SAND2017-13067C

All-electrical universal control of a double quantum dot qubit in silicon MOS

Patrick Harvey-Collard,[1,2] Ryan M. Jock,[2] N. Tobias Jacobson,[2] Andrew D. Baczewski,[2] Andrew M. Mounce,[2] Matthew J. Curry,[2,3] Daniel R. Ward,[2] John M. Anderson,[2] Ronald P. Manginell,[2] Joel R. Wendt,[2] Martin Rudolph,[2] Tammy Pluym,[2] Michael P. Lilly,[2] Michel Pioro-Ladrière[1] and Malcolm S. Carroll[2]

1. Département de physique et Institut quantique, Université de Sherbrooke
2. Sandia National Laboratories
3. Department of Physics and Astronomy, Center for Quantum Information and Control, University of New Mexico

Outline

- Quantum computing — Why do we care? — What is it?
- Qubit technology — Where silicon fits in
- This work — An all-electrical, simple CMOS-compatible qubit
- Results — Qubit readout, control, mechanisms
- Conclusion — Prospects for integration

Quantum computing — Why do we care?

(Easy answer)

Because they care

IBM

Google

intel

Microsoft

(But really...?)

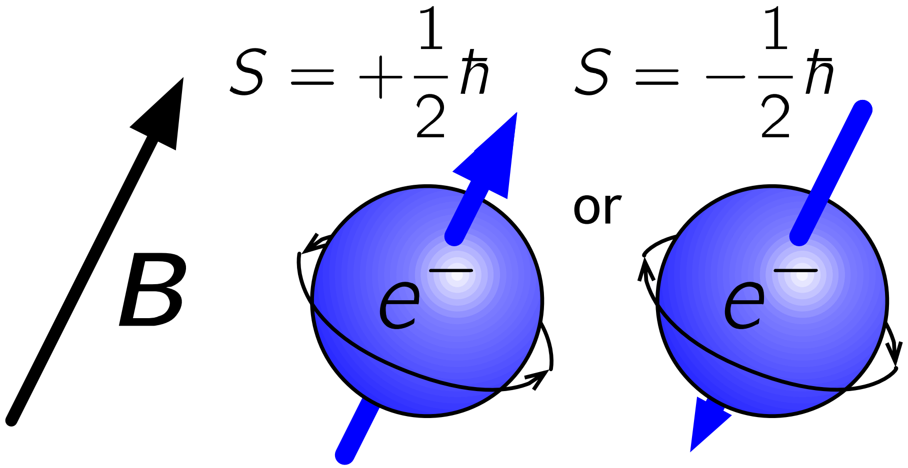
Solve certain hard problems with large speedups

- Feynman: simulate quantum nature with quantum computers
  - Chemistry, biology, materials, ...
- Deutsch, Jozsa, Simon, Shor, Grover, Farhi:
  - Unstructured search, hidden subgroup, factoring, circuit satisfiability, ...
  - Optimization, linear & FEM equations, machine learning, etc...
- Bennet, Brassard:
  - Secure cryptography
  - Quantum communications

Quantum computing — What is it?

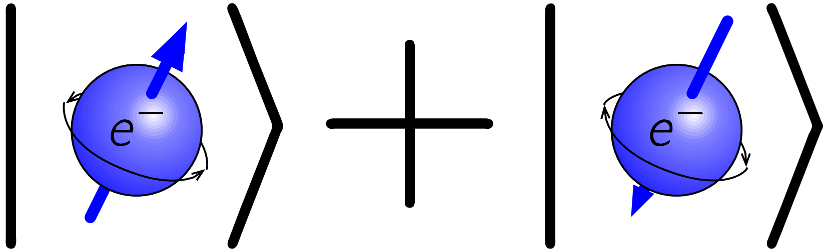
Quantum bits (qubits)

- Quantum two-level system (e.g. spin 1/2)
- Quantized (i.e. discrete) states

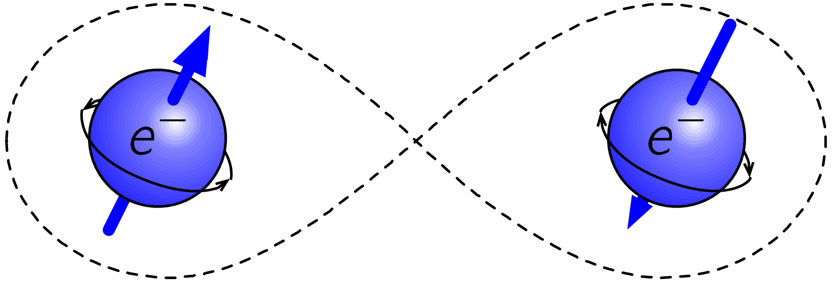


Qubits are quantum…

- State superposition (1 qubit)

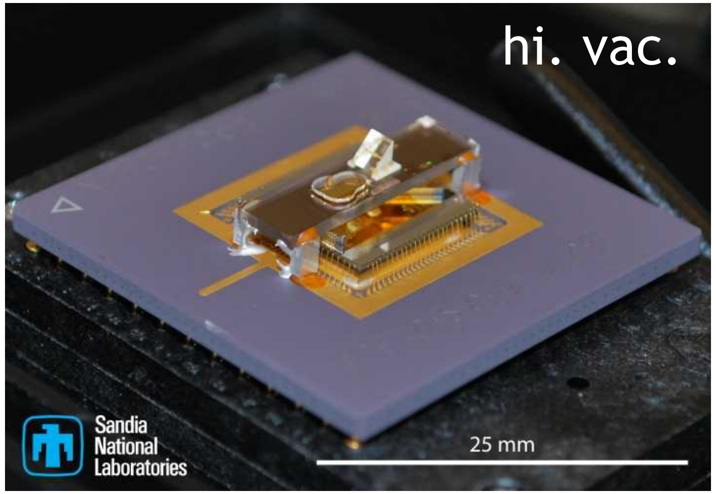


- Entanglement (2 qubits)



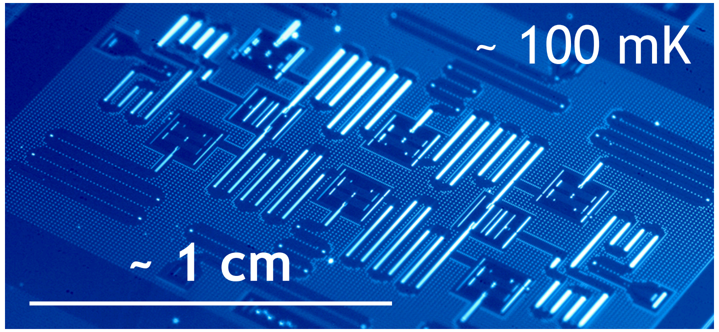
Qubit technology
— Where silicon fits in

Ion traps



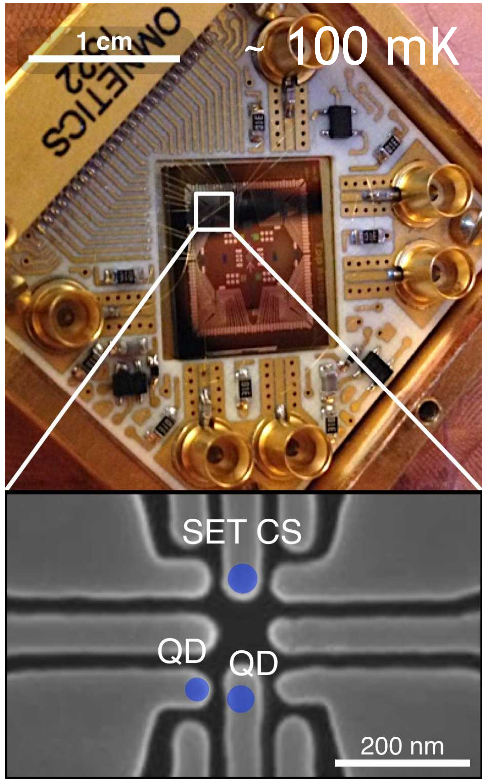
Credit: Sandia National Labs

Superconductors



Credit: IBM Research

Semiconductors



Other technologies:

✓ More mature (~ 5 qubits)

× Large size

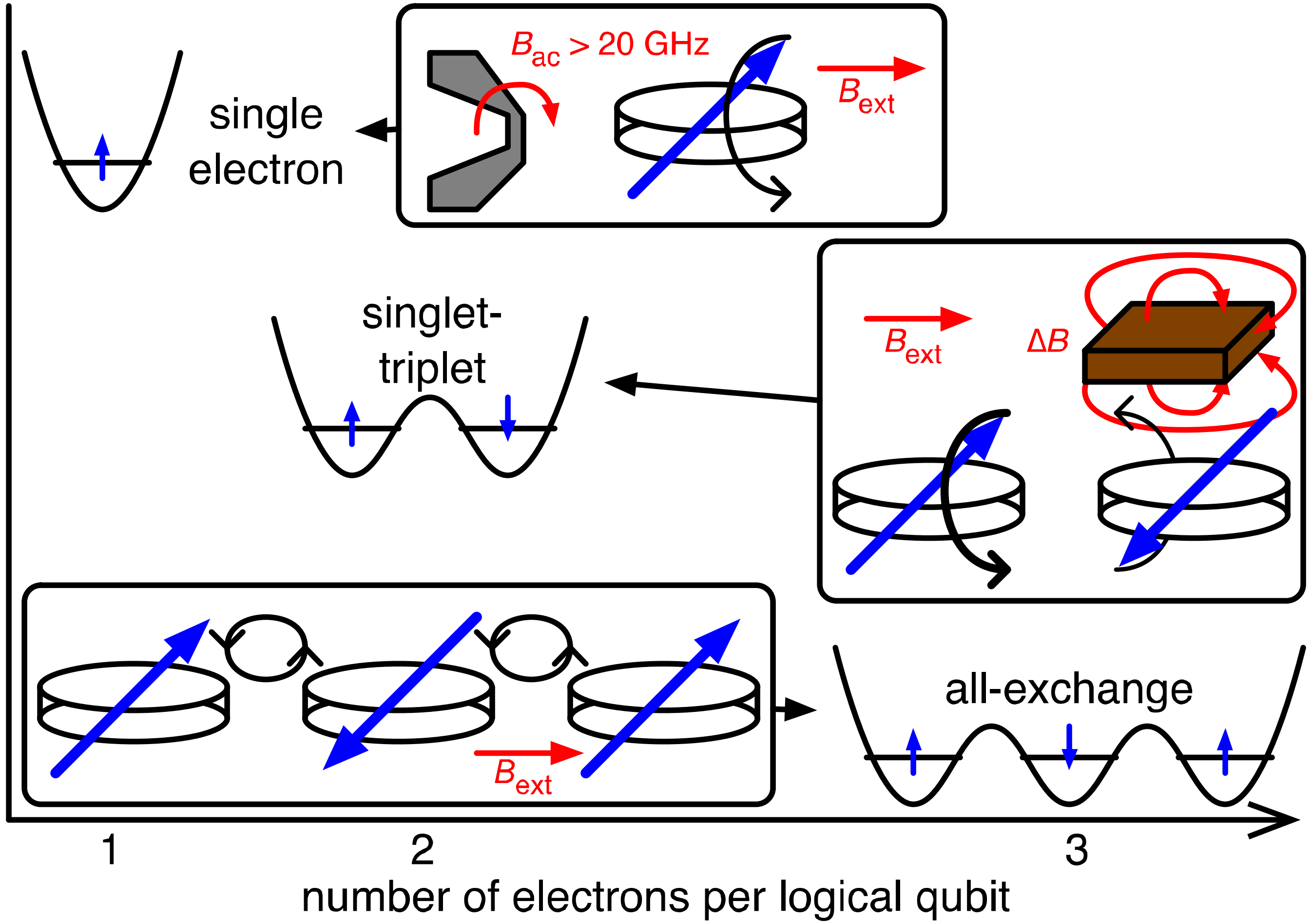
Semiconductors:

× Less mature (~ 2 qubits)

✓ Small size

✓ Leverage ULSI/SoC

Previous work — Integration complexity



Single QD

microwave antenna or micromagnet

Double QD

micromagnet or nuclear spin

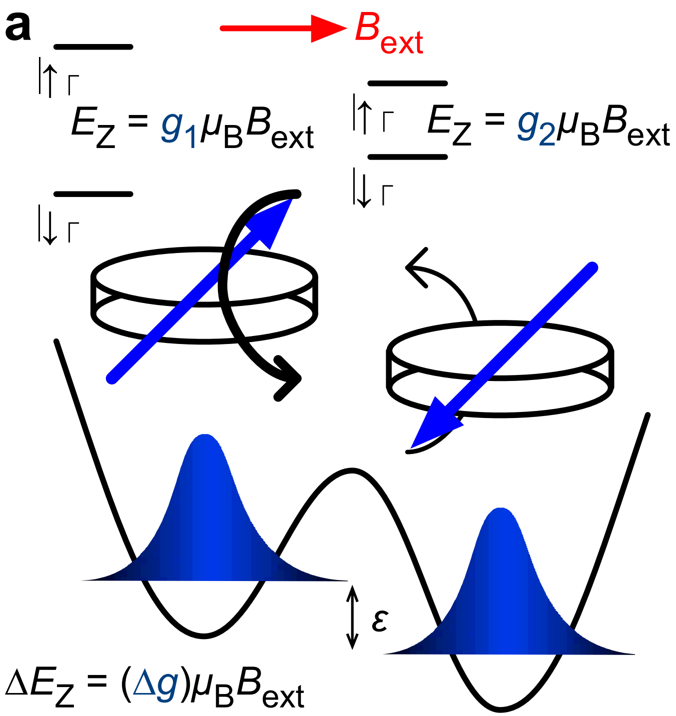
Triple QD

extra QD

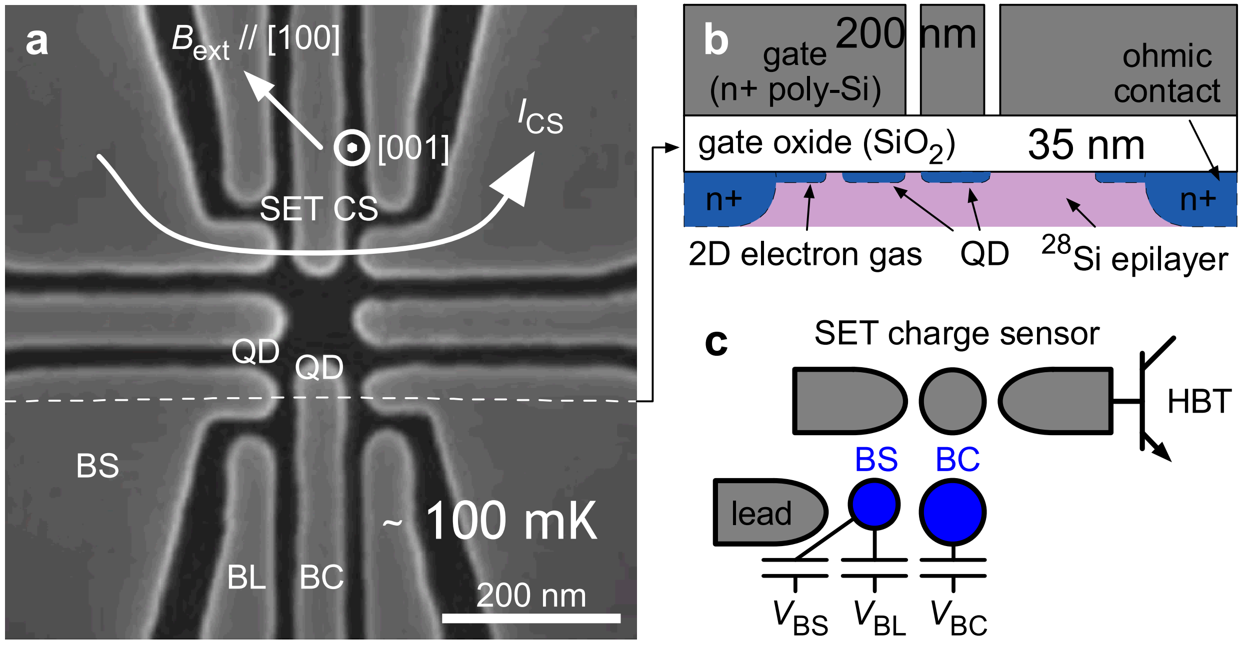
1. Harvey-Collard, P. et al. Coherent coupling between a quantum dot and a donor in silicon. *Nature Communications* **8**, 1029 (2017).

This work
— Simple CMOS-compatible qubit

Spin-orbit interaction



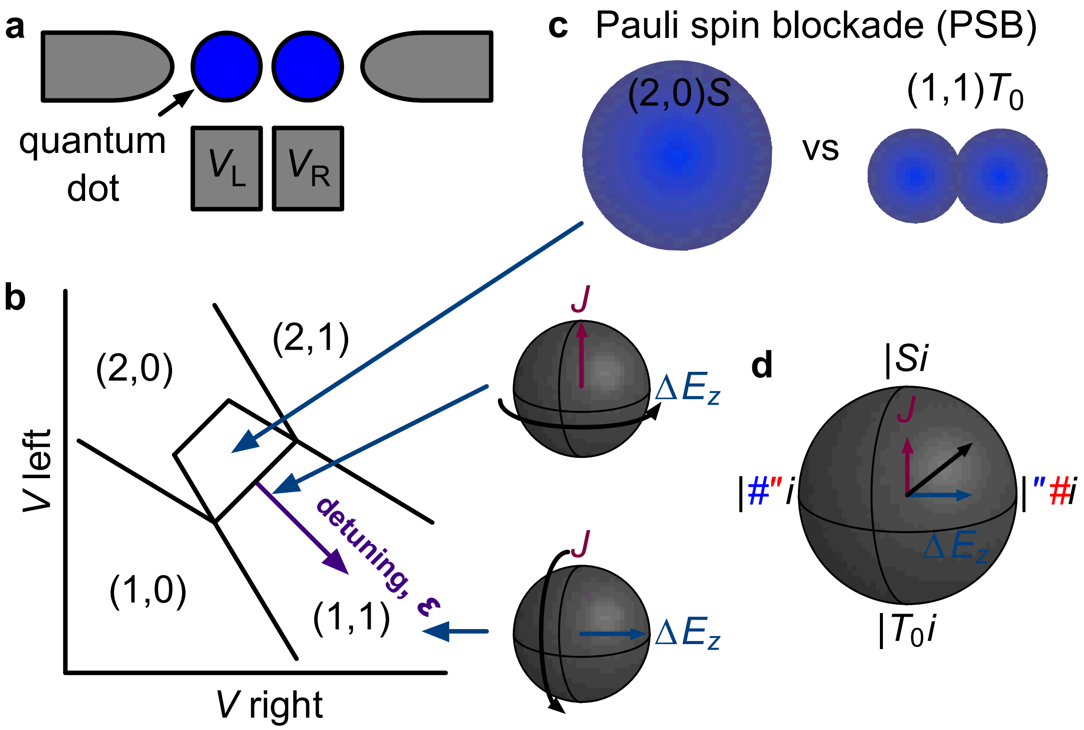
Pure CMOS design



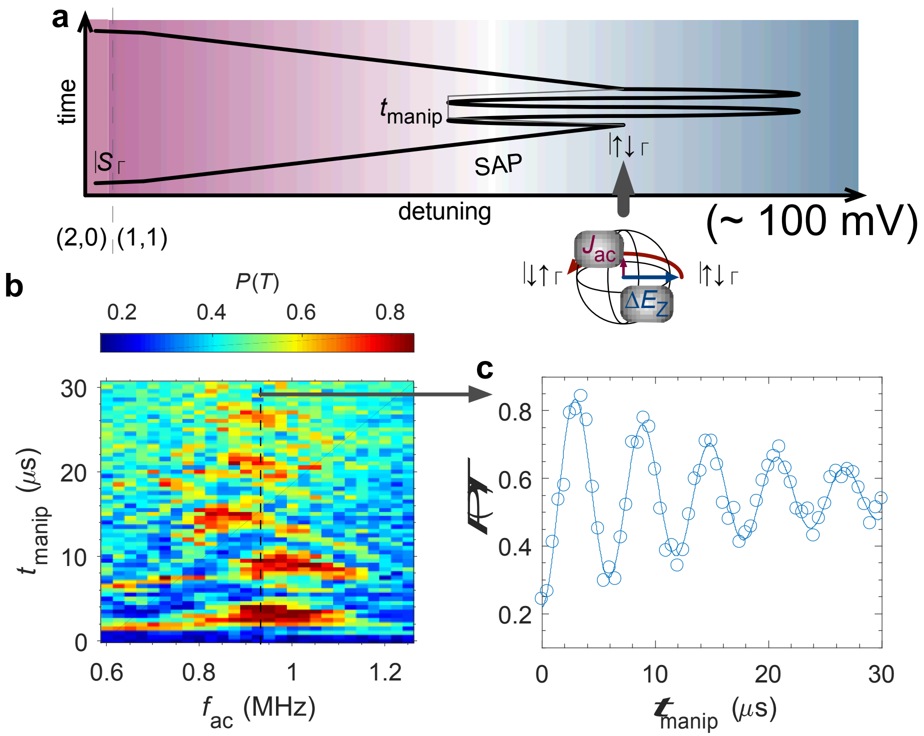
1. Harvey-Collard, P. et al. All-electrical universal control of a double quantum dot qubit in silicon MOS. *In 2017 IEEE IEDM* (2017).
2. Jock, R. M. et al. Probing low noise at the MOS interface with a spin-orbit qubit. *ArXiv*:1707.04357 (2017).

Results
— Qubit readout, control, mechanisms

Readout and control



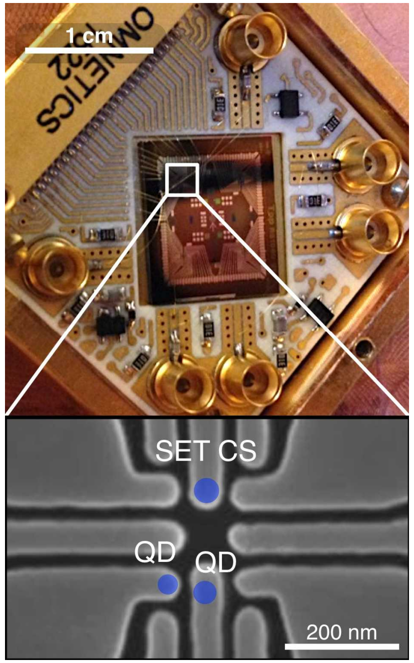
AC controlled rotations
Access any 1 qubit state

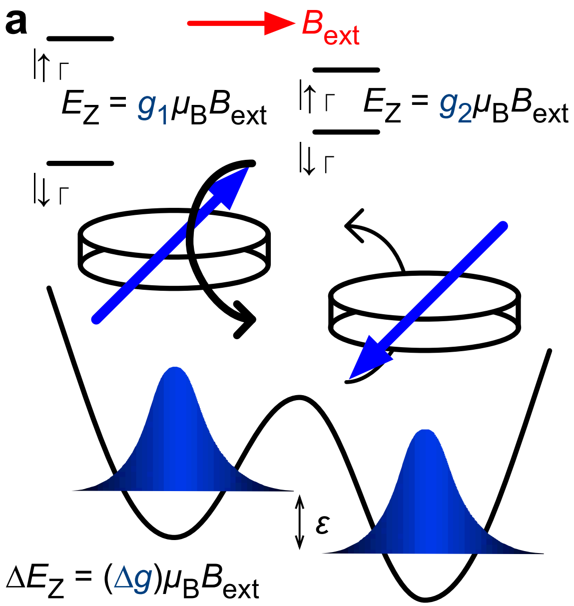


1. Harvey-Collard, P. et al. High-fidelity single-shot readout for a spin qubit via an enhanced latching mechanism. *ArXiv*:1703.02651 (2017).
2. Harvey-Collard, P. et al. All-electrical universal control of a double quantum dot qubit in silicon MOS. *In 2017 IEEE IEDM* (2017).

Conclusion

- All-electrical universal control
- No external component: completely CMOS fabrication
- Fast single-shot readout with SiGe HBT
- **Future work:** engineering of robust & fast spin-orbit drive
- **Goal:** simplify integration of quantum hardware





References

1. Gamble, J. K. et al. Valley splitting of single-electron Si MOS quantum dots. *Applied Physics Letters* **109**, 253101 (2016).
2. Curry, M. J. et al. Cryogenic preamplification of a single-electron-transistor using a SiGe HBT. *Applied Physics Letters* **106**, 203505 (2015).
3. Harvey-Collard, P. et al. Coherent coupling between a quantum dot and a donor in silicon. *Nature Communications* **8**, 1029 (2017).
4. Harvey-Collard, P. et al. High-fidelity single-shot readout for a spin qubit via an enhanced latching mechanism. *ArXiv*:1703.02651 (2017).
5. Jock, R. M. et al. Probing low noise at the MOS interface with a spin-orbit qubit. *ArXiv*:1707.04357 (2017).
6. Harvey-Collard, P. et al. All-electrical universal control of a double quantum dot qubit in silicon MOS. *In 2017 IEEE IEDM* (2017).

Acknowledgements & Team

Experiments

- Ryan M. Jock
- Andrew M. Mounce
- Matthew J. Curry
- Martin Rudolph
- Michael P. Lilly
- Malcolm S. Carroll

Theory

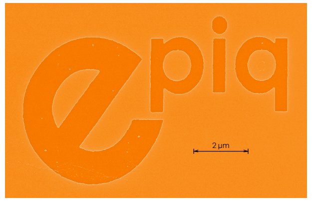
- N. Tobias Jacobson
- Andrew D. Baczewski
- John King Gamble
- Wayne M. Witzel

Fabrication

- Daniel R. Ward
- John M. Anderson
- Ronald P. Manginell
- Joel R. Wendt
- Tammy Pluym

Université de Sherbrooke

- Michel Pioro-Ladrière



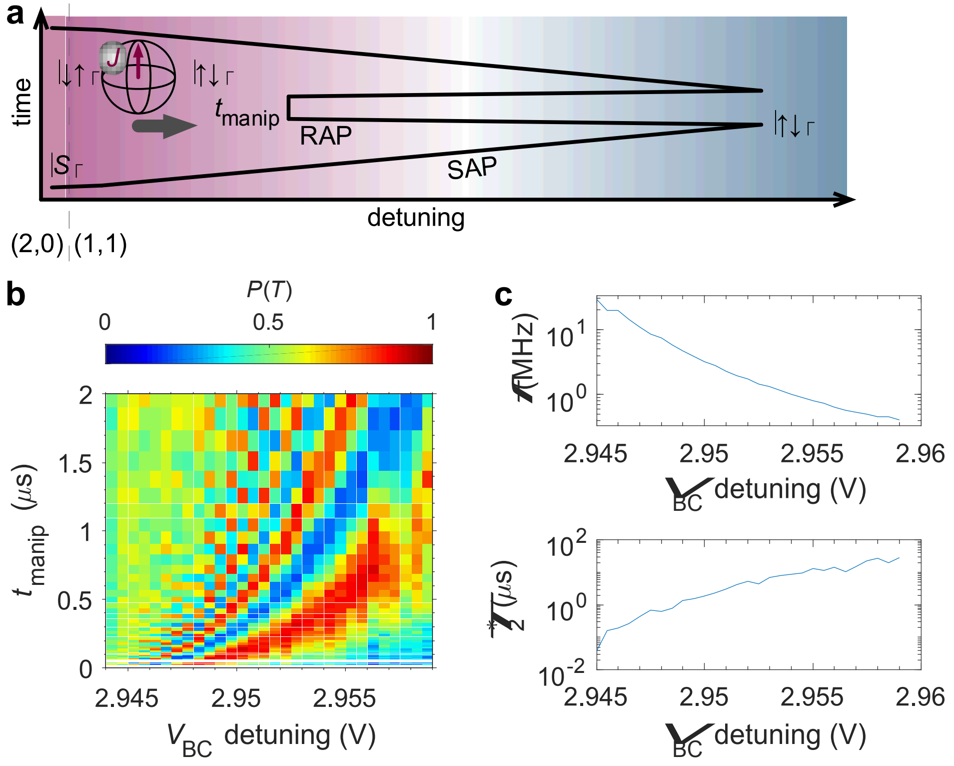
And the rest of the QIST team!

This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the DOE's National Nuclear Security Administration under contract DE-NA0003525.

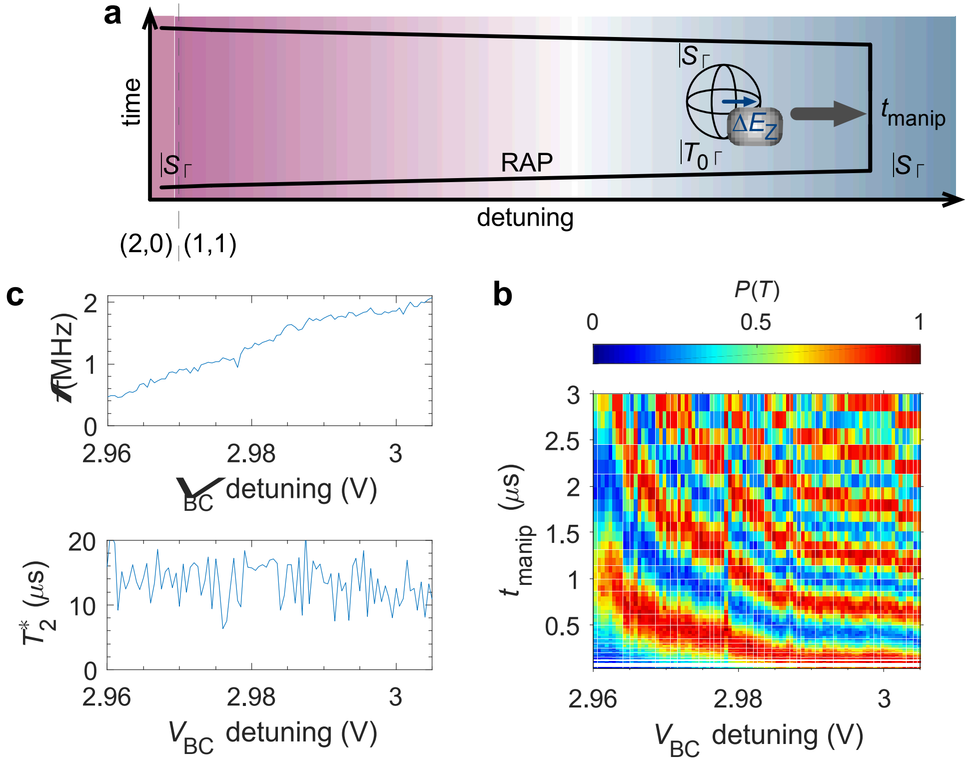
Supplementary slides

DC control

Exchange rotations

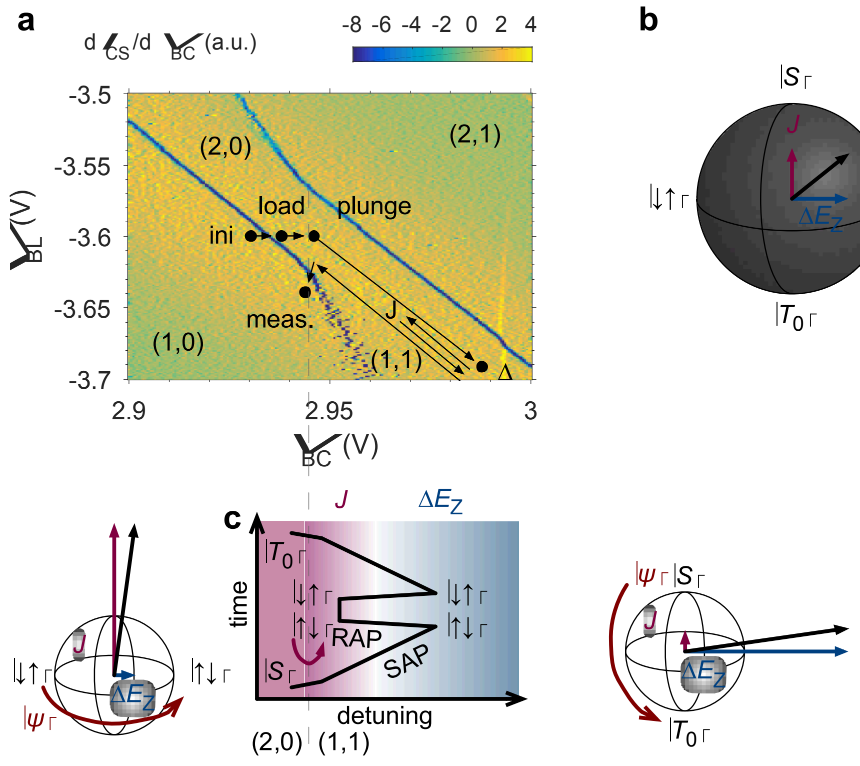


Zeeman rotations



Pulse sequence experiment

Pulse sequence (exp.)



SAP vs FAP, and spin-orbit