Universität Basel

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# Resonantly Driven Singlet-Triplet Spin Qubit in Silicon

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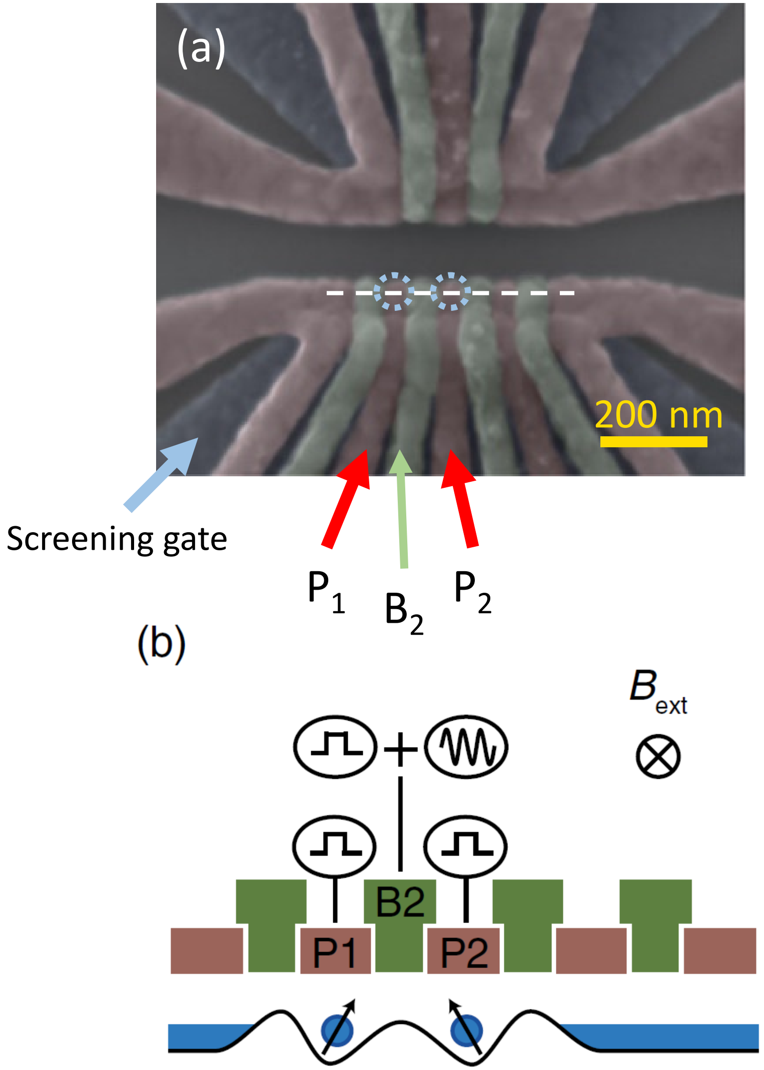
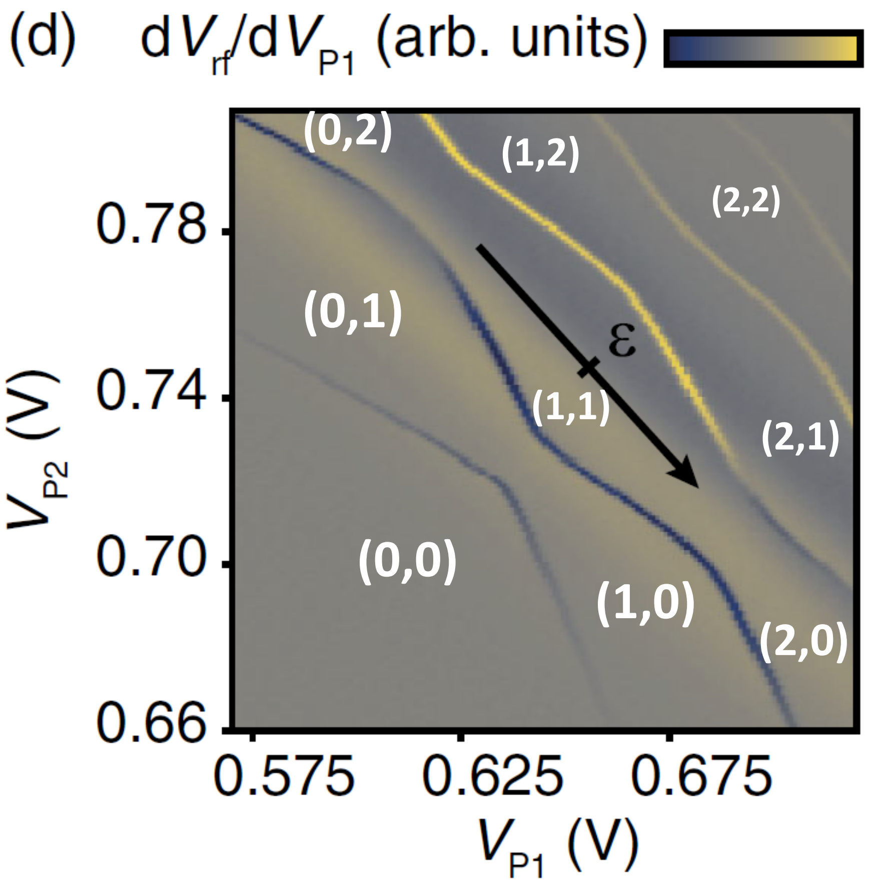
Pierre Chevalier Kwon
24.04.2020

# Device architecture

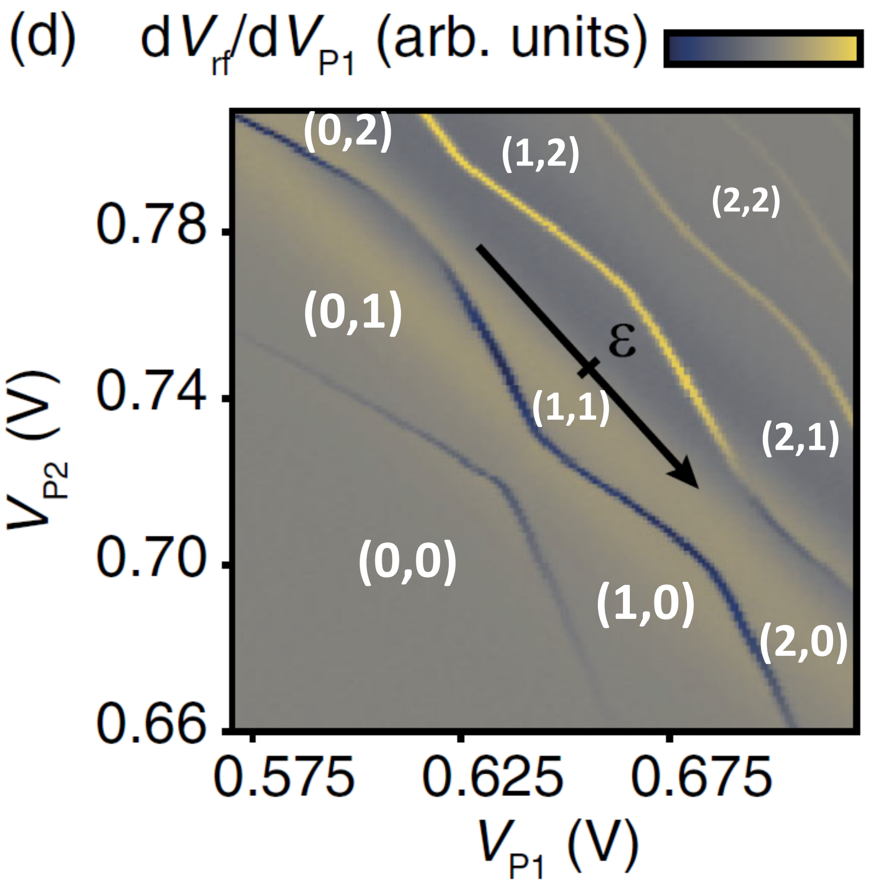


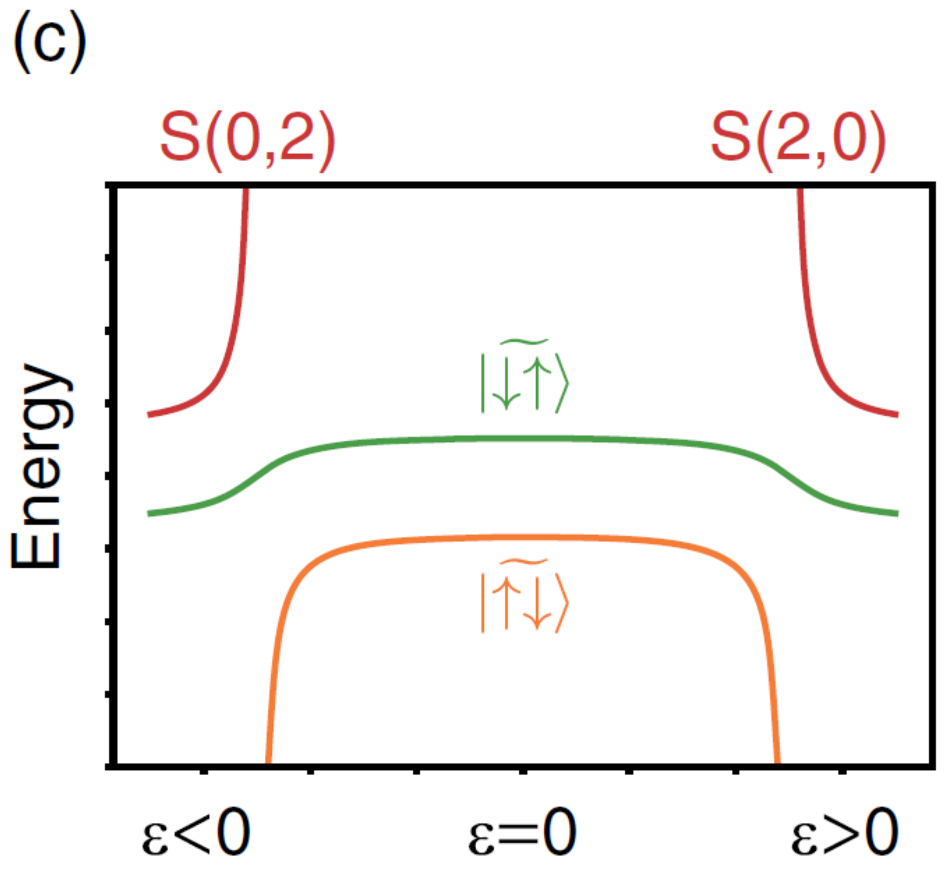

- Si/SiGe heterostructure (2DEG)
- 3 Al layers
- Dilution refrigerator: $T_e \sim 40$ mK
- Inplane magnetic field: $B_{ext} \sim 0.5$ T + a "large" magnetic field gradient (in and outplane)
- (Radio-frequency) Sensor QD (at top)
- Coherent driving of the qubit by modulating the exchange interaction ($\lesssim$1 GHz)

# Charge stability diagram

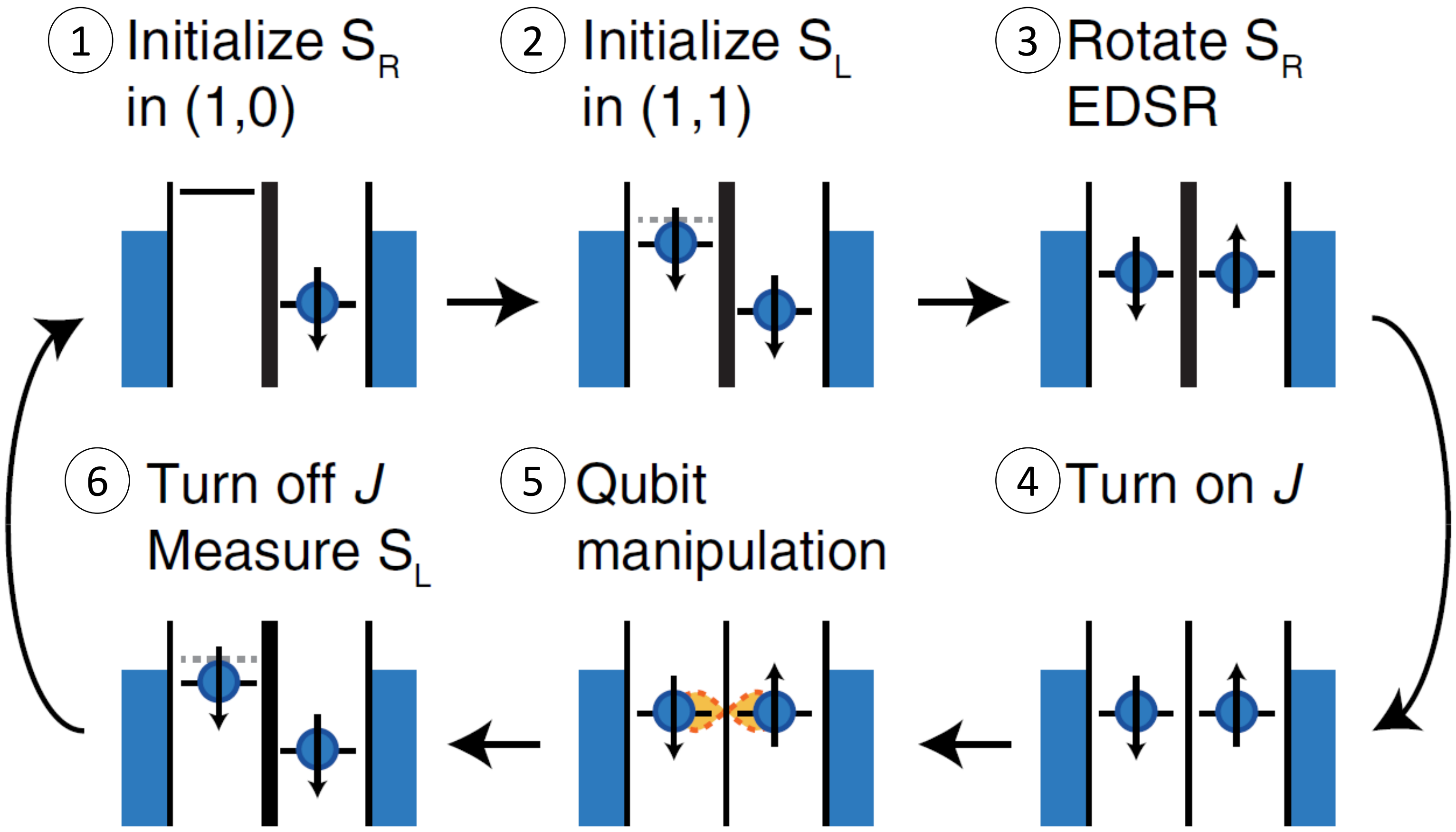


# Charge stability diagram



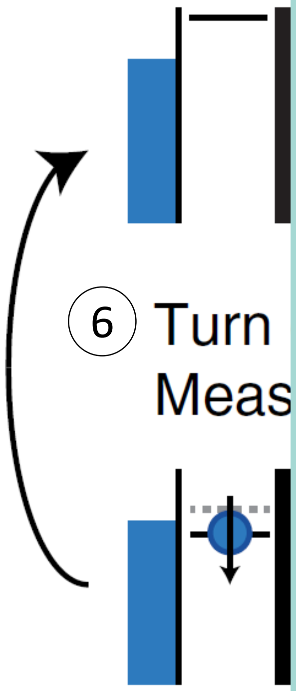



# Measurement sequence: Basic operations

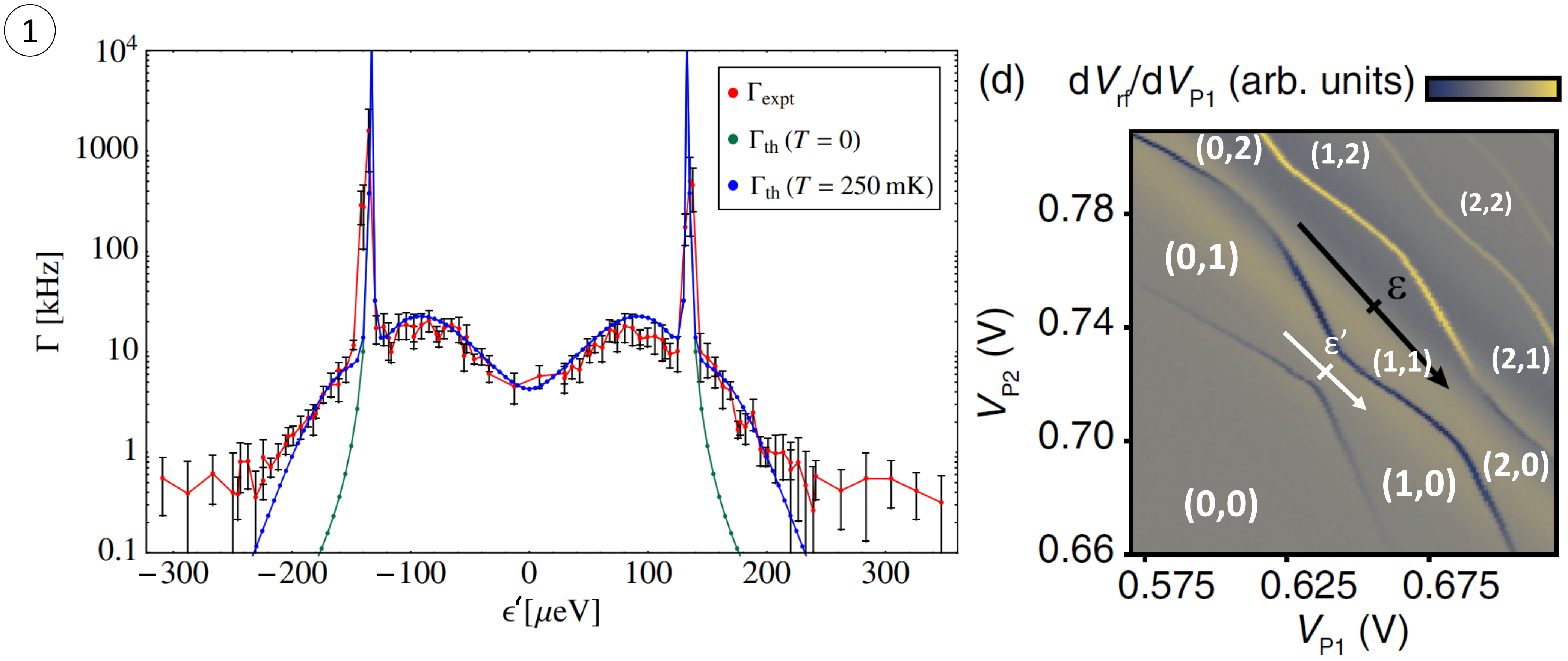


# Measurement sequence: Basic operations

1 Initializ
in (1,0



6 Turn
Meas




V. Srinivasa, K. C. Nowack, M. Shafiei, L. M. K. Vandersypen, and J. M. Taylor, Phys. Rev. Lett. 110, 196803 (2013).

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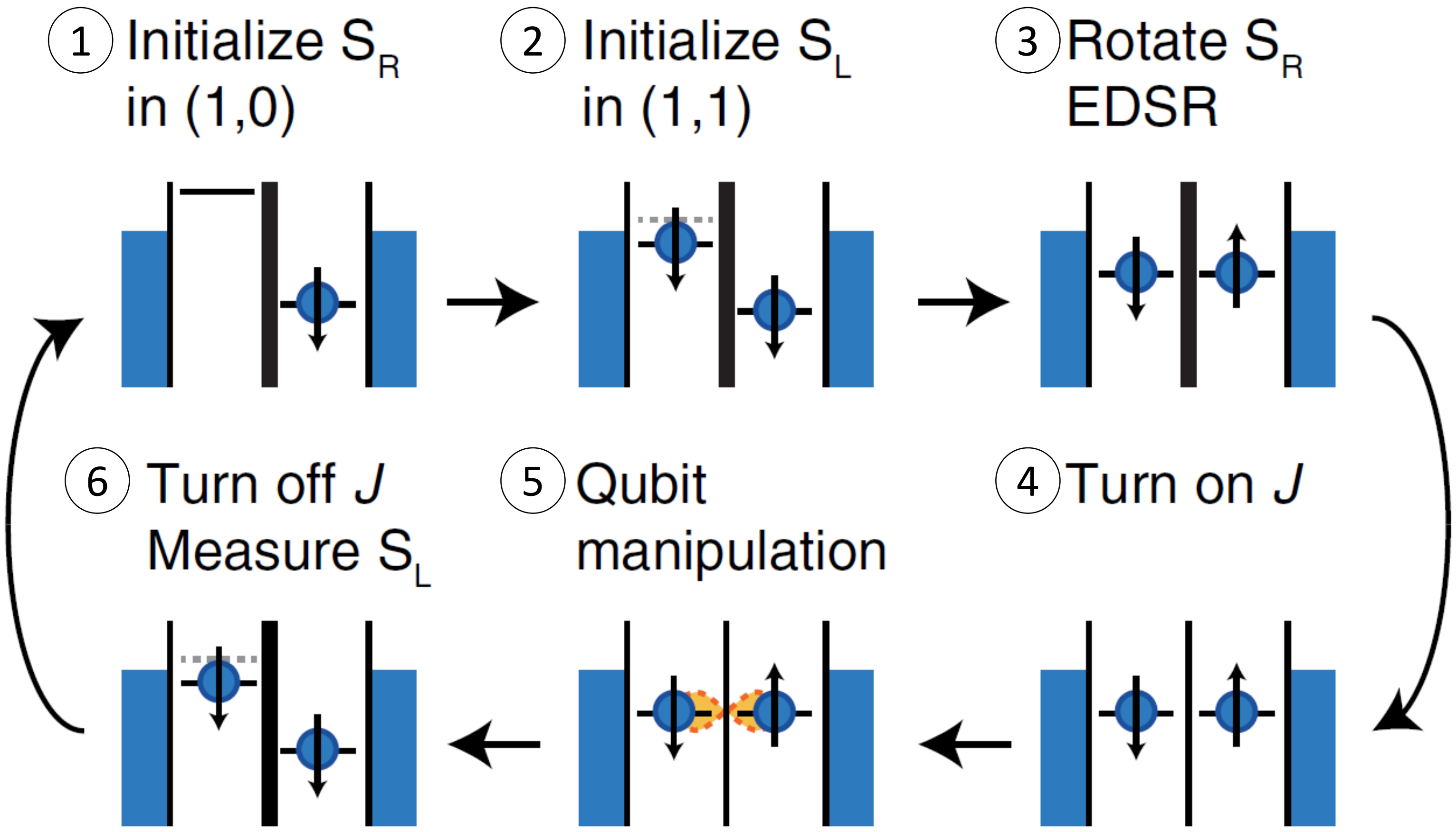

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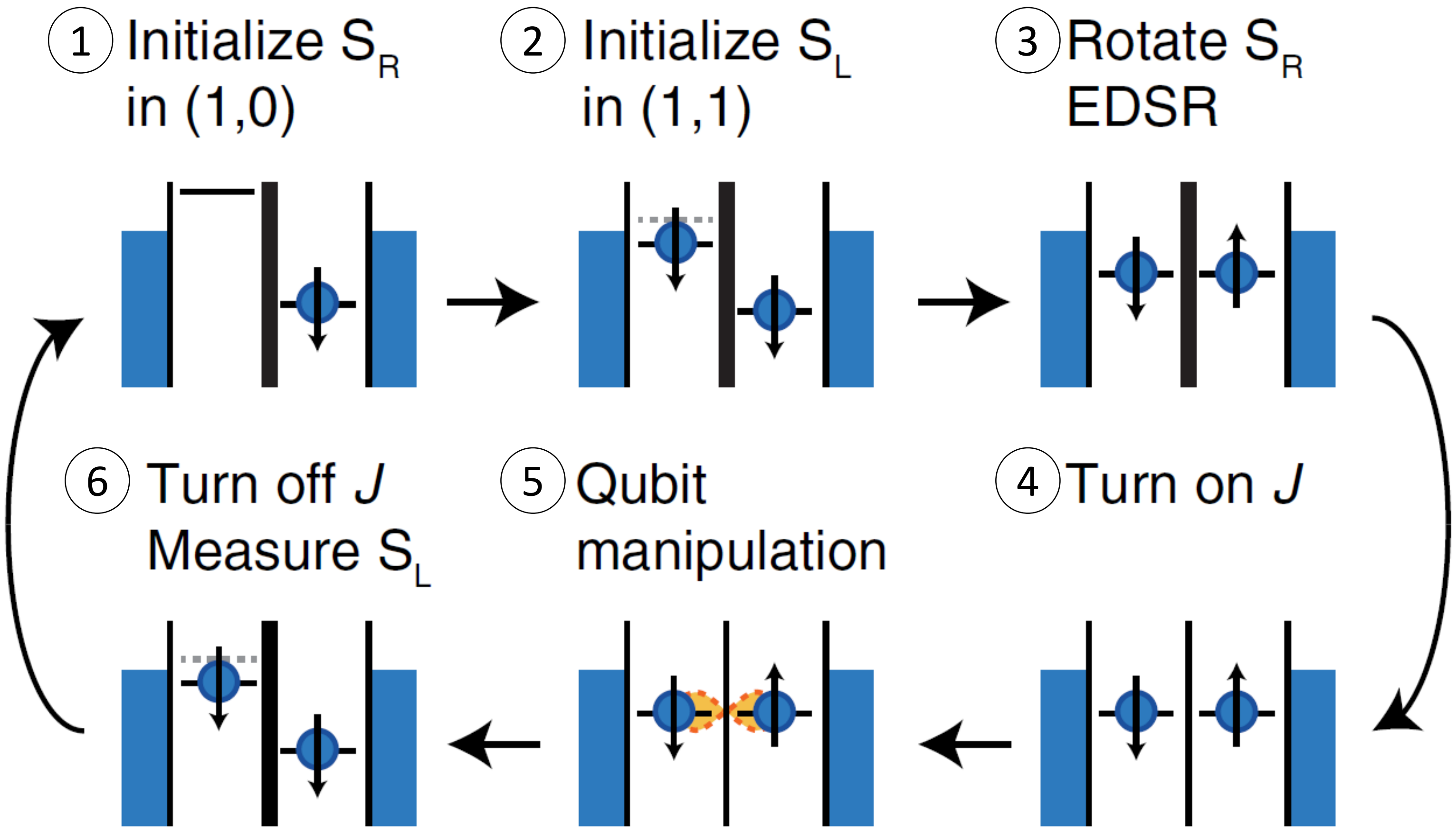


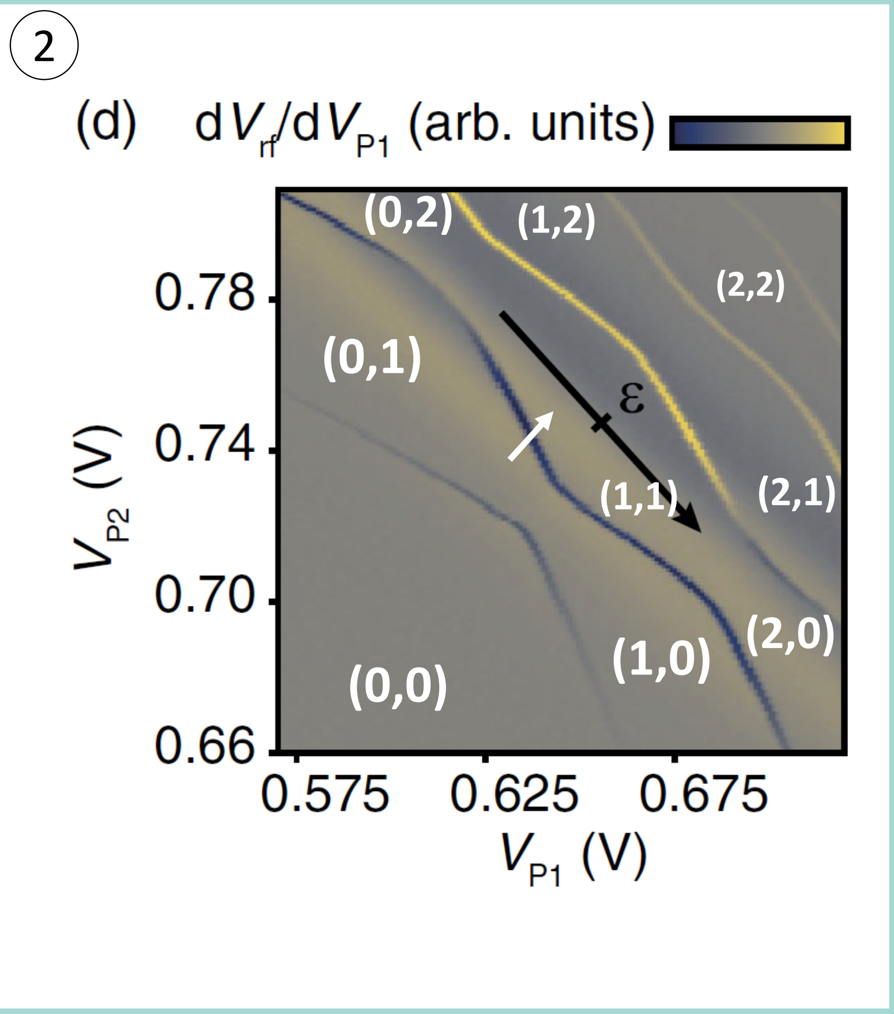

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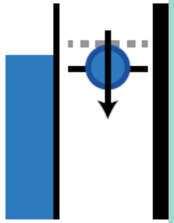
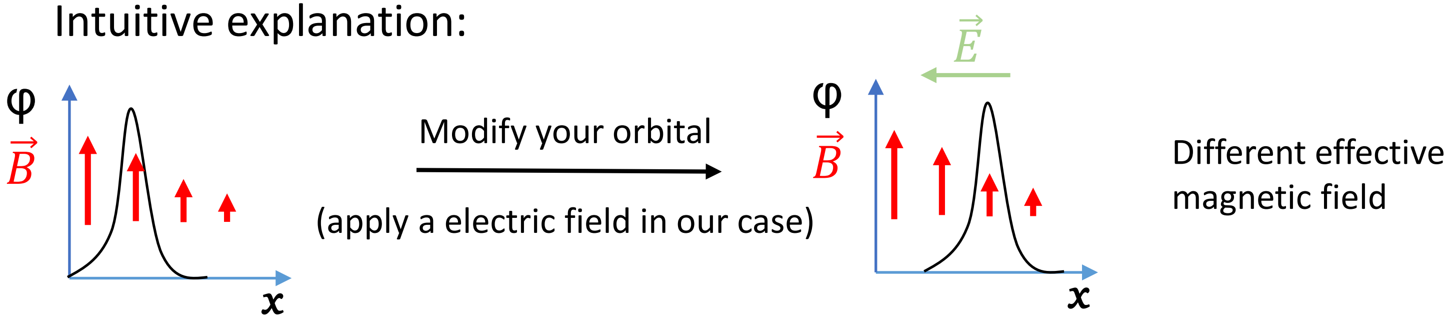


3 Electric-Dipole Spin Resonance (EDSR)

- Gradient of B outplane ($B_{outplane}$) is used to couple electron's spin and orbital degrees of freedom (in other words: allows the ESR)

Intuitive explanation:

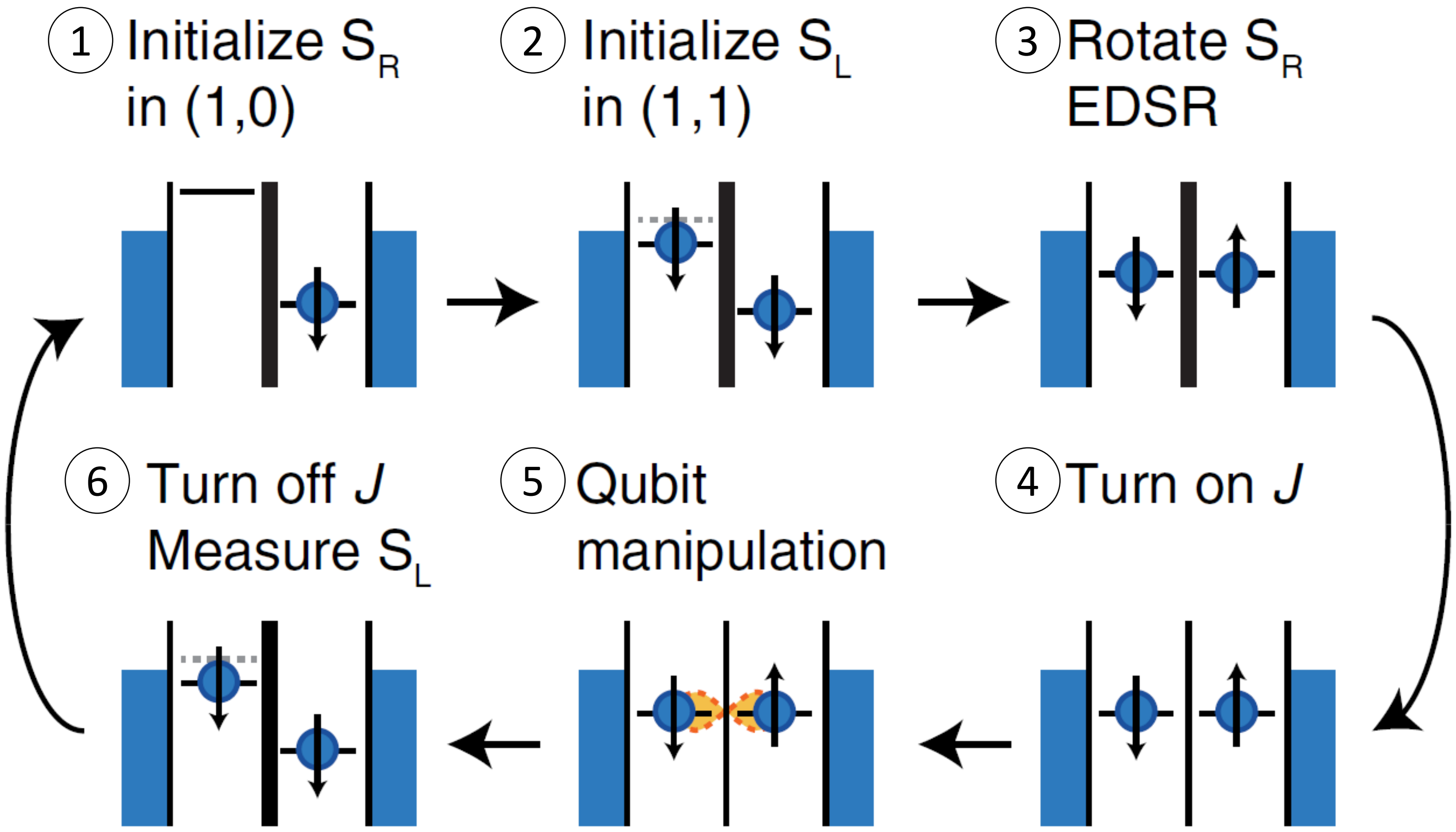



- Gradient inplane is used to give different Larmor frequencies for spin in each QD. Hence, we can selectively rotate $S_R$ or $S_L$ (resonant frequency ∝ $B_{inplane}$)

- Typical values*: $\delta B_{outplane}$ > 0.8 mT/nm and $\Delta B_{inplane}$ > 18 mT

*Yasuhiro Tokura, Wilfred G. van der Wiel, Toshiaki Obata, and Seigo Tarucha, Phys. Rev. Lett. 96, 047202 (2006).

# Measurement sequence: Basic operations

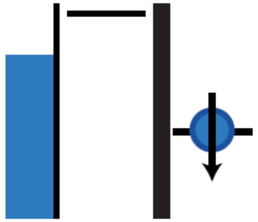



4

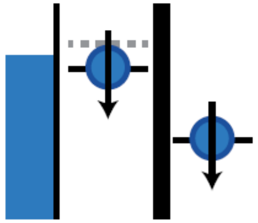
- Square pulse on B2 with $\delta V_{B_2}$= 70 mV
- Then, the 2 QDs interact

# Measurement sequence: Basic operations

(1) Initialize S
in (1,0)

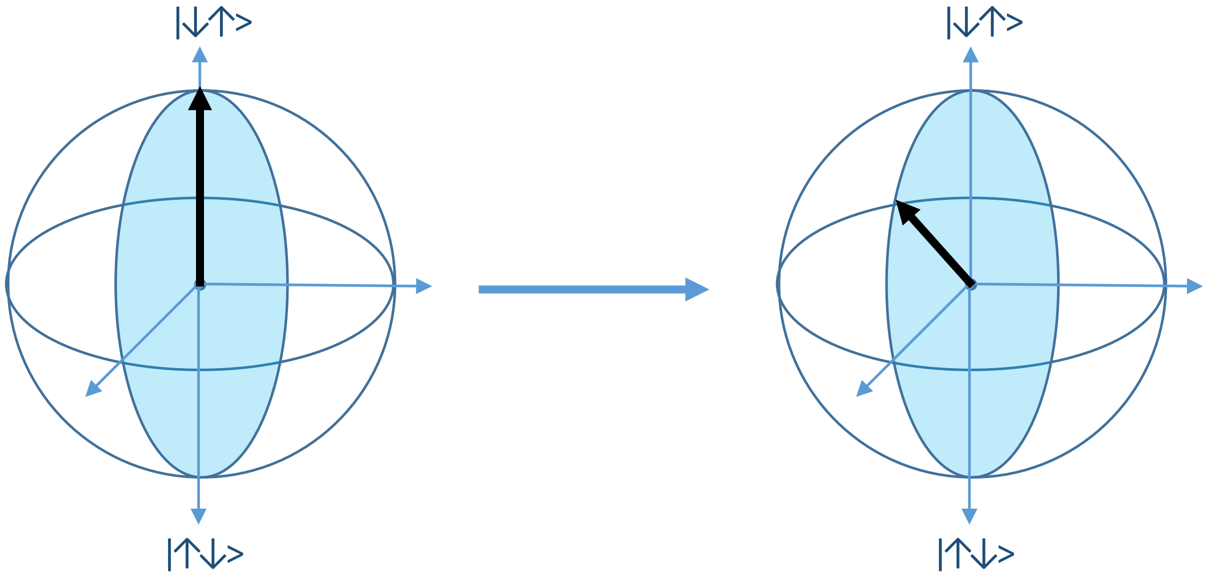


(6) Turn off J
Measure

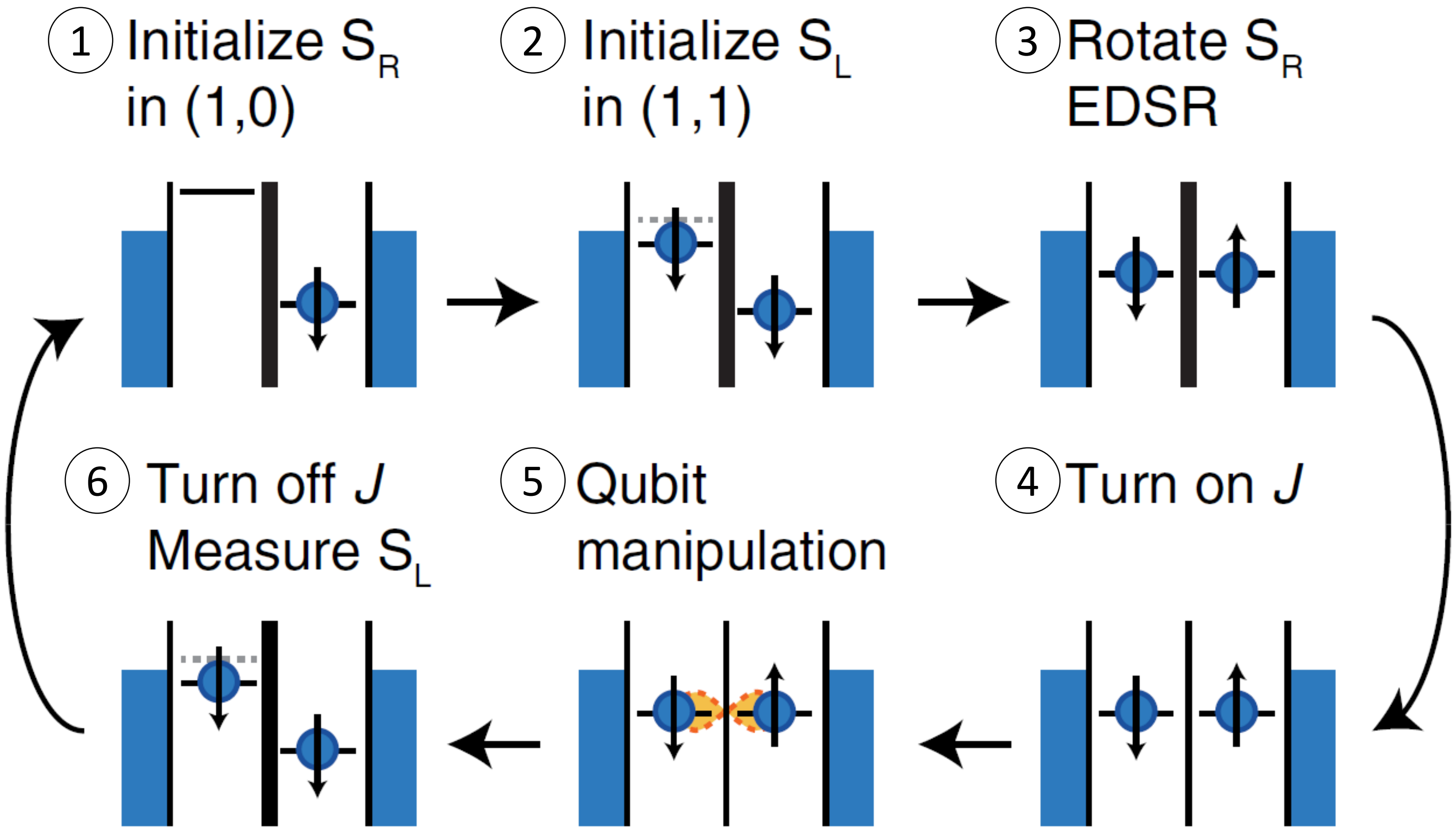


(5)

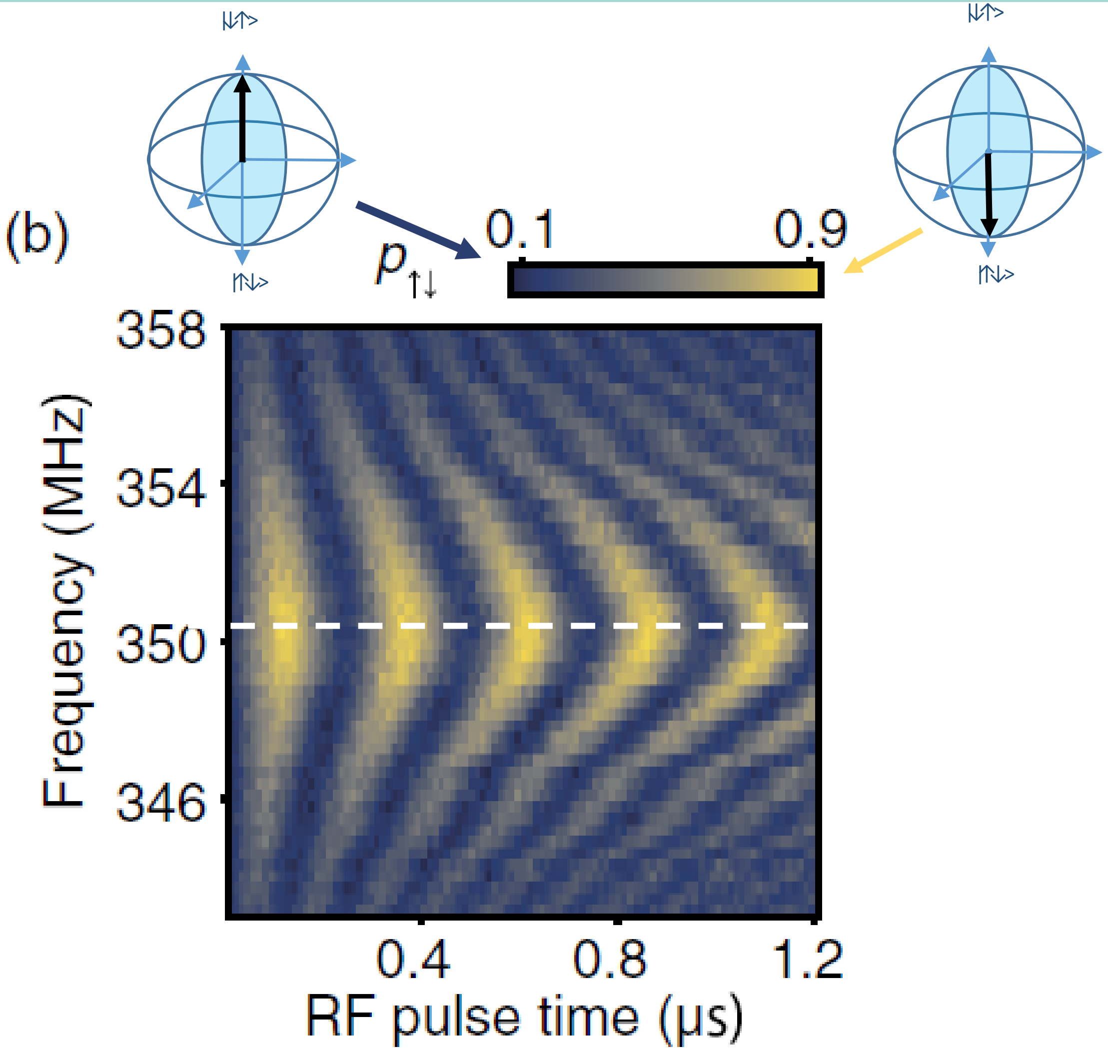
- ac voltage pulses to the B2 gate
- That induce a rotation in our Bloch sphere



# Measurement sequence: Basic operations

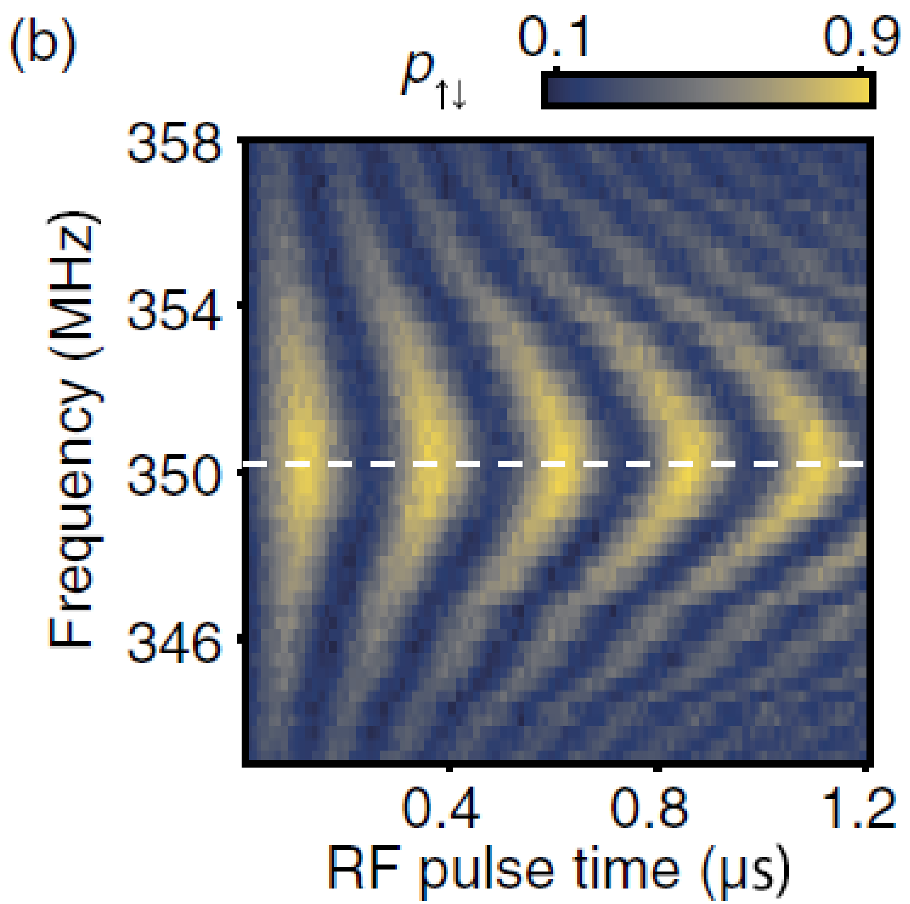


# Rabi chevron oscillations




- ac pulse amplitude (on B2) of 6.3 mV
- Qubit resonance frequency = 351 MHz

# Rabi chevron oscillations

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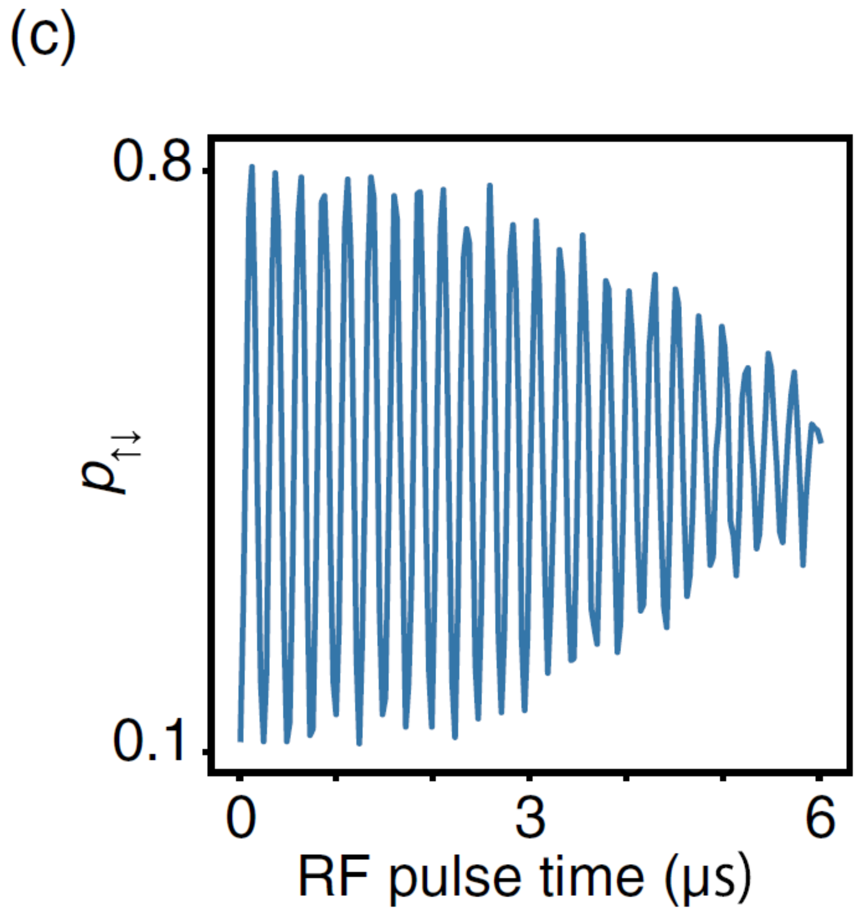
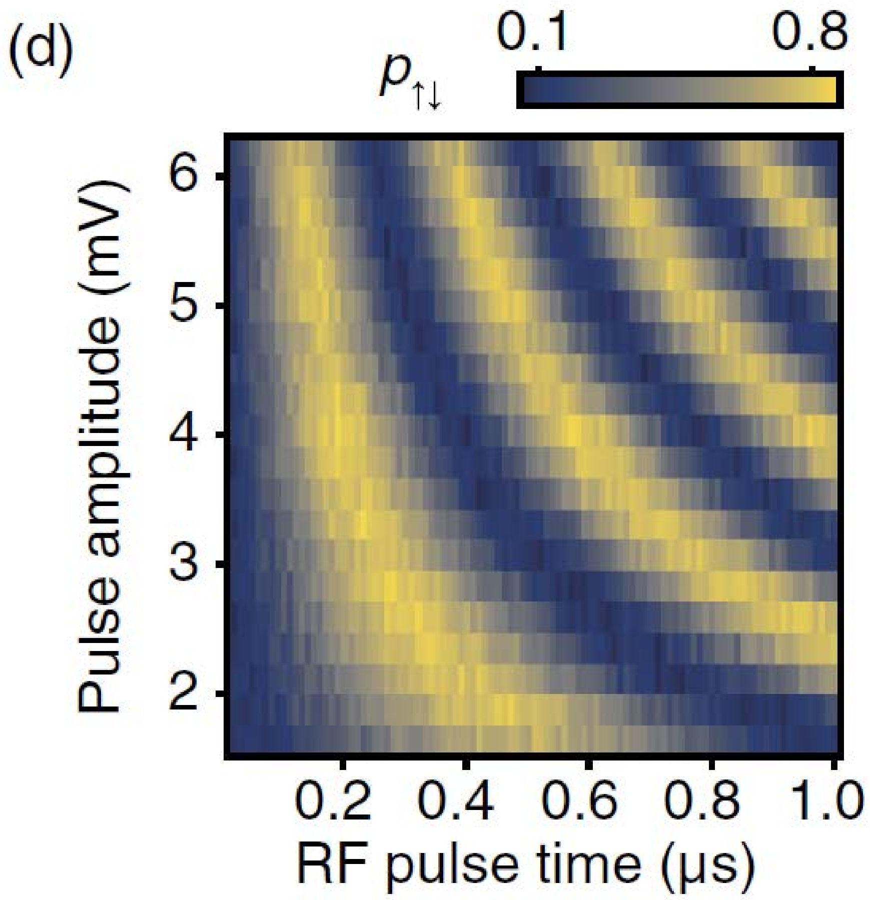



Rabi oscillation decay time $T_R \sim 6$ μs

# Amplitude dependence of the Rabi oscillations



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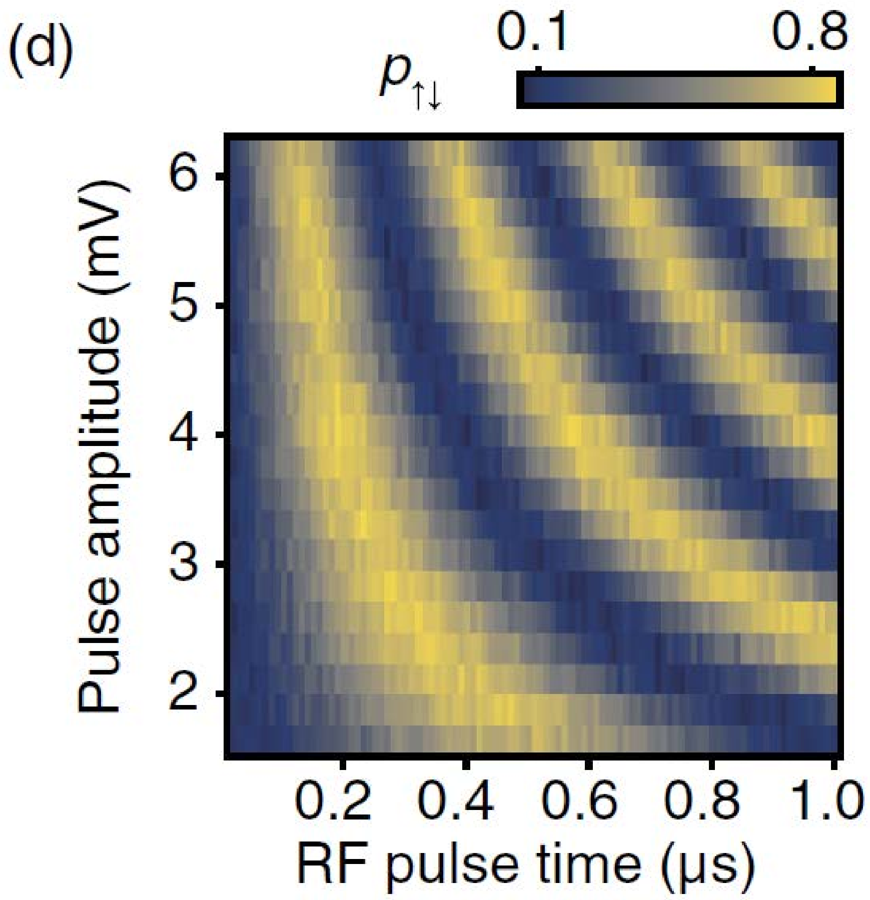
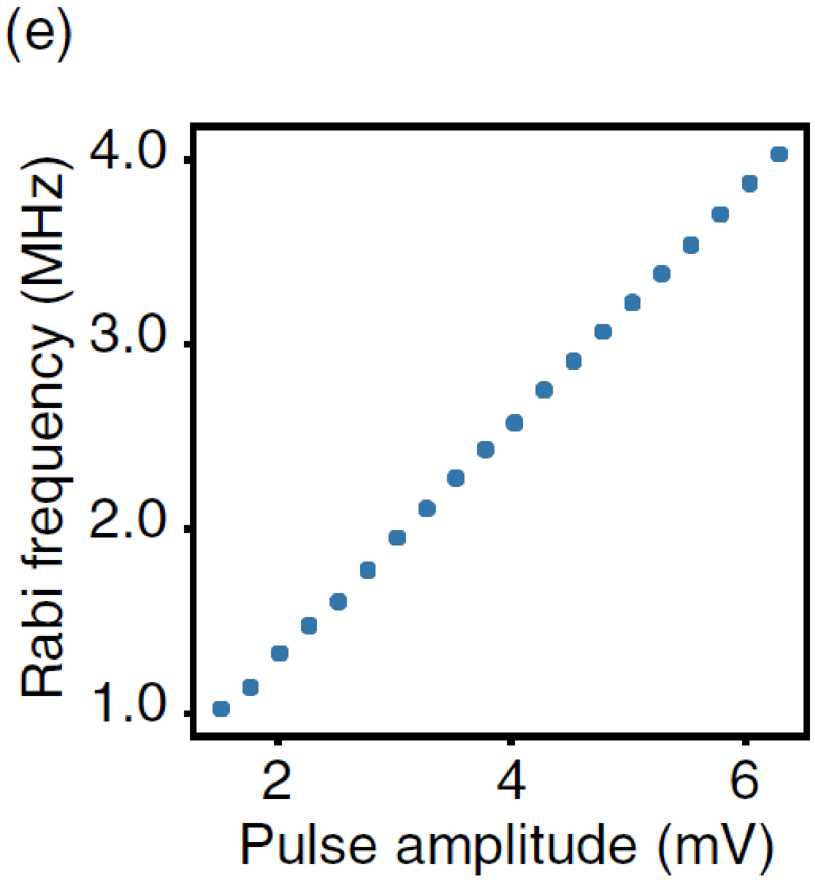
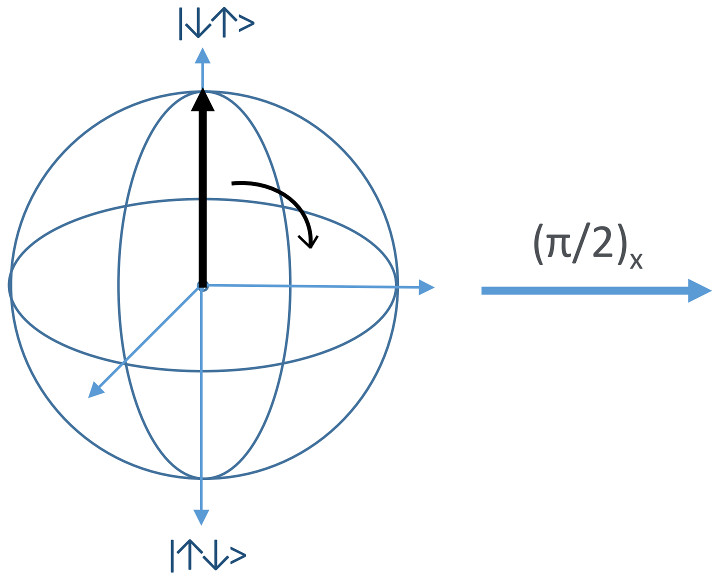



Linear => The qubit is in the regime where J changes linearly with $\delta V_{B_2}$

# Ramsey interferometry: Principle



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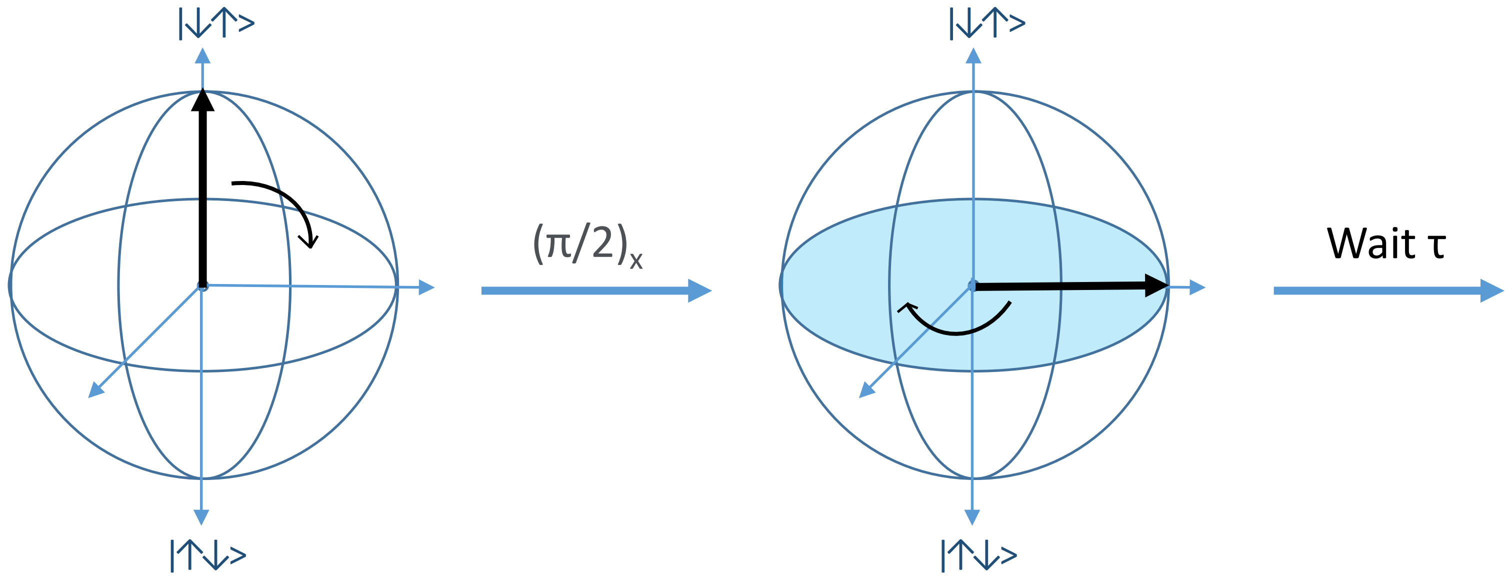

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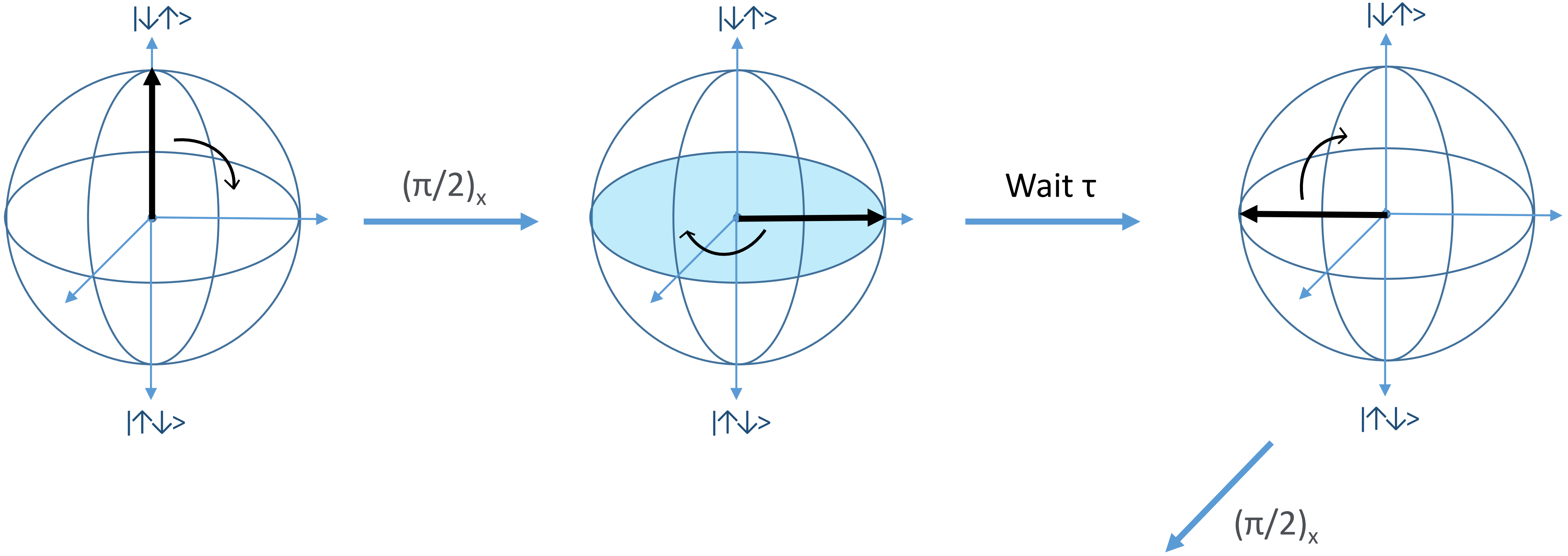

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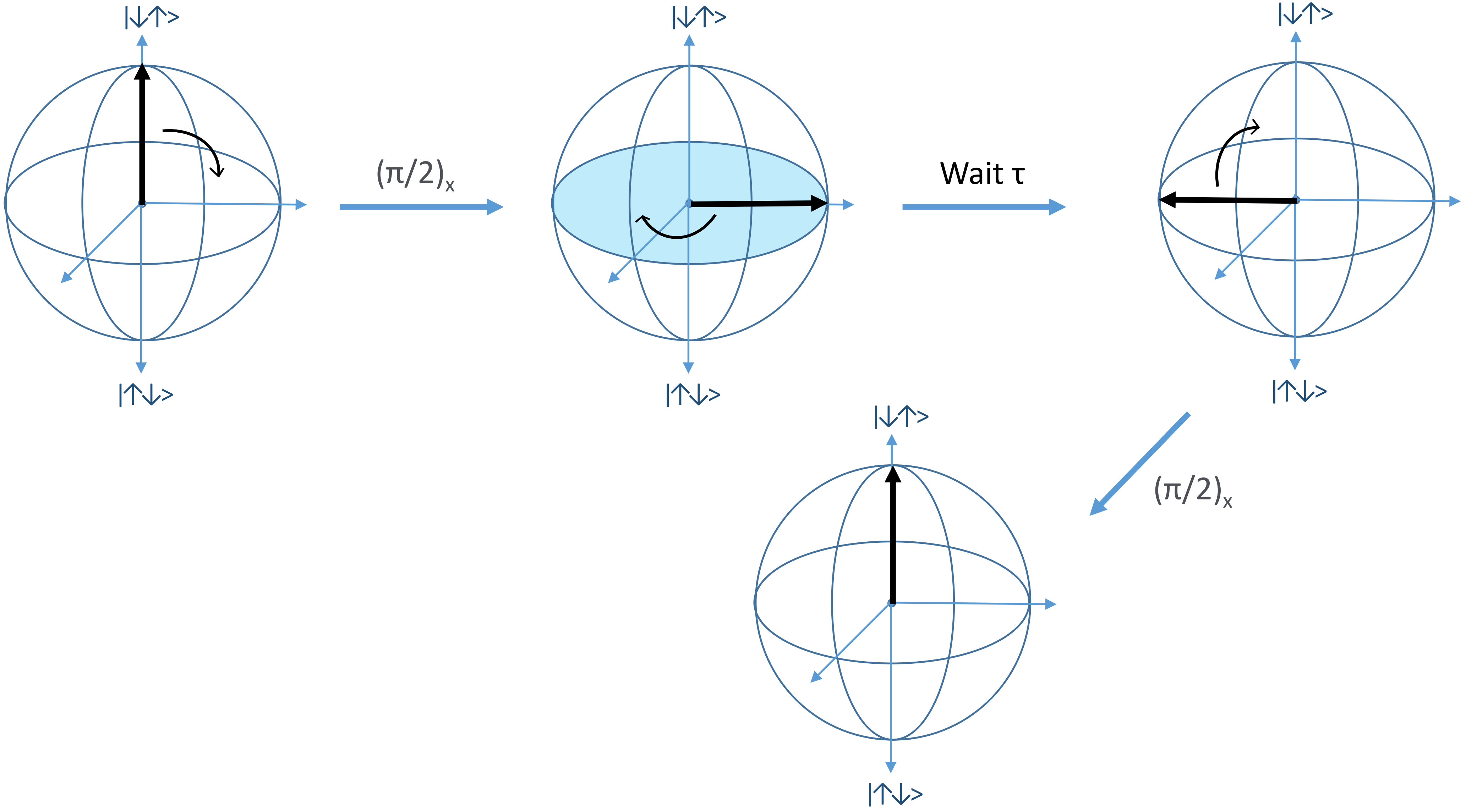

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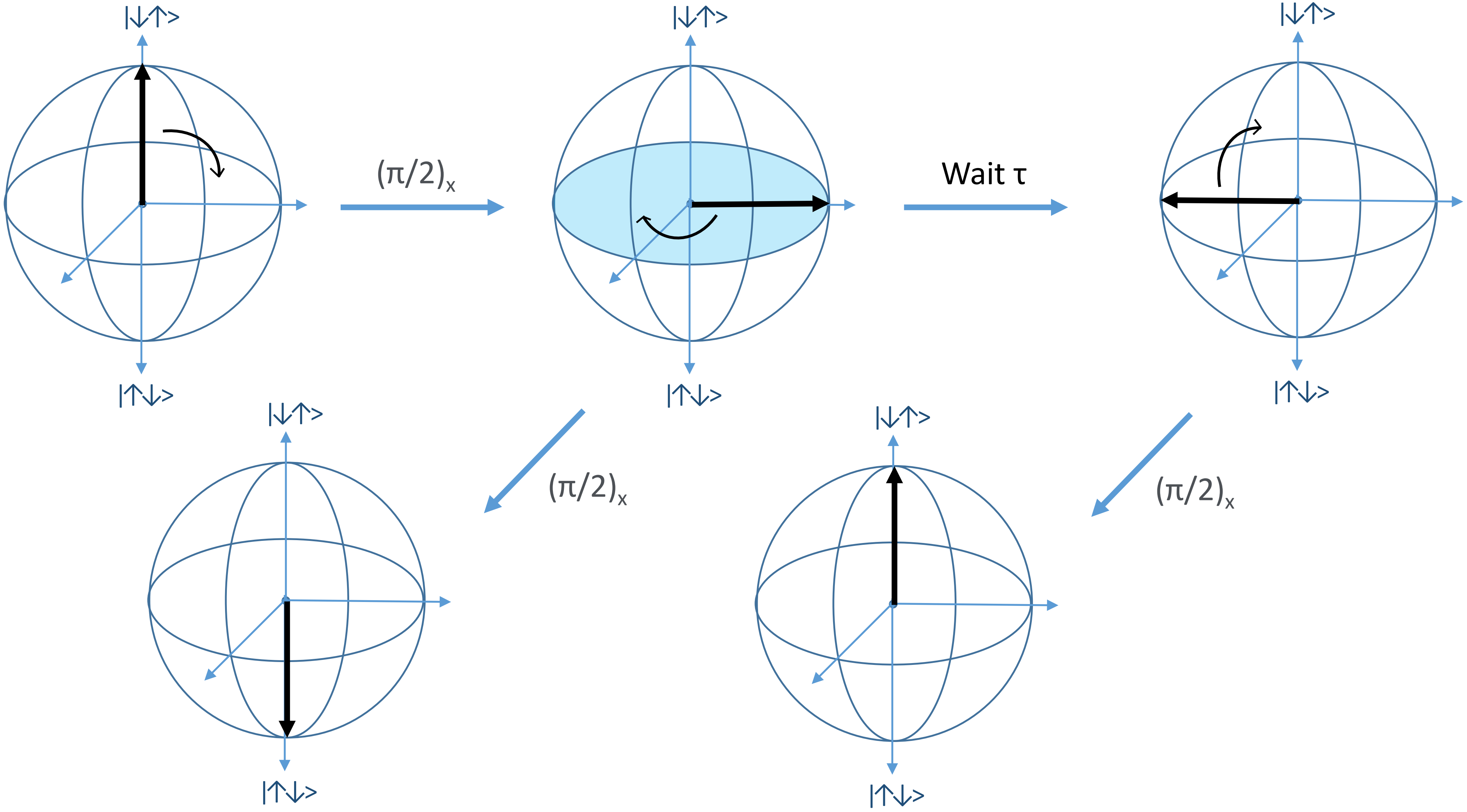
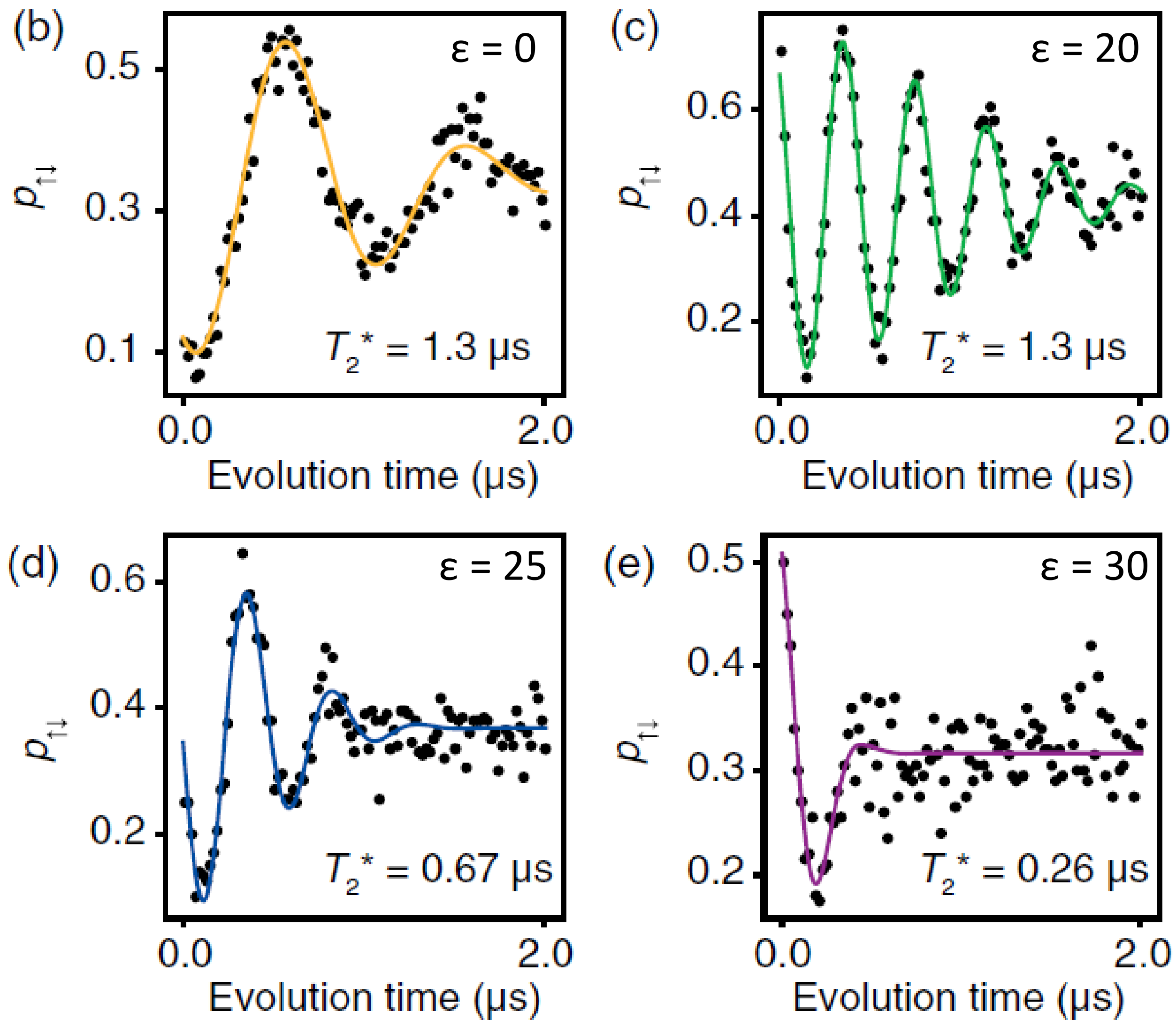
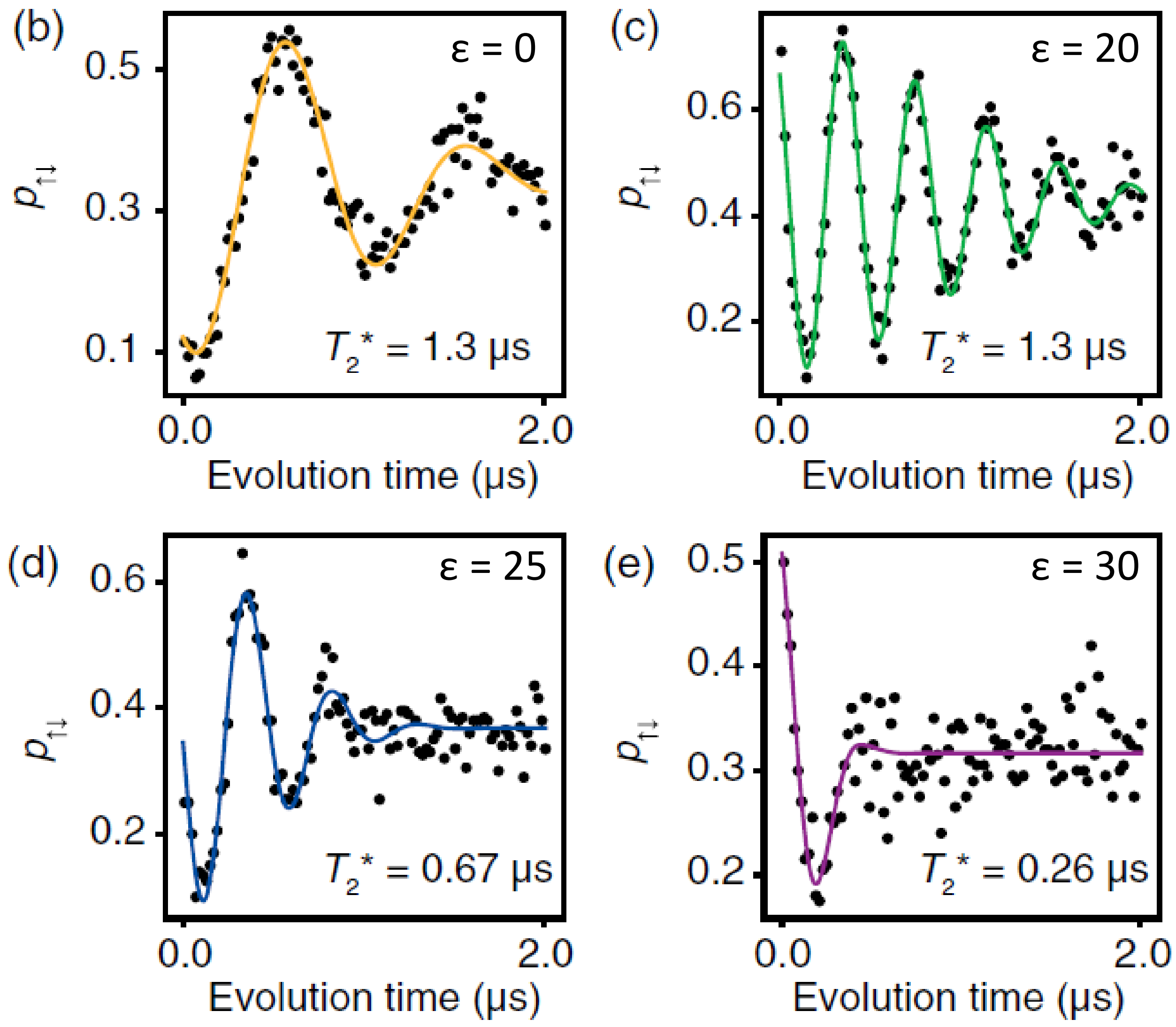
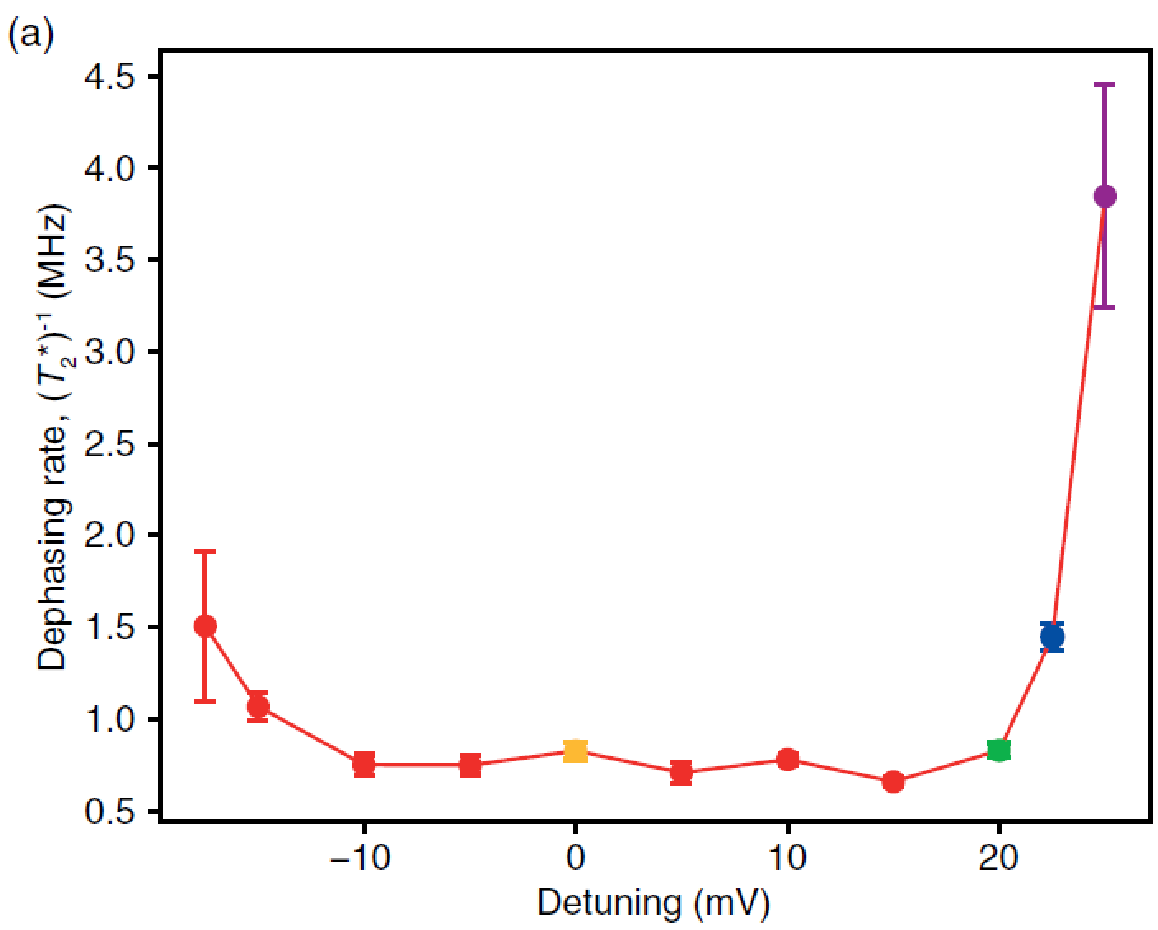


# Ramsey interferometry: calculate $T_2^*$



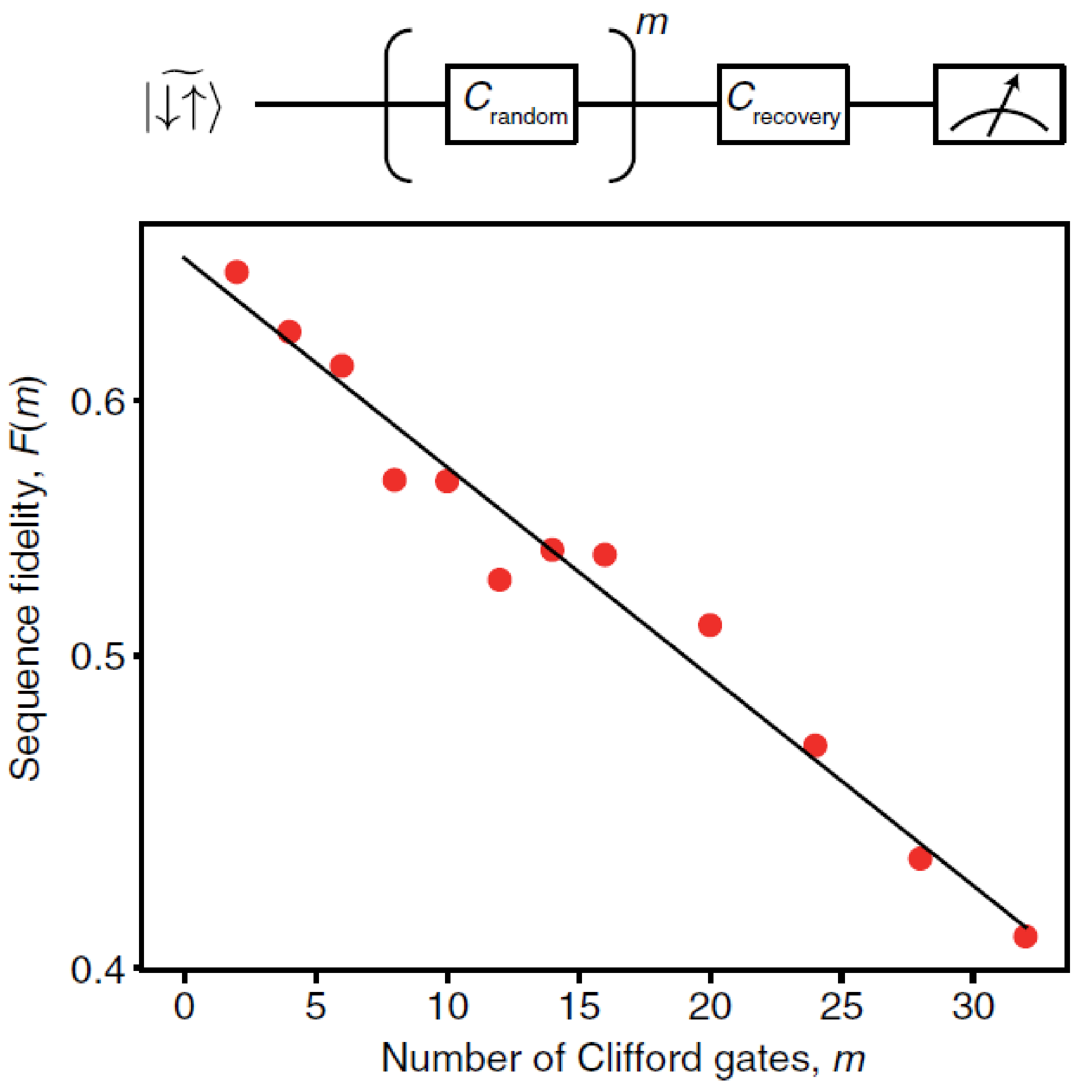
# Ramsey interferometry: ε dependence of $T_2^*$




- $T_2^*$ is quite constant for −10 mV ≲ ε ≲ 20 mV.
- So, for other experiment they choose ε = 20 mV
  ($T_2^*$ still high but Rabi frequency twice faster than ε = 0)

# Fidelity benchmark




- Clifford gates are rotations in the Bloch Sphere. They are decomposed into rotations around the x and y axes (1.875 single gates on average)
- Fidelity $F(m) = P_{|\downarrow\uparrow>}(m) - P_{|\uparrow\downarrow>}(m) = V p^{m}$
- From the fit: **p = 0.985 ± 0.0009**
  Clifford gate fidelity $\mathbf{F_C}$ **= 99.2 ± 0.045%**
  Single gate fidelity $\mathbf{F_{single}}$ **= 99.6 ± 0.024%**

# Conclusion

- Demonstration of the operation and fidelity benchmark of a resonantly driven singlet-triplet qubit in natural Si

- Good $T_2^* \sim 1.3\ \mu s$ for a natural Si made qubit

- Highest reported fidelity for “singlet-triplet spin qubit”

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# Thanks

## Thank you for your attention!