Universität Augsburg
Mathematisch-Naturwissenschaftlich-Technische Fakultät

Polarimetry with spins in the solid state

University of Augsburg

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Group: Quantum computing and devices (QCoDe)

Emmy Noether-Programm DFG Deutsche Forschungsgemeinschaft

Floquet
spin qubits

Funded by the European Union

EU Horizon Pathfinder (QuKit)

ConQuMat-TRR360

QuantERA
(GeMOS)

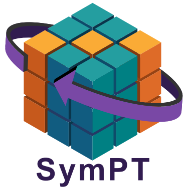
DFG Deutsche Forschungsgemeinschaft

Group‘s research

Fundamental aspects of quantum systems → Modeling quantum devices

- Light-matter interaction: from the semiclassical to the quantum regime
  - Floquet hole spin qubits
  - Cavity-based control of quantum magnets

- Universal solution to the Schrieffer-Wolff generator

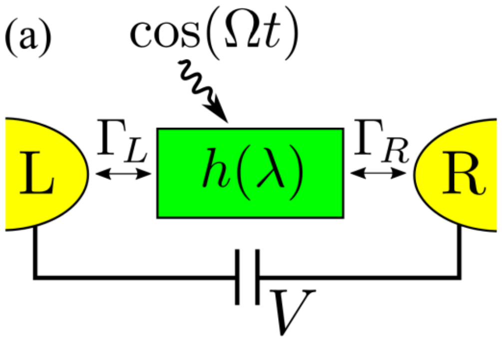


Reascos, Diotallevi, and **MB**, arXiv:2411.11535
Diotallevi, Reascos and MB, arXiv:2412.10240

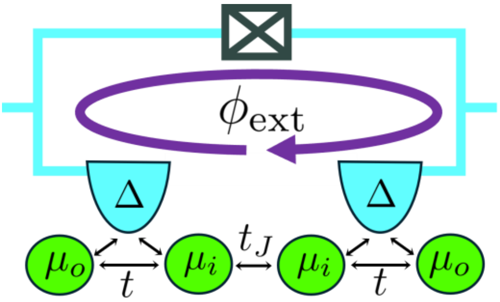
- Linear-response theory of quantum electronic circuits

Peri, **MB**, *et al.*, npj Quantum Inf 10, 114 (2024)

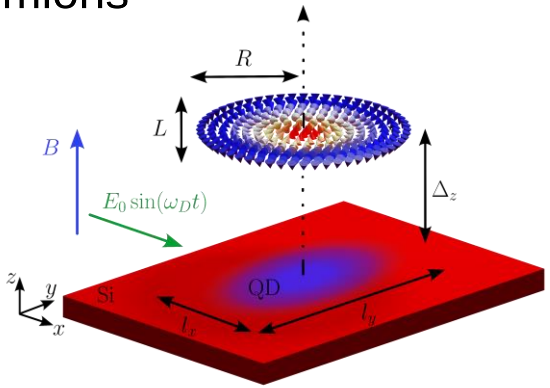
- Transport and topology in quantum devices



- Hybrid super-semiconductor qubits



- Control of Si qubits by magnetic skyrmions



- Rydberg-spin qubits on He and Ne

Kawakami, **MB**, *et al.*, Phys. Rev. Appl. **20**, 054022 (2023).

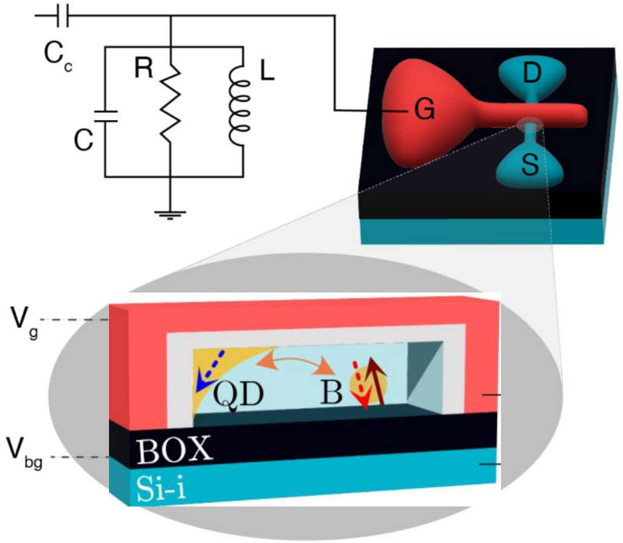
- Electrical readout of spins

Peri, **MB**, *et al.*, Nano Lett. **25**, 9181 (2025).

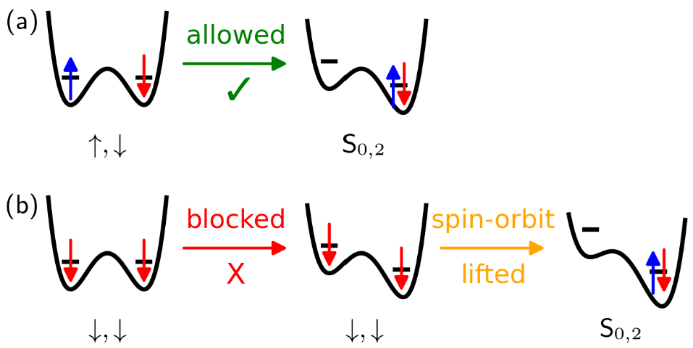
von Horstig, **MB**, et al., arXiv:2403.12888.

Polarimetry with spins in the solid state

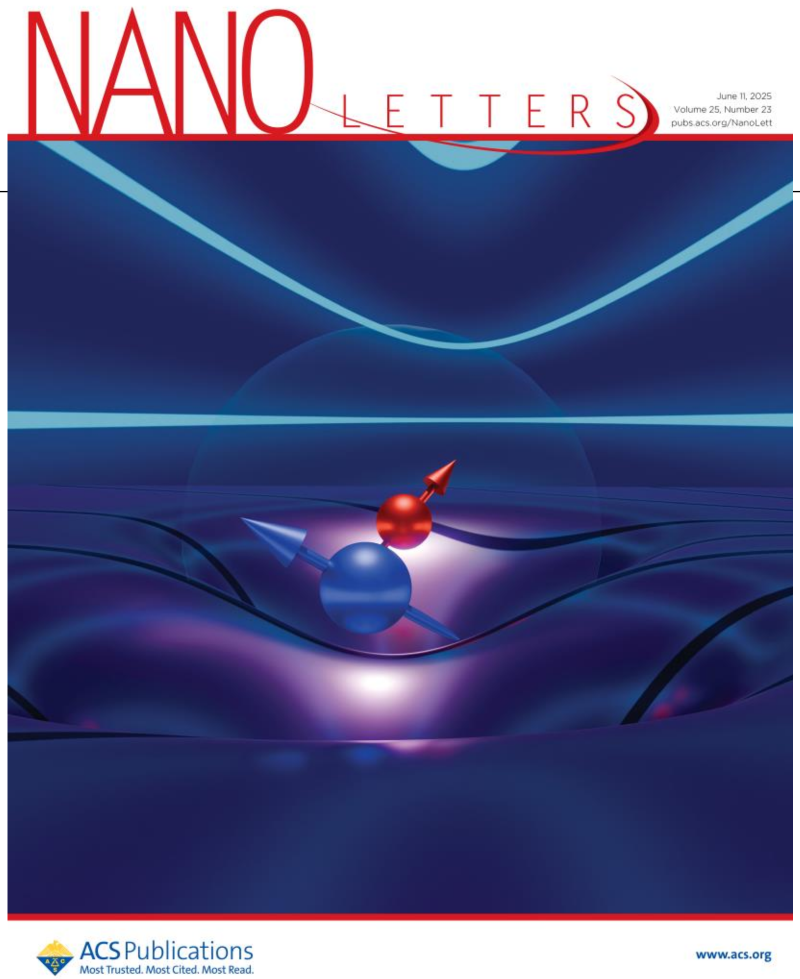
- Hole QD-acceptor in Si NW transistor



- Magic magnetic field directions and Pauli spin blockade (PSB)



von Horstig, **MB**, et al., arXiv:2403.12888



Peri, **MB**, *et al.*, Nano Lett. **25**, 9181 (2025).

- Analogy to light polarimetry

- Electrical spin readout fidelity

F. Gonzalez-Zalba

F. von Horstig

L. Peri

QUANTUM MOTION

Spin-orbit (SO)-coupled double quantum dots (DQDs)

SO coupling effects:

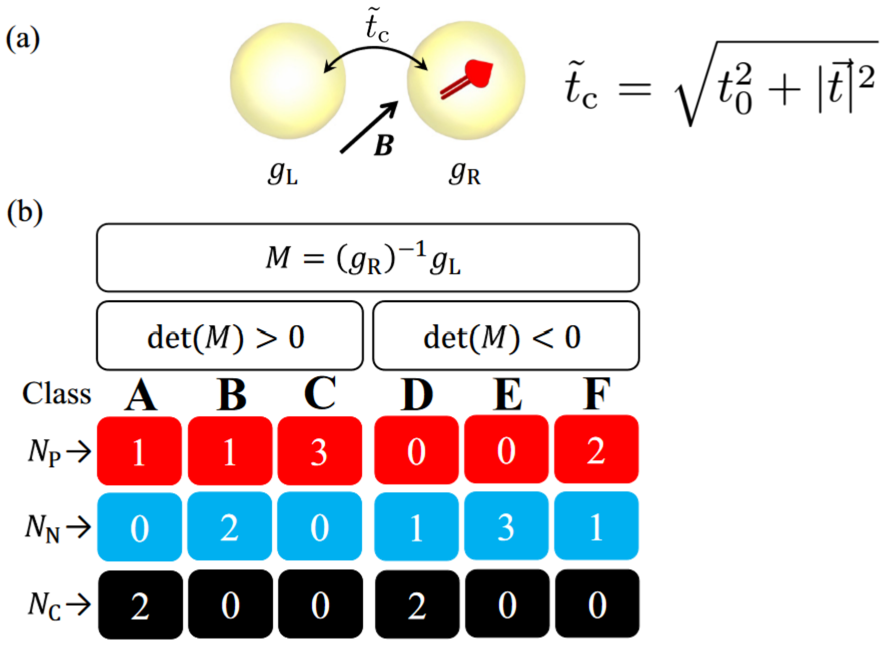
- Different g-tensors

$$H_Z = \frac{1}{2}\mu_B(\boldsymbol{\sigma}_L \cdot g_L \boldsymbol{B} + \boldsymbol{\sigma}_R \cdot g_R \boldsymbol{B})$$

$$H_t = t_0 \tau_x + \vec{t} \cdot \vec{\sigma}\, \tau_y$$

- Spin-conserving + spin-flip tunneling

$$\theta_t/2 = \arctan\left(|\vec{t}|/t_0\right) \qquad W = \exp\left(\frac{\theta_t}{2i}\frac{\vec{t}}{|\vec{t}|} \cdot \vec{\sigma}\right)$$



Sen *et al.*, PRB, **108**, 245406 (2023).

- In the gauge of pseudospin-conserving tunneling:

$$H = \frac{\epsilon}{2}\tau_z + \tilde{t}_c \tau_x + \frac{1}{2}\mu_B(\tilde{\boldsymbol{\sigma}}_L \cdot \tilde{g}_L \boldsymbol{B} + \tilde{\boldsymbol{\sigma}}_R \cdot \tilde{g}_R \boldsymbol{B})$$

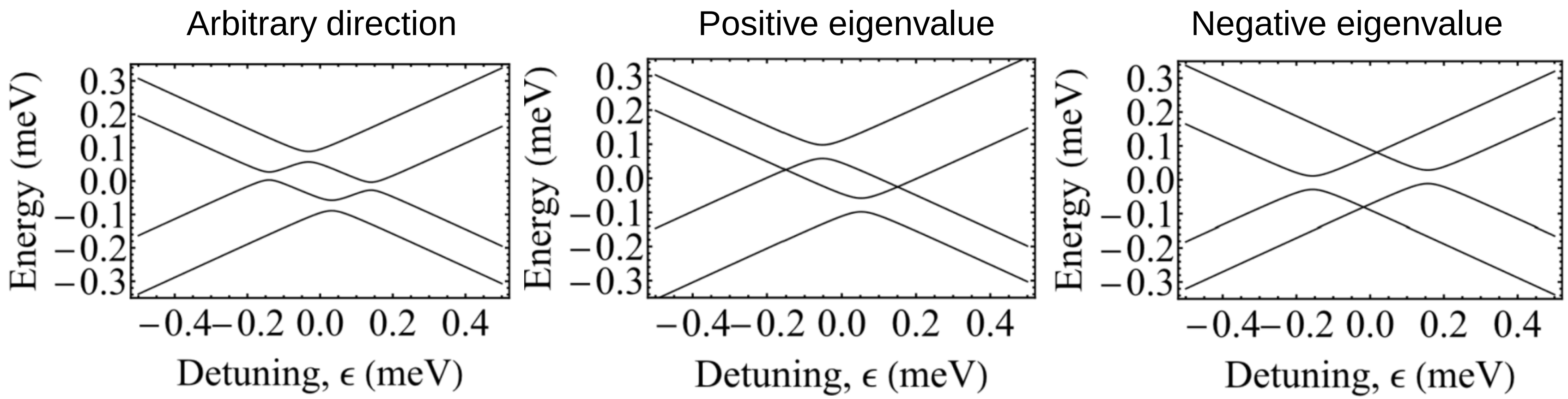
$$\tilde{g}_L = g_L \qquad \tilde{g}_R = R g_R$$

- Parallel internal Zeeman fields and PSB:

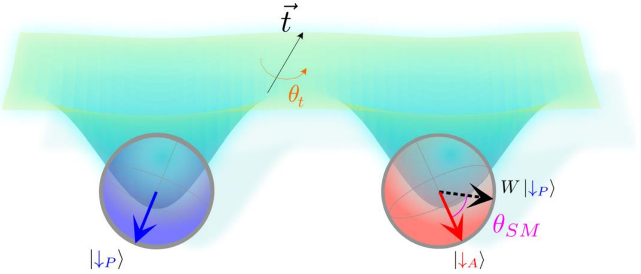
$$\tilde{g}_L \boldsymbol{B} \parallel \tilde{g}_R \boldsymbol{B} \longrightarrow M\boldsymbol{B} = \lambda \boldsymbol{B}$$

- Categorised in 6 classes

SO-coupled DQDs: odd transition ((1,0) ↔ (0,1))



Sen *et al.*, PRB, **108**, 245406 (2023).



$$H = \frac{\epsilon}{2}\tau_z + \tilde{t}_c \tau_x + \frac{1}{2}\mu_B(\tilde{\boldsymbol{\sigma}}_L \cdot \tilde{g}_L \boldsymbol{B} + \tilde{\boldsymbol{\sigma}}_R \cdot \tilde{g}_R \boldsymbol{B})$$

- In the gauge of local internal Zeeman fields: $H_Z = \frac{1}{2}\mu_B\left(\left|g_P\vec{B}\right|\sigma_z^P + \left|g_A\vec{B}\right|\sigma_z^A\right)$

$$H_t^{\mathrm{odd}} = \tilde{t}_c\big(Q\,|{\downarrow_P}\rangle\langle{\downarrow_A}| + Q^*\,|{\uparrow_P}\rangle\langle{\uparrow_A}| + \Lambda\,|{\downarrow_P}\rangle\langle{\uparrow_A}| - \Lambda^*\,|{\uparrow_P}\rangle\langle{\downarrow_A}|\big) + h.c.$$

$$|Q| = |\langle{\downarrow_A}|W|{\downarrow_P}\rangle| = \cos\frac{\theta_{\mathrm{SM}}}{2}$$

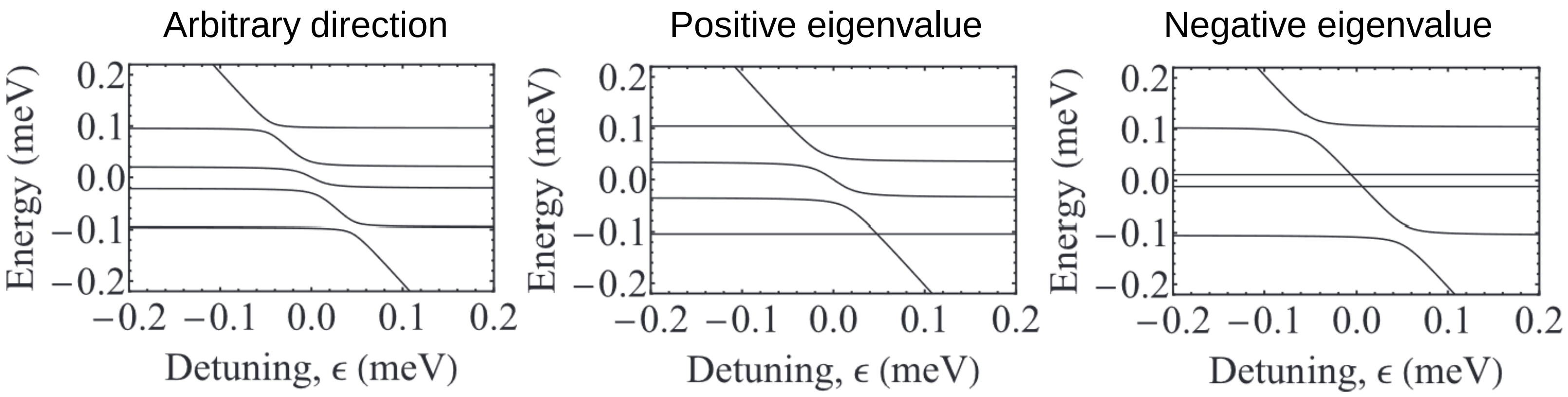
$$|\Lambda| = |\langle{\uparrow_A}|W|{\downarrow_P}\rangle| = \sin\frac{\theta_{\mathrm{SM}}}{2}$$

Spin misalignment

$$\cos\theta_{\mathrm{SM}} = \frac{\left(\mathbf{R}\mathbf{g}_P\vec{B}\right)\cdot\left(\mathbf{g}_A\vec{B}\right)}{|\mathbf{g}_P\vec{B}||\mathbf{g}_A\vec{B}|}$$

Peri, **MB**, *et al.*, Nano Lett. **25**, 9181 (2025).

SO-coupled DQDs: even transition ((1,1) ↔ (0,2))

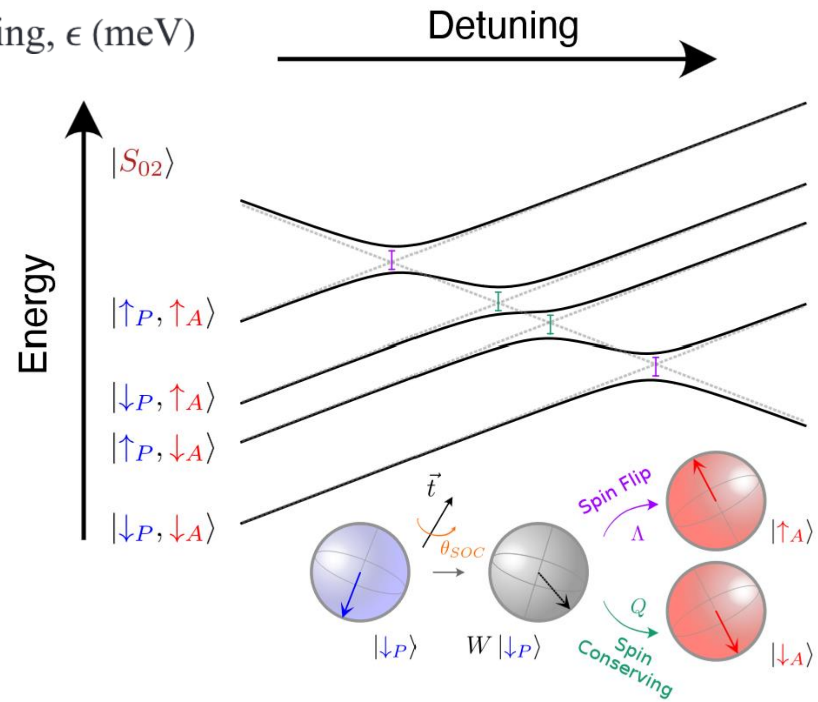


Sen *et al.*, PRB, **108**, 245406 (2023).

$$H^{(2)} = \tfrac{1}{2}\mu_B(\tilde{\boldsymbol{\sigma}}_\mathrm{L} \cdot \tilde{g}_\mathrm{L}\boldsymbol{B} + \tilde{\boldsymbol{\sigma}}_\mathrm{R} \cdot \tilde{g}_\mathrm{R}\boldsymbol{B}) + \sqrt{2}\,\tilde{t}_\mathrm{c}|\mathcal{S}\rangle\langle\mathcal{S}_{02}| + \mathrm{H.c.}] - \epsilon|\mathcal{S}_{02}\rangle\langle\mathcal{S}_{02}|$$

- In the gauge of local internal Zeeman fields:

$$H_\mathrm{t}^\mathrm{even} = \frac{\tilde{t}_\mathrm{c}}{\sqrt{2}}\Big(Q\,|{\downarrow_\mathrm{P}},{\uparrow_\mathrm{A}}\rangle\,\langle S_{02}| - Q^*\,|{\uparrow_\mathrm{P}},{\downarrow_\mathrm{A}}\rangle\,\langle S_{02}| + \Lambda\,|{\downarrow_\mathrm{P}},{\downarrow_\mathrm{A}}\rangle\,\langle S_{02}| + \Lambda^*\,|{\uparrow_\mathrm{P}},{\uparrow_\mathrm{A}}\rangle\,\langle S_{02}|\Big) + h.c.$$



Peri, **MB**, *et al.*, Nano Lett. **25**, 9181 (2025).

Polarimetry: light versus spins

Tunneling under SO coupling as an active medium

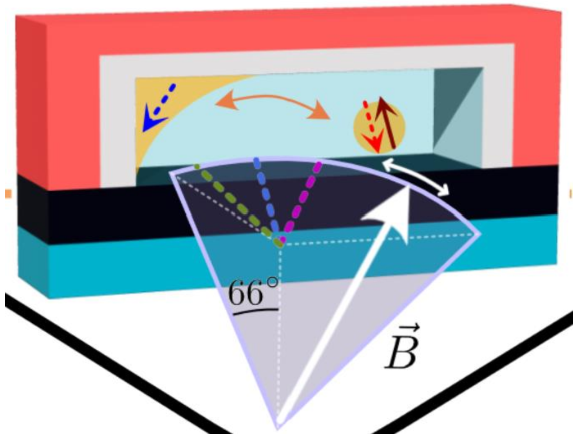
Polarimetry with light:

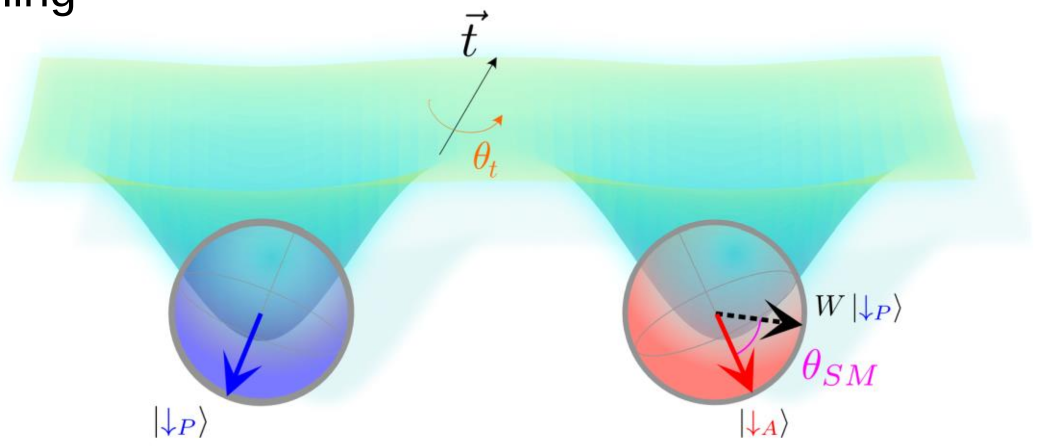
- Optical transmission measured as a function of polarizer angle
- Polarization misalignment between A and the image of P after rotation by the medium
- Perfect transmission for one specific angle

Polarimetry with spins:

- Tunneling measured as a function of magnetic field angle (3D)
- Spin misalignment between A and the image of P after tunneling
- =0 Pauli spin blockade (PSB) at magic angles

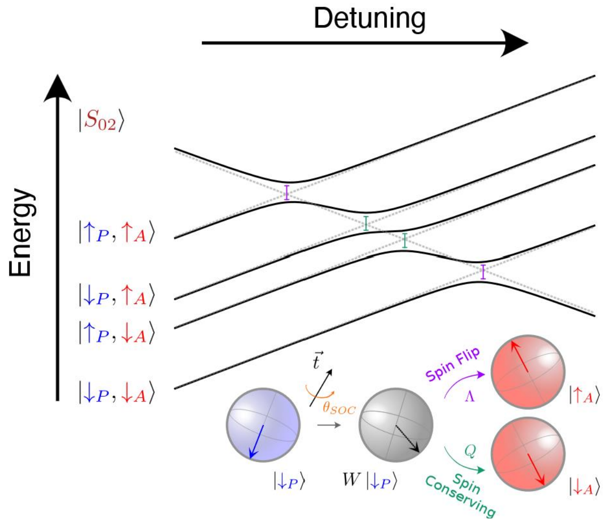
Hole QD-acceptor in
Si nanowire transistor





Peri, **MB**, *et al.*, Nano Lett. **25**, 9181 (2025).

Polarimetry: measuring spin misalignment



Effective Hamiltonian $|\downarrow_P, \downarrow_A\rangle \leftrightarrow |S_{02}\rangle$

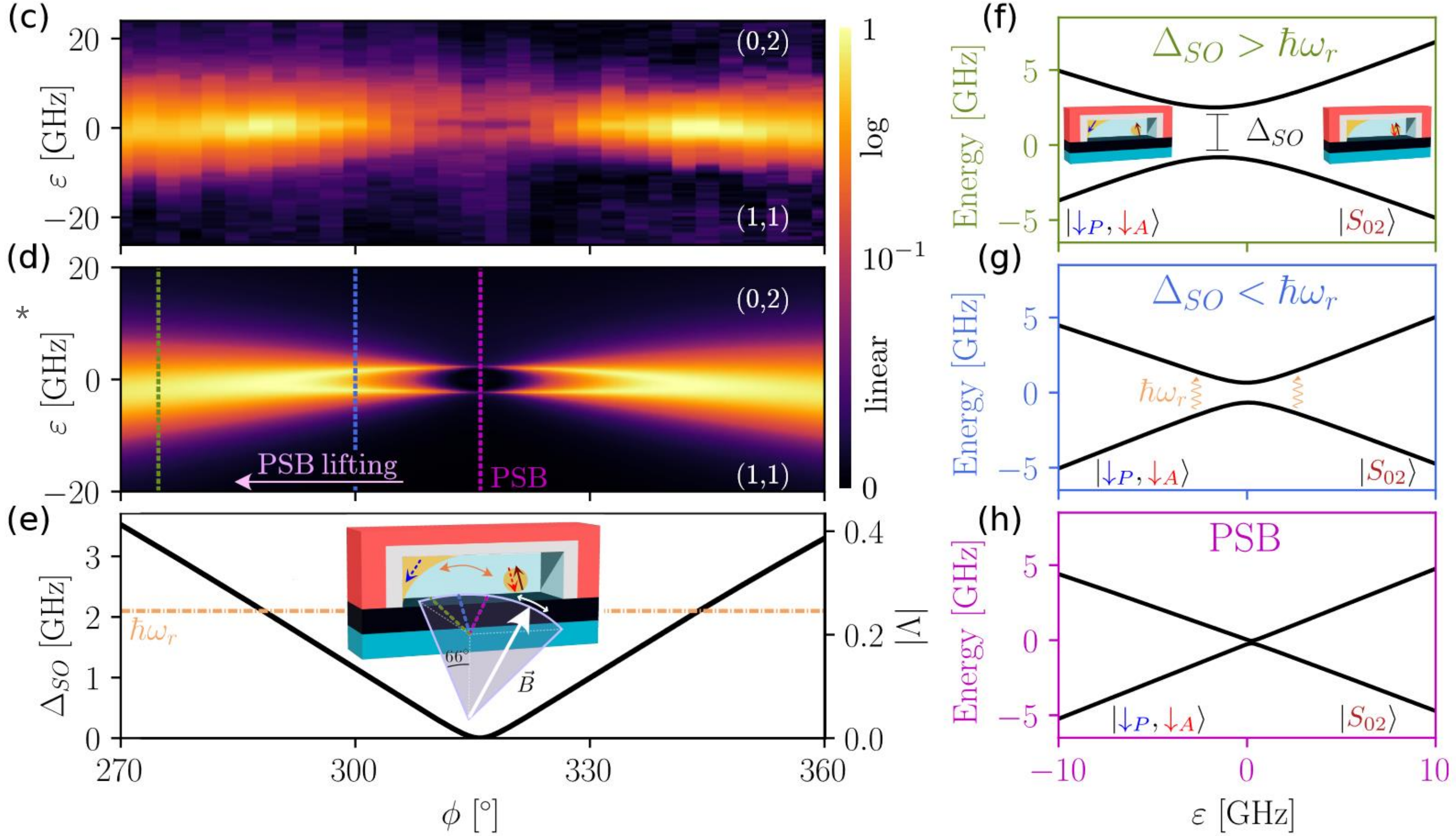
Δ_{SO}

$$H = \frac{1}{2}\begin{bmatrix} \varepsilon - \mu_B\left(|\mathbf{g}_P\vec{B}| + |\mathbf{g}_A\vec{B}|\right) & \sqrt{2}\Lambda\tilde{t}_c \\ \sqrt{2}\Lambda^*\tilde{t}_c & -\varepsilon \end{bmatrix}$$

$$\tilde{t}_c = \sqrt{t_0^2 + |\vec{t}|^2}$$

$$|\Lambda| = |\langle\uparrow_A|W|\downarrow_P\rangle| = \sin\frac{\theta_{SM}}{2}$$

Dispersive sensing ($\omega_r/2\pi = 2.1$ GHz)



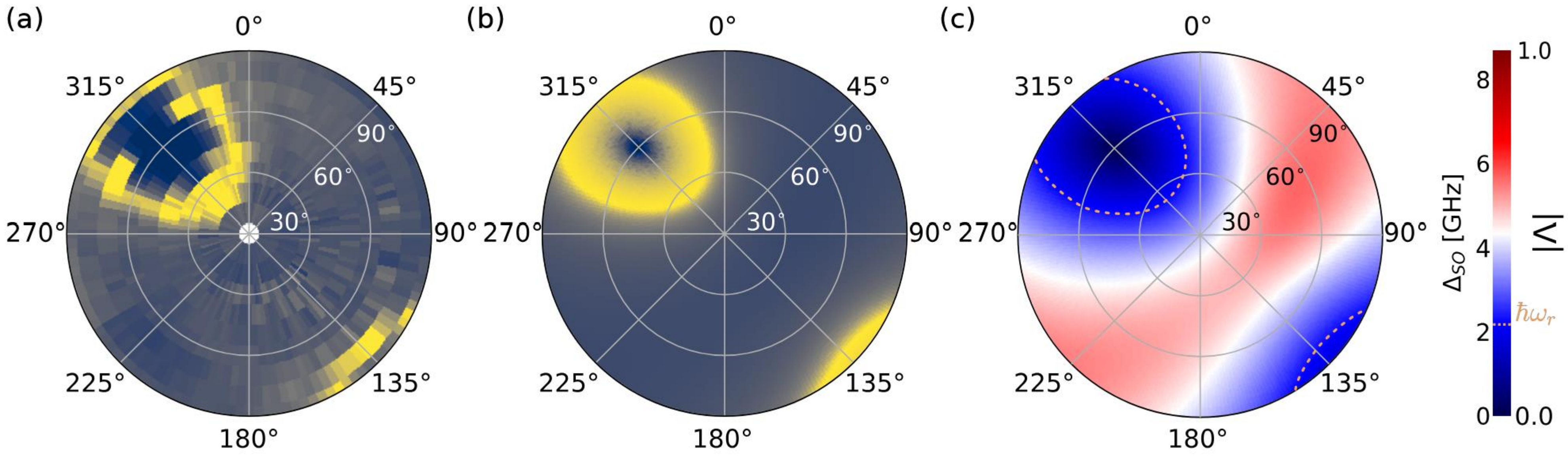
Peri, **MB**, *et al.*, Nano Lett. **25**, 9181 (2025).

* Fit uses the theory in: Peri, **MB**, *et al.*, npj Quantum Inf 10, 114 (2024)

Polarimetry: looking for PSB

PSB halo to find PSB

Dispersive sensing ($\omega_r/2\pi = 2.1$ GHz) Fit



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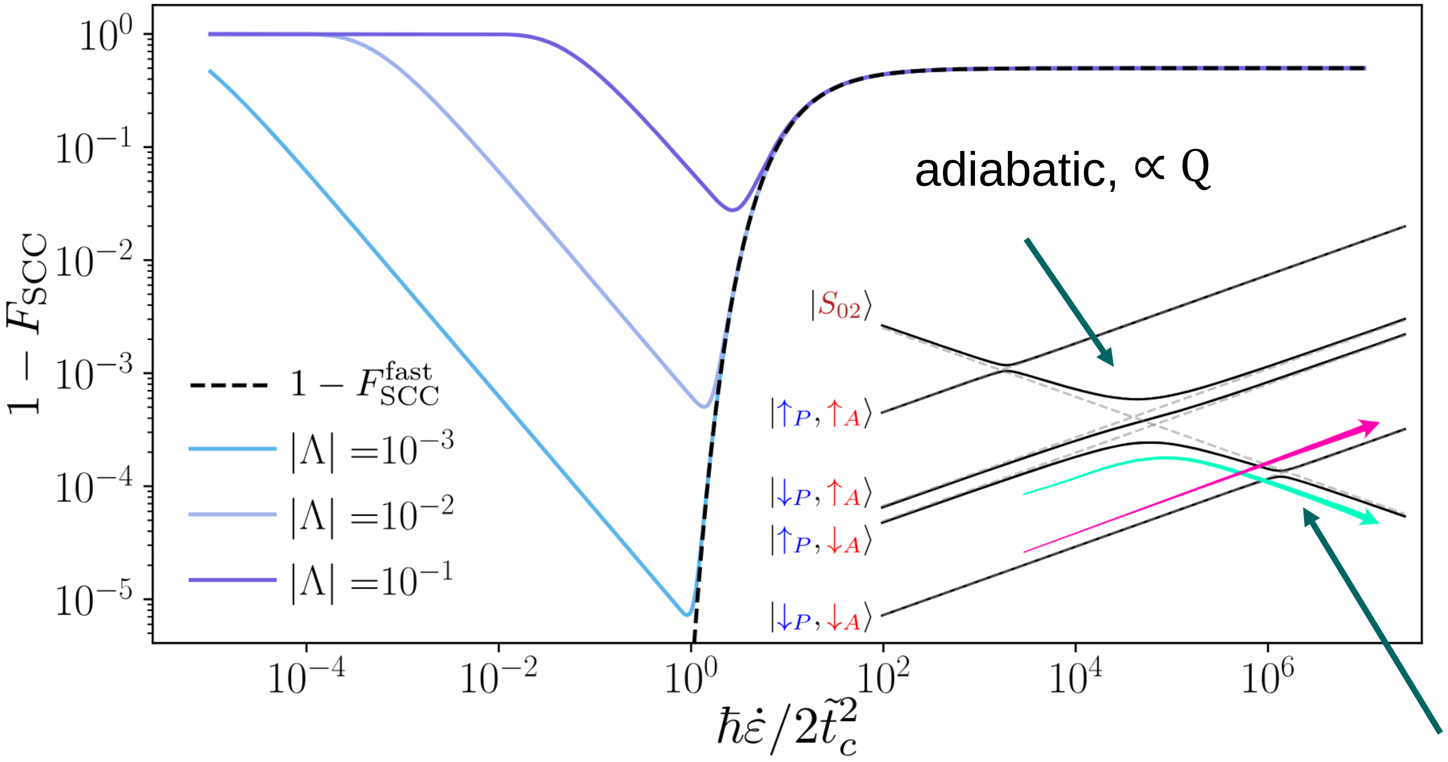
* Fit uses the theory in: Peri, **MB**, *et al.*, npj Quantum Inf 10, 114 (2024)

Electrical readout: fast VS slow



adiabatic, $\propto$ Q

$$\max\left(F_{\mathrm{SCC}}\right) = \frac{1}{1+\zeta/2}\left(\frac{\zeta}{1+\zeta/2}\right)^{\frac{\zeta}{2}}$$

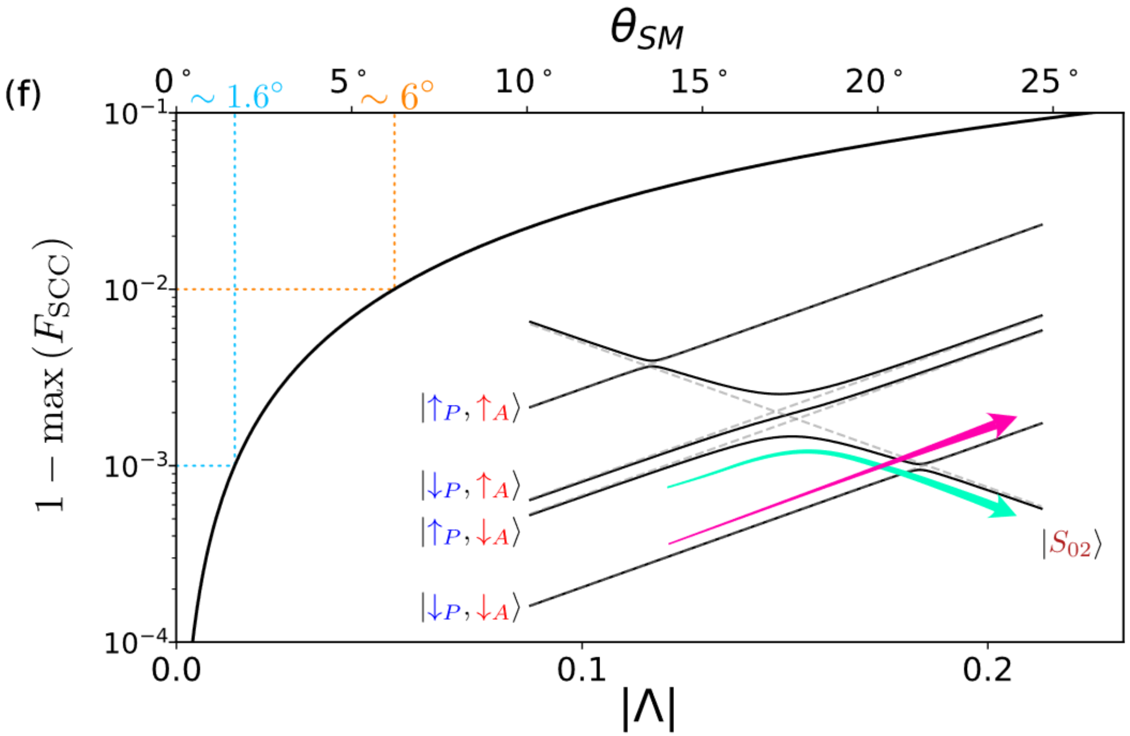
$$\zeta = |\Lambda|^2/|Q|^2 = \tan^2(\theta_{\mathrm{SM}}/2)$$

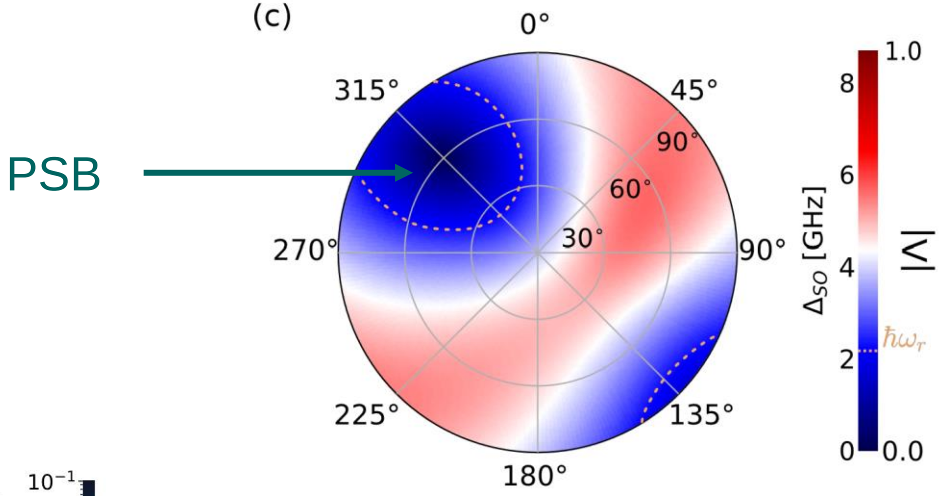
diabatic, $\Delta_{so} \propto \Lambda$

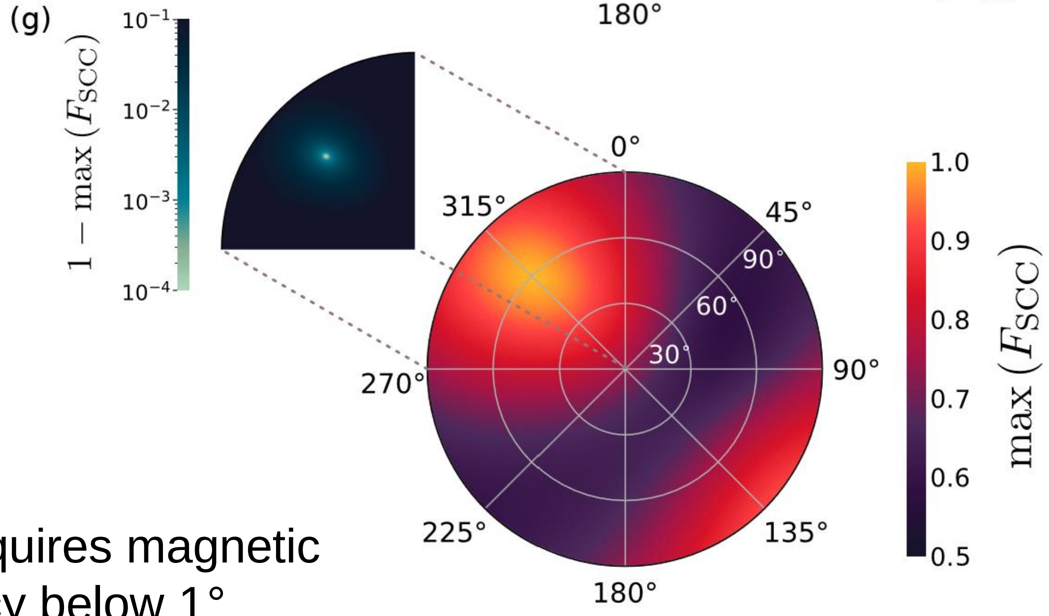
Peri, **MB**, *et al.*, Nano Lett. **25**, 9181 (2025).

Electrical readout: fidelity

$$1 - \max\left(F_{\mathrm{SCC}}\right) \approx |\Lambda|^2 \left(\frac{1}{2} - \log|\Lambda|\right)$$







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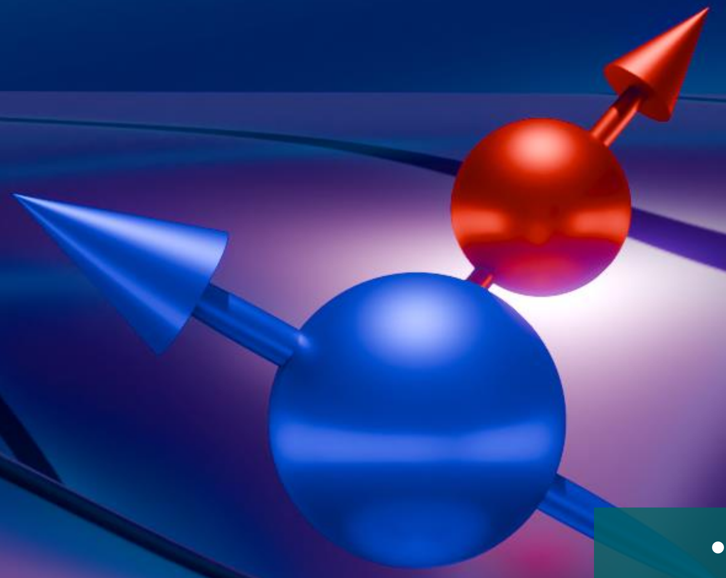
F>99.9% requires magnetic field accuracy below 1°

Polarimetry with spins in the solid state



- Spin misalignment angle is a better parameter to describe SO in QDs
- SO-coupled DQDs are the natural extension of polarimetry to the third dimension
- Electrical readout fidelity is limited under SO coupling