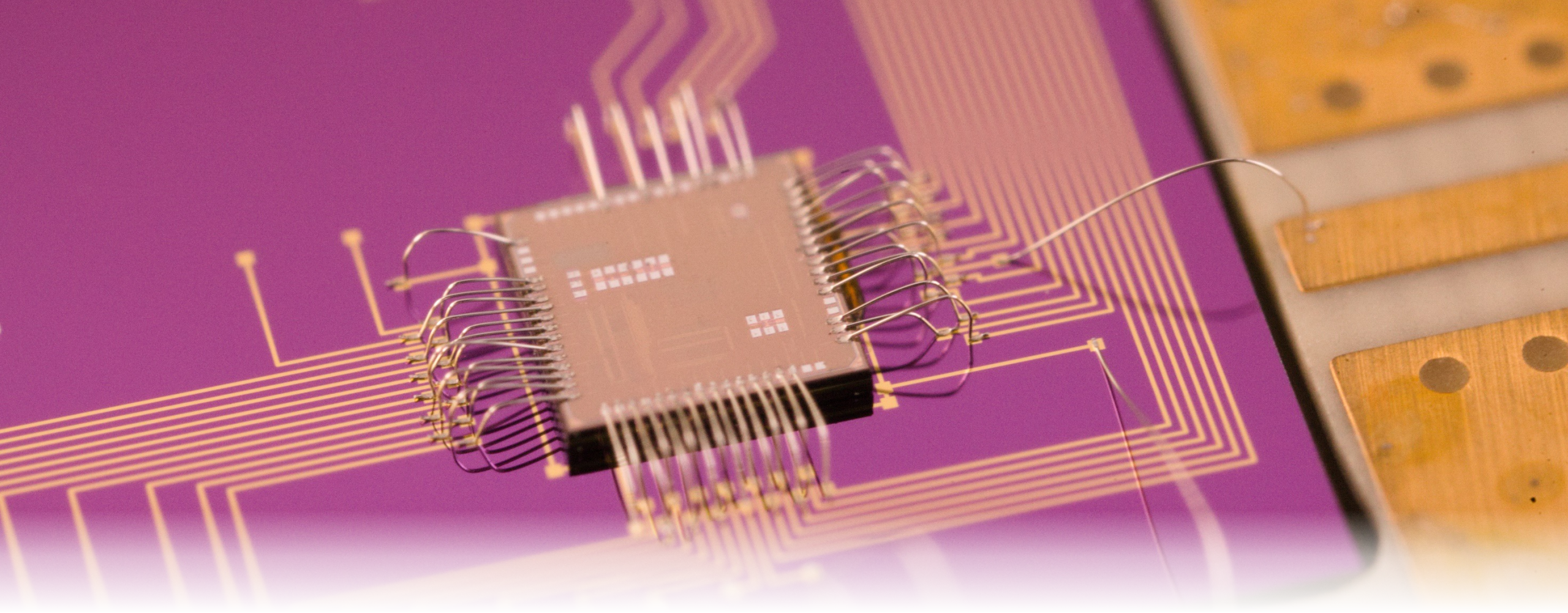


A Scalable Architecture for Integrating Spin Qubits with Cryogenic Electronics

Rene Otten – *24.10.2023*

ARQUE IQI QuTech Quantum Technology Group | RWTH AACHEN UNIVERSITY JÜLICH Forschungszentrum

NISQ applications

Universal QC with QEC

Operations per error (physical)

10^6
10^5
10^4
10^3
10^2
10

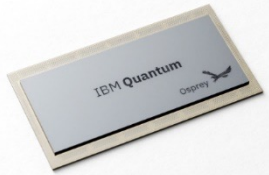
Classical simulation

Practical error correction

Superconducting qubits

2019 2022 2024 2026

Google IBM



December 2022
433 Qubits

1 10 10^2 10^3 10^4 10^5 10^6 10^7 10^8

Qubit number

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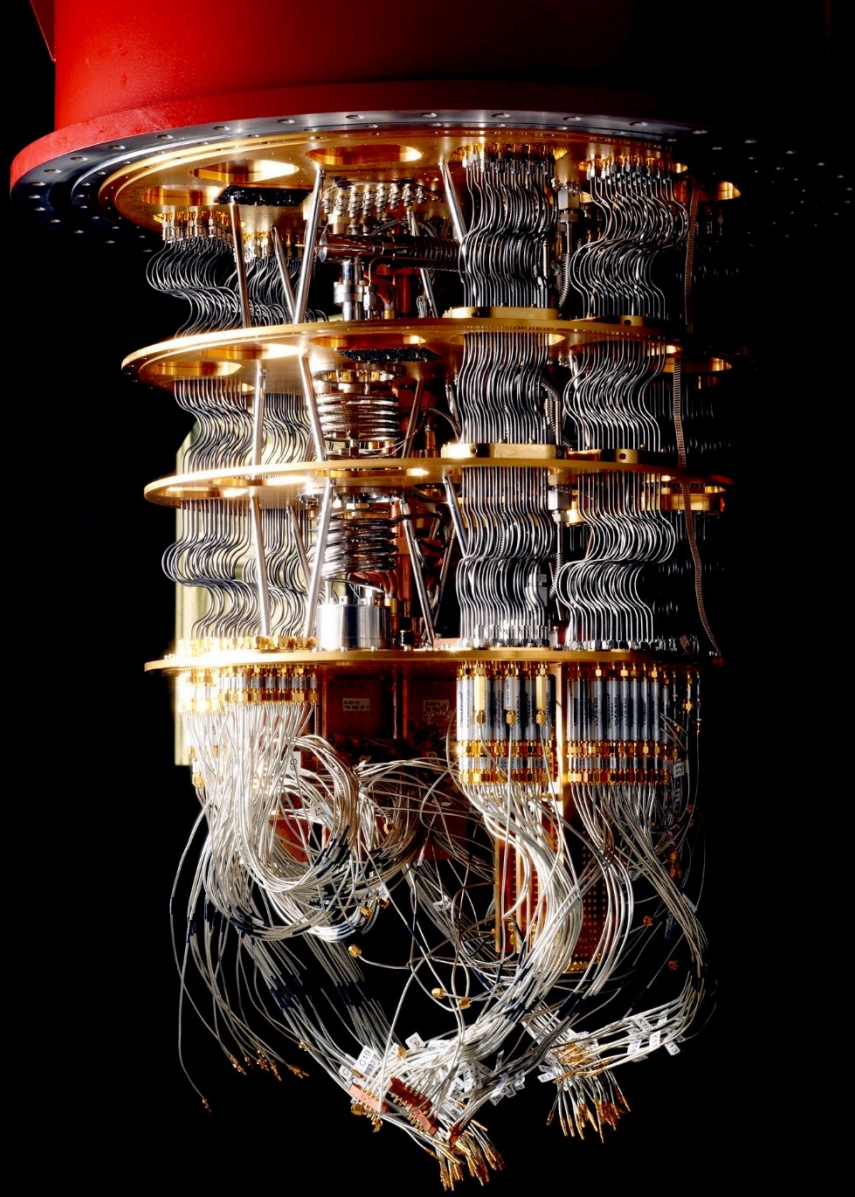
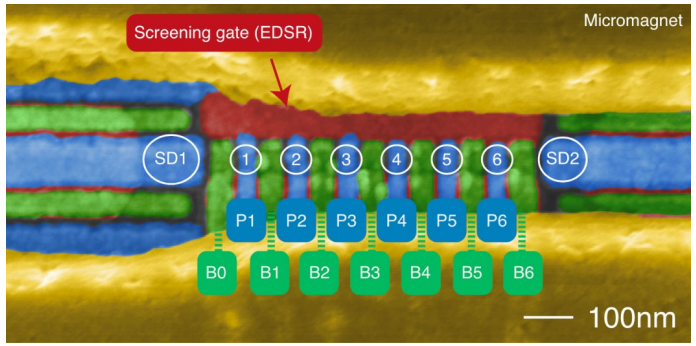
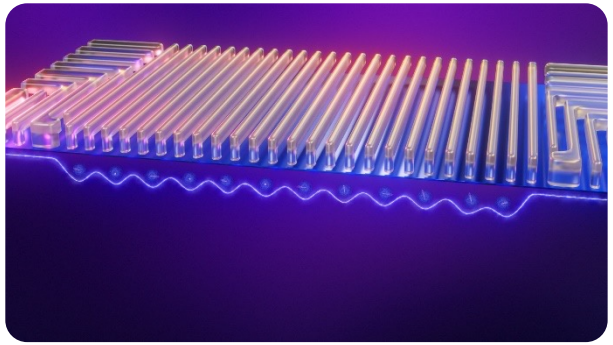


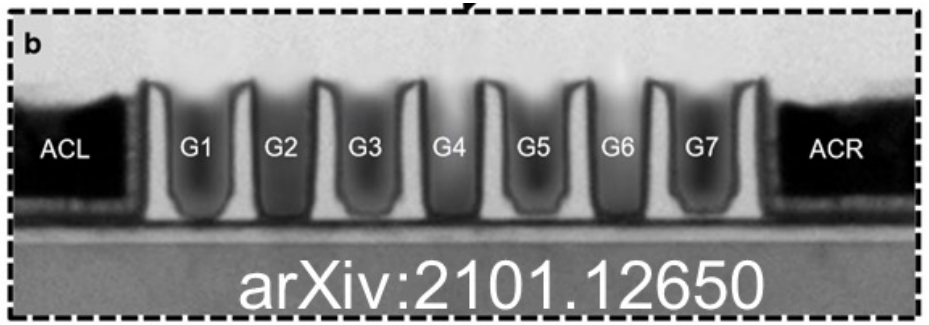
SiGe Spin Qubits are an ideal platform for integration

Delft



Intel



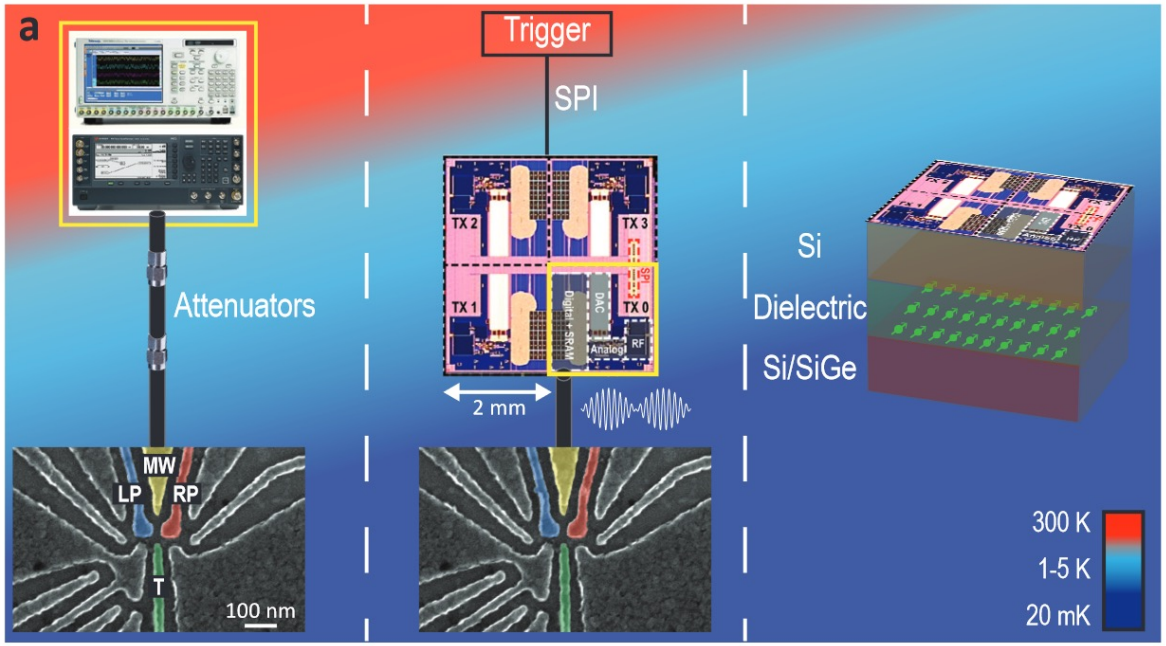


„Semiconductor spin qubits are promising candidates for quantum computing because of their long coherence and compatibility with semiconductor technology“.

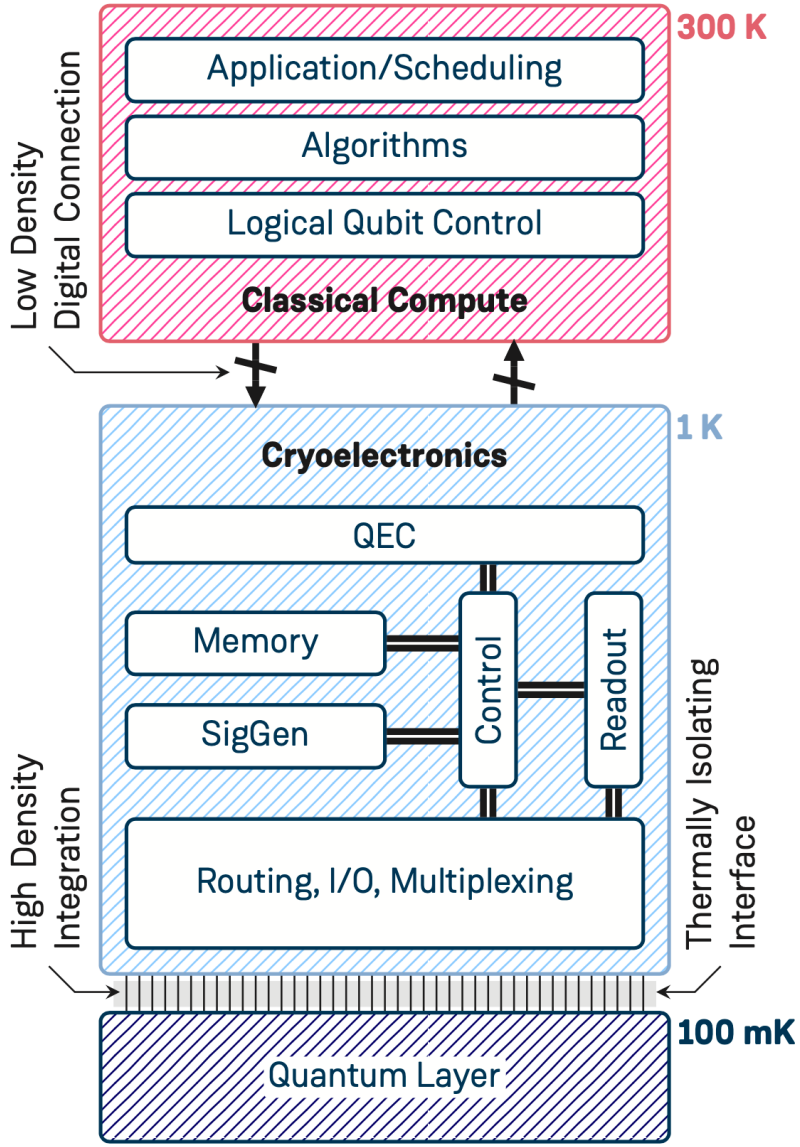
Coherence and control fidelity at or near required level

Lifetime of quantum states	Single qubit error rate	Two qubit error rate
30 ms	0.05 %	0.2 %

Formulating an full stack approach for integration



Integrate everything into single package



How can we match qubit spacing with size of electronics (and connections)?

Xue et al. Nature 593 7858 (2021)
Pauka et al. Nat. El. volume 4, 64–70 (2021)
Boter et al. ,Phys. Rev. App. 18, 024053 (2022)

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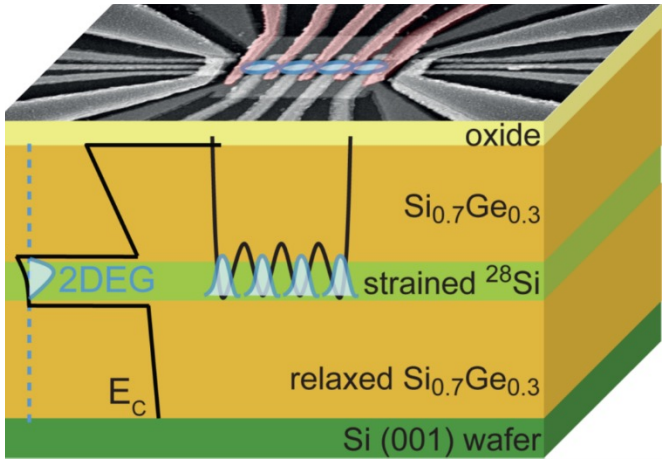
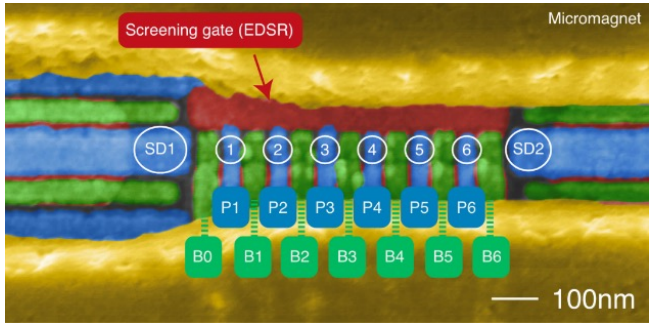
Electron shuttling in a spin bus can relax the qubit pitch

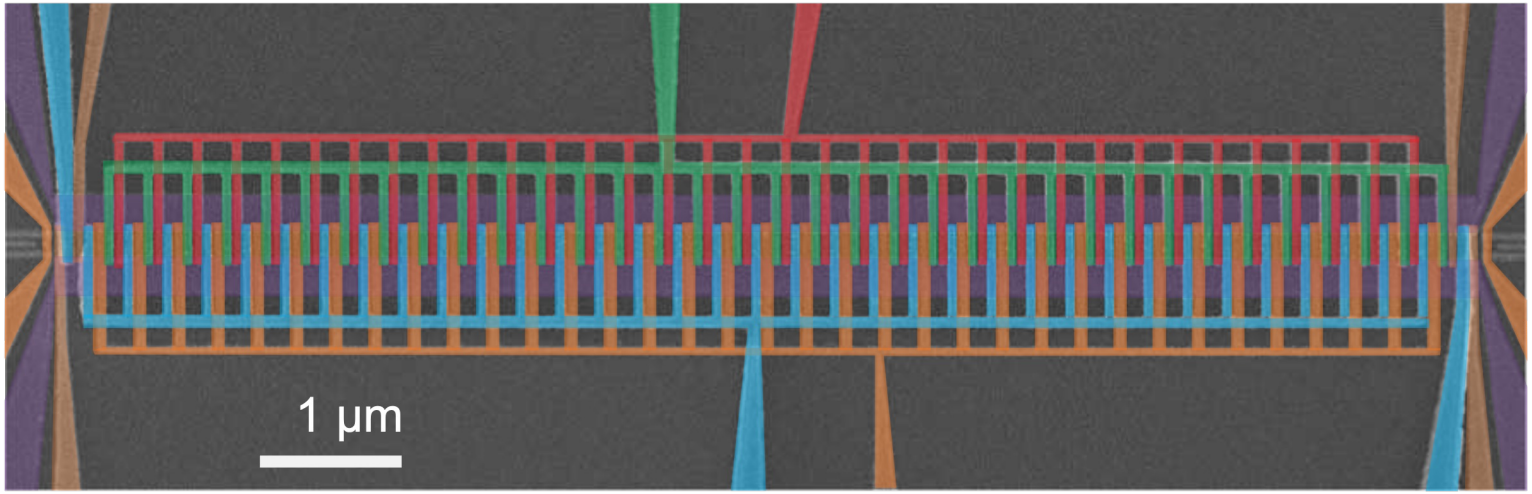


SiGe devices are compatible with industry fabs



Native spin qubit pitch is too small for integration

Periodic layout limits necessary connections



Philips et al., arXiv:2202.09252v1
Kuenne, Willmes *et al.* arXiv:2306.16348 (2023)
Langrock *et al.* PRXQuantum **4**, 020305 (2023)
Xue *et al.* arXiv:2306.16375 (2023)
Struck *et al.* arXiv:2307.04897 (2023)

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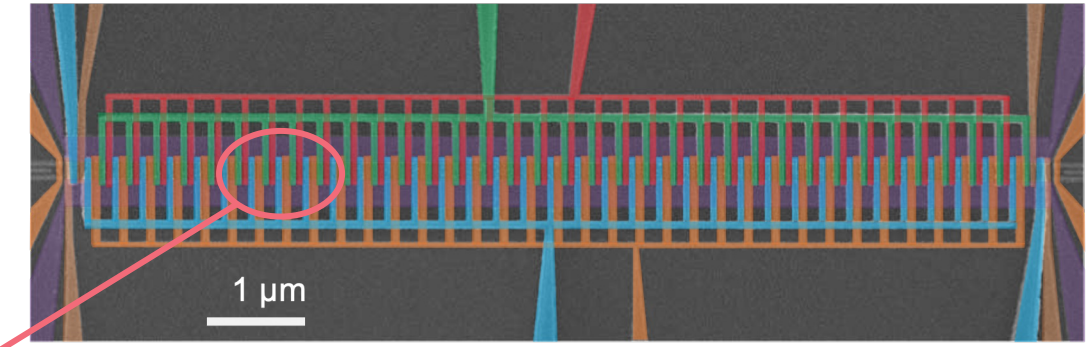
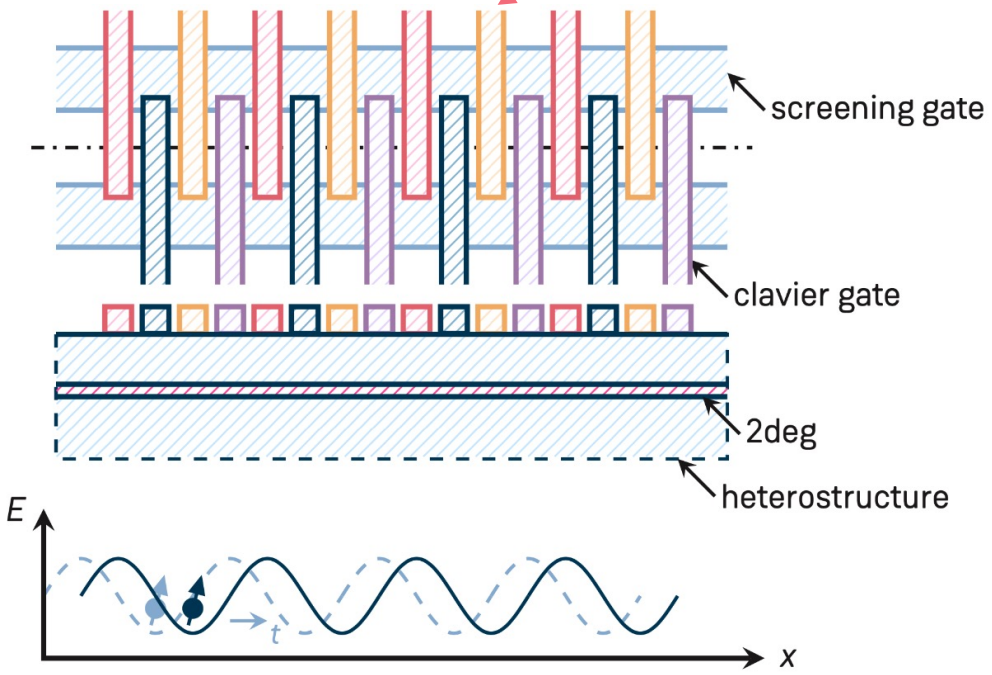
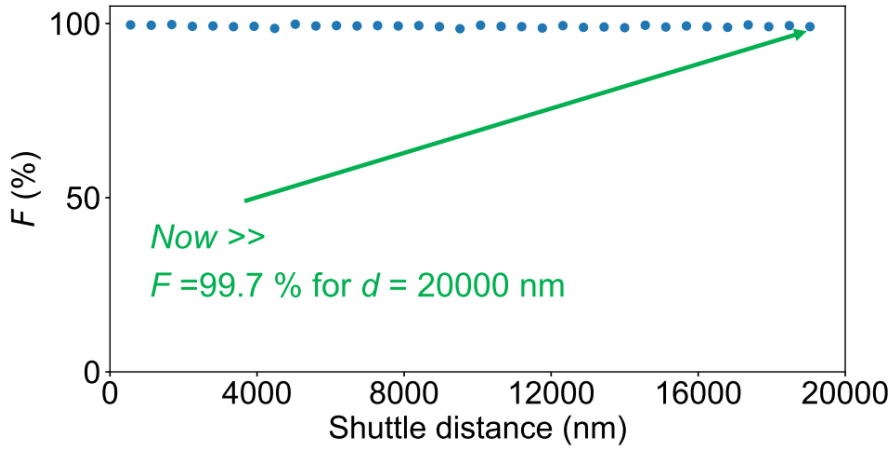
We can create a moving potential with 4 signals







Charge Shuttling with >99 % fidelity possible

Xue *et al.* arXiv:2306.16375 (2023)

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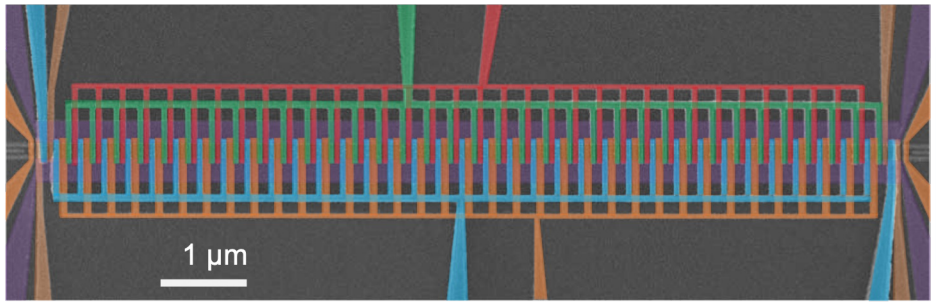
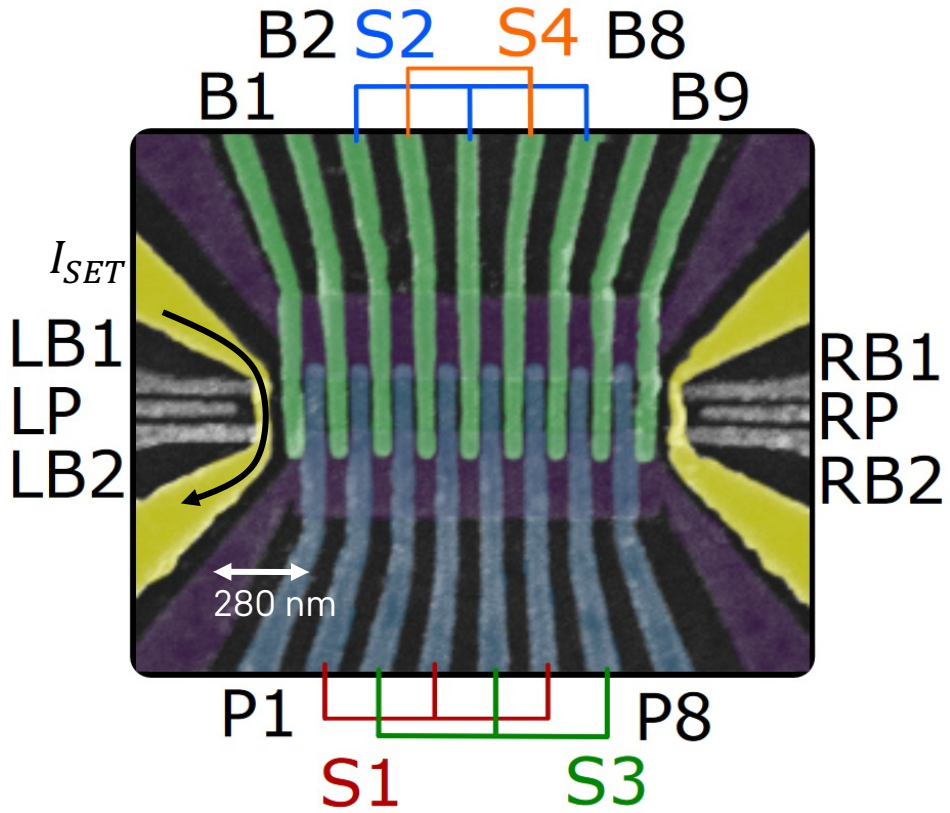
Coherent shuttling is the next step towards a scalable system



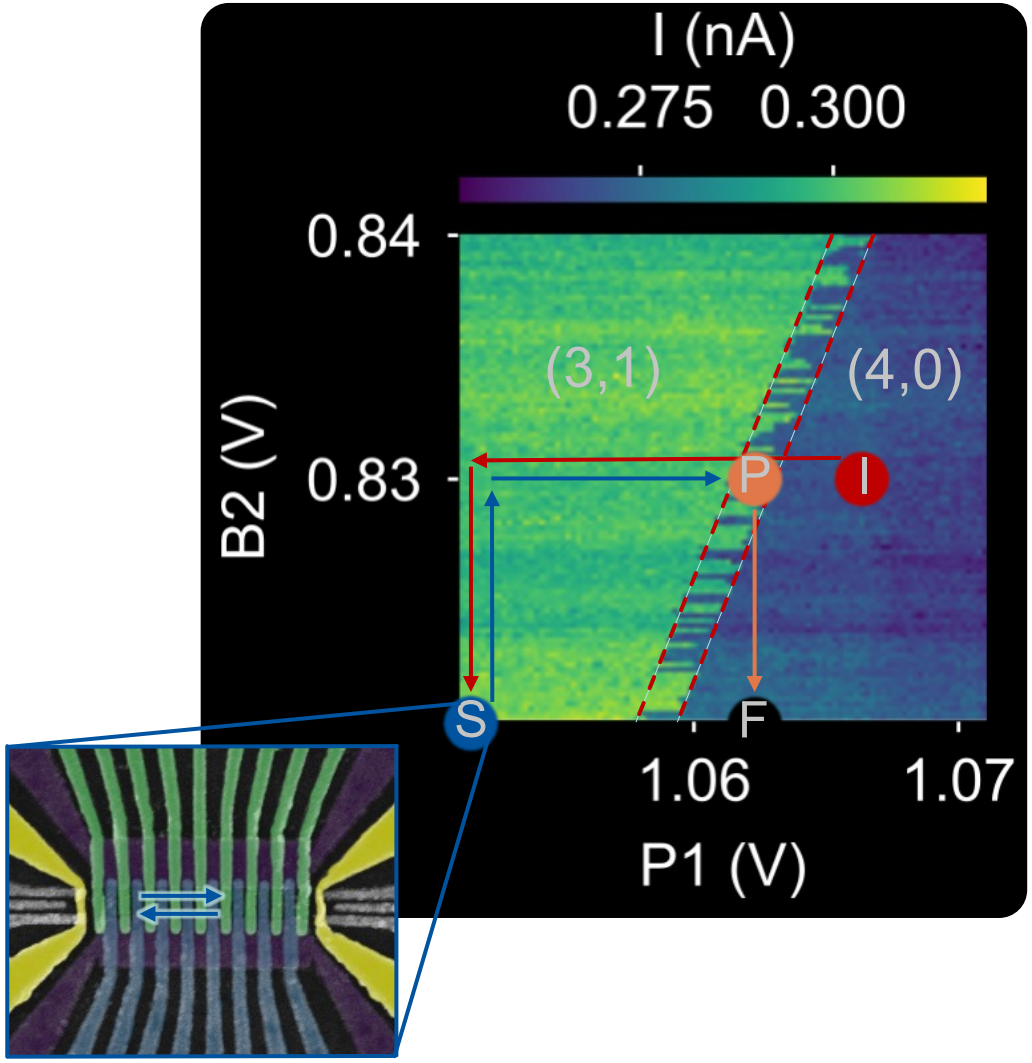
Small scale test device



No micromagnet on device yet
Still on nat. silicon

Struck *et al.* arXiv:2307.04897 (2023)
Seidler. I et al. npj Quantum Inf 8, 100 (2022)

Load and separate an EPR-Pair



- DQD (4,0)-(3,1) → wider Pauli Spin Blockade (PSB)
- Barrier to SET closed → longer PSB region

I Initialization of S(4,0) EPR pair

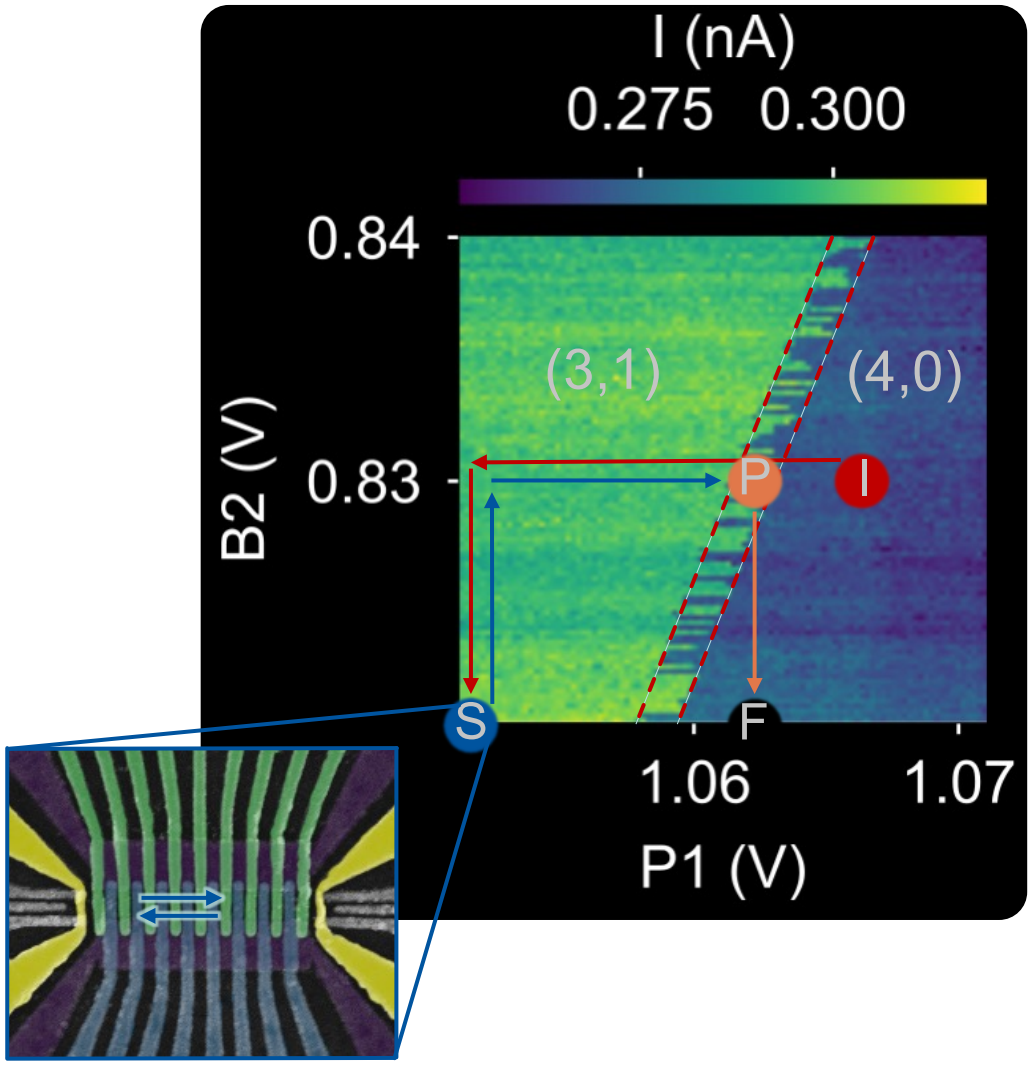
S Separation into S(3,1), interdot barrier closed and shuttle → S-T_0 oscillations due to ΔE_z

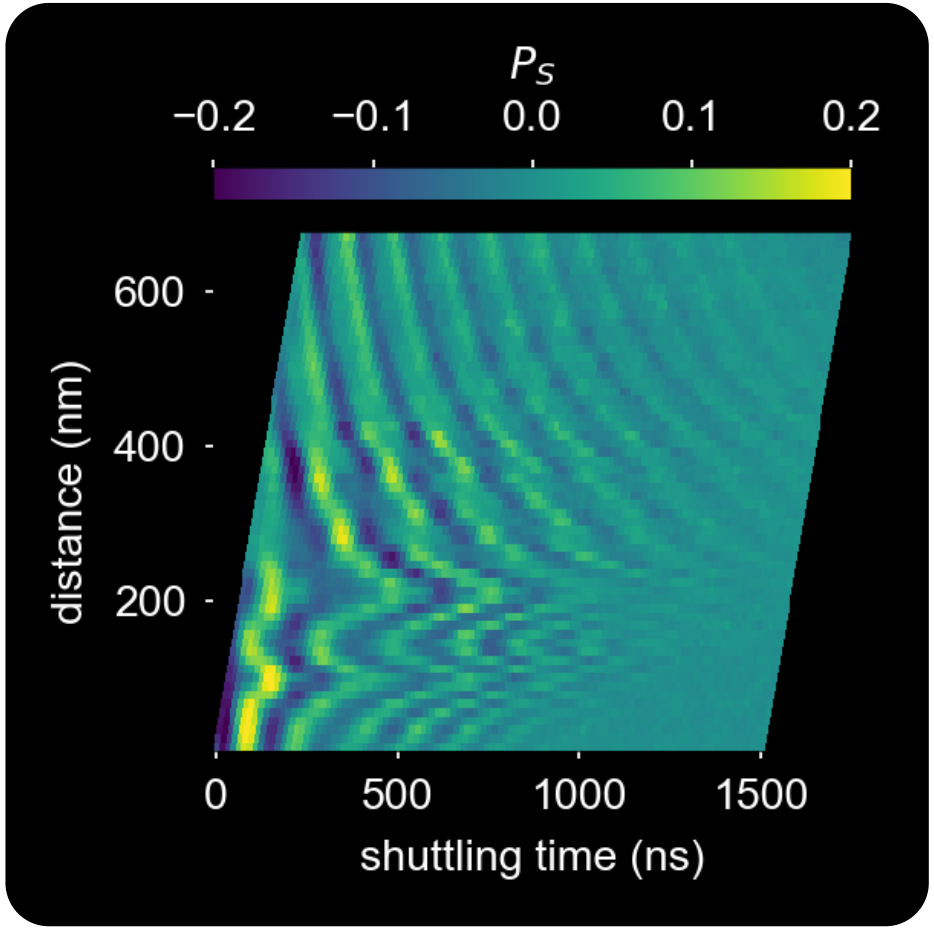
P S(4,0)/T(3,1) via PSB

F Freezing of charge state and readout

Struck *et al.* arXiv:2307.04897 (2023)

We observe coherent oscillations after shuttling





Struck *et al.* arXiv:2307.04897 (2023)

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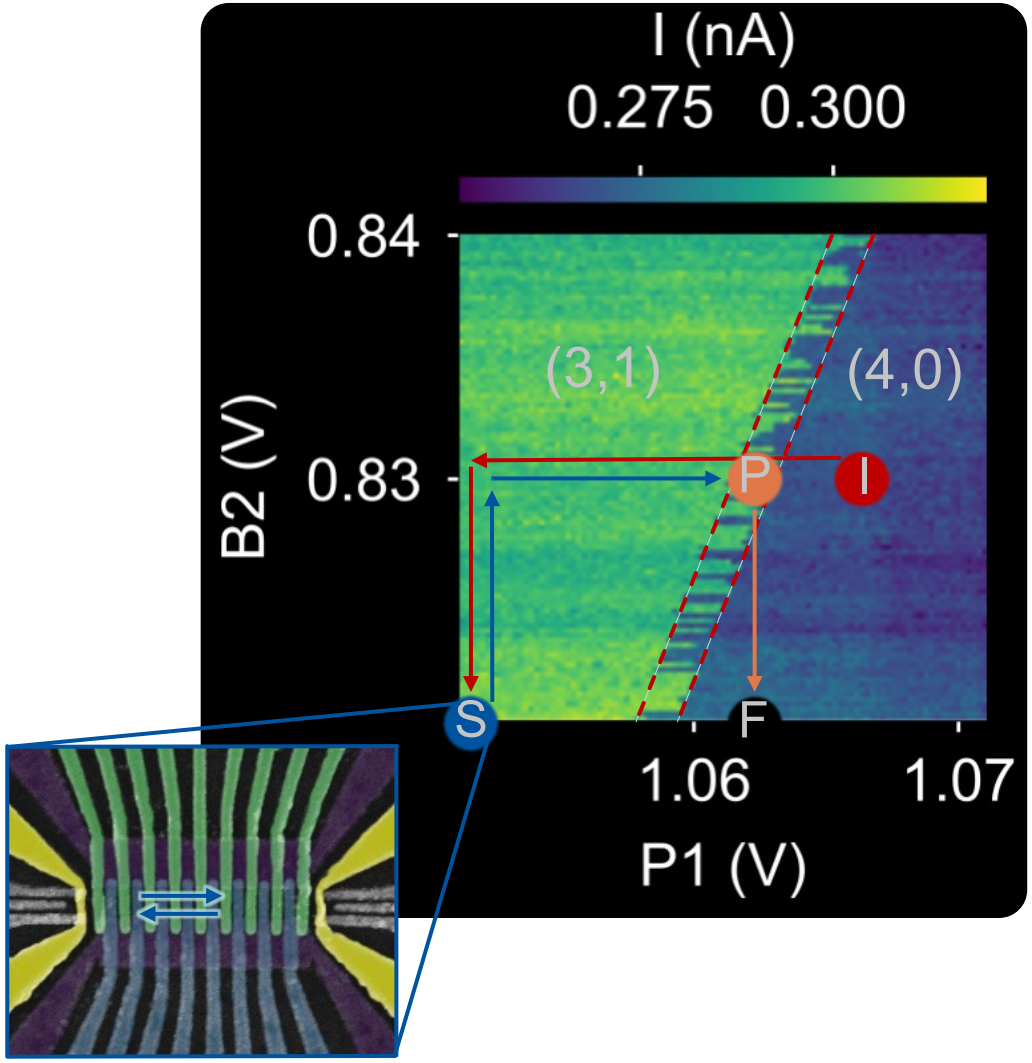
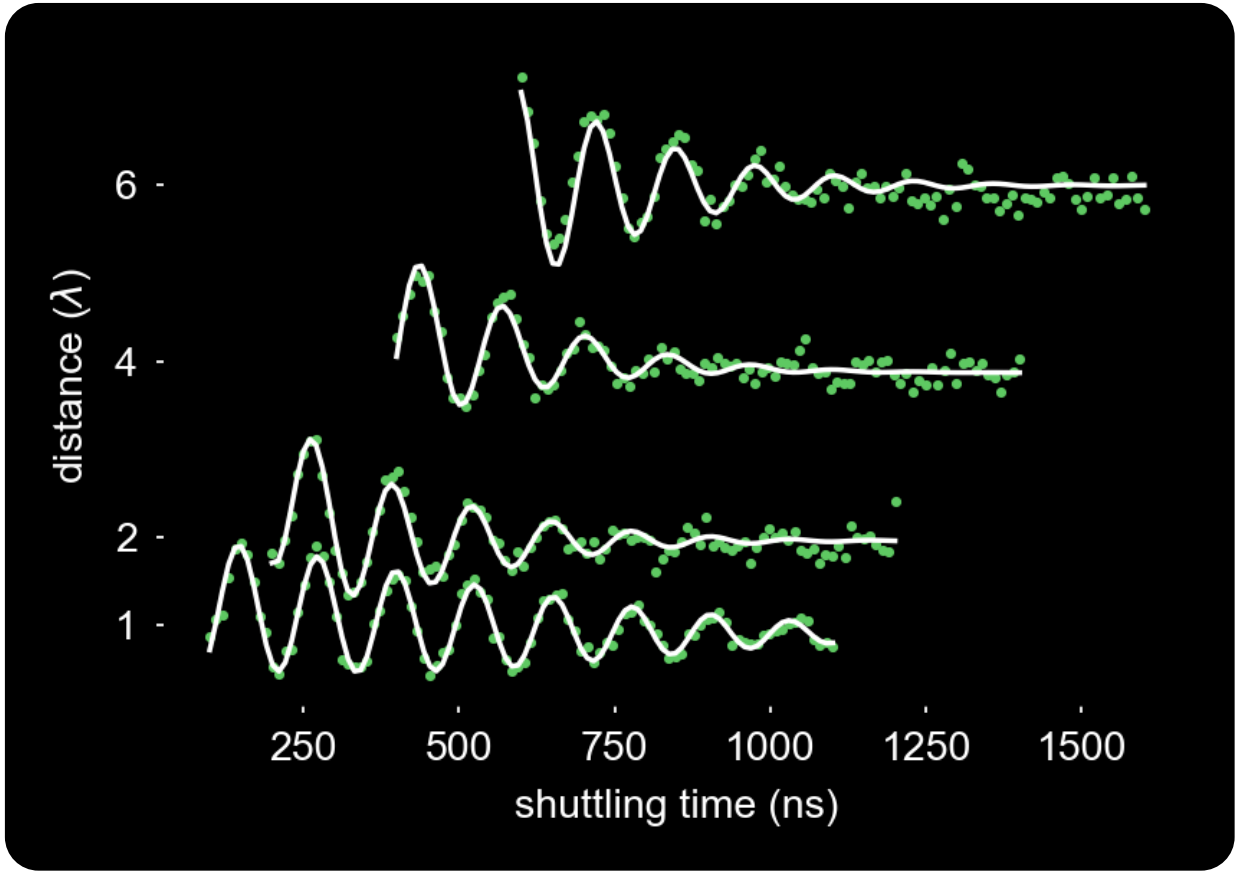
Coherence remains even for larger distances





- Shuttling back and forth multiple times
- Shuttling for up to 1.68 µm

Struck *et al.* arXiv:2307.04897 (2023)

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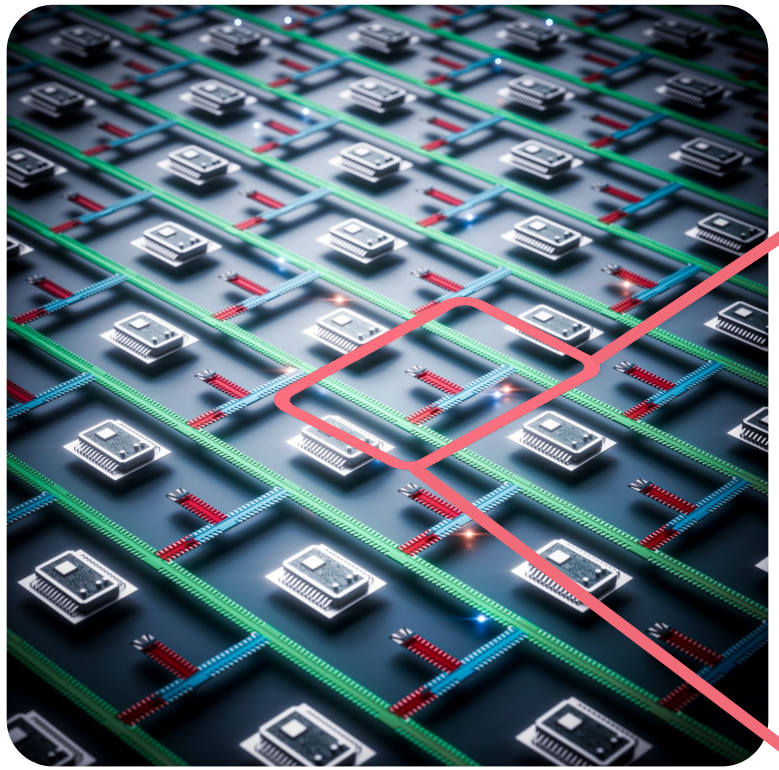
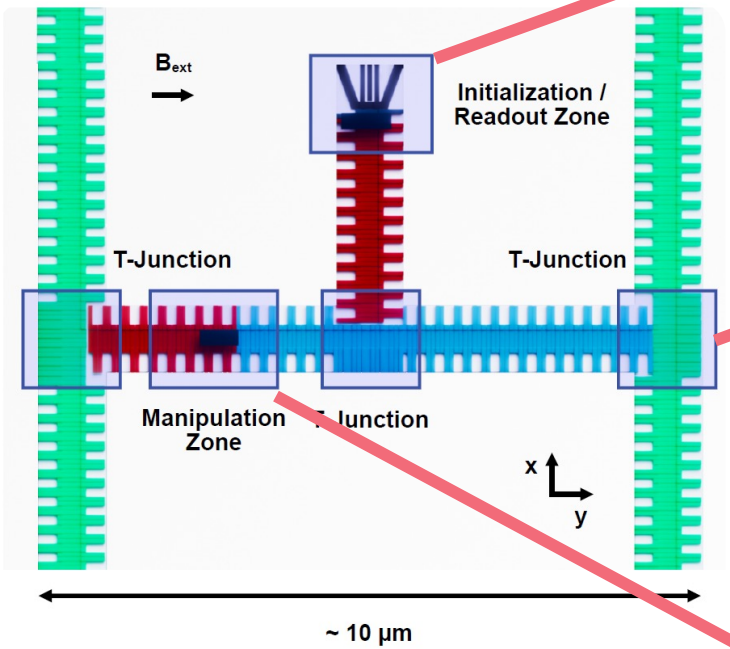
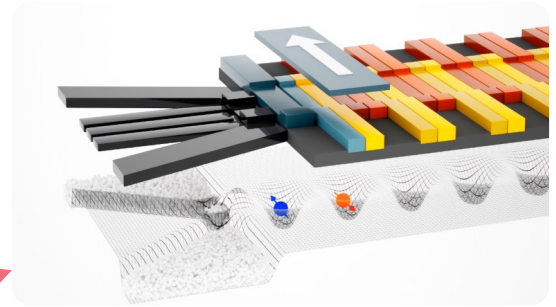
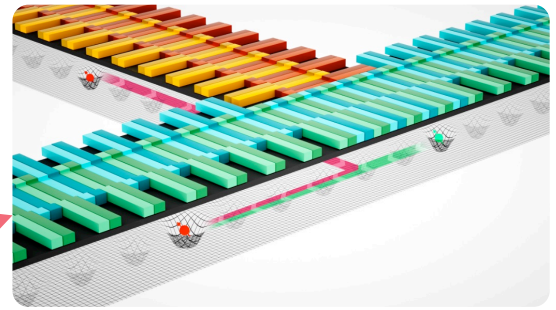
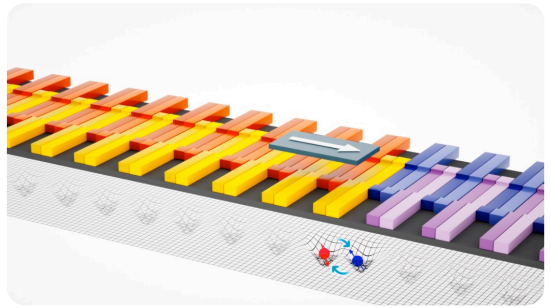
We define a scalable unitcell based on shuttling











Kuenne, Willmes *et al.* arXiv:2306.16348 (2023)

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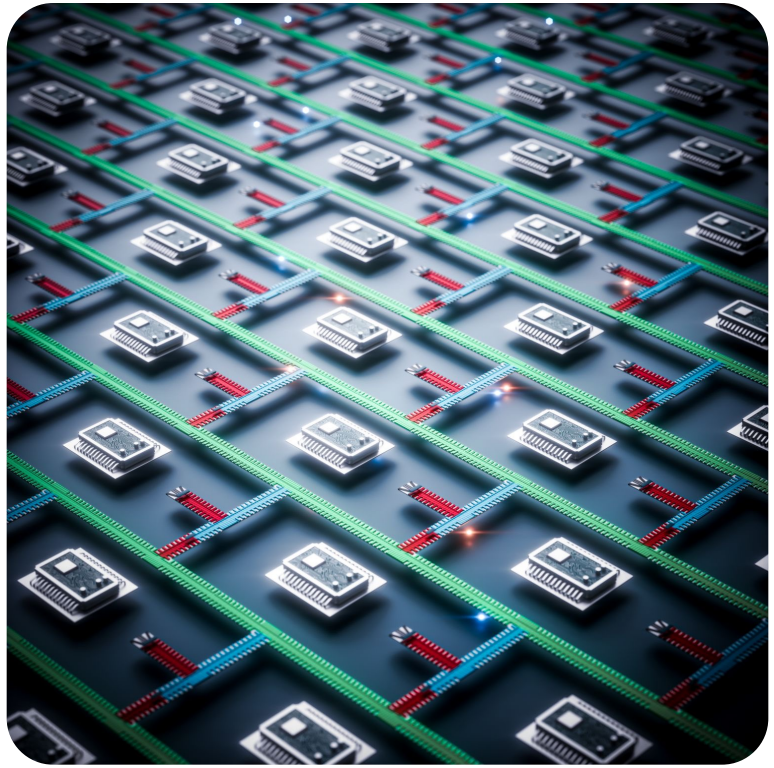
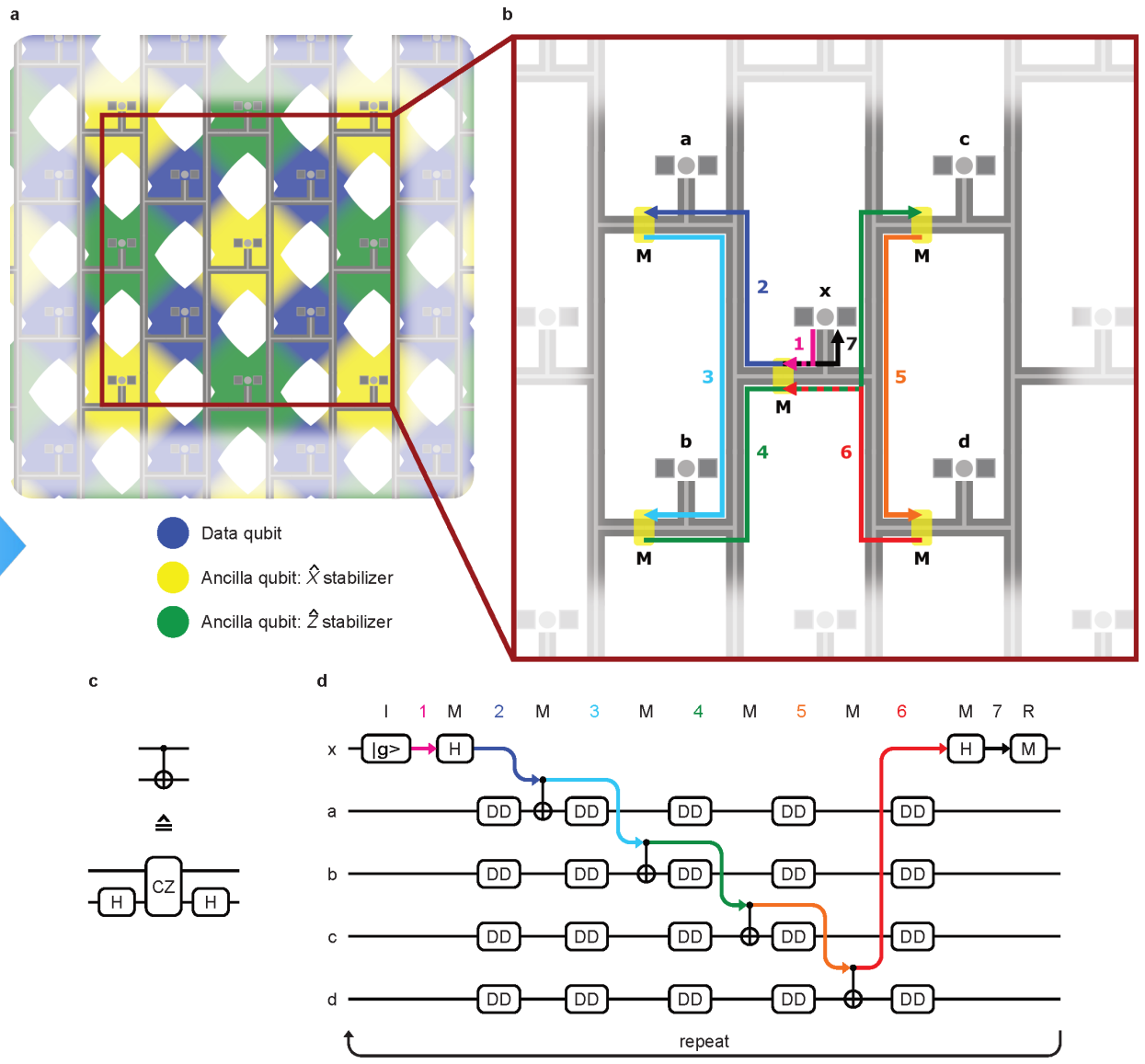
Our architecture easily implements surface code





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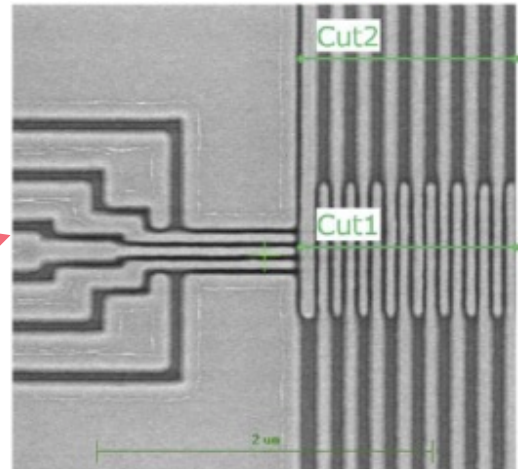
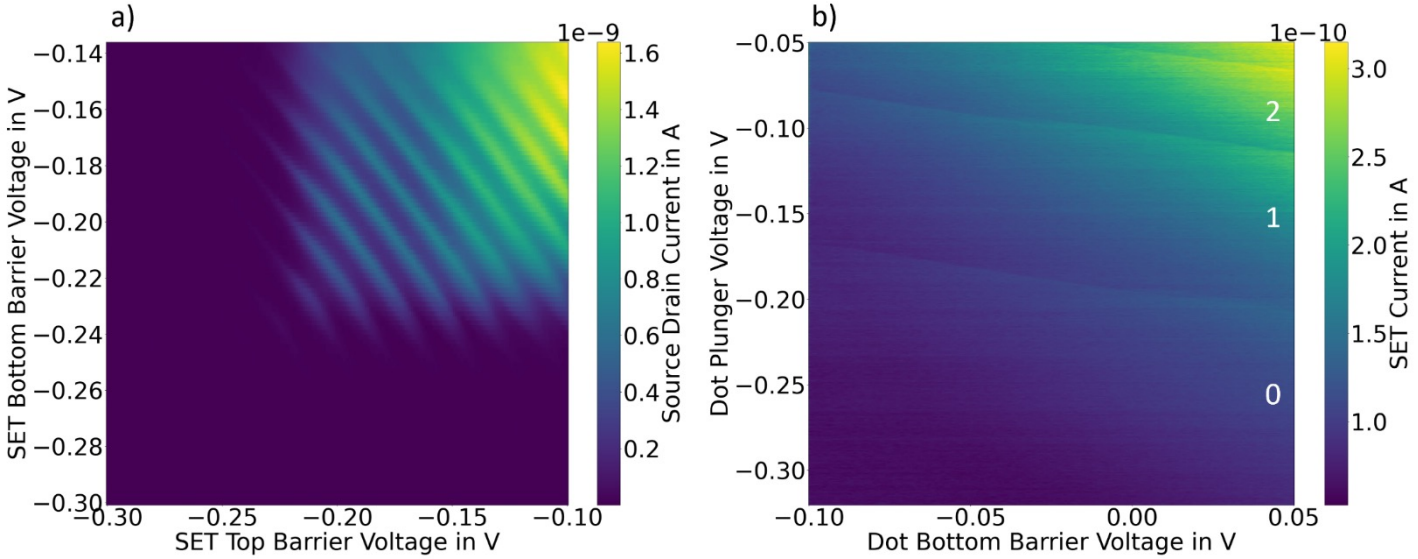
First devices fabricated by industry partners



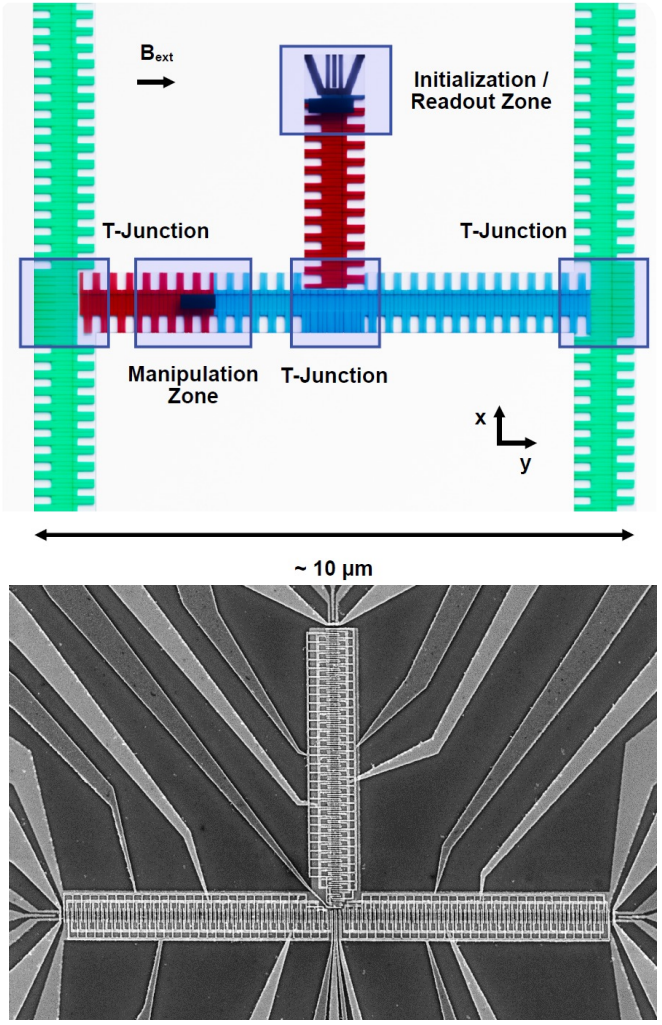
- Fist devices fabricated by Infineon
- State of the art performance and noise levels

- **Next:** Integration of micro-magnets and qubit measurements

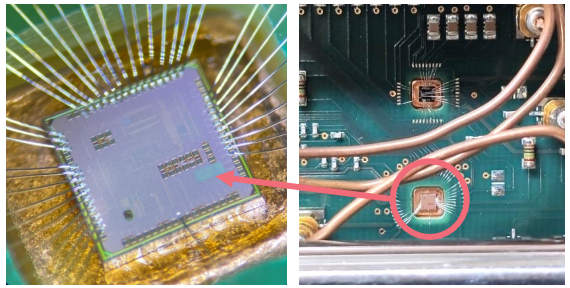


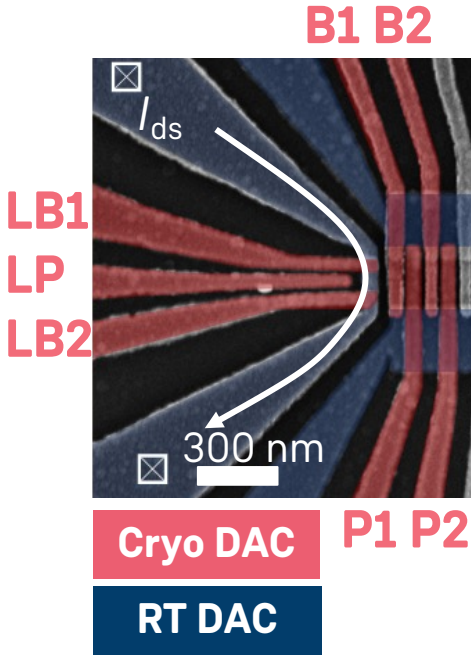
Next steps towards a fully integrated spin qubit processor

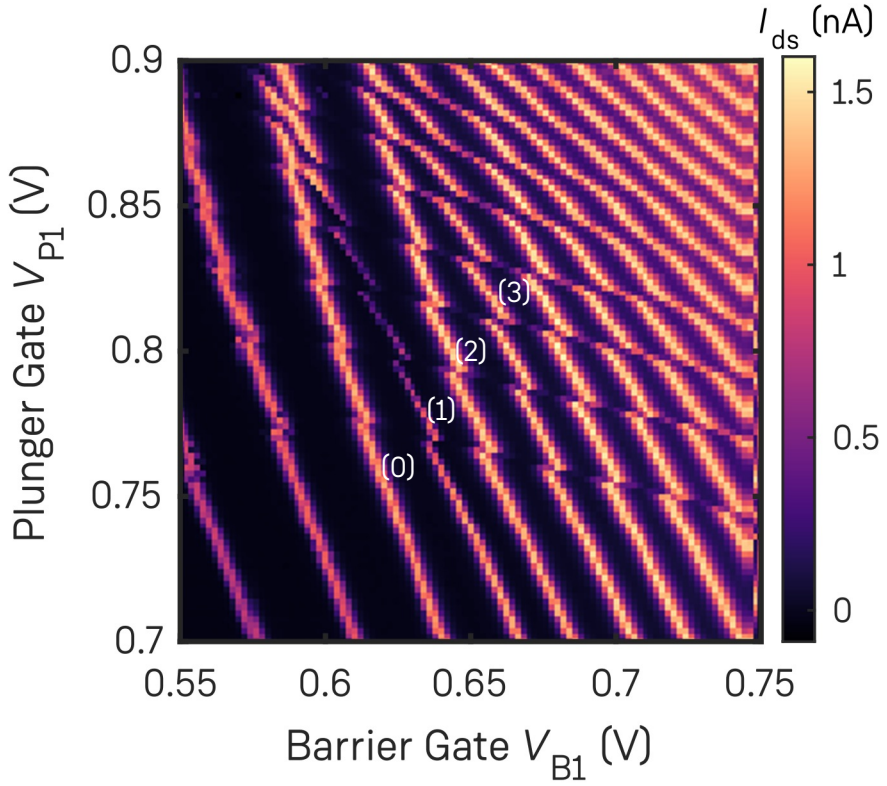
Validation of quantum layer



Integration of custom electronics







Talk by Lea Schreckenberg tomorrow

Schreckenberg, Otten *et al.* ESSCIRC 2023

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Stefan van Waasen

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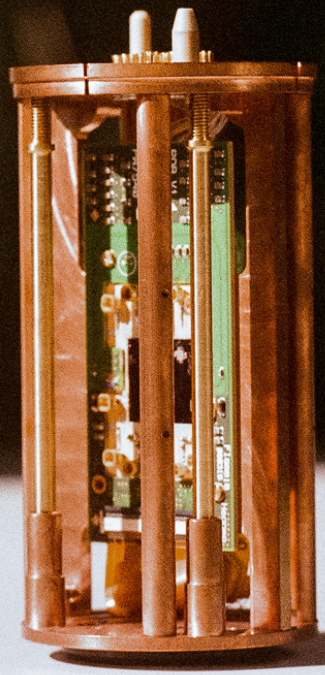

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