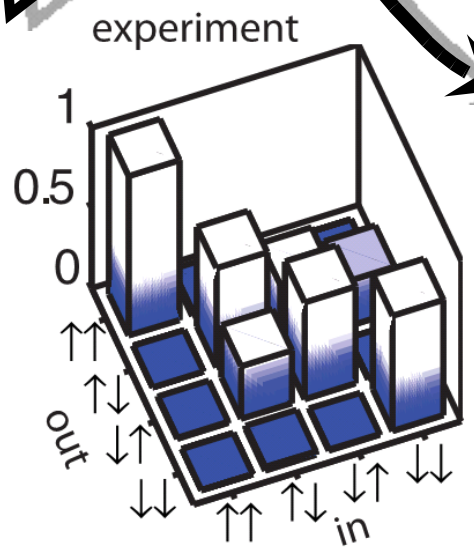


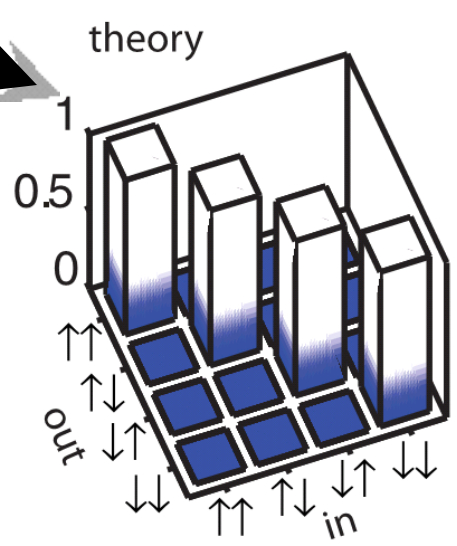


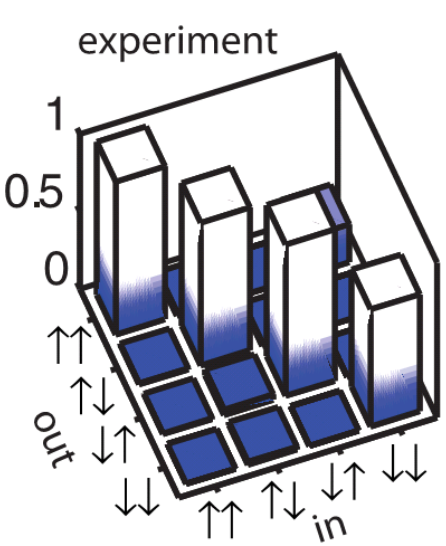
SWAP: Theory vs. Experiment











Summary

Summary

- Read-out fidelity $\approx$ 86 %
- Dephasing time $\approx$ 10 ns
- Echo-coherence time $\approx$ 1.2 μs

Thank you for attention!

It's time for your questions.

Used literature

- Hanson, R; Kouwenhoven, LP; Petta, JR; et al.
  - **Spins in few-electron quantum dots**
  - Reviews of Modern Physics **79**, 1217 (2007)

- Petta, JR; Johnson, AC; Taylor, JM; et al.
  - **Coherent manipulation of coupled electron spins in semiconductor quantum dots**
  - Science **309**, 2180 (2005)

- Nowack, K. C.; Shafiei, M.; Laforest, M.; et al.
  - **Single-Shot Correlations and Two-Qubit Gate of Solid-State Spins**
  - Science **333**, 1269 (2011)

- Special thanks to Arkady Fedorov for his willing advice.

Final note

Hello, whoever you are!

If you got this far, please send me an email to tomas(dot)bzdusek(at)gmail(dot)com. I am really curious how many people finds this presentation useful, say, during 5 years after my talk.

However, considering ammount of words used in the slides, I think they won't help you much, if you did not attend my talk.

I wish you good luck anyway, whatever reason has led you here. ☺

(ancient words of the author, 5th December 2011)