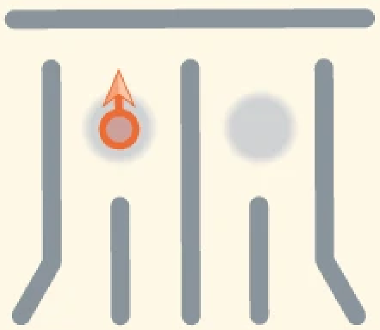
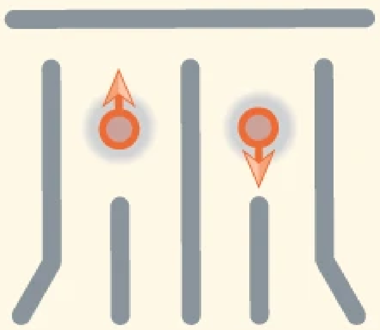
University of Basel

A Singlet-Triplet Hole Spin Qubit in Planar Ge

Jirovec, D., Hofmann, A., Ballabio, A. *et al. Nat. Mater.* **20,** 1106–1112 (2021)

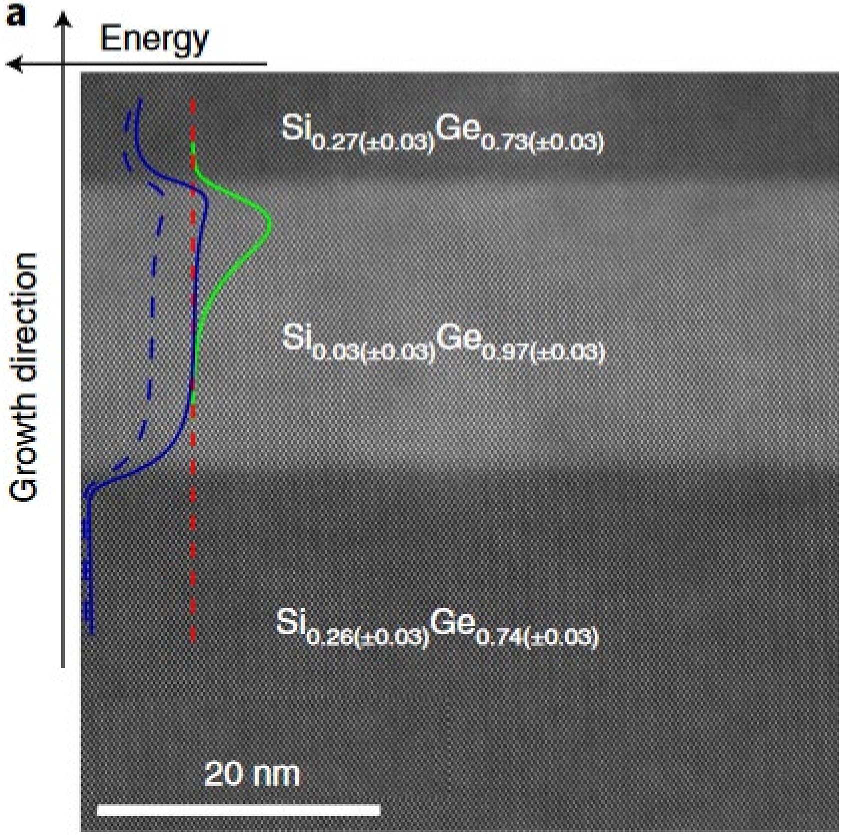
Spin Journal Club, 11.07.22, Eric Jutzi

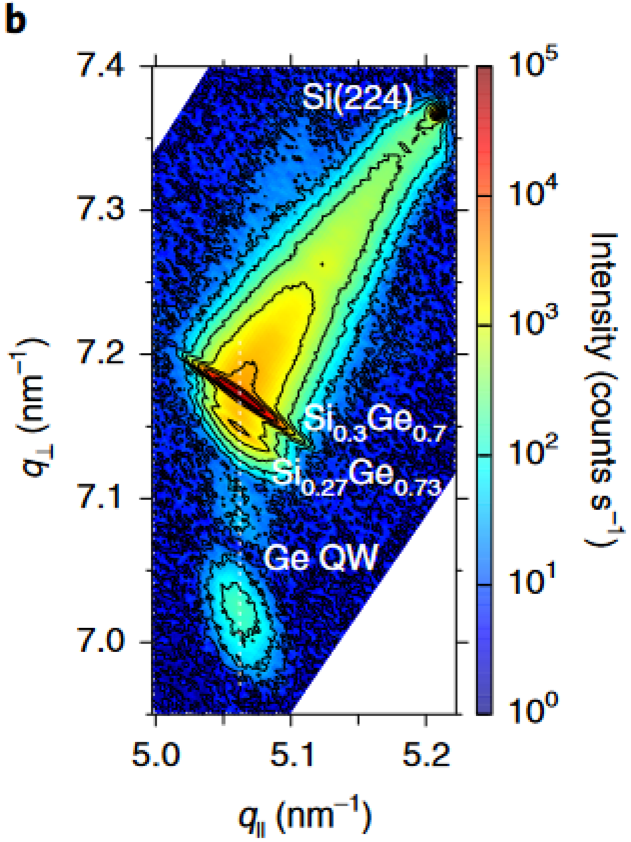
Encoding Schemes

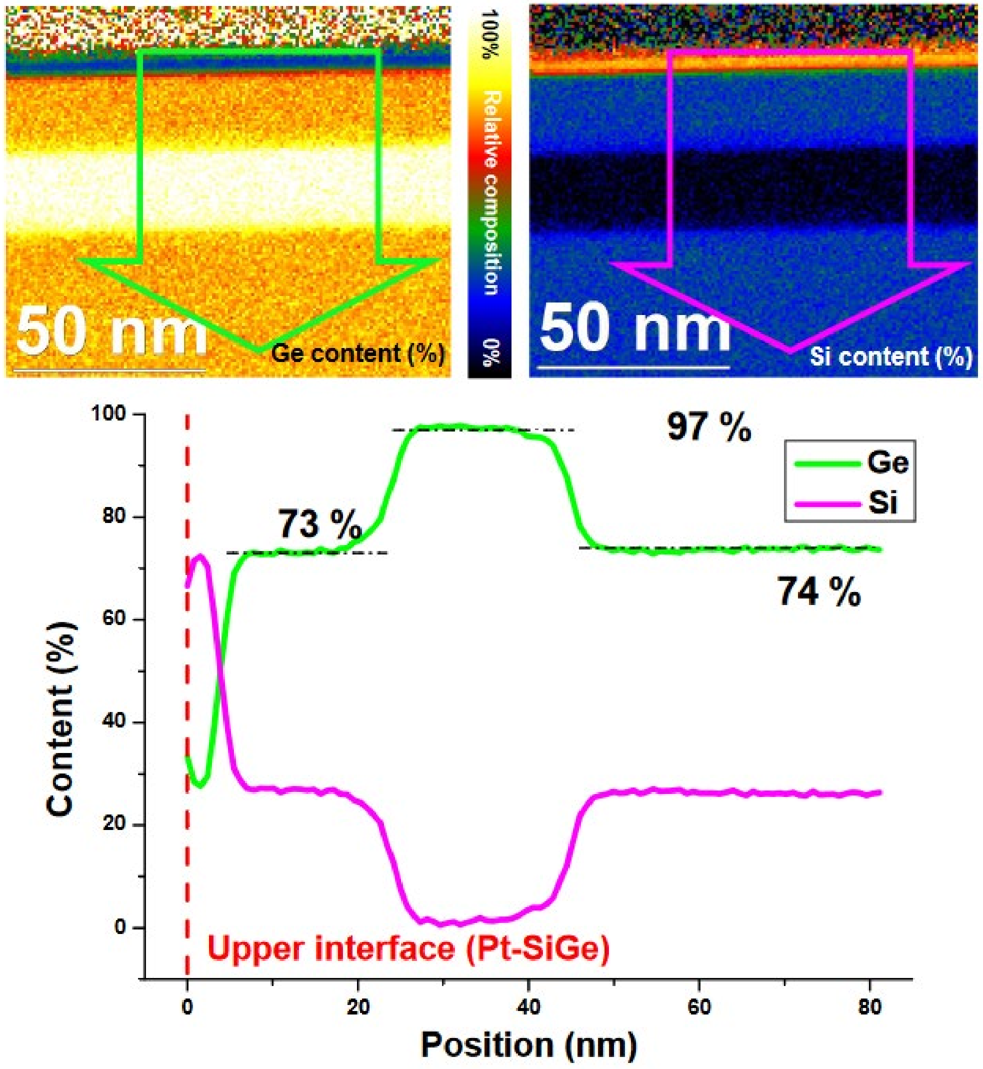
Qubit encoding			f_{Rabi} (MHz)	T_2^* (µs)	B (T)	Ref.
LD qubit	$\vert 0\rangle : \vert\downarrow\rangle$ $\vert 1\rangle : \vert\uparrow\rangle$		85 140 435 >100 147 542	0.06 0.13 0.011 0.833 0.44 0.082	0.144 0.127 0.206 1.65 0.3 0.1	2 4 5 6 15 16
ST_0 qubit	$\vert 0\rangle : \frac{1}{\sqrt{2}}(\vert\uparrow\downarrow\rangle - \vert\downarrow\uparrow\rangle)$ $\vert 1\rangle : \frac{1}{\sqrt{2}}(\vert\uparrow\downarrow\rangle + \vert\downarrow\uparrow\rangle)$		**150**	**1**	**<0.01**	1

Braakman, F., Scarlino, P. *Nat. Mater.* **20,** 1047–1048 (2021)

The heterostructure

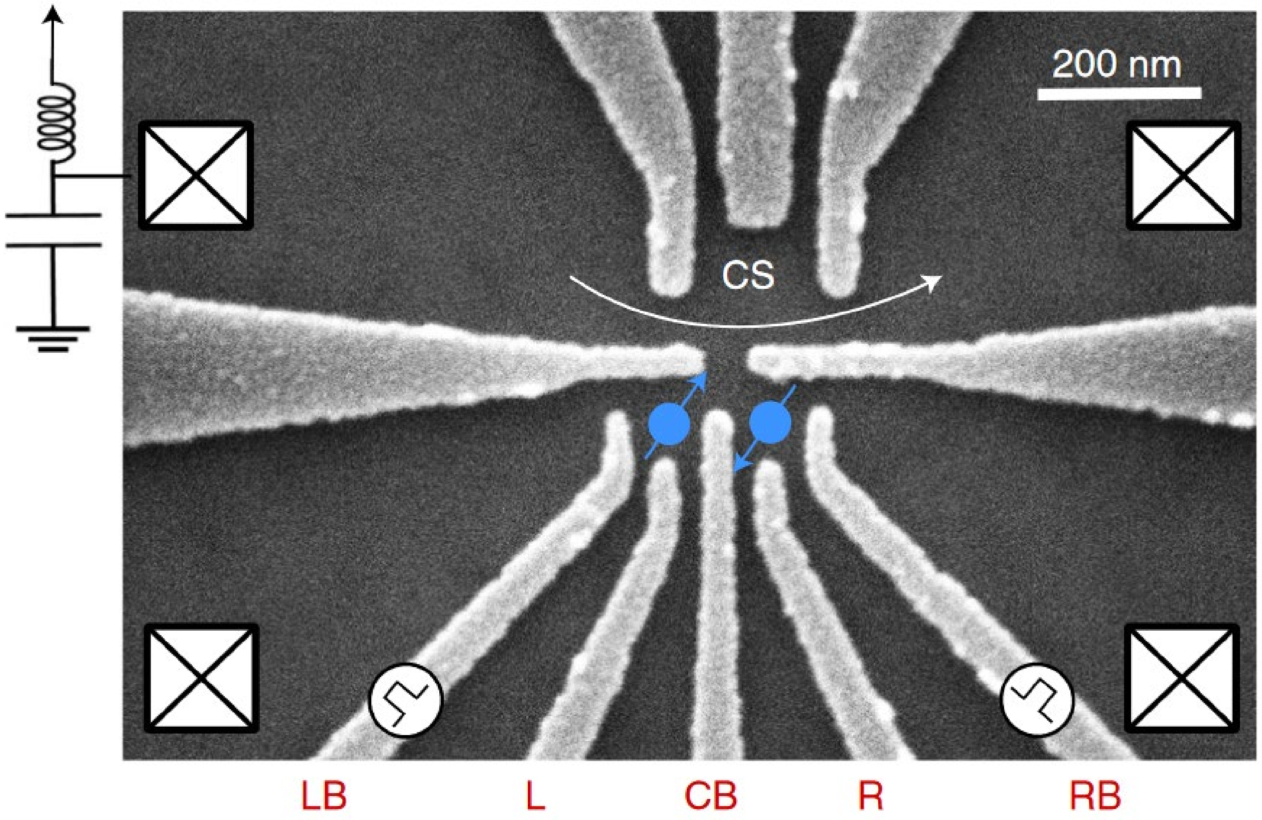






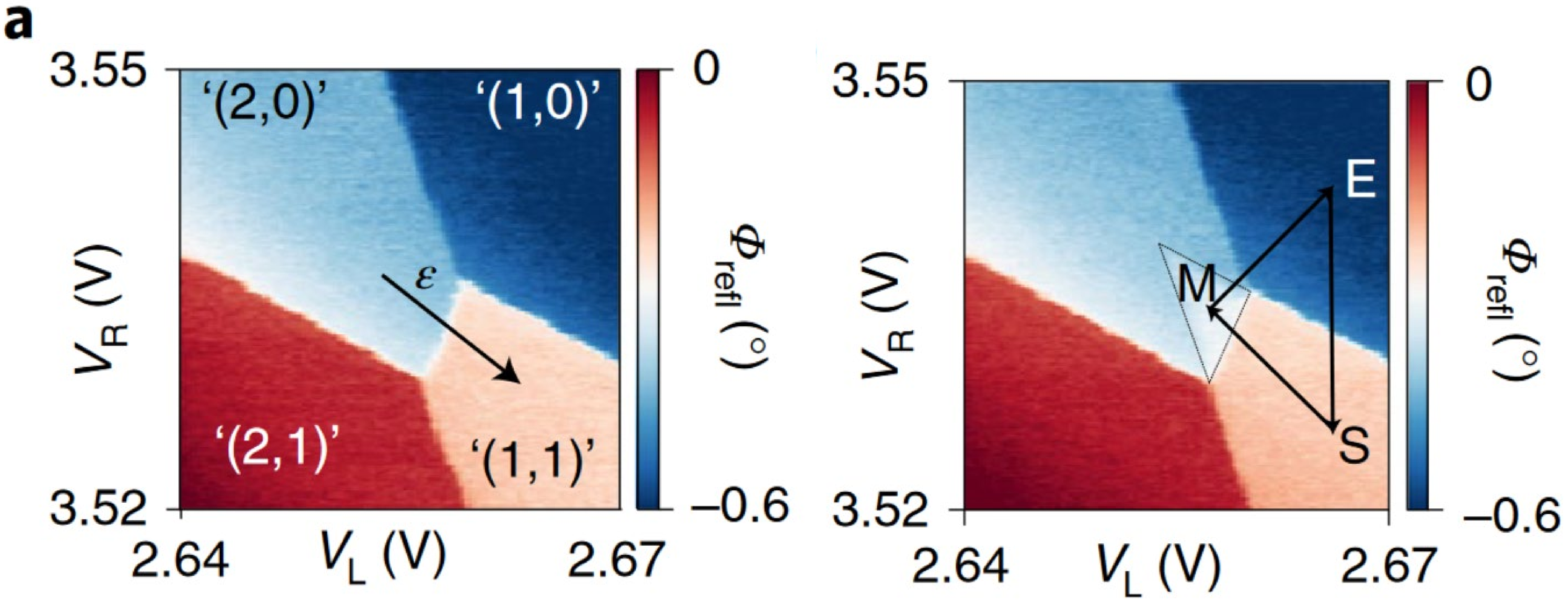
- -0.15 % in-plane in barrier
- -1.18% in-plane in Ge QW

The device

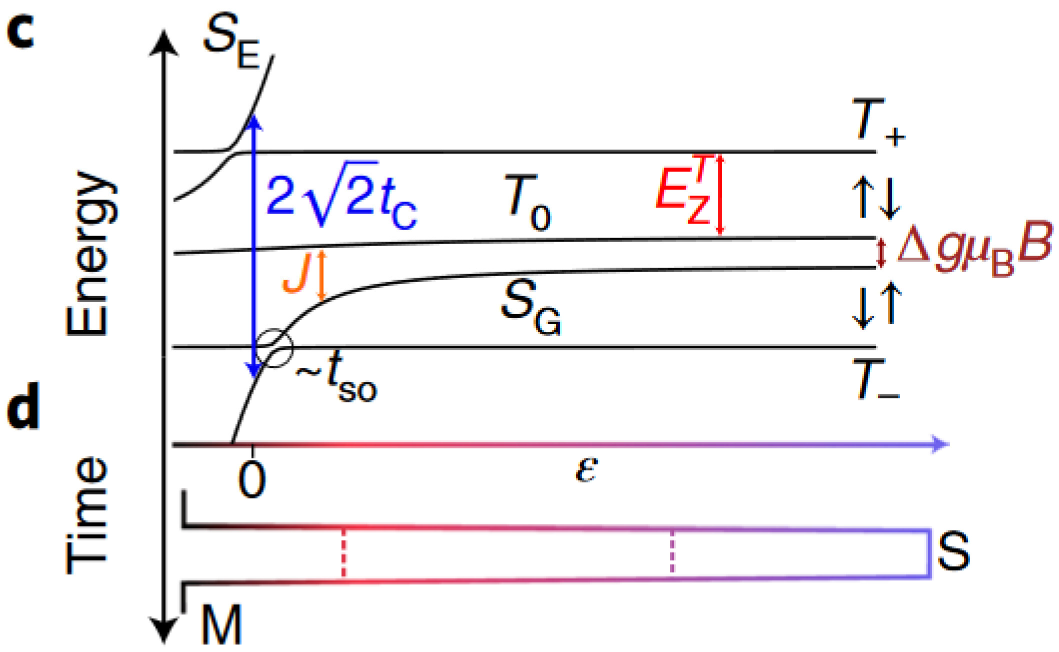


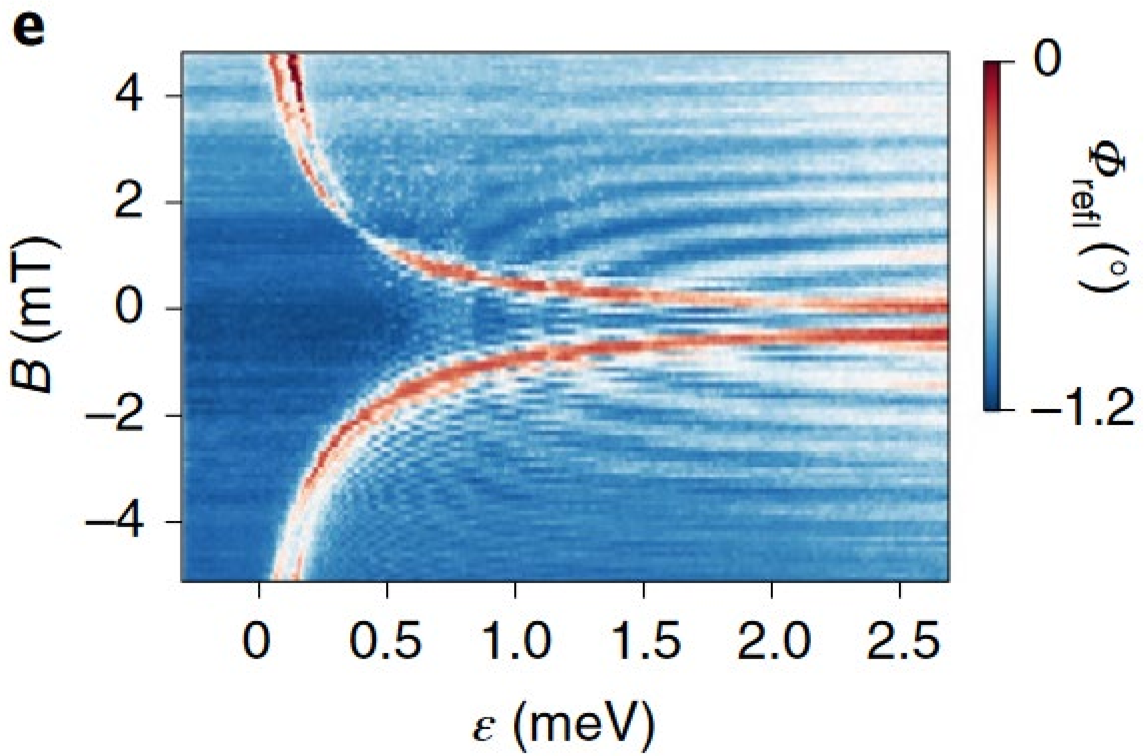
- Carrier density of $9.7 \times 10^{11} cm^{-2}$ without accumulation
- Boron dopants excluded from secondary ion mass spectroscopy; attribute to fixed negative charge in the oxide
- CB controls Δg and tunnel coupling t_c
- Pulses applied to LB+RB (affect mostly t_C, not Δg)

Operation region



Energy dispersion and spin funnel

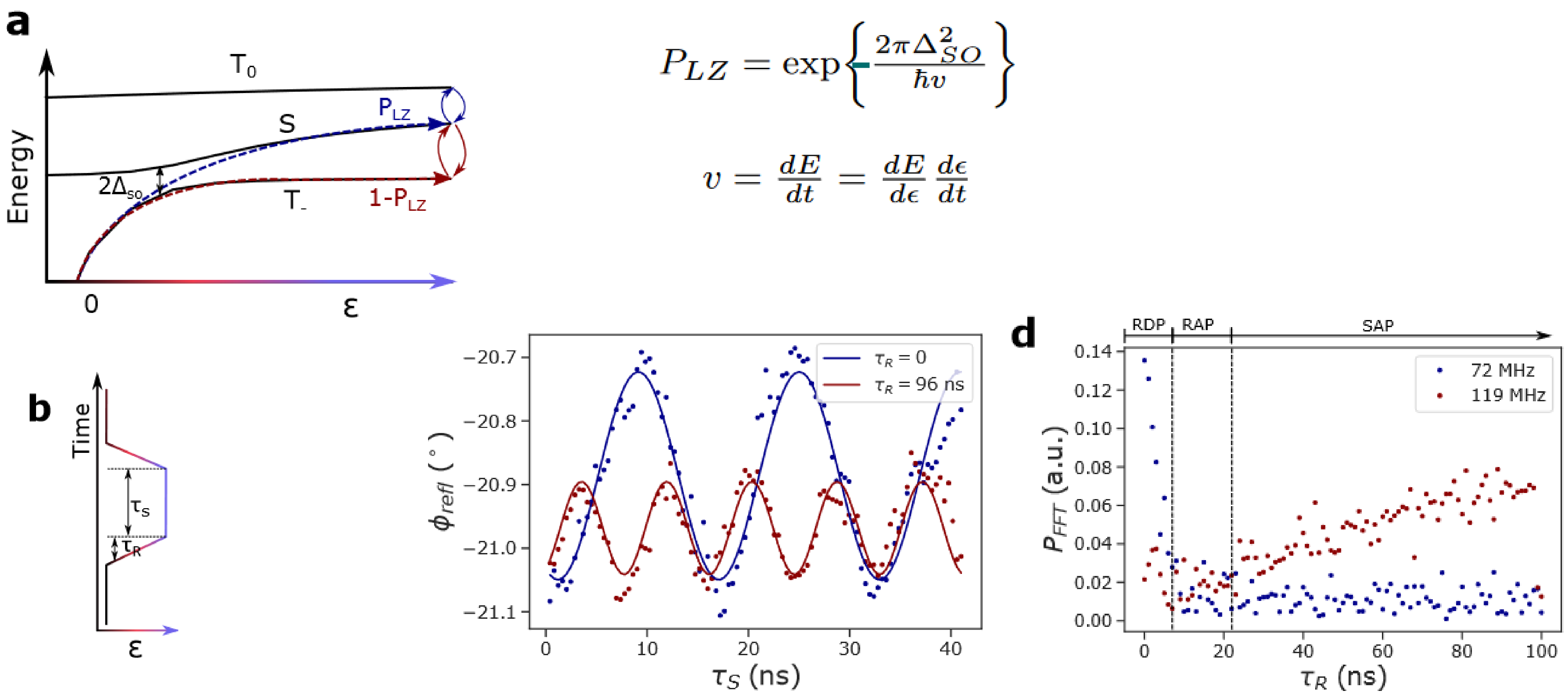




- Pulse sequence of **e**:
  - Start in (2,0)
  - Pulse to (1,1) at varying ε
  - Pulse back to (2,0) after 100 ns

- Red line: $E_Z^T = J(\varepsilon)$
- Doubling due to SOI induced S-T_- oscillations
- S-T_0 oscillations at higher ε

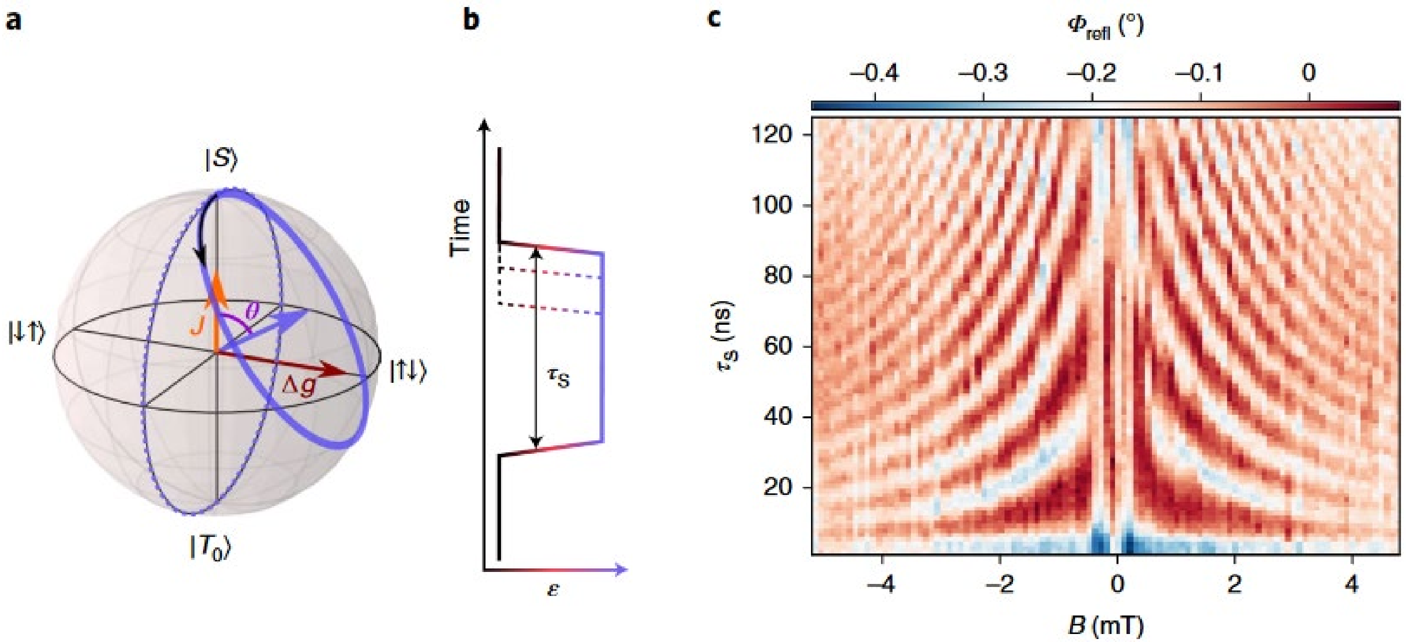
Distinction between S-T_0 and S-T_- oscillations



$$P_{LZ} = \exp\left\{-\frac{2\pi\Delta_{SO}^2}{\hbar v}\right\}$$

$$v = \frac{dE}{dt} = \frac{dE}{d\epsilon}\frac{d\epsilon}{dt}$$

Partial X rotations



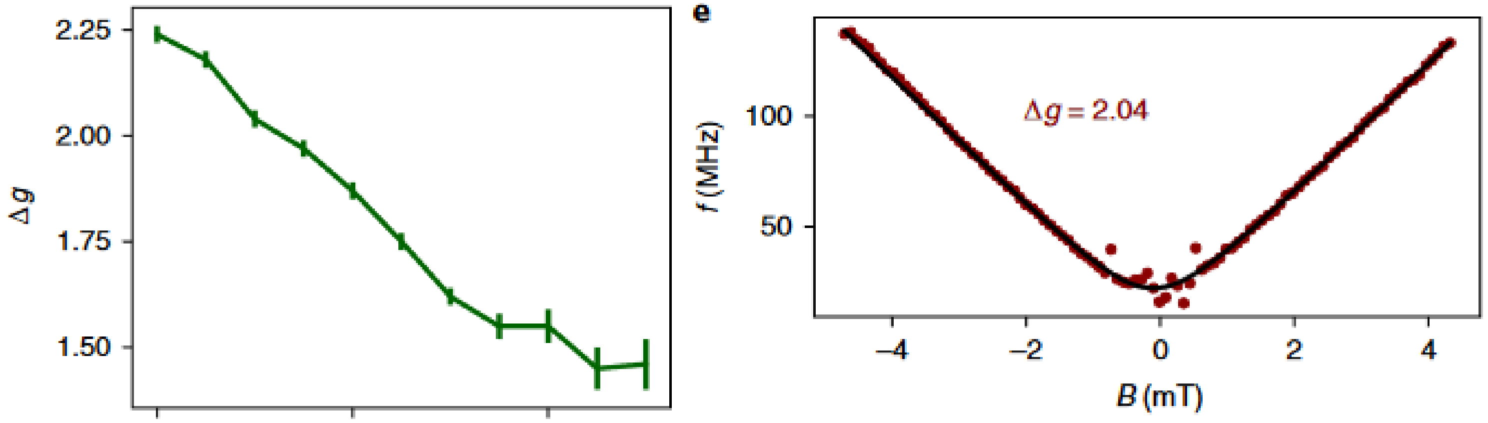
- Residual exchange coupling prevents ideal X rotations
- Actual rotation axis is:

$$\theta = \arctan\left(\frac{\Delta g \mu_B B}{J(\varepsilon)}\right)$$

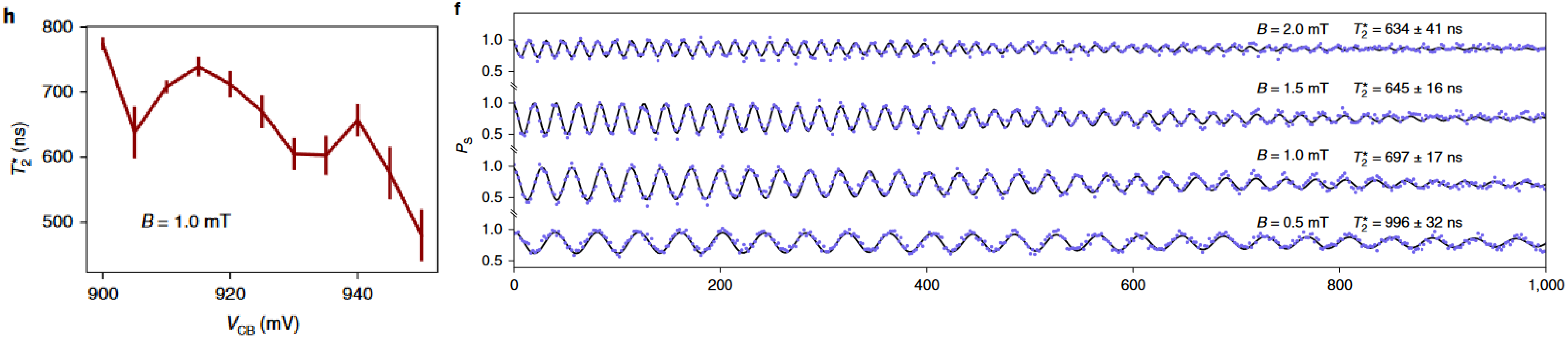
- Oscillations occur at frequency

$$f = \frac{1}{h}\sqrt{J^2 + (\Delta g \mu_B B)^2}$$

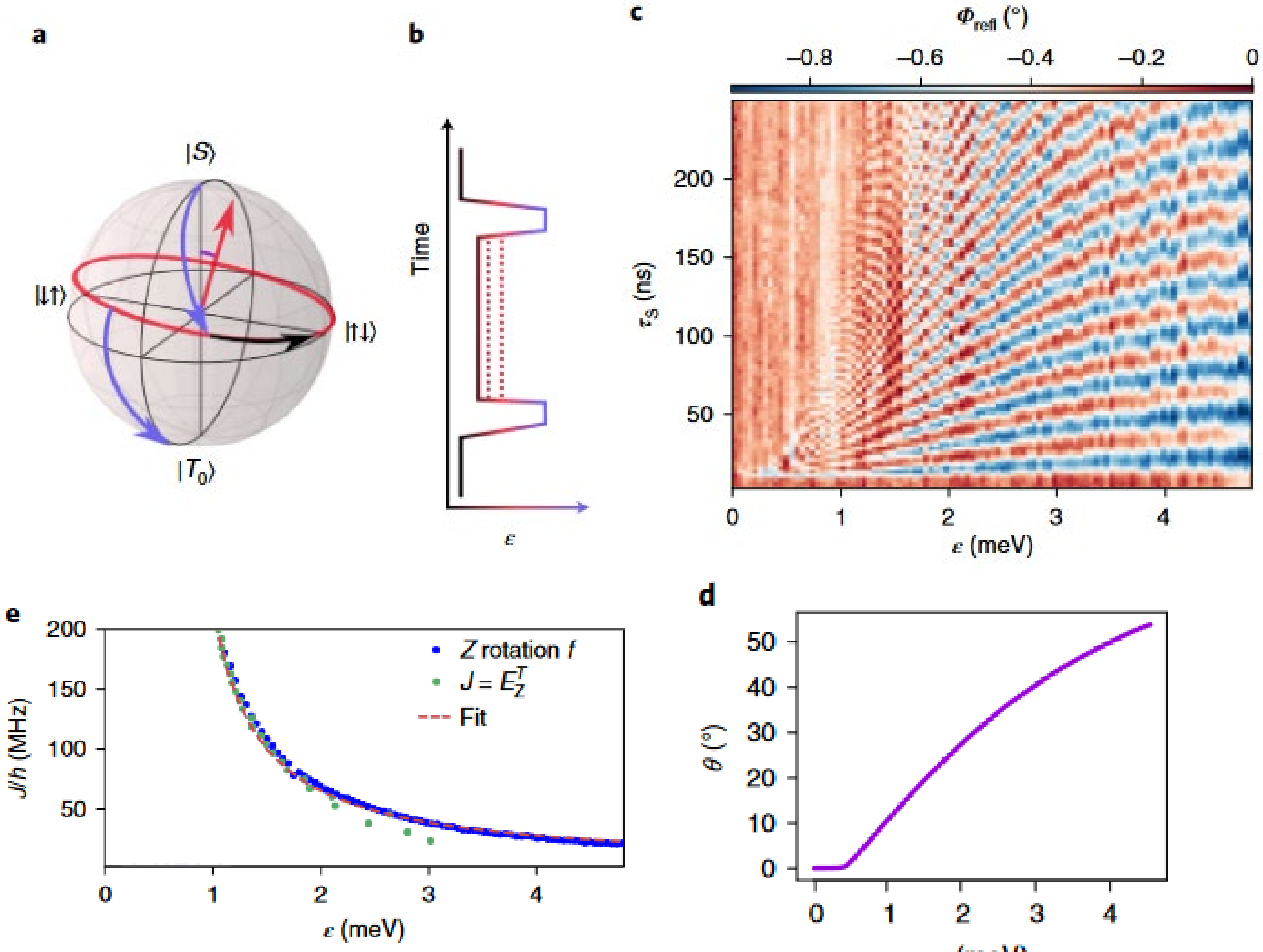
Δg tunability



$$f = \frac{1}{h}\sqrt{J^2 + (\Delta g \mu_B B)^2}$$



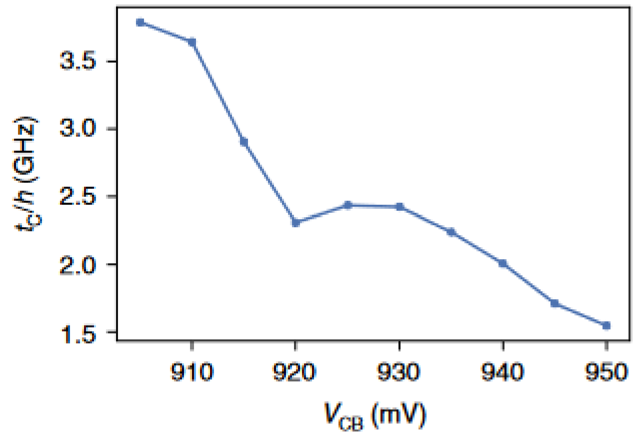
Complete X rotations and Z rotations



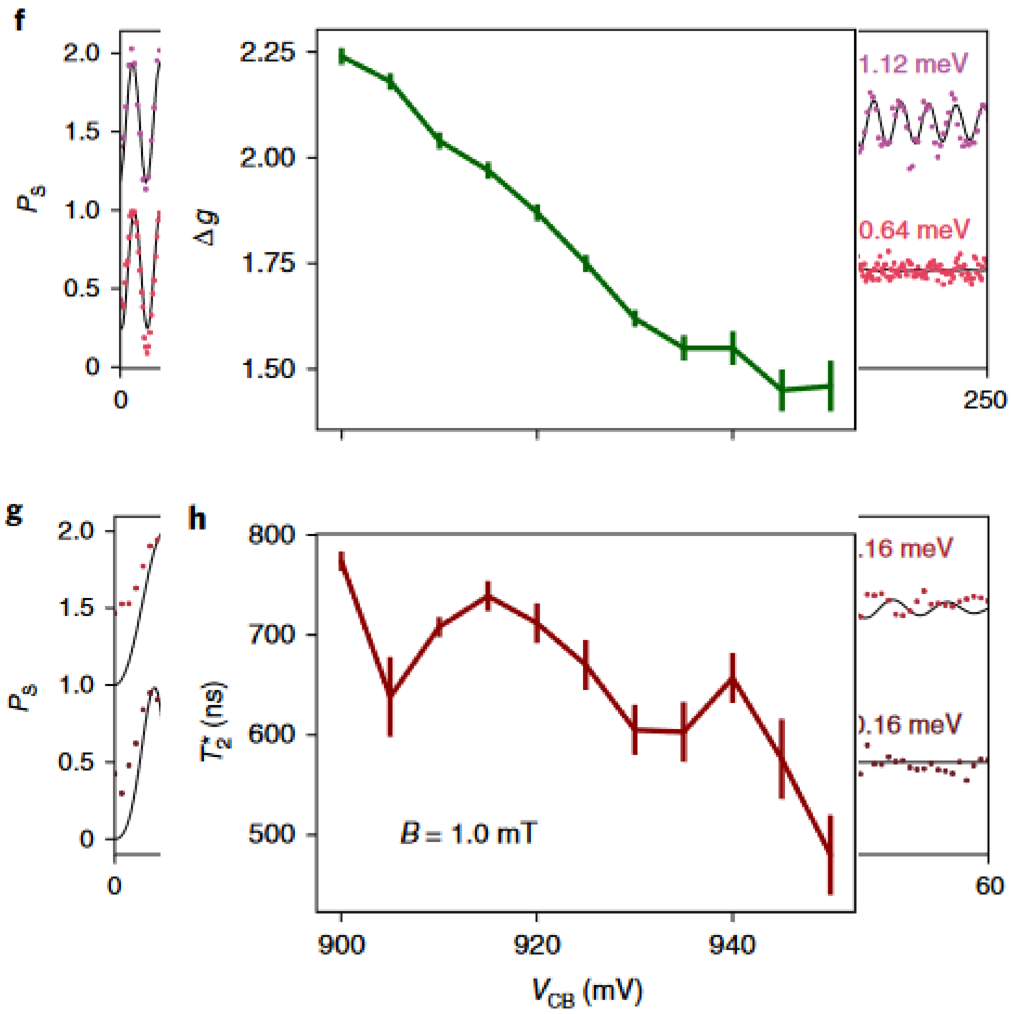
- Extract J(ε) from oscillaction frequency and compare to spin funnel measurement

$$J(\varepsilon) = \left| \frac{\varepsilon}{2} - \sqrt{\frac{\varepsilon^2}{4} + 2t_C^2} \right|$$

- Lines coincide for Σg=11.0 -> g_L = 4.5, g_R = 6.5
- Tunnel coupling t_C extracted as free fit parameter

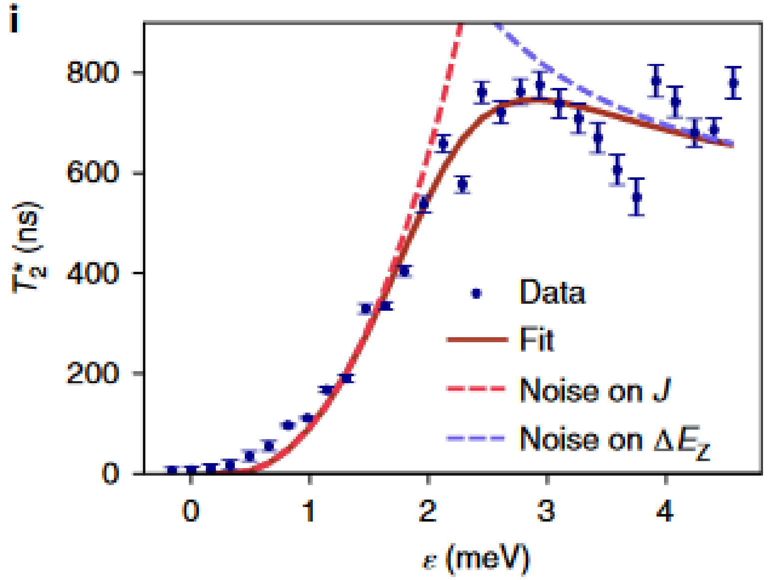


Complete X rotations and noise

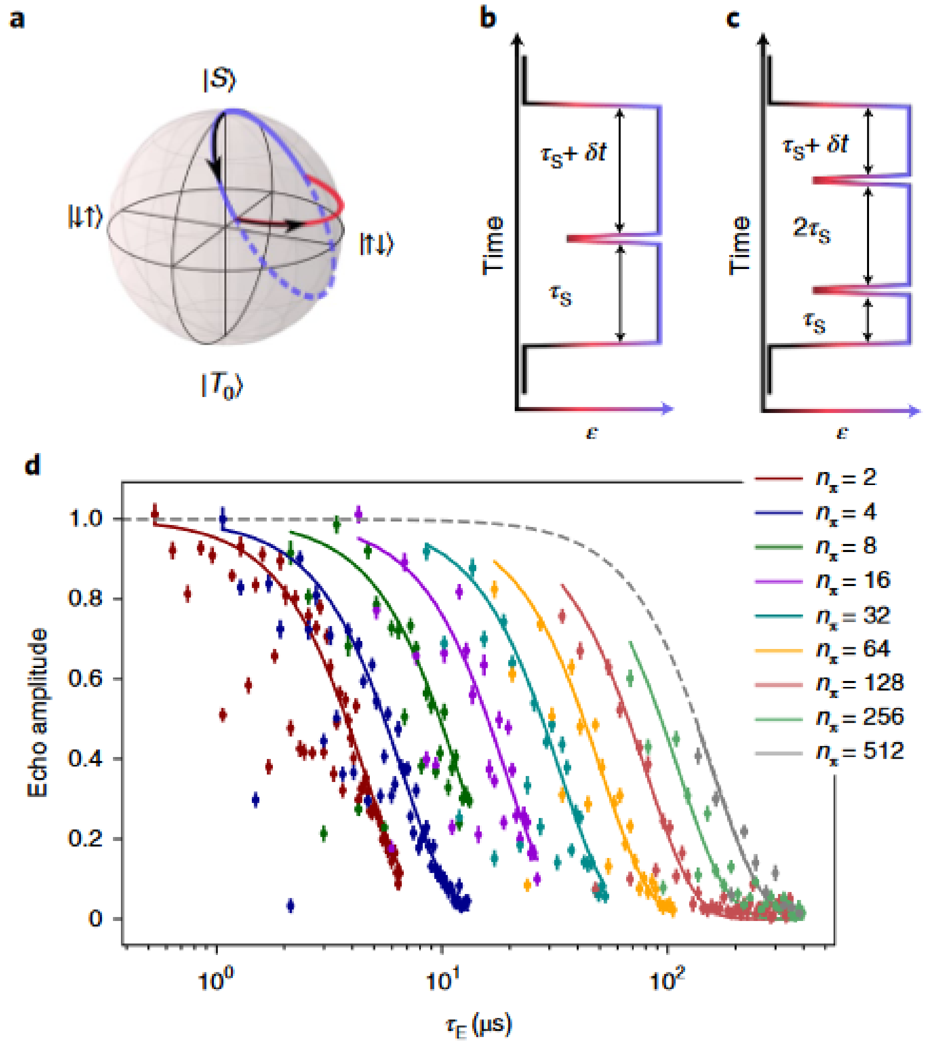


$$\frac{1}{T_2^*} = \frac{\pi\sqrt{2}}{h}\sqrt{\left(\frac{J(\varepsilon)}{E_{\text{tot}}}\frac{\mathrm{d}J}{\mathrm{d}\varepsilon}\delta\varepsilon_{\text{rms}}\right)^2 + \left(\frac{\Delta E_Z}{E_{\text{tot}}}\delta\Delta E_{Z\text{rms}}\right)^2}$$

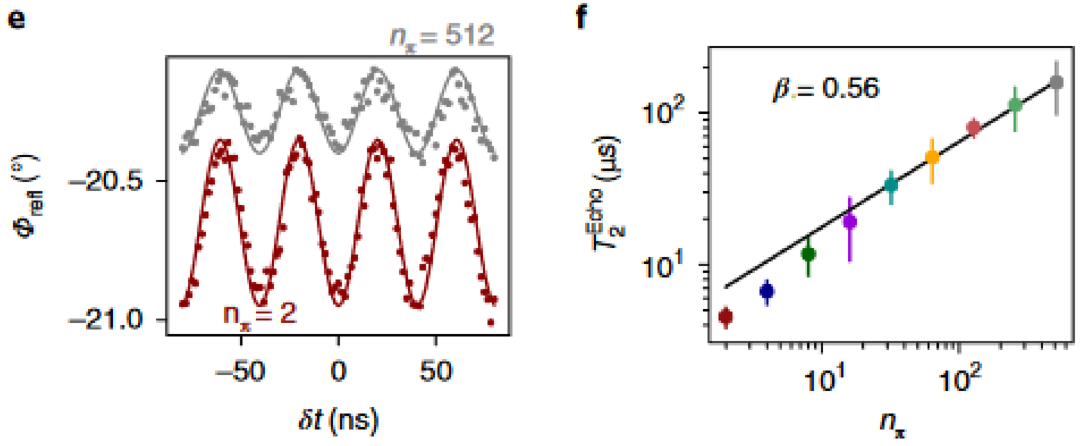
- Increase in Δg does not reduce T_2^*: increase in t_C of 2 GHz -> increase of J larger than ΔE_Z and $\Delta E_Z/E_{tot}$ is reduced



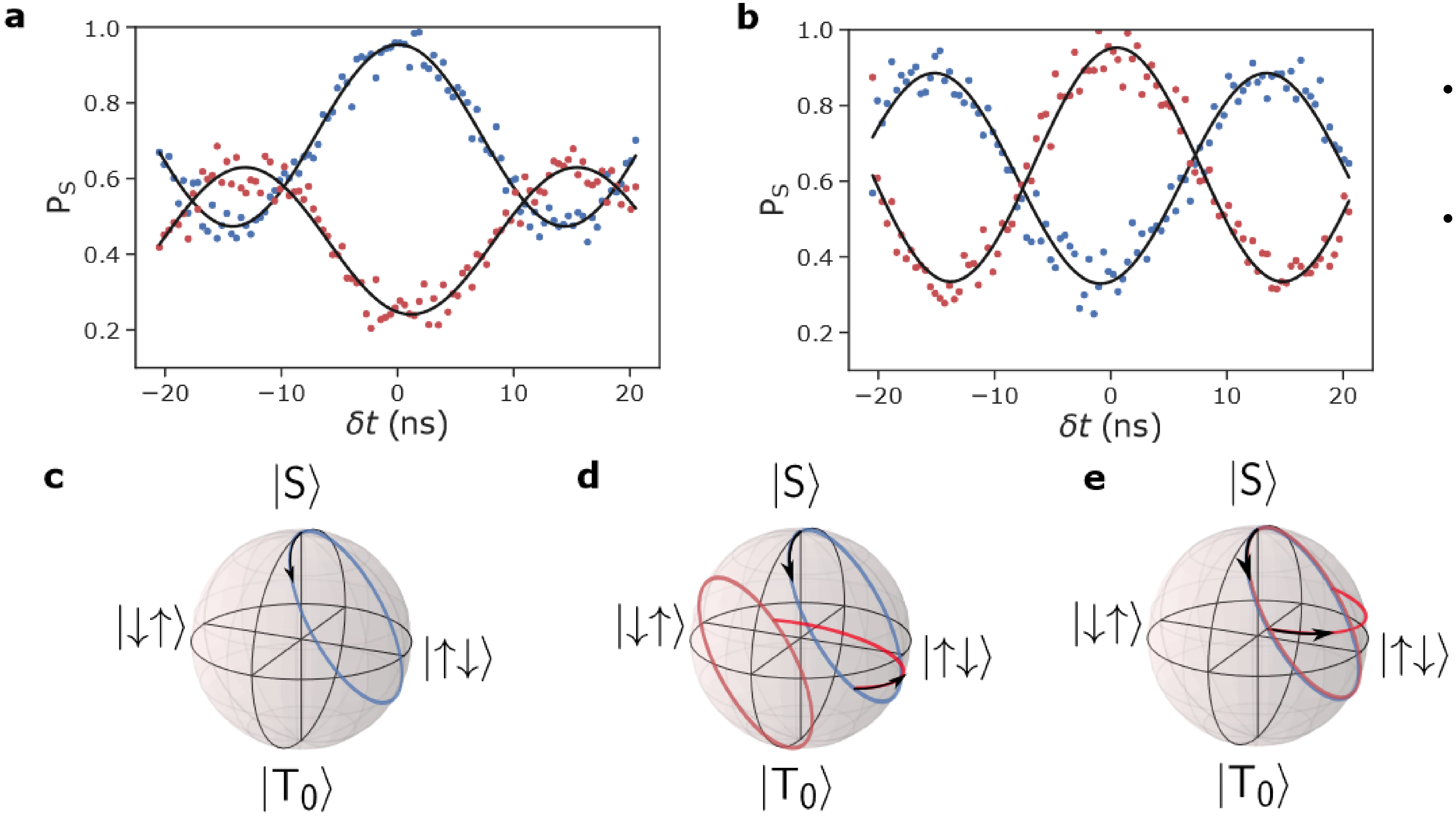
Refocusing pulses



- Choose $\tau_S = (2n+1/2)*t_{\pi,x}$ to keep the system in the same state if no decoherence has occurred
- Calibration of refocusing pulse tricky, because J and Δg are never completely off
- Refocusing pulse needs to be applied in



Calibration of refocusing pulse



- Bad calibration in **a** and **d**
- Good calibration in **b** and **e**

Summary and outlook

Summary:

- Demonstration of two-axis control
- Dephasing time of 1 μs at B=0.5 mT
- Electrically driven Δg rotations of 150 MHz at 5 mT
- Mostly low-frequency 1/f noise

Outlook:

- Move to latched or shelved readout:
  - improve visibility
  - operate at higher magnetic fields → potentially surpass fastest Rabi frequencies