A single hole spin with enhanced coherence in natural silicon

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https://arxiv.org/pdf/2201.08637.pdf

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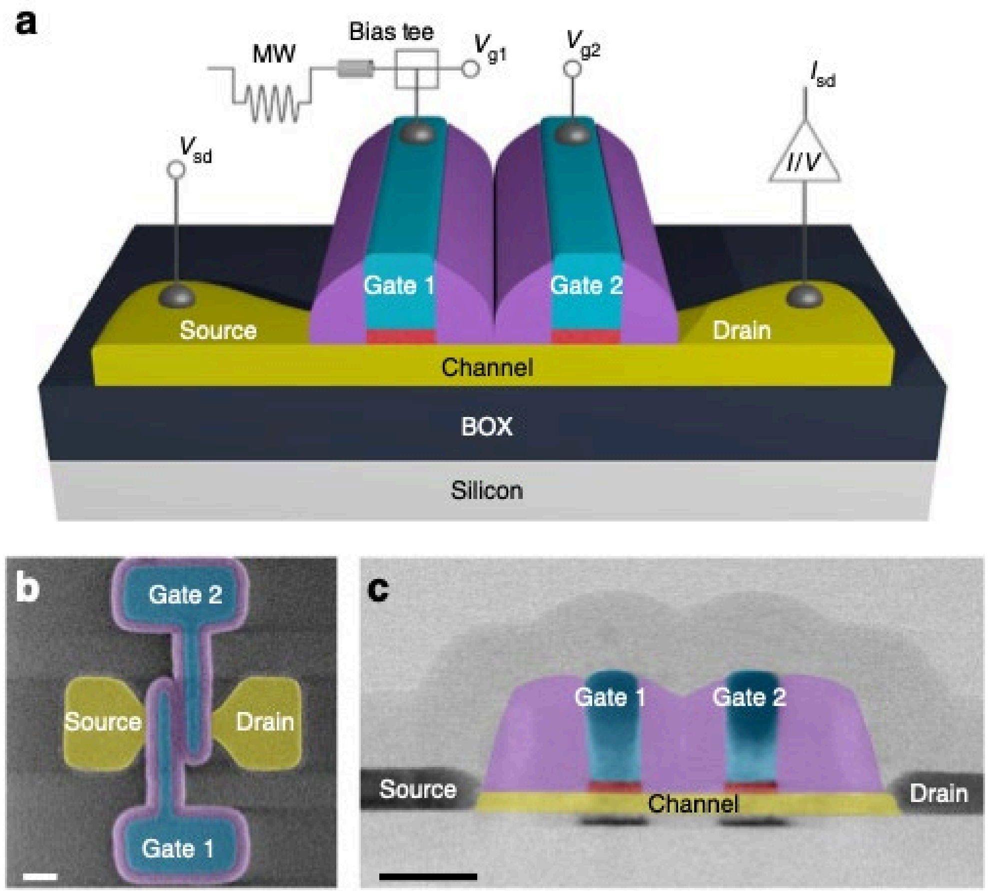
Nico Hendrickx

LETI devices

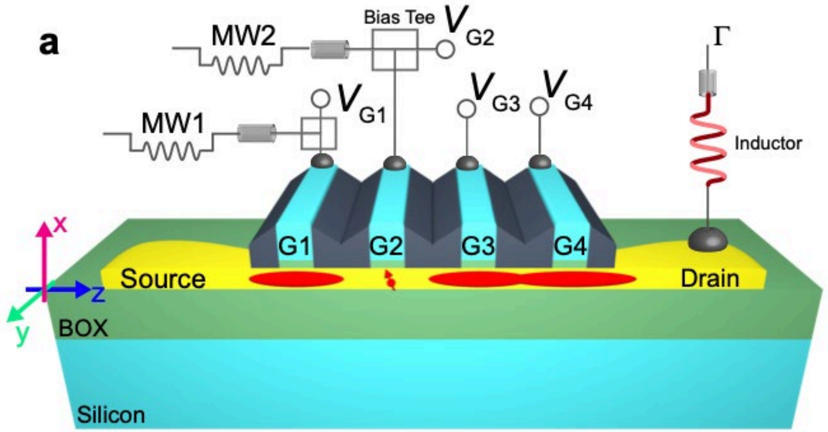
- Silicon finFET devices
- SOI fin
- Transport qubits in 2016
- Optical + ebpg
- LETI/Copenhagen/UCL/EPFL

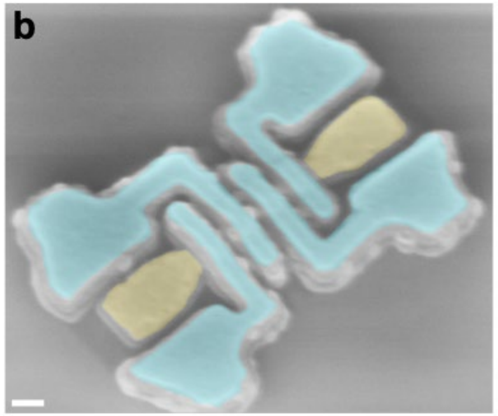


Maurand et al. Nat. Comm. 13575 (2016)
https://www.nature.com/articles/ncomms13575.pdf

Device design (fig. 1a-b)

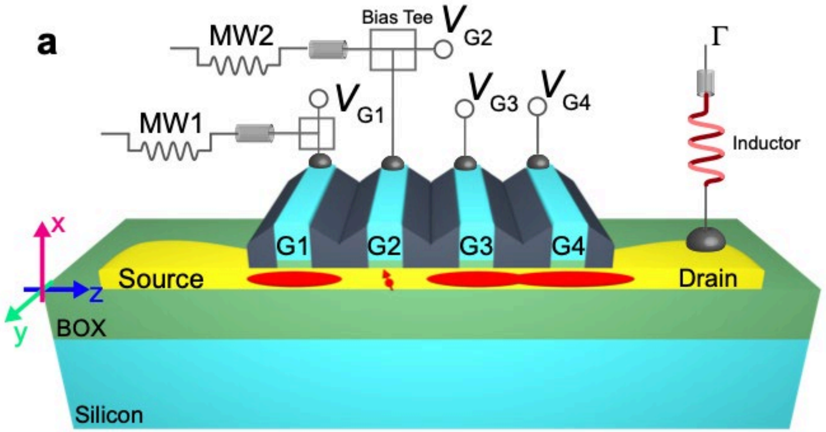
- Gate stack:
  - Metal topgate
  - 250 nm SiO_2
  - 35 nm Si_3N_4 (etch stop)
  - 50 nm polySi
  - 6 nm TiN
  - 6 nm SiO_2
  - Natural Si fin
  - BOX
  - Doped Si (back gate)

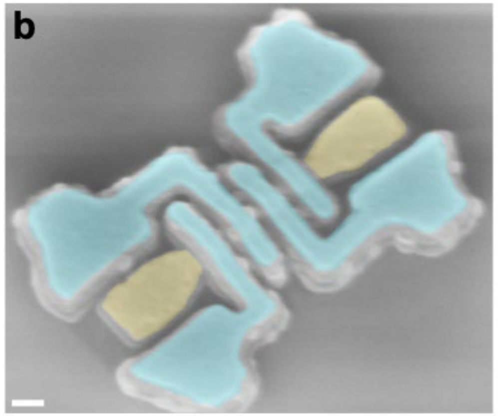




Device design (fig. 1a-b)

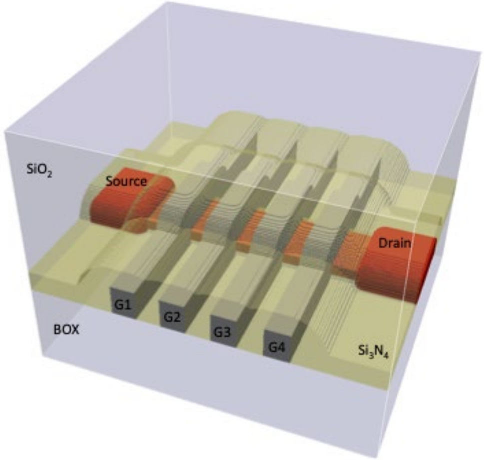
- Four gate device
  - G3/G4 large dot (sensor)
  - G1 dot to screen S (no mention of effect)
  - Scalebar = 100 nm

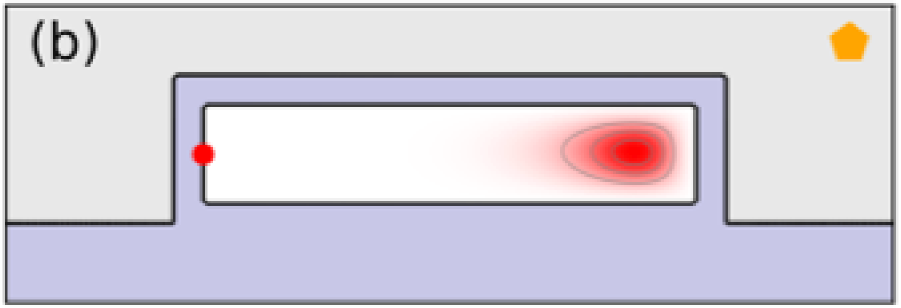


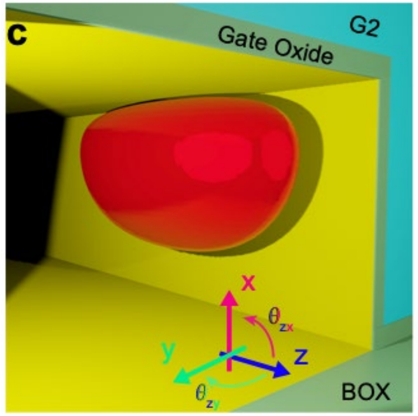


Dot accumulation (fig. S2 / S4b)

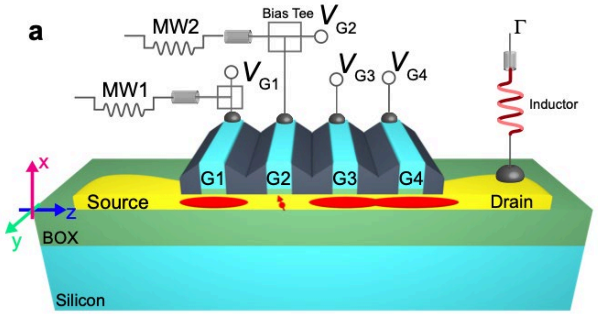
- Poisson solver
  - Two corner dots are preferred
    - E-field is stronger
  - Assume: degeneracy due to disorder
    - Result: only a single corner dot
      - Strong intermixing of LH/HH states



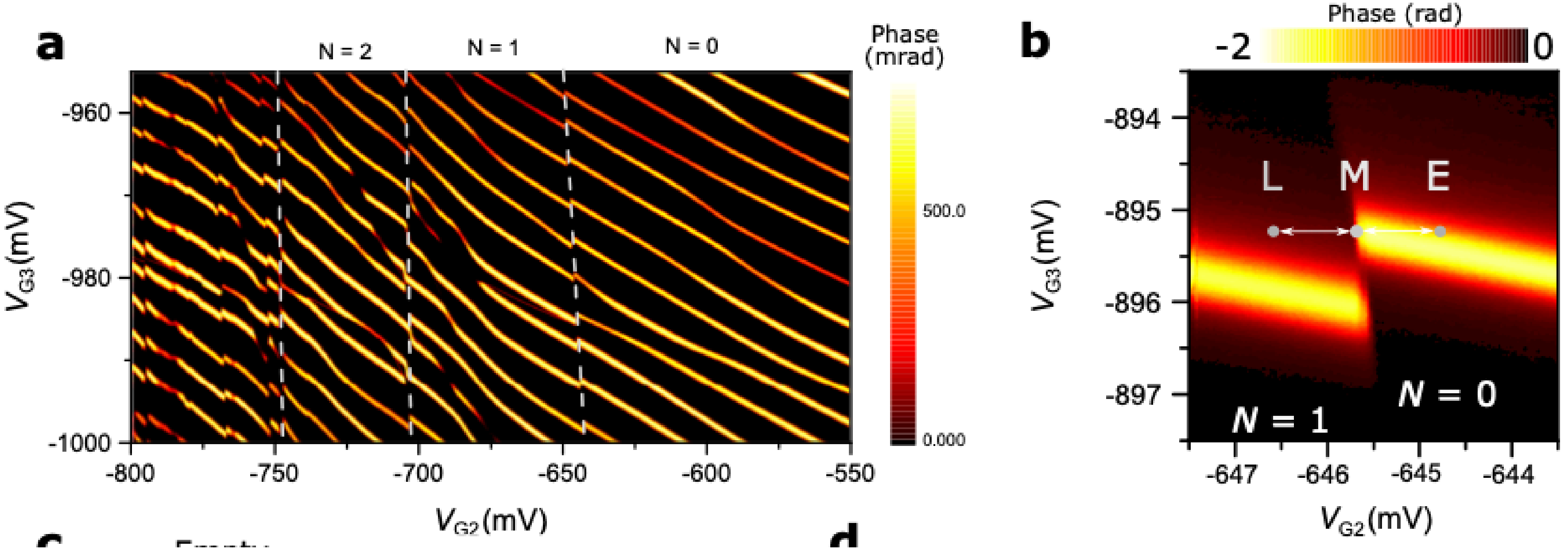




Charge stability diagram (fig. S1)

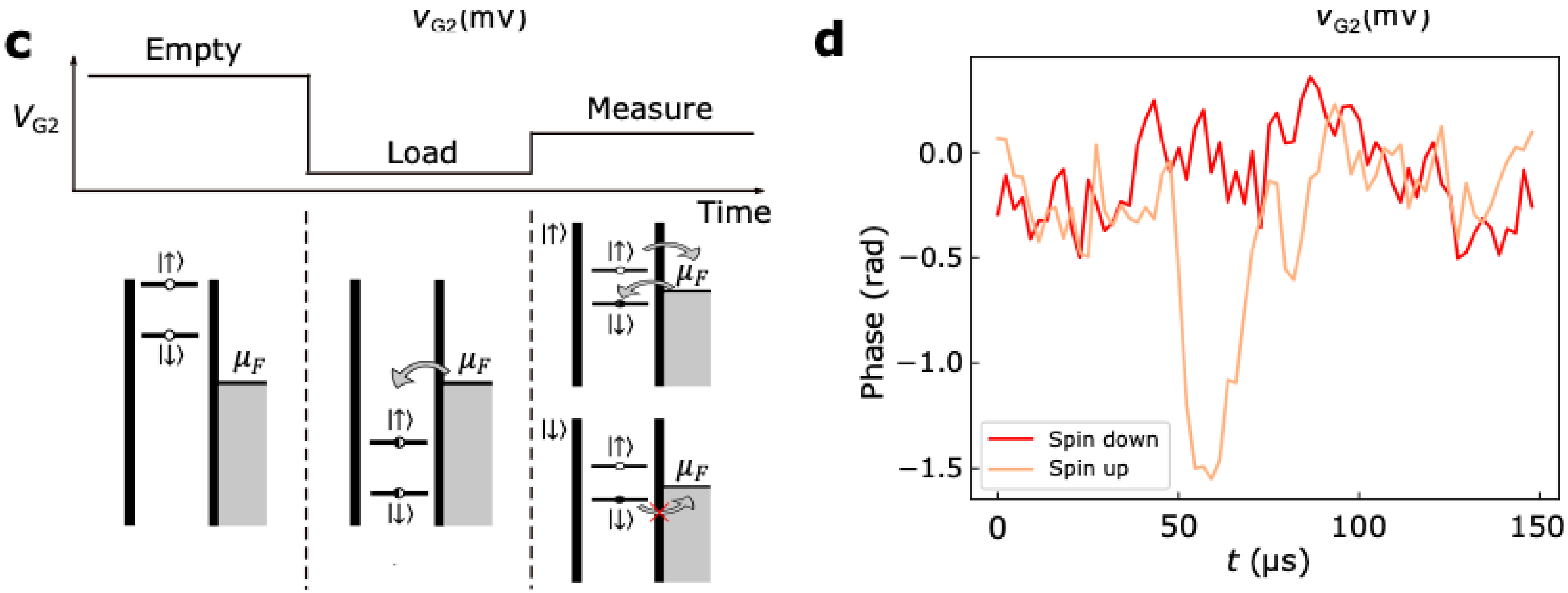


- Off-the-shelve resonator connected to drain.
- D <-> G3/G4 dot transitions as sensor

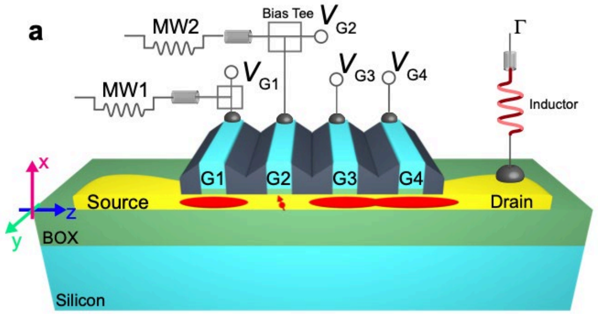


Spin readout (fig. S1)

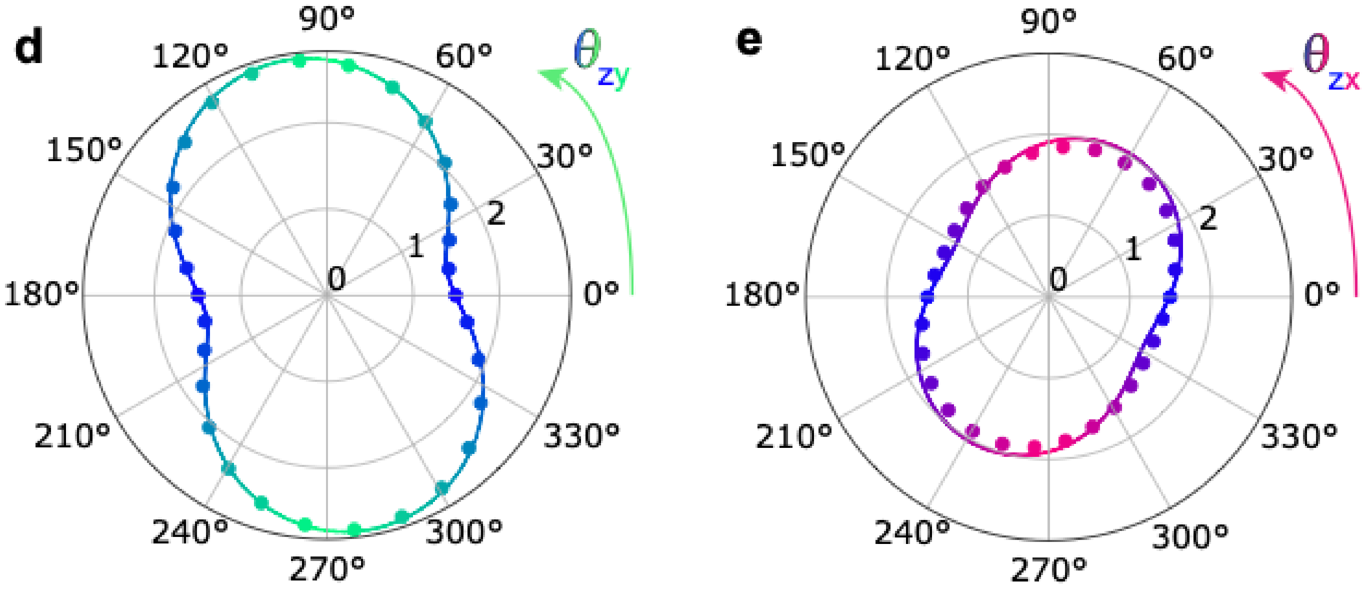
- Elzerman readout



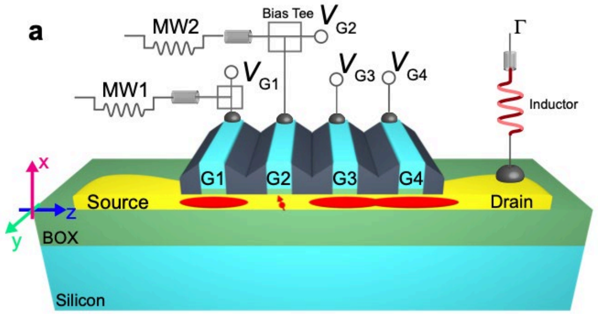
g-factor measurement (fig. 1d/e)



- Measure resonance frequency a.f.o. field orientation (B = ??)
- Not very anisotropic
- No XY data (1 axis of their vector magnet broken …)



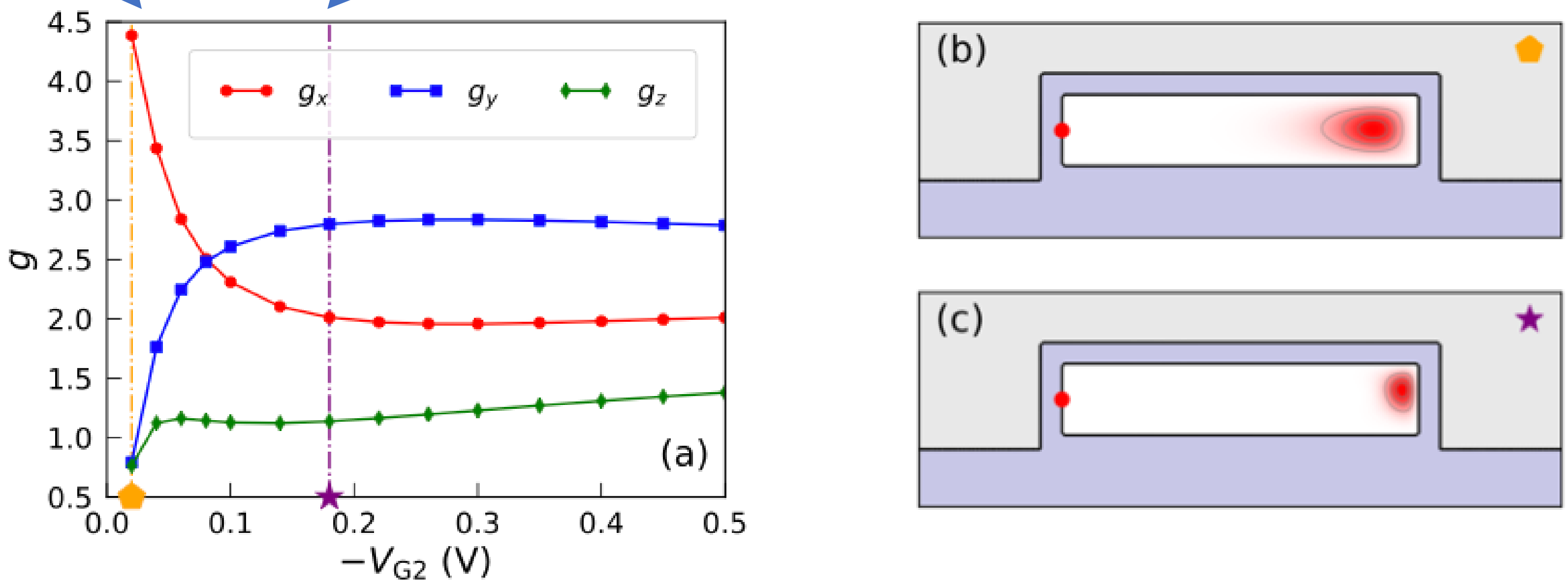
g-factor measurement (fig. 1d/e)



- Not very anisotropic
  - Result of the strong HH/LH mixing (due to lateral fields)

Dominant Ex
more 'planar'
purer HH

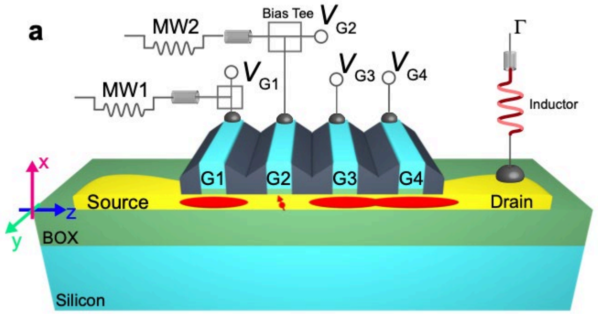
Ex + Ey
more 'corner'
mixed LH/HH



g-factor fit (fig. S5)

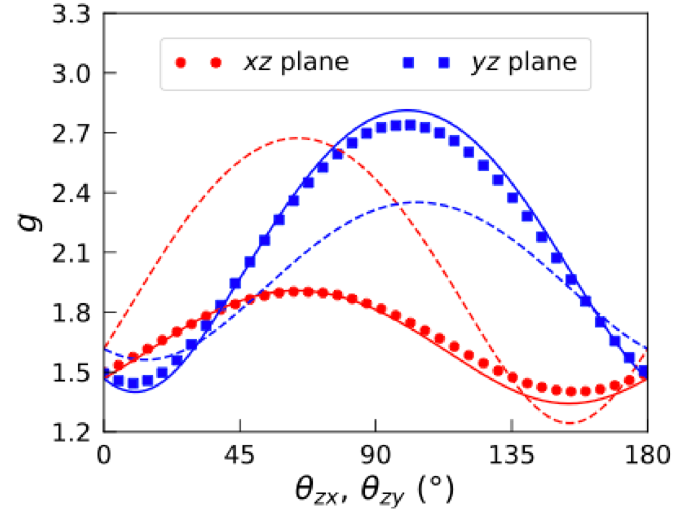
- Rotational shift
  - 35 deg shift in ZX
  - 10 deg shift in ZY
  - In modelling: assume B-field misalignement
    - Hypothesis is cool down strain (but polySi gates ?)
    - shear strain: 0.1 %

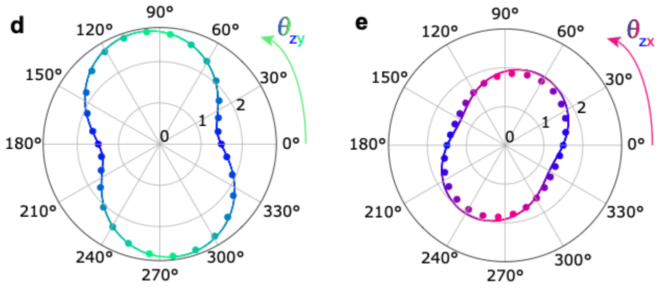
- Discrepancy in size
  - Disorder
    - σ_{trap} at Si/SiO2 interface
    - ρ_{trap} in Si3N4 spacer



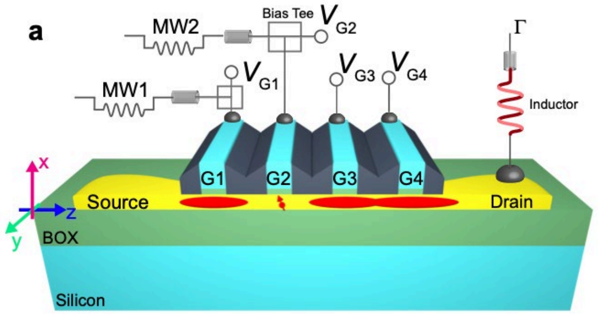
---- no disorder

— disorder





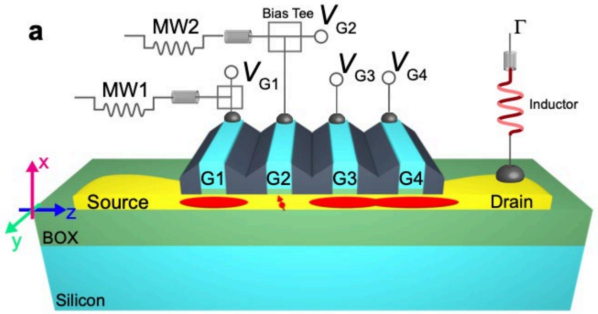
E-field dependence of Larmor frequency (fig. 2)



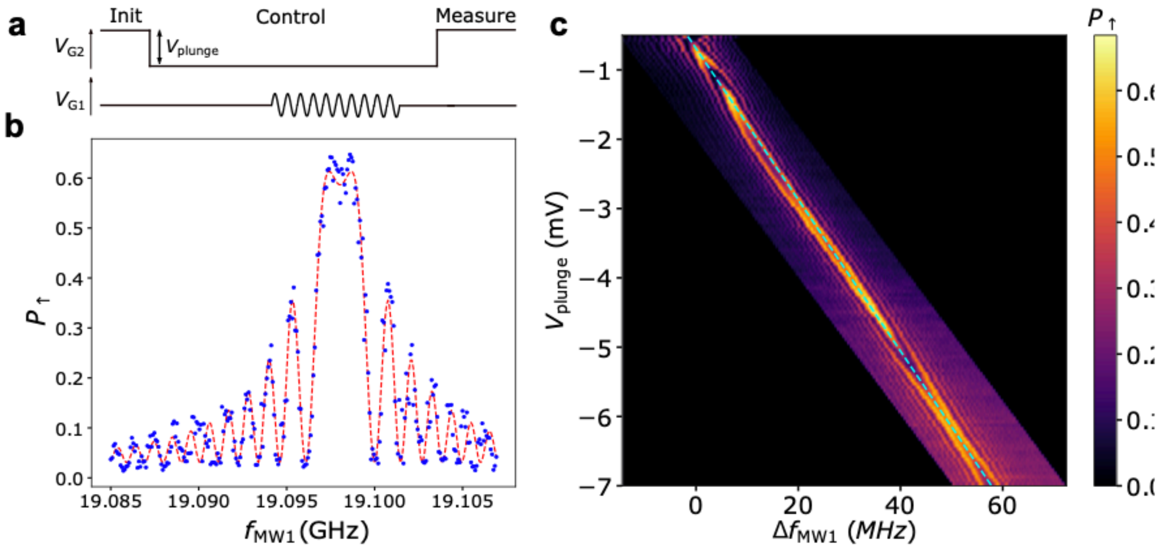
- They coin the term LSES: Longitudinal spin-electic susceptibility
  - i.e. $\mathrm{LSES} = \frac{\delta f_q}{\delta V_{gate}}$

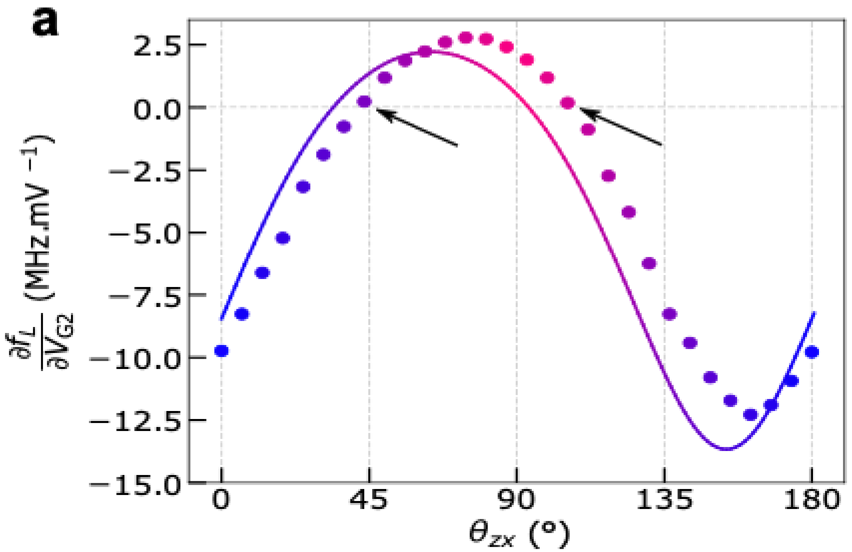
- Assumptions:
  - G1 purely parallel
  - G2 purely perpendicular
  - But also: "*Note that the action of VG1 is strongly screened by the hole gas beneath*"

LSES of gate 2 (vertical) (fig. 2a / S6)

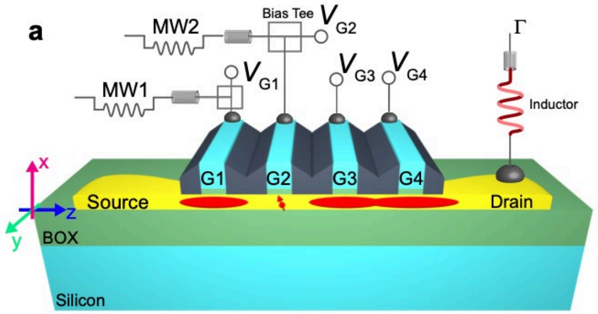


- Probe Chevron while applying gate voltage pulse to G2
- Rabi frequency clearly varying
- Measure df/dV for different angles in ZX plane

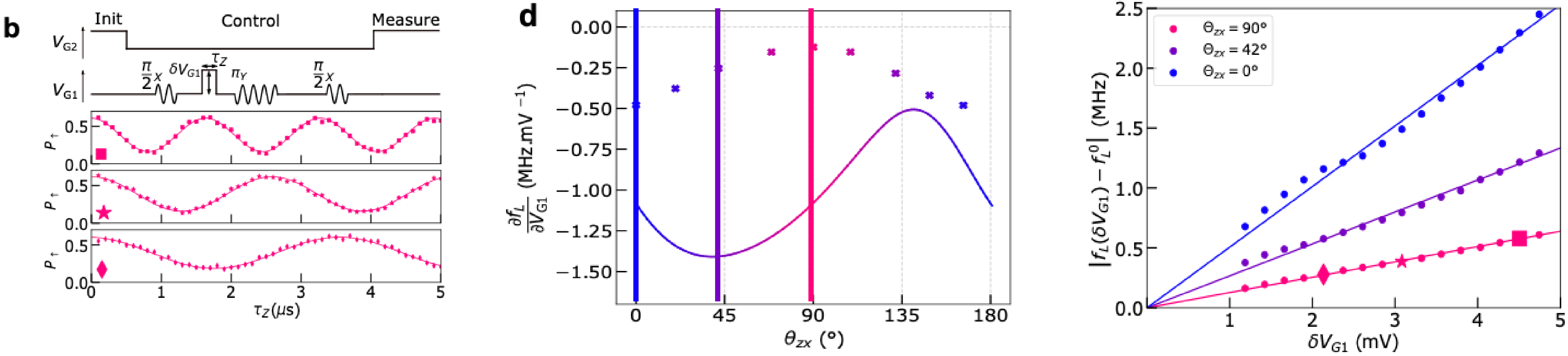




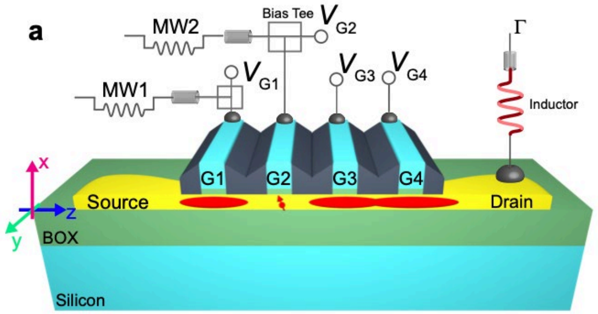
LSES of gate 1 ('horizontal') (fig. 2bcd)



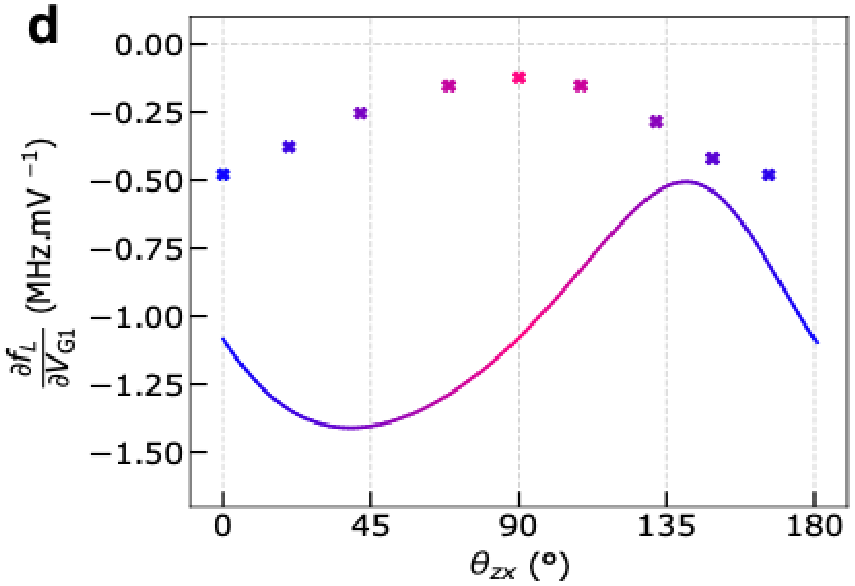
- Use Hahn echo to measure frequency shift
  - Unclear why the different methods for G1/G2
- No zero nodes for G1

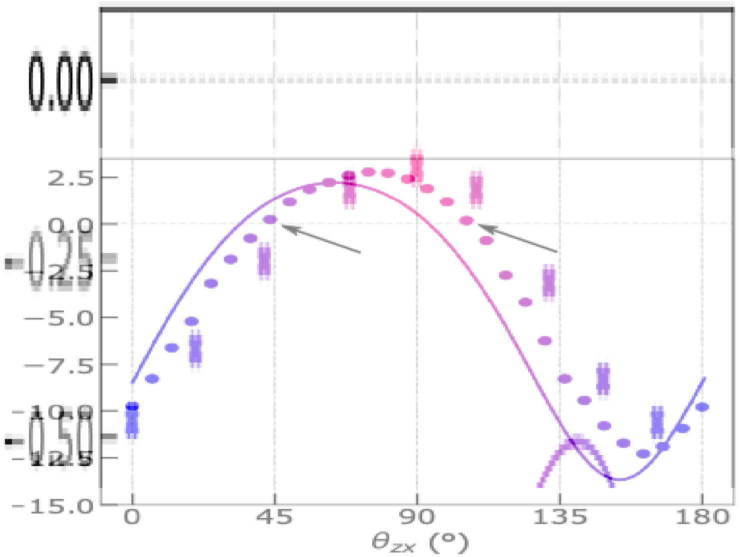


LSES of gate 1 (‘horizontal’) (fig. 2)

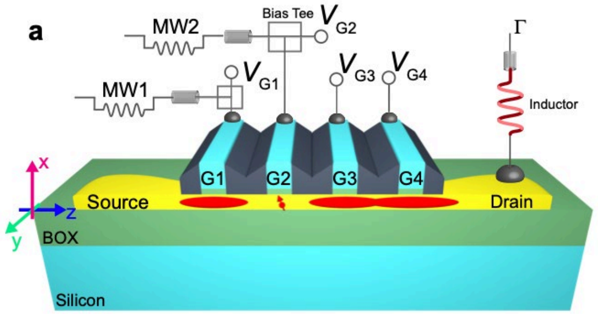


- Large discrepancy with the fit
  - They attribute this to charge disorder
- I wonder if this is a result of the horizontal/vertical assumption

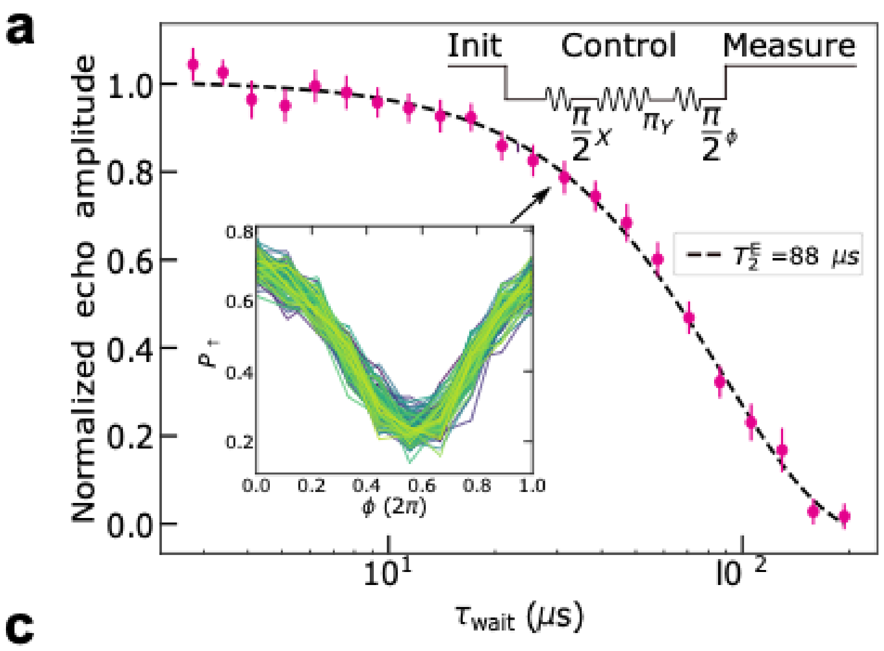




Coherence times (fig. 3a)



- Measure Hahn coherence time to probe coherence
  - This eliminates low freq noise
  - $\exp\left(-\left(\frac{\tau_w}{T_2^E}\right)^{\beta}\right)$
  - $\beta = 1.5$, i.e. noise spectrum $S \propto \sqrt{f}$



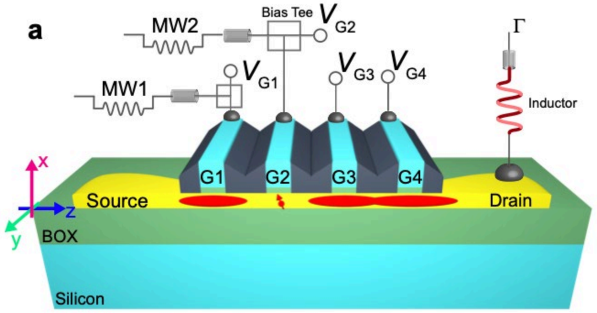
Coherence times (fig. 3b)

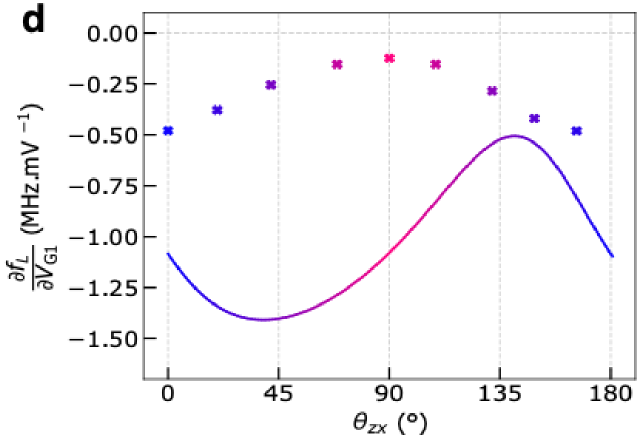
- Measure dependence on angle B in ZX plane
- Fit using obtained df/dV from before

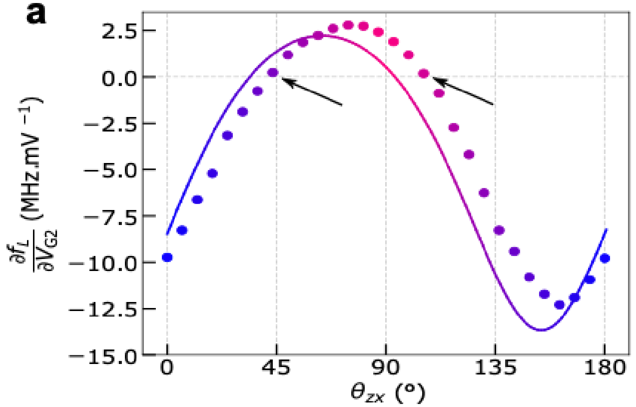
$$\frac{1}{T_2^{\mathrm{E}}} \approx 7.8 f_0^{1/3} \left(\sum_i \left(\frac{\partial f_L}{\partial V_{\mathrm{G}i}} \right)^2 S_{\mathrm{G}i}^{\mathrm{hf}} \right)^{2/3}$$

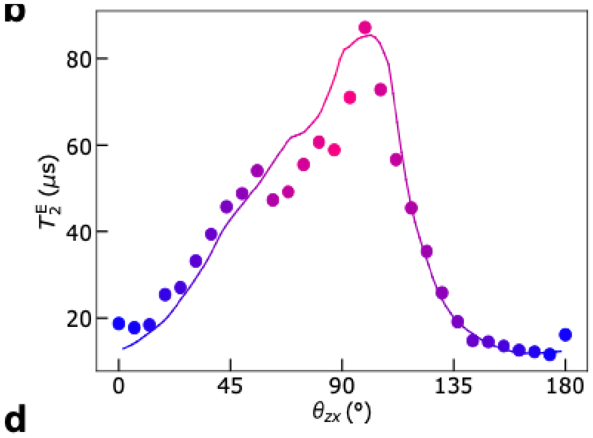
hf = high frequency, not hyperfine!

- Optimum near best points in G1 and G2

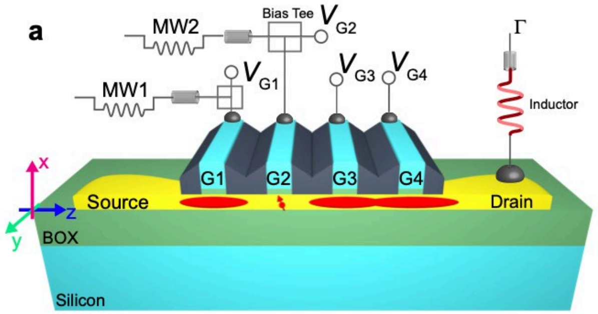








Coherence times



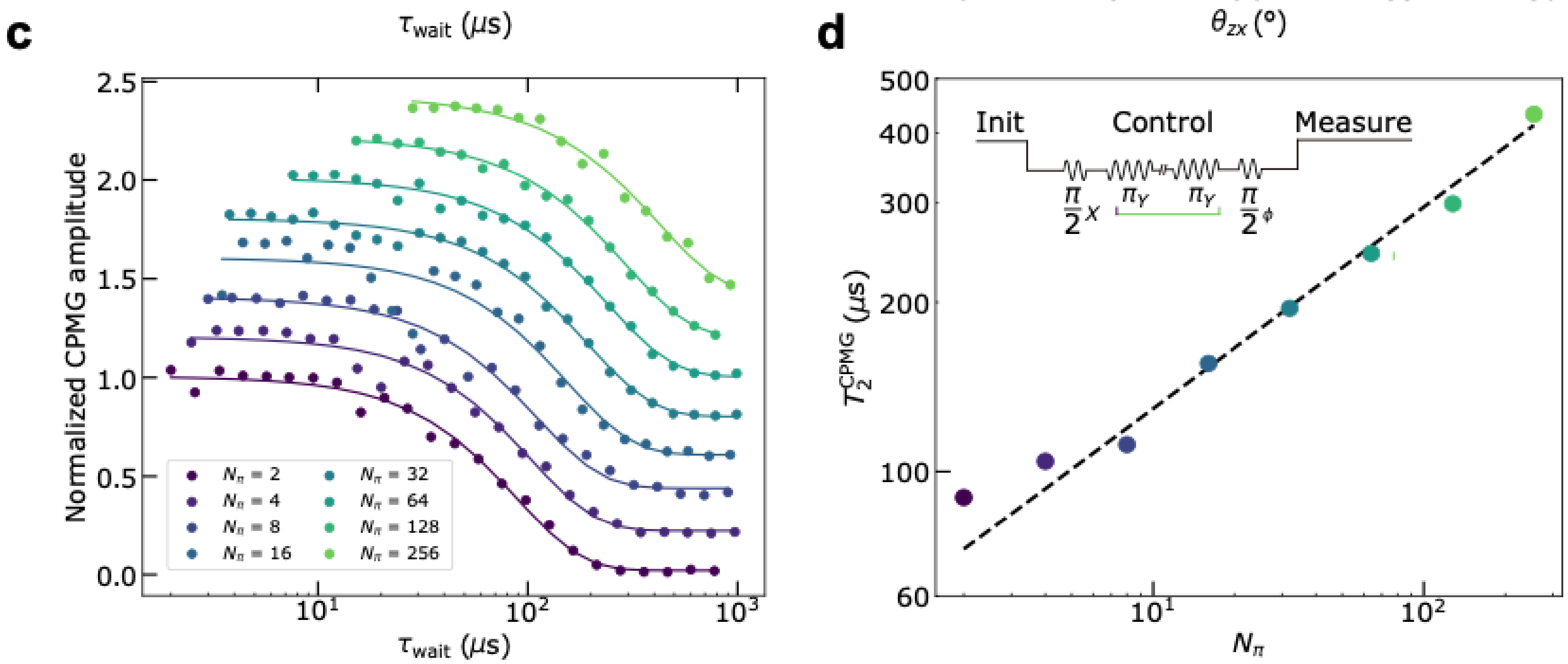
- Would there be much charge noise in z direction?
- Their fit:

$$S_{\mathrm{G1}}^{\mathrm{hf}} = (2.6\,\mu\mathrm{V}/\sqrt{\mathrm{Hz}})^2$$
$$S_{\mathrm{G2}}^{\mathrm{hf}} = (0.1\,\mu\mathrm{V}/\sqrt{\mathrm{Hz}})^2.$$

- Not much comment, but I find it highly unlikely…
  - (or the fins are really dirty)

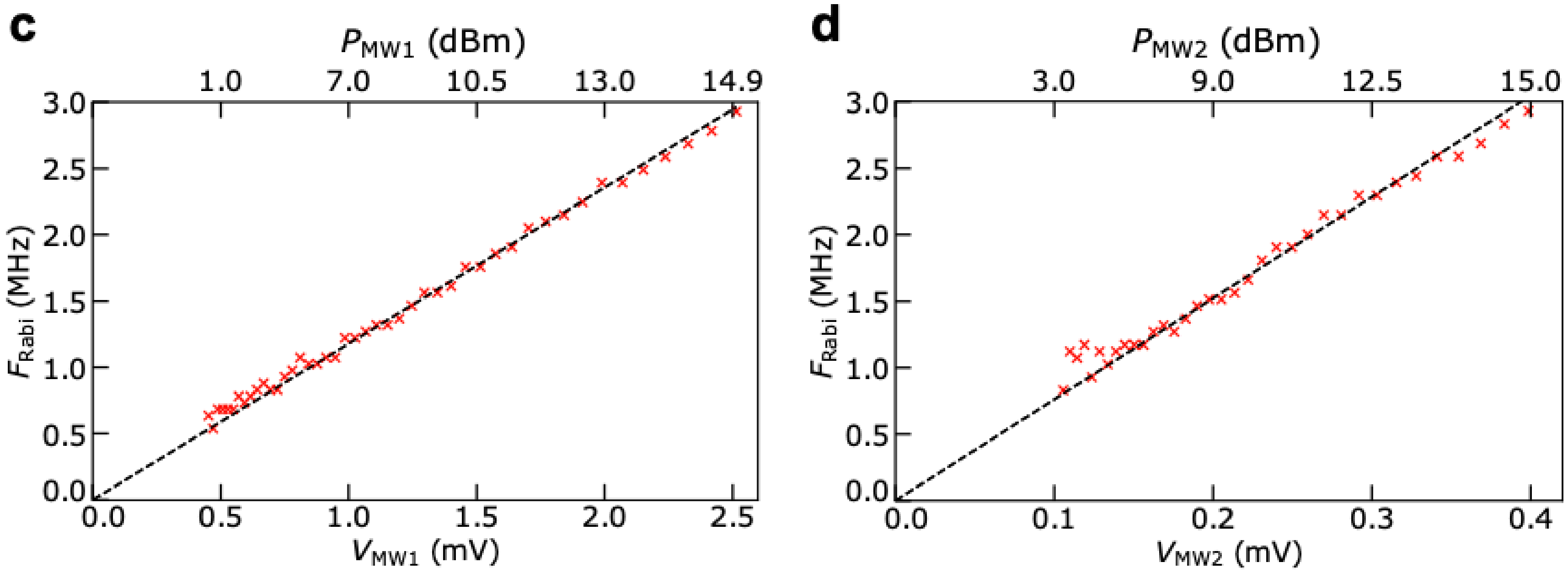
CPMG (fig. 3cd)

- Up to 400 us coherence
- Confirms noise spectrum $S \propto \sqrt{f}$



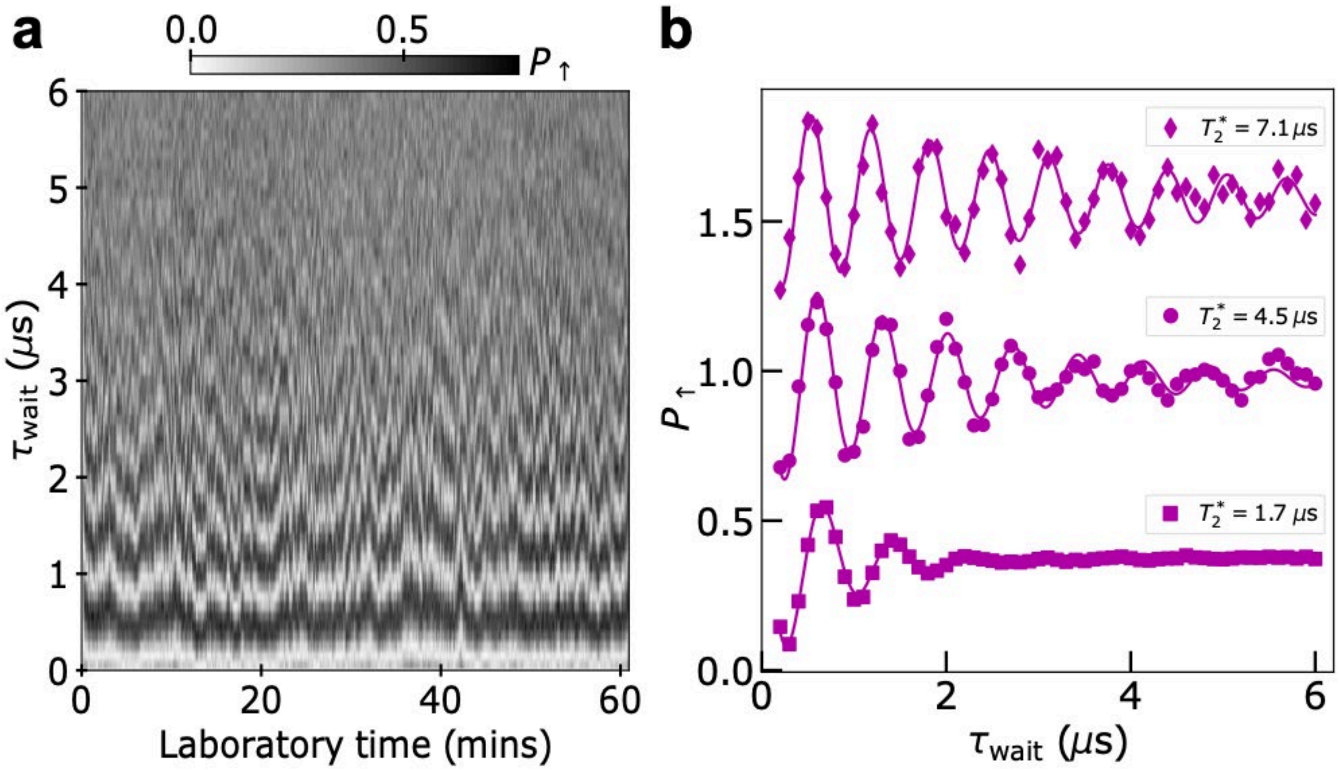
Driving (fig. S7cd)

- Driving possible for all field angles
- Rabi frequency changes, don't specify how much
- At the sweet spot max ~ 3 MHz, a lot stronger driving on G2.



T2* (fig 4ab)

- Measured (at sweet spot) as a function of integration time
  - Decreases for longer measurements, as expected



integration: 5.5 s (1 trace)

integration: 27.5 s (5 traces)

integration: 1 h (600 traces)

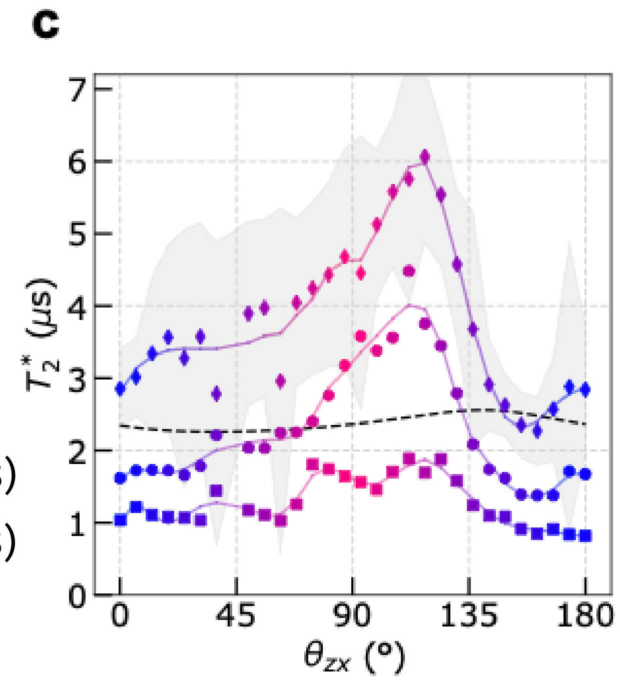
T2* (fig 4c)

- Angle dependence of T2*
- Deminishes for longer integration
  - ➢Low freq noise is not dominated by charge noise
  - ➢Supported by calculation of expected T2* for only the $\sqrt{f}$ noise: ~50 us.
  - ➢Hyperfine?

integration: 5.5 s (1 trace)

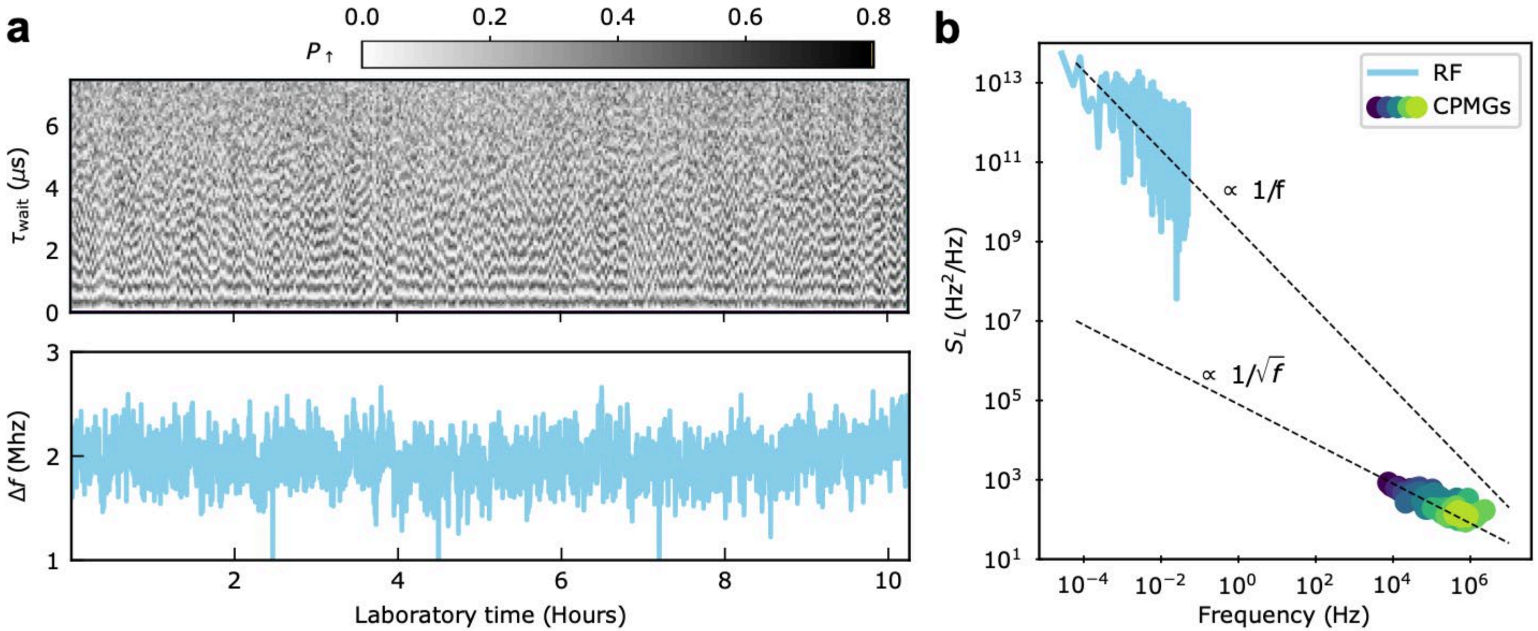
integration: 27.5 s (5 traces)

integration: 1 h (600 traces)



Noise spectrum (fig. S8)

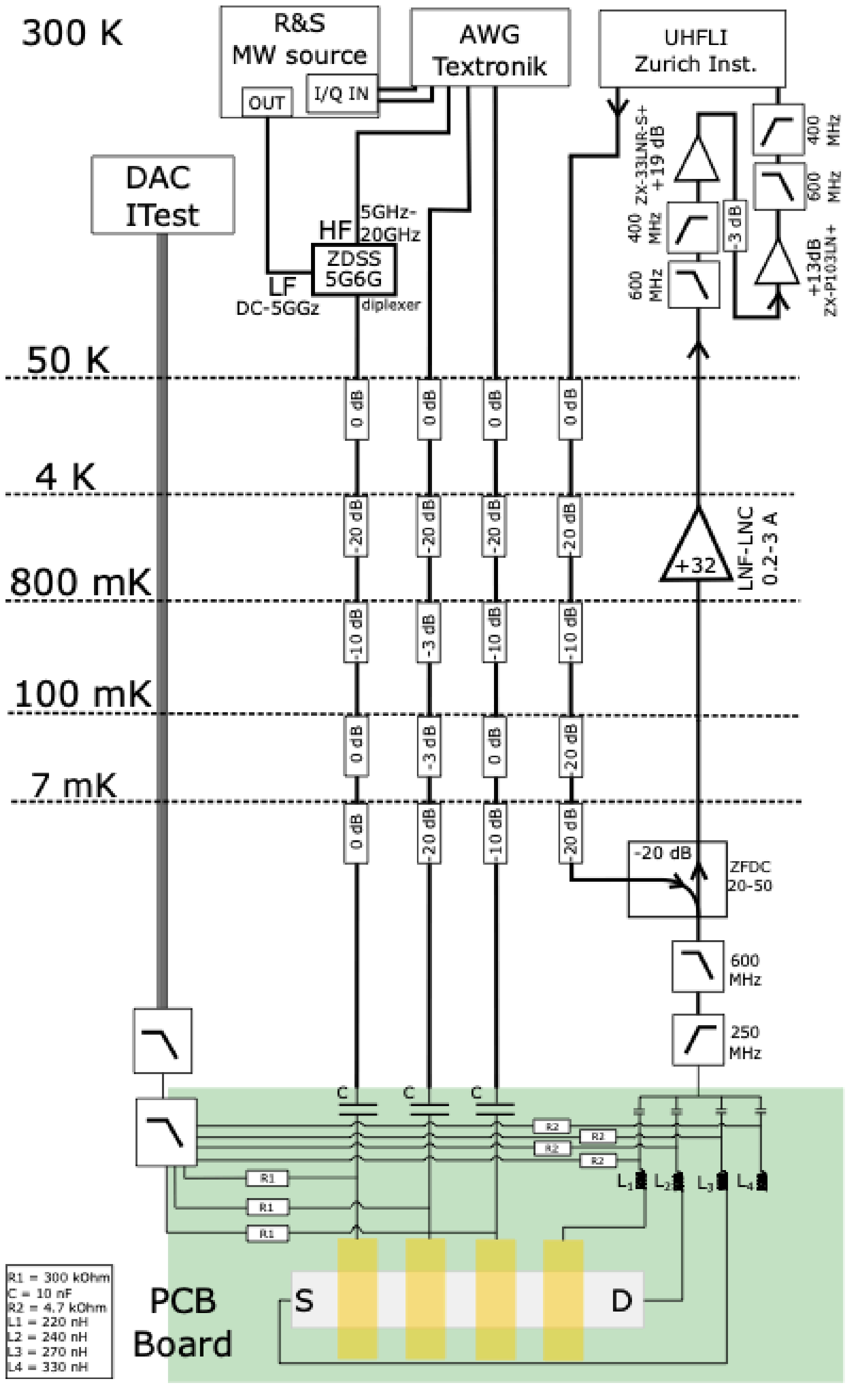
- CPMG: $S \propto \sqrt{f}$ at high freq
- FID: $S \propto f$ at low freq



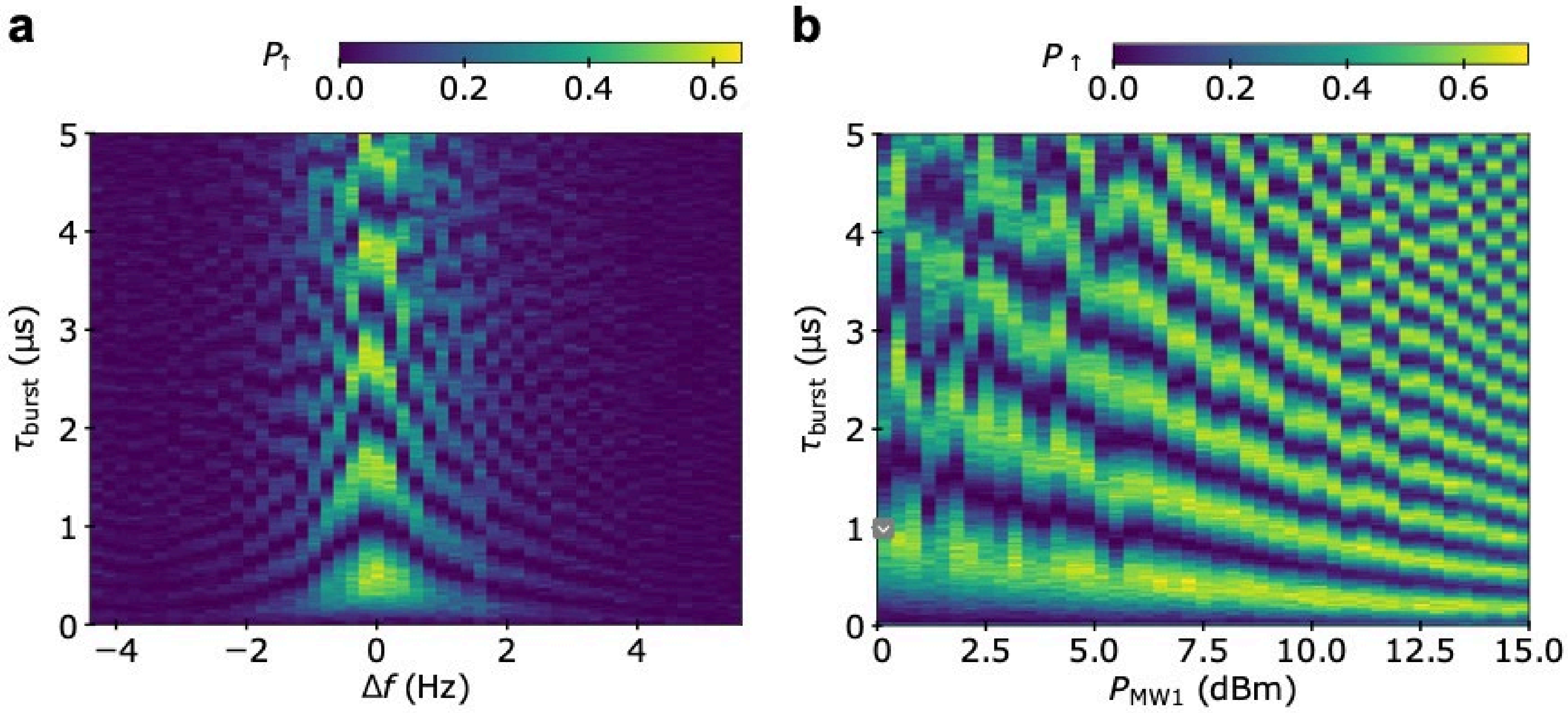
Conclusion

- Nice data, showing good promise for using sweet spots to increase hole coherence.
- I have some doubts with some of their fits/explanations
  - Many degrees of freedom and bold assumptions in my opinion.

Other figures: setup (fig. S9)



Other figures: chevron and power (fig. S7ab)



Other figures: different random charge arrangements (fig. S5b)