SIGNATURES OF ATOMIC-SCALE STRUCTURE IN THE PROPERTIES OF SI QD QUBITS

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JOSÉ CARLOS ABADILLO-URIEL

JCGAU64@GMAIL.COM

UNIVERSITY OF WISCONSIN-MADISON

Introduction

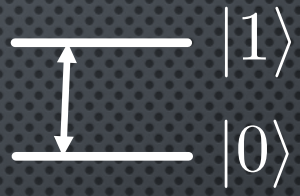
Building a quantum computer

- Why build a QC? Efficciency
  - Information security. Shor algorithm for prime factorization. Quantum cryptography.
  - Database search. Grover algorithm.
  - Quantum simulations.
  - For the fun of it

INTRODUCTION

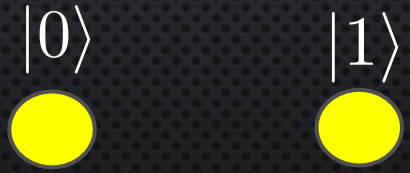
THE DIVINCENZO CRITERIA

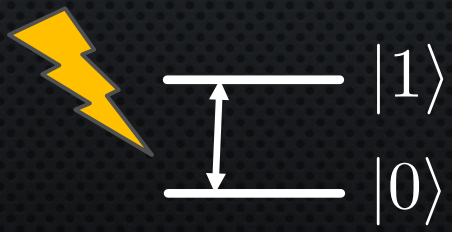
- SCALABLE WELL-DEFINED QUBITS
- INITIALIZATION OF STATES
- UNIVERSAL QUANTUM GATES
- QUBIT-SPECIFIC MEASUREMENT
- LONG COHERENCE TIMES



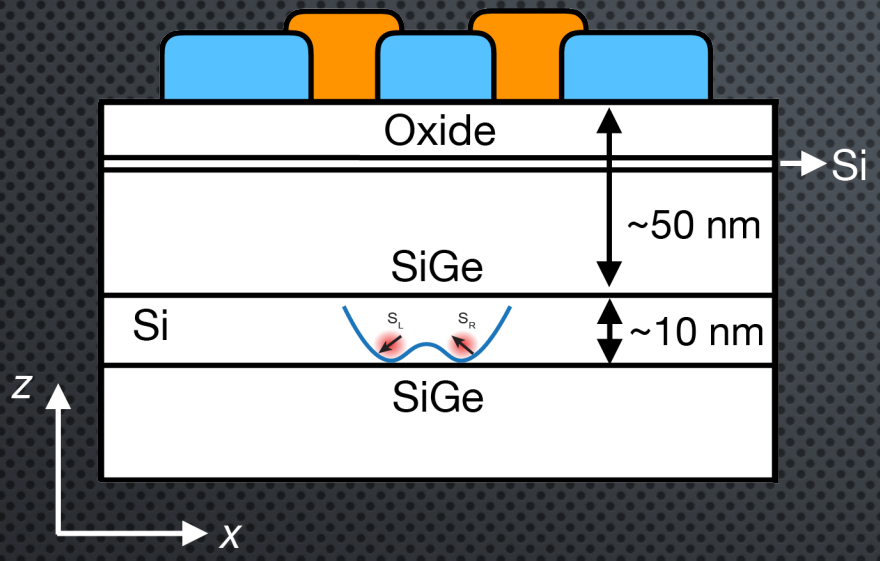
$|000...0\rangle$

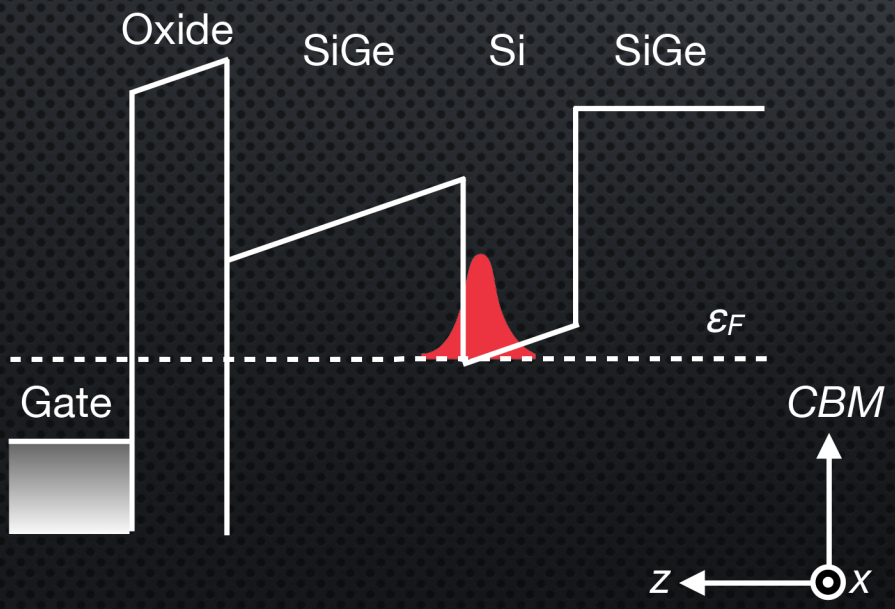
$\vec{\sigma}$ U_{CNOT}





SI/SIGE QUANTUM DOT QUBITS

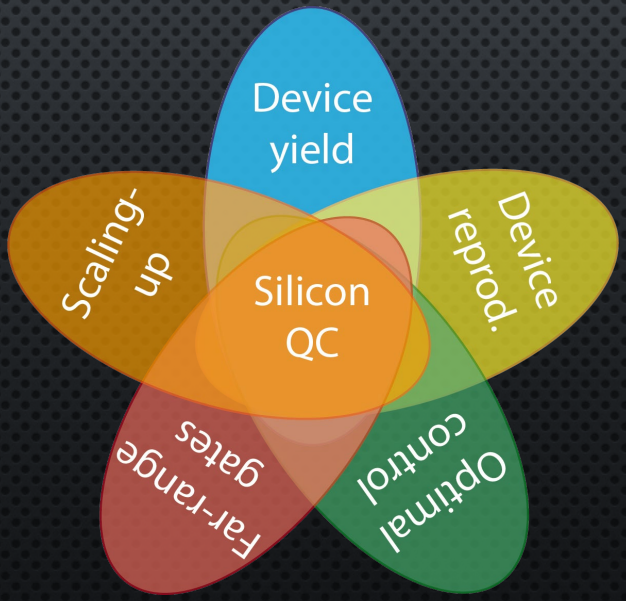




- Electrons/holes are confined in the Si quantum well
- The electron/hole is pushed against the interface
- Top gates are used to manipulate the qubit parameters
- Readout: spin-to-charge conversion

STATUS AND CHALLENGES

Metric	Spin	Orbital
T_2^* (μs)	113 [Yoneda et al., Nature Nano 13, 102–106 (2018)]	0.157 [Thorgrimsson et al., npj Quantum Inf.3, 32 (2017)]
F_{single} (%)	99.96 [Yang et al., Nature 580, 350-354 (2020)]	93 [Kim et al., npj Quantum Inf.1, 15004 (2015)]
$F_{2\text{-qubit}}$ (%)	98 [Huang et al., Nature 569, 532(2019)]	68 [Li et al., Nat. Commun.6, 7681 (2015)]



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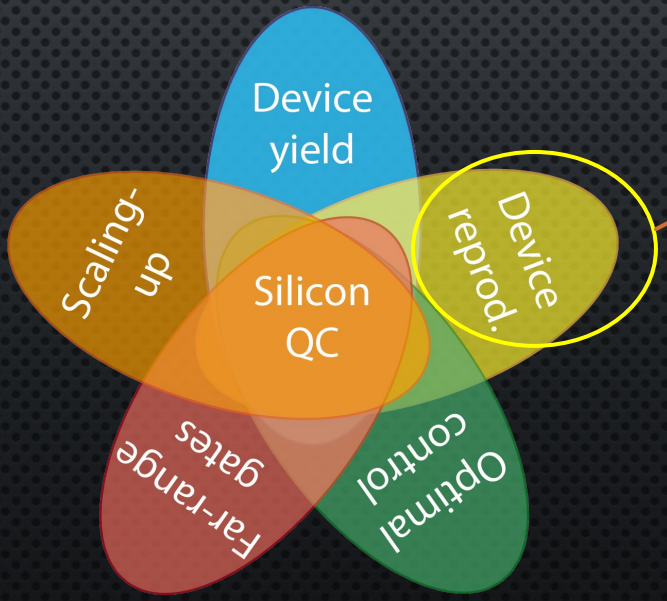
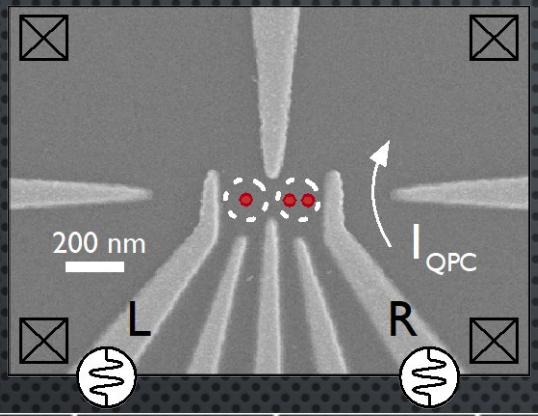
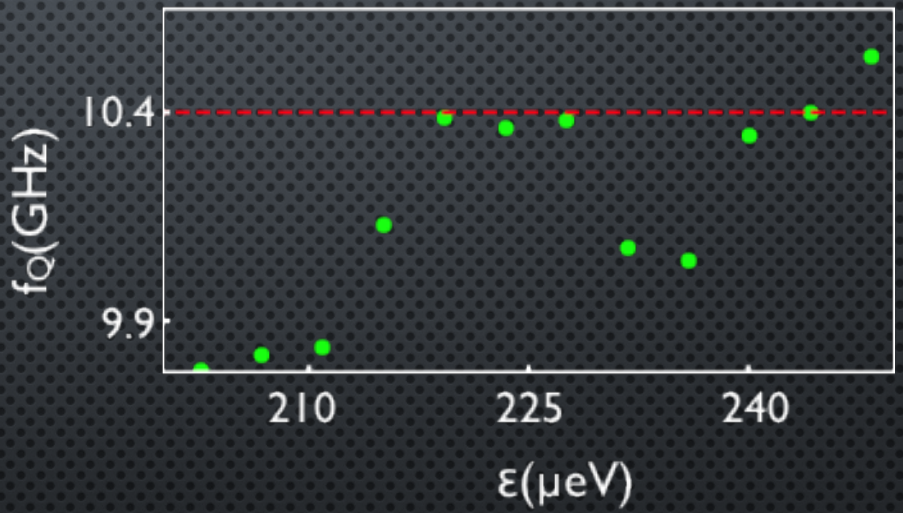


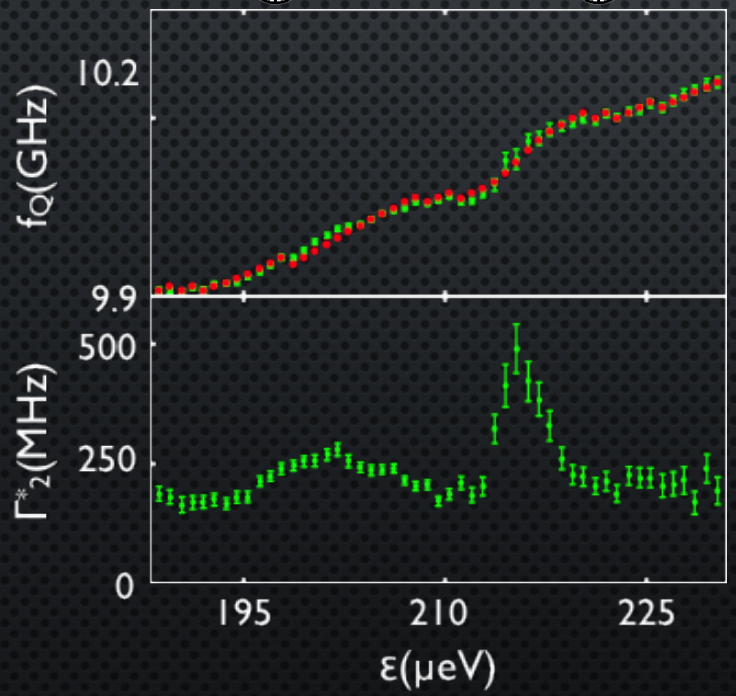
Valley physics
Spin-orbit coupling
Tunnel couplings
Noise sources

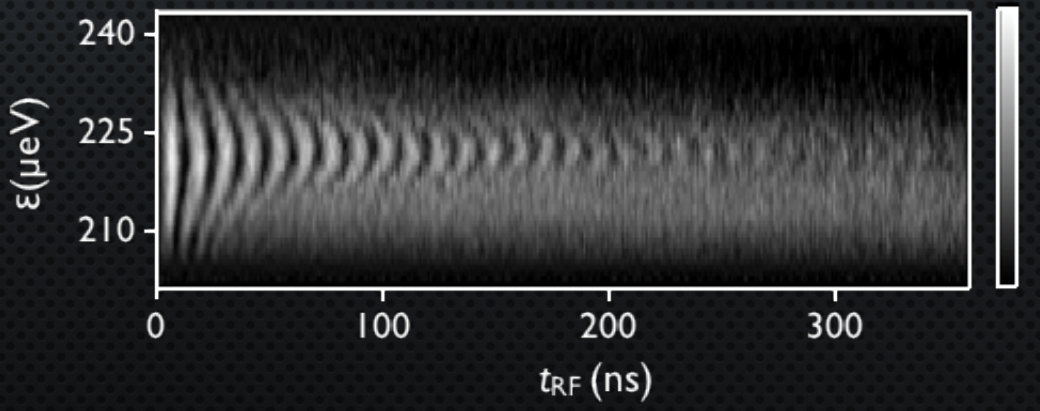
ANOMALOUS EXPERIMENTAL RESULTS

$$T_2^* \propto \left(\frac{dE}{d\epsilon}\right)^{-1}$$

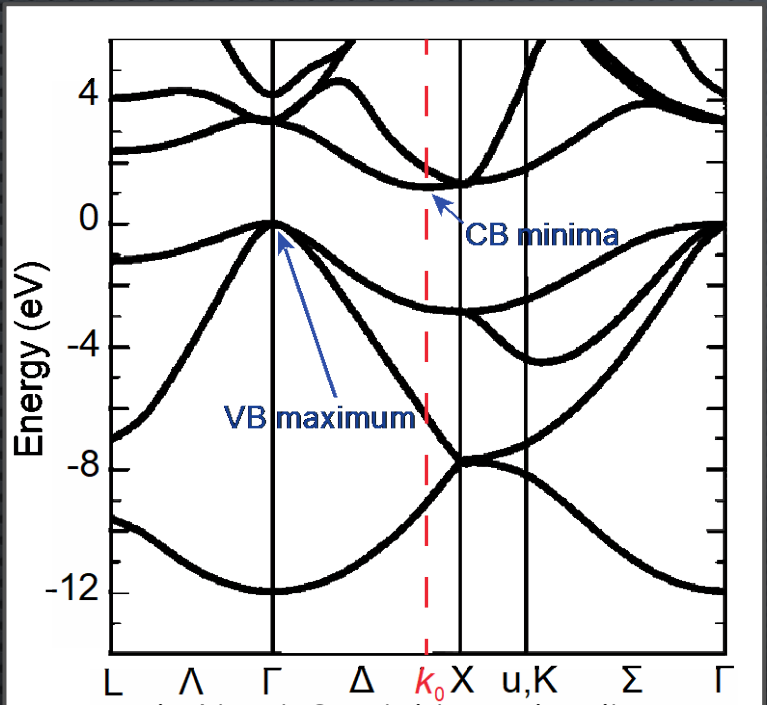








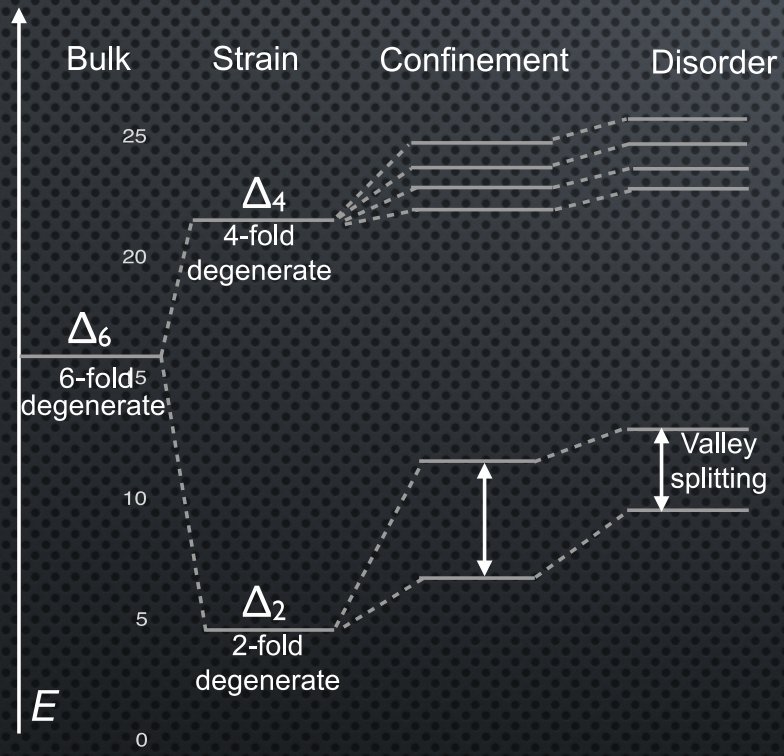
THE VALLEY ISSUE (OR ADVANTAGE)



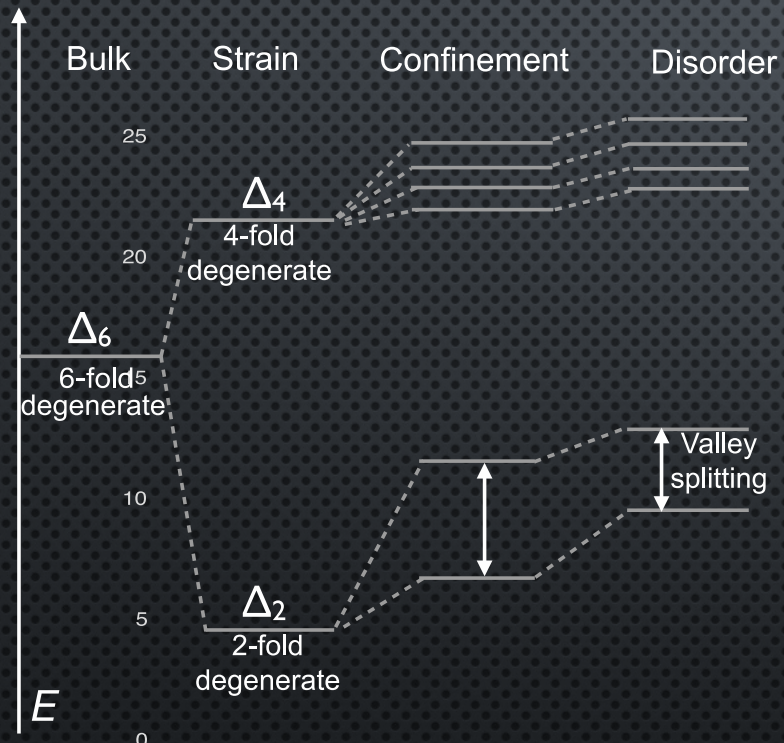
From Davies' book Cambridge University Press, Cambridge, UK, 1997

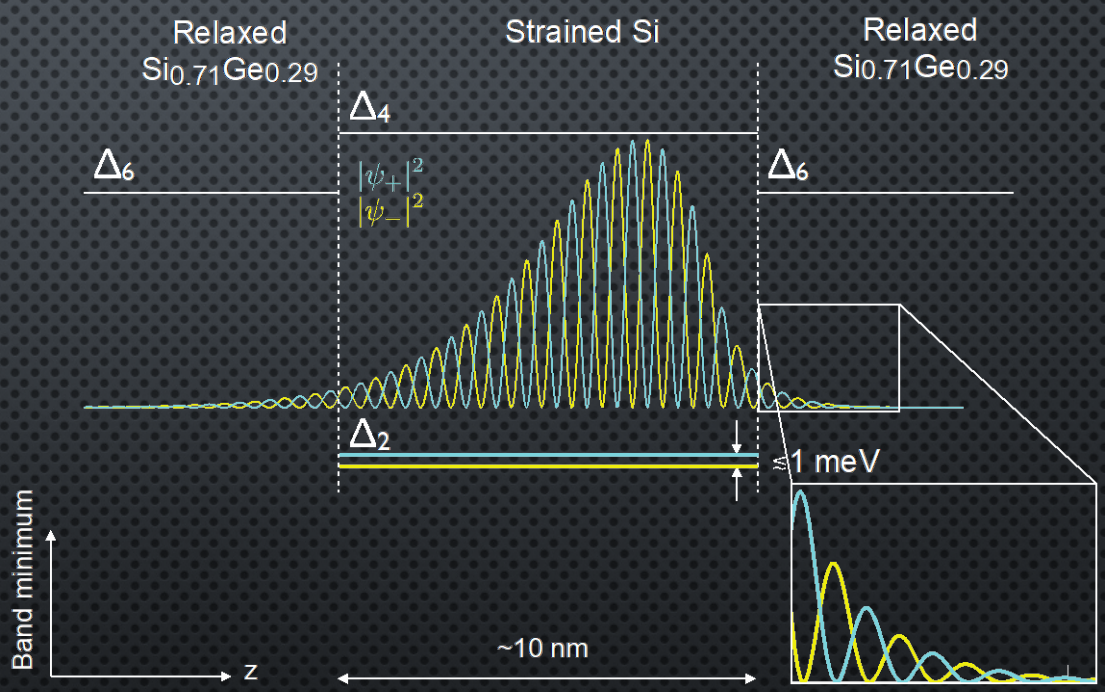
- At low temperatures, the confined electrons inherit the behavior from the conduction band mínima:
- 6-fold degenerate valley states
- Leakage channel

VALLEY PHYSICS: ORIGINS



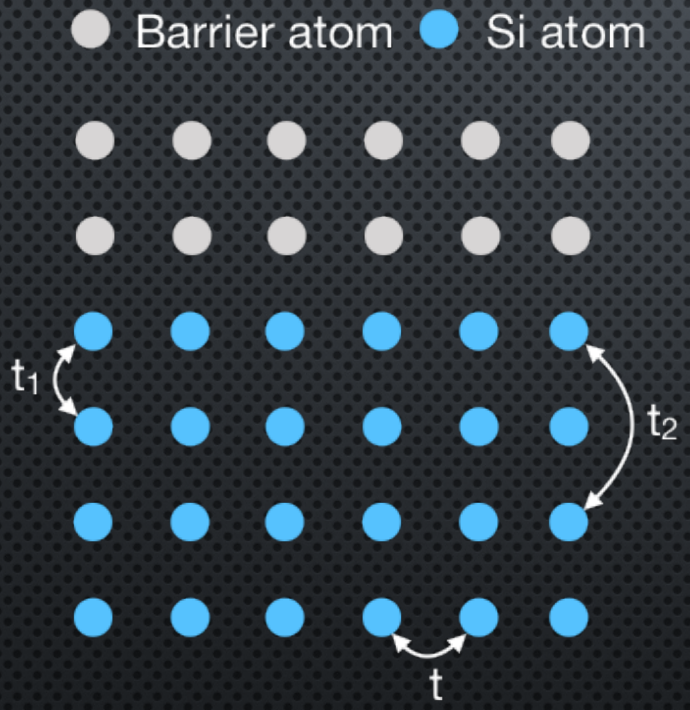
VALLEY PHYSICS: ORIGINS AND IMPORTANCE





DIFFERENT VALLEY STATES SEE THE INTERFACE IN A DIFFERENT WAY

SIMULATING VALLEY PHYSICS WITH A SIMPLIFIED MODEL

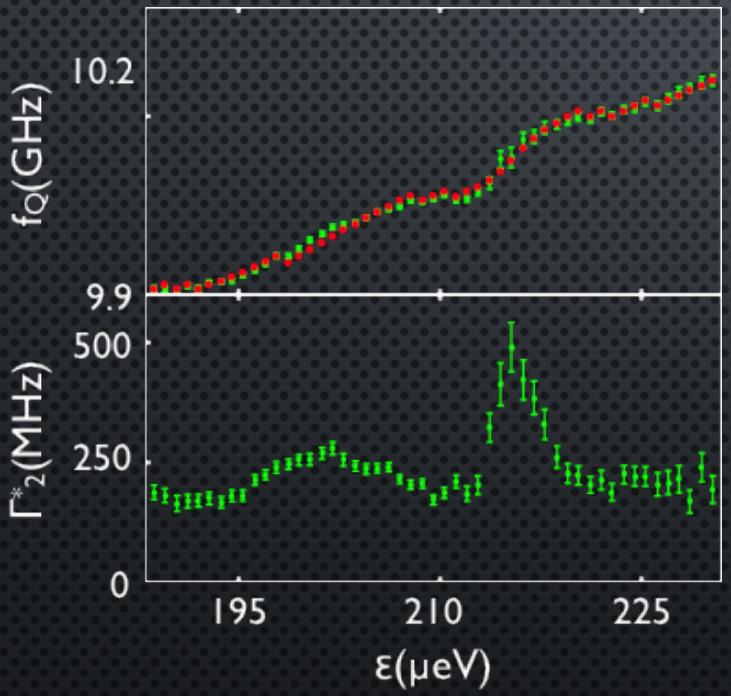


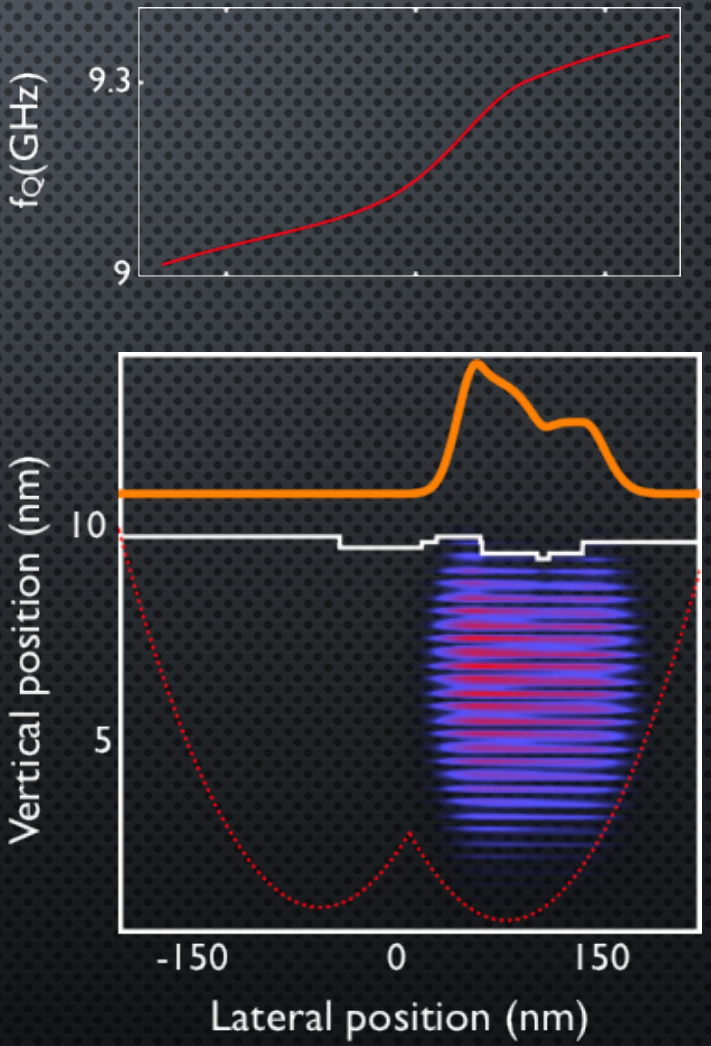
- Minimal tight-binding that approximates the conduction band mínima of Si
- The hopping parameters are chosen to reproduce the effective masses and CB minima position
- This simple model reproduces the behavior of valley splitting in the presence of fields, interfaces, disorder…

Details:
Boykin et al., APL 84, 115 (2004)
Abadillo-Uriel et al., Phys. Rev. B 98, 165438 (2018)

SHARP CHANGES IN THE INTERFACE RESULT IN FASTER DECOHERENCE

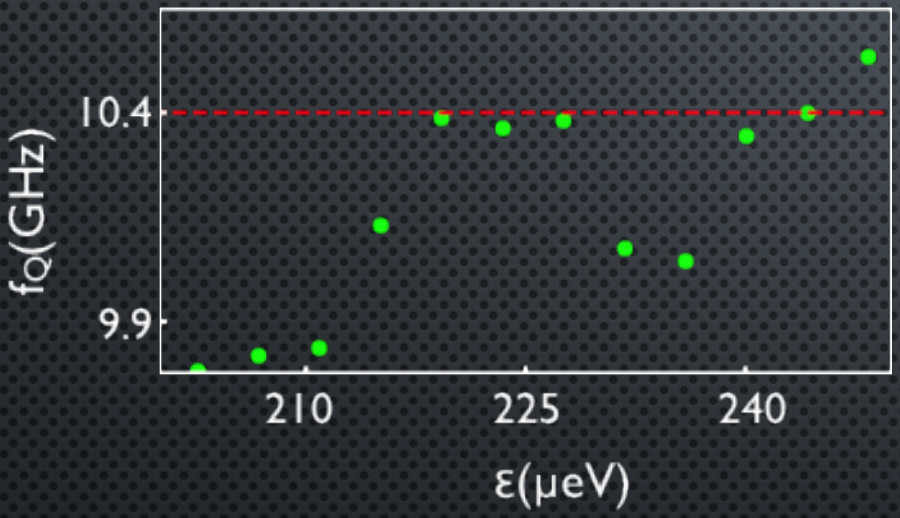
Abadillo-Uriel et al., Phys. Rev. B 98, 165438 (2018)

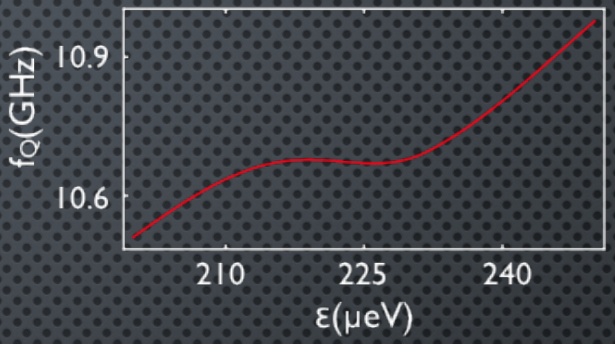


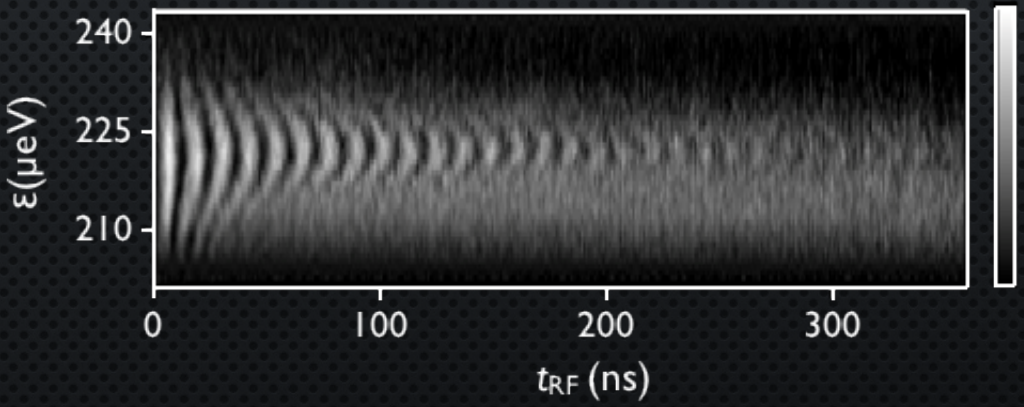


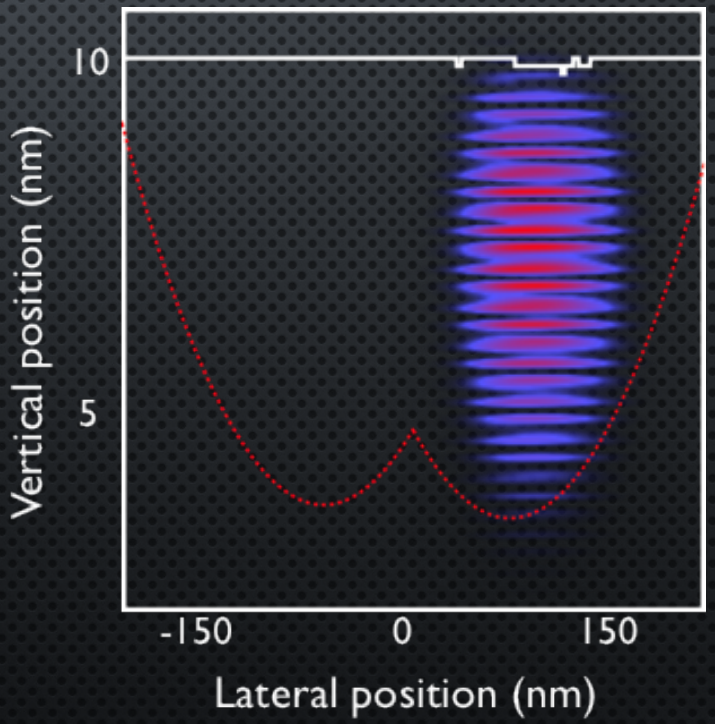
Measurements from Brandur Thorgrimsson

INTERFACIAL DISORDER SLOWS DOWN THE ELECTRON EXTENDING THE COHERENCE



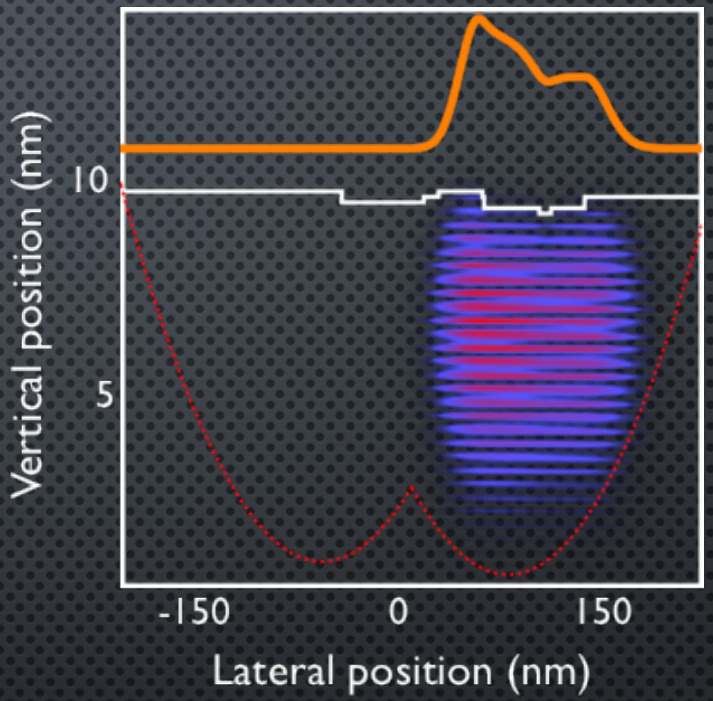






CONCLUSIONS

- The material physics of Si has an impact in quantum computation
- Valley physics can be an asset
- With electric fields the disorder landscape of the electron can be changed: sweet spots appear in certain cases

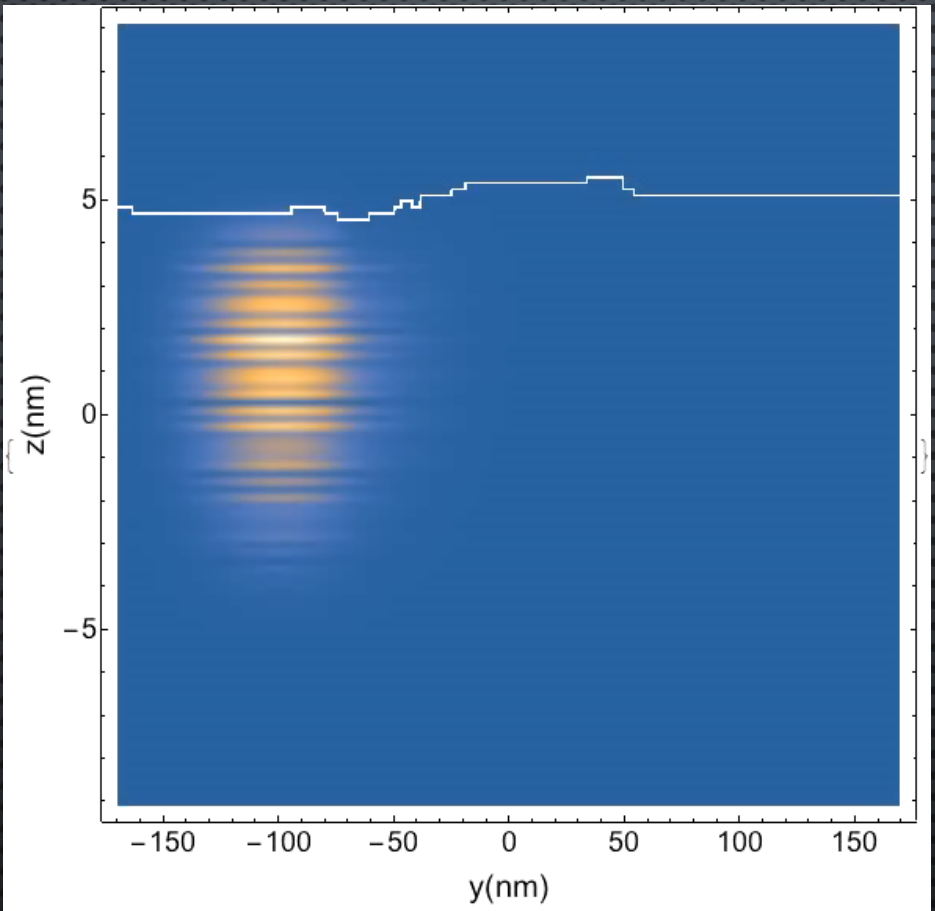


FUTURE WORK

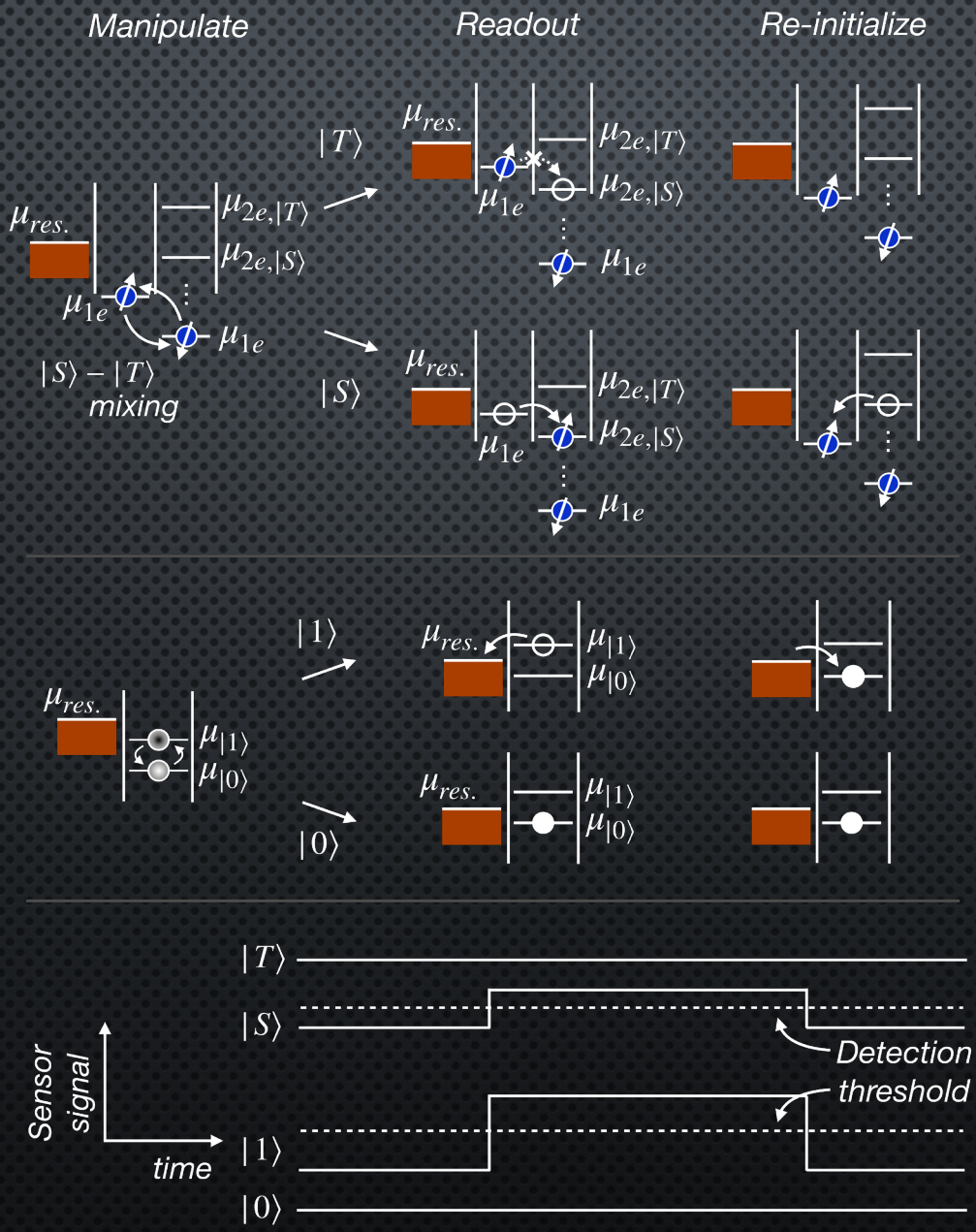
- Modifying the confinement potential
- e-e interactions

BACK UP SLIDES

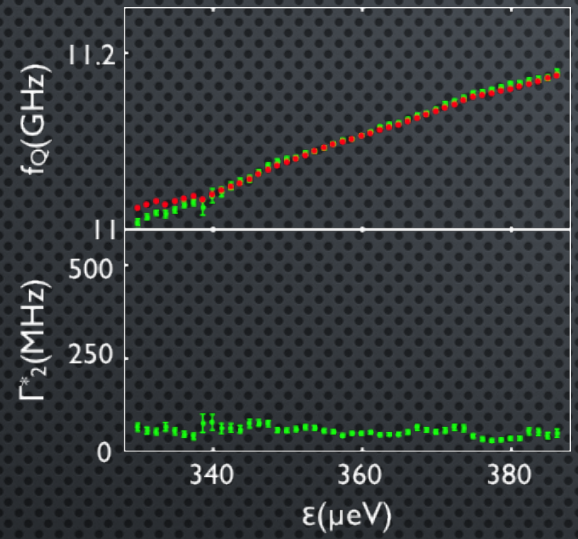
EXAMPLE OF SUPER FAST BEHAVIOR

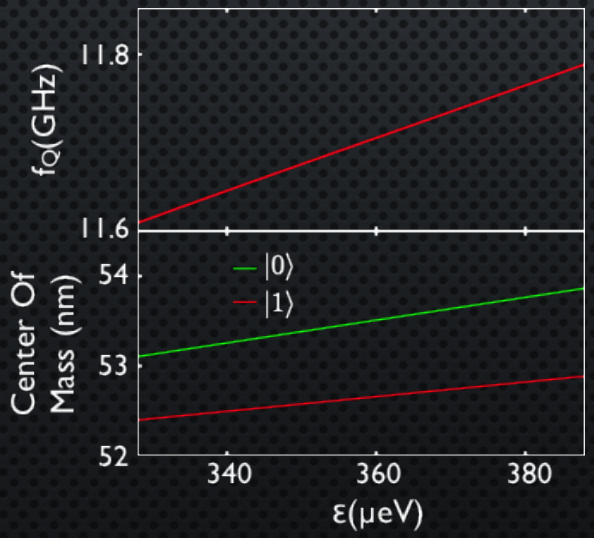


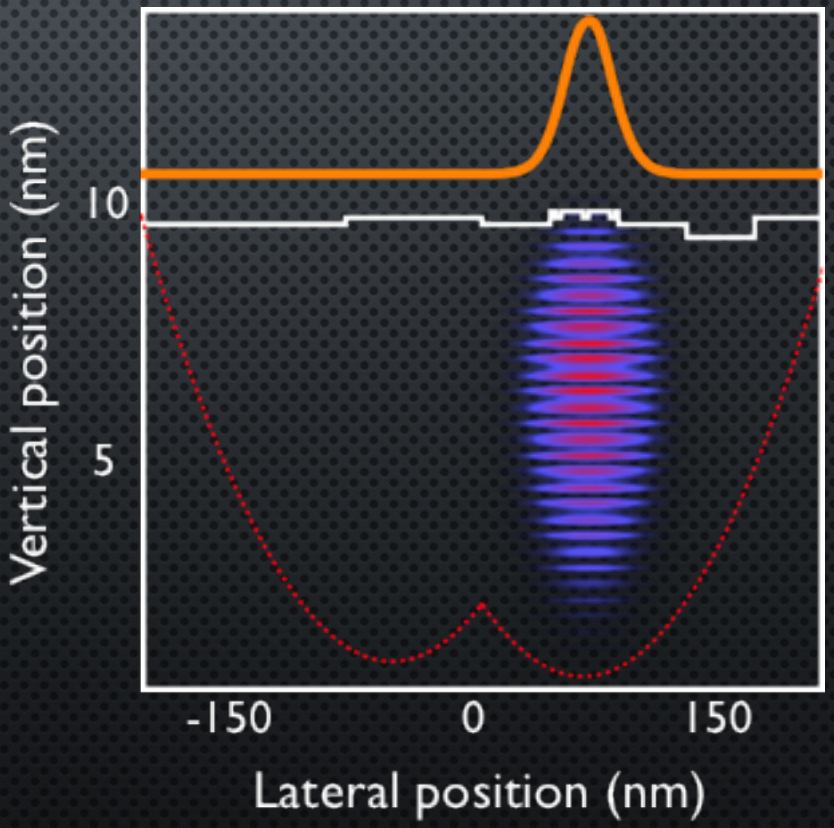
READOUT MECHANISMS FOR QD QUBITS



EXPECTED BEHAVIOR



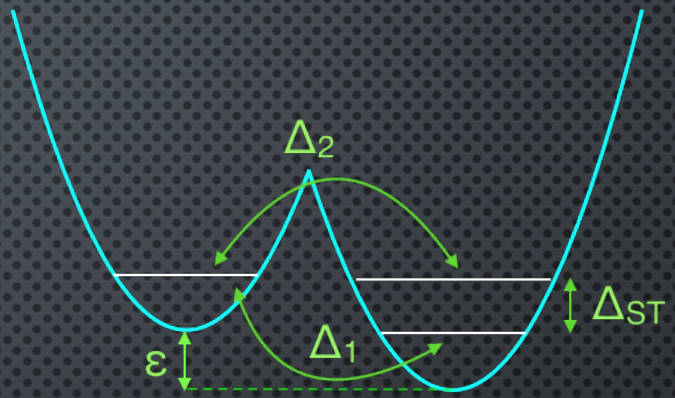


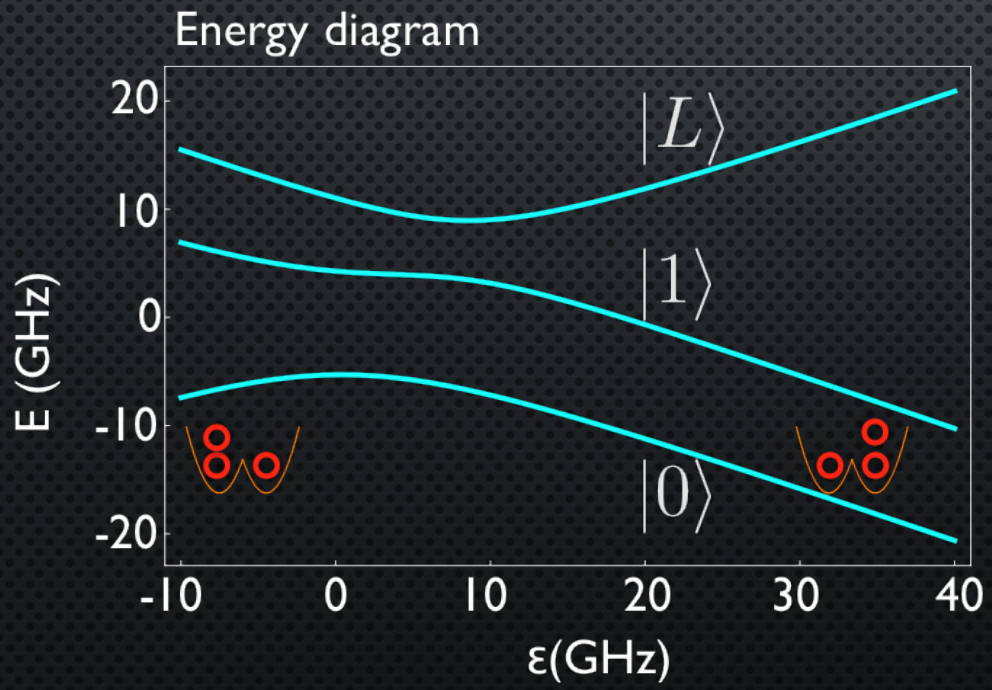


VALLEY-ORBIT MECHANISMS

IN DETAIL HYBRID QUBIT

$$H = \begin{pmatrix} -\varepsilon/2 & 0 & \Delta_1 \\ 0 & -\varepsilon/2 + \Delta_{ST} & \Delta_2 \\ \Delta_1 & \Delta_2 & \varepsilon/2 \end{pmatrix}$$





Two anticrossings related to the qubit parameters

Far-detuned regime

Dipolar coupling maximized near the 1st anticrossing