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Variable and Orbital-Dependent Spin-Orbit Field Orientations in an InSb Double Quantum Dot Characterized via Dispersive Gate Sensing

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Introduction

- Spin-orbit interaction (SOI) - coupling between spin and momentum of a charge moving in an electromagnetic field
  - positive: electric dipole spin resonance (EDSR), spin-cavity coupling
  - negative: relaxation, decoherence
- SOI can be described by the spin-orbit field $\mathbf{B}_{so}$
- Rashba SPI: $\mathbf{B}_{SO} \propto \mathbf{E} \times \mathbf{p}$, **E** - electric field, **p** – momentum, **E** from gates assumed to be perpendicular to the surface
- $\mathbf{B}_{so}$ perp to $\mathbf{B}_{ext}$ – precondition to open topological gap
- Extract $\mathbf{B}_{so}$ direction
  - from spin blockade leakage current
  - using dispersive gate sensing (DGS)

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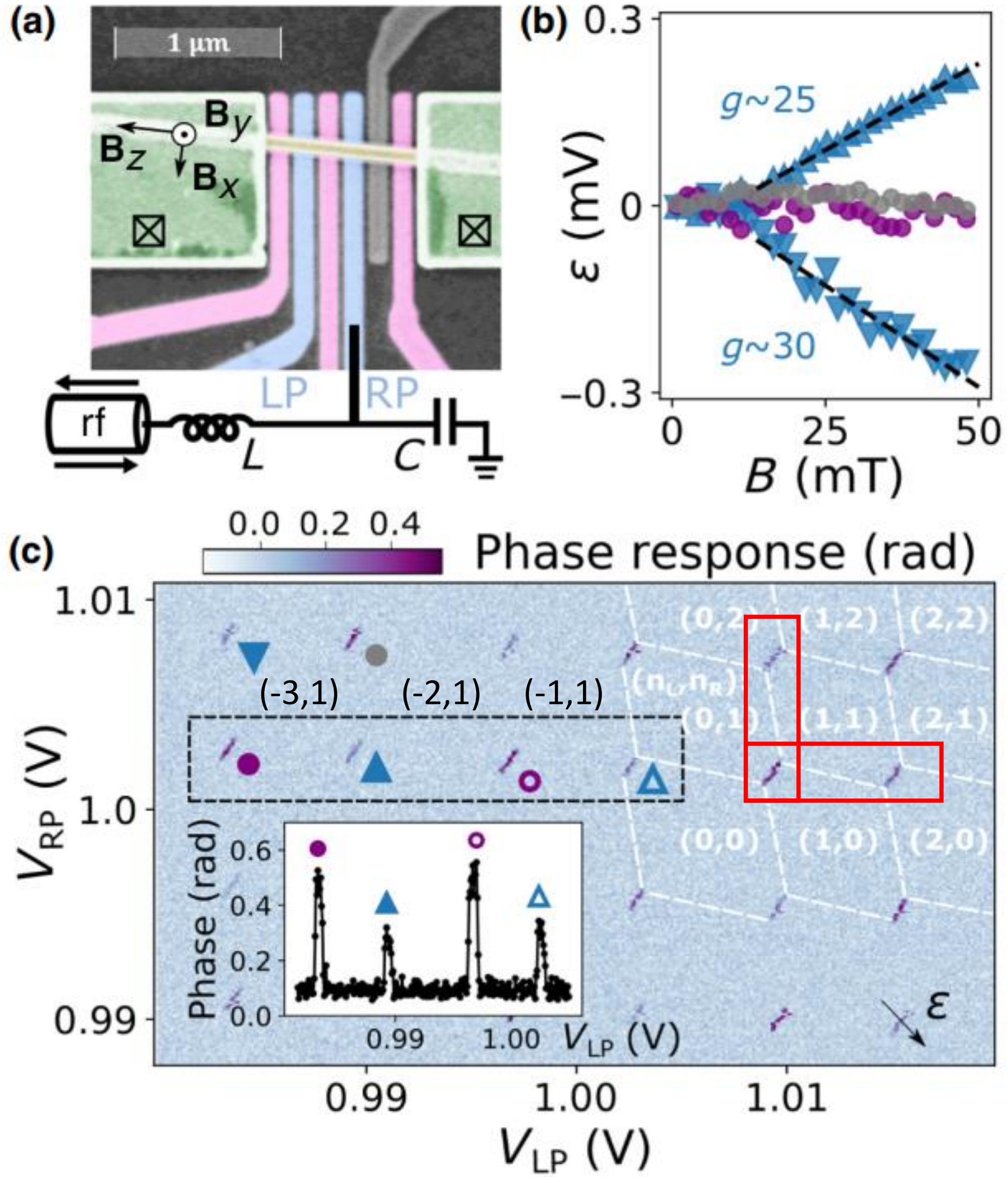
Outline

- InSb many-electron double dot
- dispersive gate sensing
- + magnetic field
  amplitude, orientation
- extract orientation of $\mathbf{B}_{so}$
- $\mathbf{B}_{so}$ orientation for different dot occupation

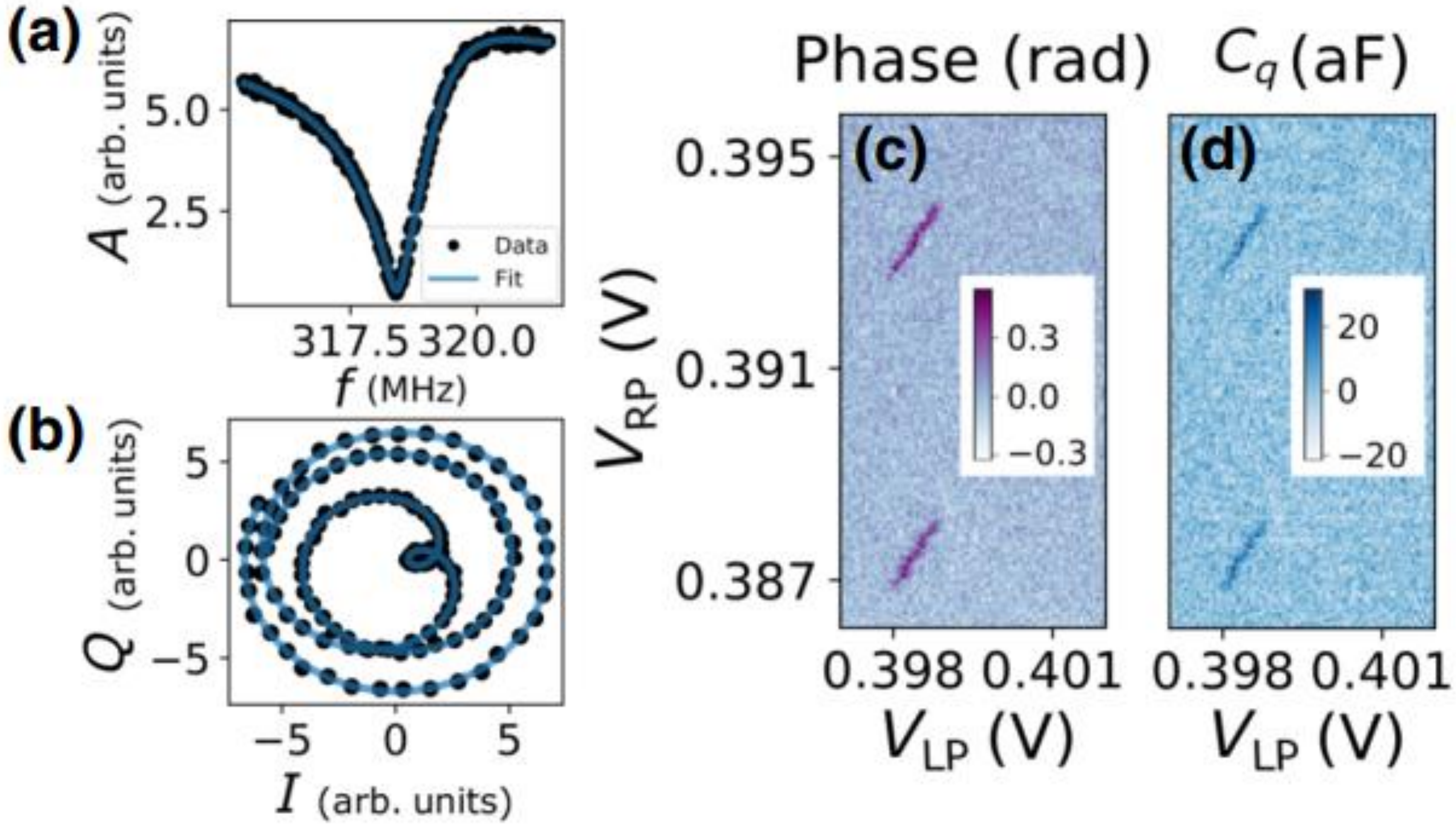
Device



- InSb nanowire, [111] direction, Rashba SOI
- Off-chip superconducting inductor
  $L = 730$ nH, $f_0 = 318.4$ MHz
- T = 30 mK
- 70-150 electrons in each dot

- Hybridization of electrons – quantum capacitance C_q – shift if f_0
- No leads transitions – closed barriers
- Spacing in V_{LP}/V_{RP} left/right dots
  - Small spacing - charging energy – odd number of electrons
  - Large spacing - level spacing + charging energy – even number of electrons
- Total number of electrons odd – large phase shift
  spin degeneracy in even state – reduction of C_q
- Total number of electrons even – interdot shift in B

Quantum Capacitance

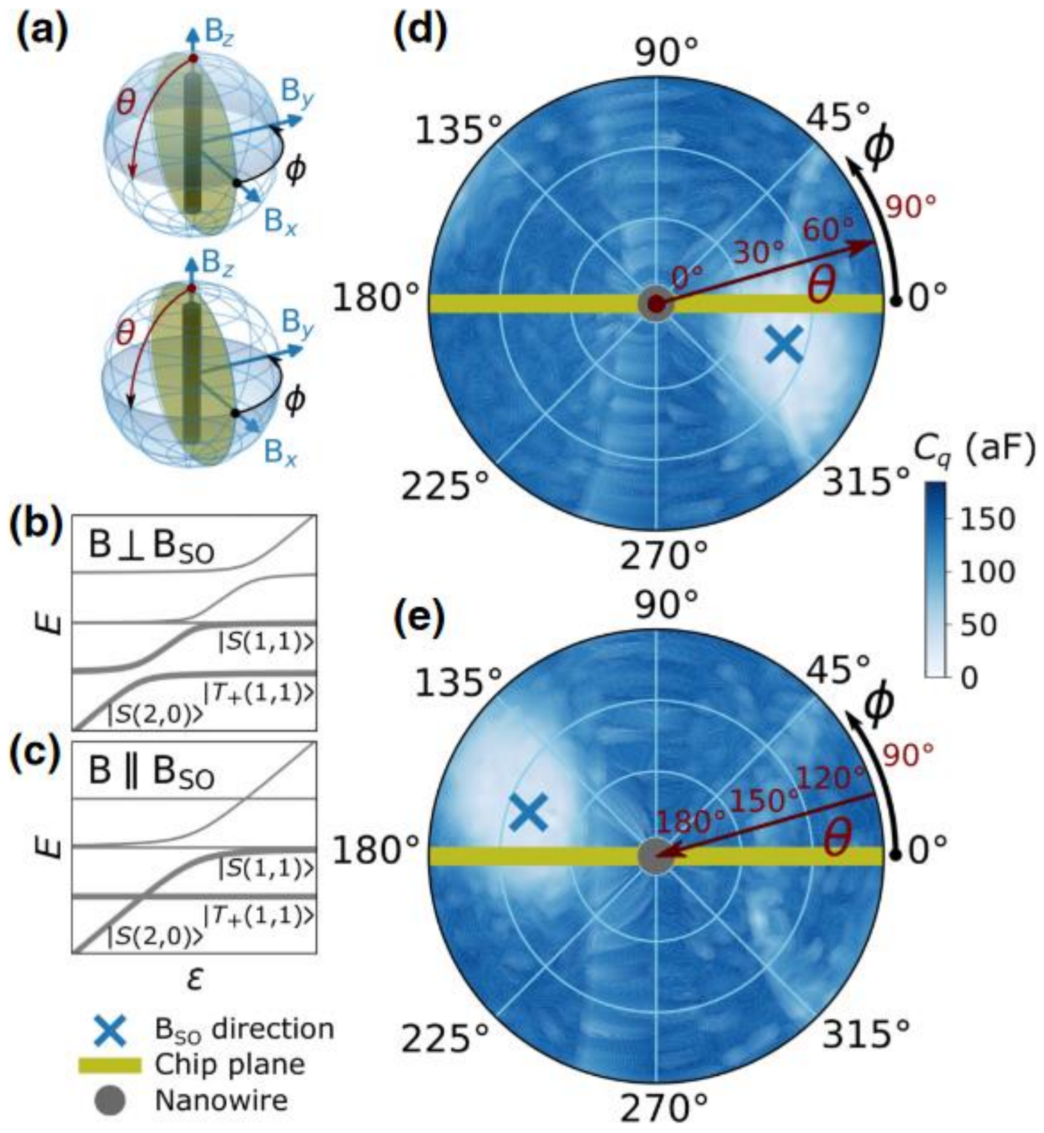


- C_q – quantum capacitance
- C – measured capacitance
- C_{cb} – capacitance at Coulomb blockade
- f_{cb} – resonance frequency at Coulomb blockade
- Δf – resonance frequency shift
- $Q_{i/e}$ – internal/external quality factor
- $Q = 1/(1/Q_i + 1/Q_e)$
- reference data – extract all the resonator parameters

$$C_q = C - C_{cb} = \frac{1}{(2\pi)^2(f_{cb} + \Delta f)^2 L} - \frac{1}{(2\pi)^2 f_{cb}^2 L}.$$

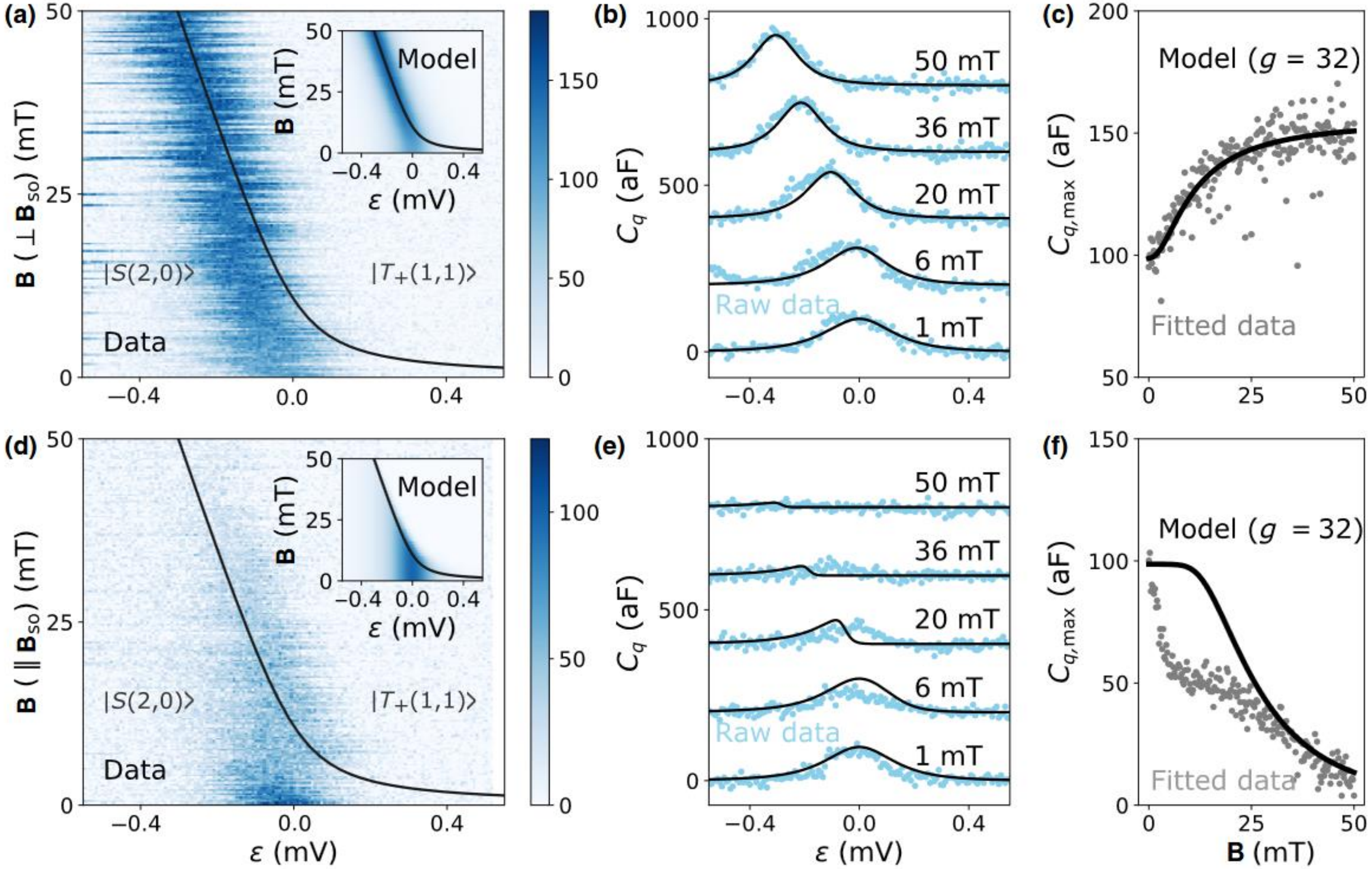
$$S_{11} = 1 - \frac{2e^{i\Phi}\frac{Q}{Q_e}}{1 + 2iQ\frac{f_p - f_0}{f_0}}$$

Spin-Orbit field orientation



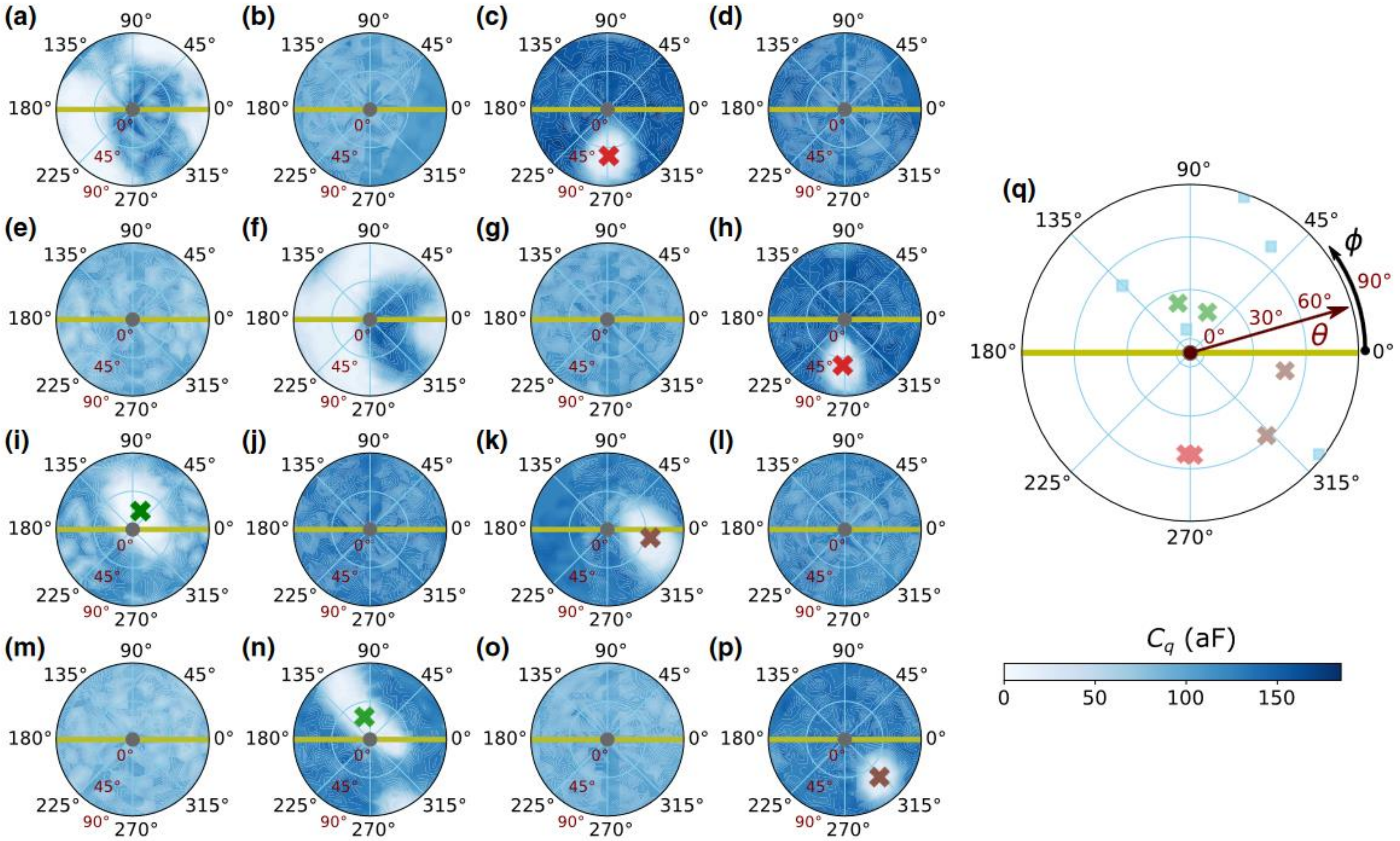
- external field |**B**|=30 mT
- extract $C_{q,max}$ as a function of angles
- two regions of strong $C_{q,max}$ suppression
- centers of the suppresion – parallel/antiparallel to $\mathbf{B}_{so}$
- S(2,0) and T_+(1,1) couple through spin flip – requires **B** not aligned to $\mathbf{B}_{so}$
- orientation of Bso:
  - complicated gate structure, nonuniform potential, field not perpendicular to the sample plane
  - many-electron regime, overlap not coincide with the direction of the nanowire
  - finite Dresselhaus SOI

C_q vs B



- two-site Hubbard model
- SOI – effective field pointing in arbitrary direction
- spin precessing tunneling element
- total tunneling strength
- isotropic g equal in both dots
- captures $\mathbf{B} \perp \mathbf{B}_{SO}$, no free parameters
- does not capture two-stage suppresion of $C_{q,max}$
  - g-factor nonuniformity, anisotropy
  - unaccounted Pauli spin blockade

Spin-Orbit field orientation



- $C_{q,max}$ independent for odd occupations
- $\mathbf{B}_{so}$ direction for even occupations
- same color – same valence orbitals

Conclusion

- extract charge parity
- extract $\mathbf{B}_{so}$ orientation using dispersive gate sensing for even-occupied transitions
- transitions with the same valence orbital – similar $\mathbf{B}_{so}$ orientation