Electron charge qubits on solid neon with 0.1 millisecond coherence time

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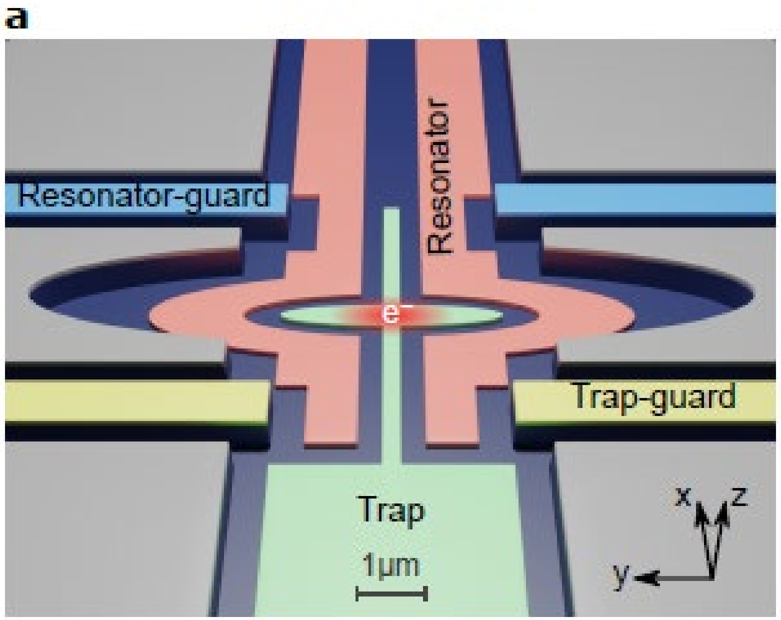

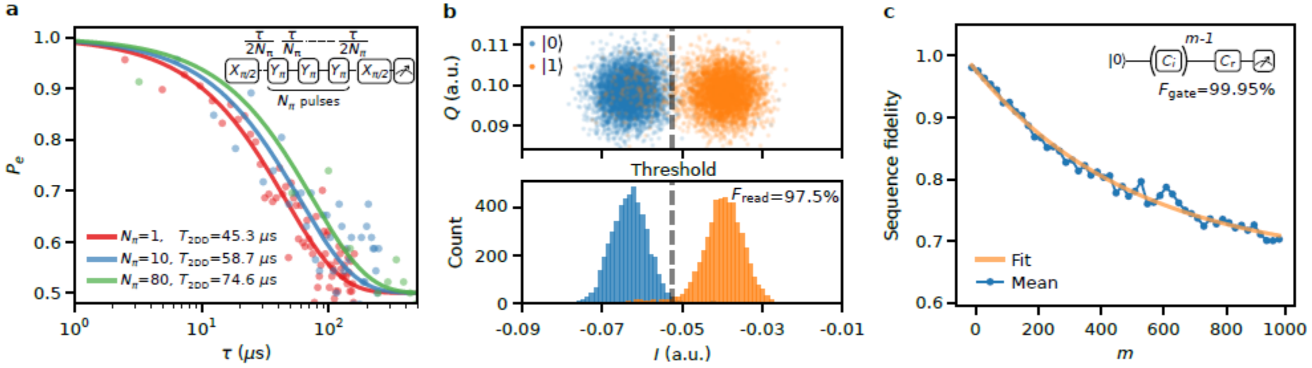

Theory/proposal and related work

- Idea is to remove “solid state qubit” from noisy crystal.
  (Similar idea exists for superfluid Helium)

- Proposal/theory paper on **spin-qubit on solid Ne**: https://arxiv.org/pdf/2205.00589.pdf

Metric	T_1	T_2^*	T_2^{echo}
Natural Ne (2700ppm ^{21}Ne)	Long (not specified)	0.16 ms	30ms
purified Ne (1000ppm ^{21}Ne)	Long (not specified)	0.43 ms	81s

- Related work: Electrons on superfluid LHe (probably same device but different “filling”)

ARTICLE

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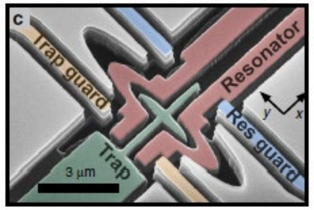
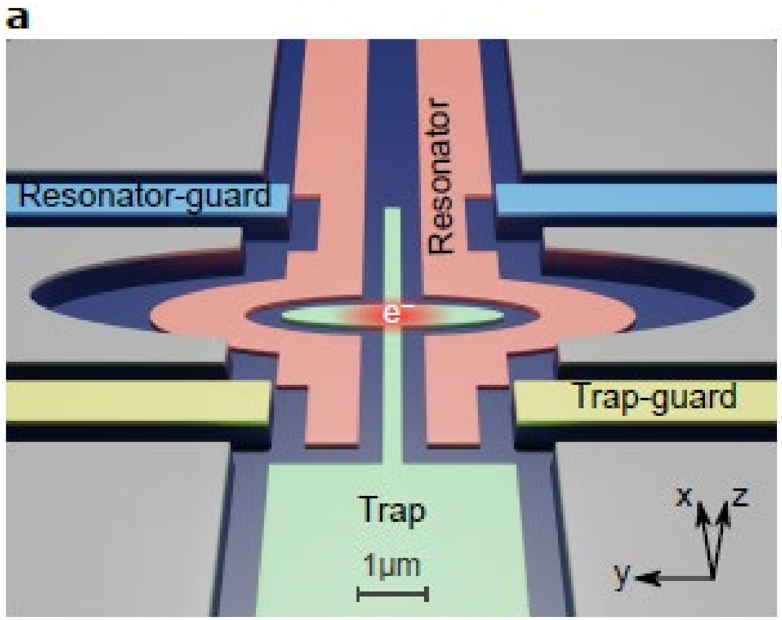
Coupling a single electron on superfluid helium to a superconducting resonator

Gerwin Koolstra[1], Ge Yang[1] & David I. Schuster[1]*

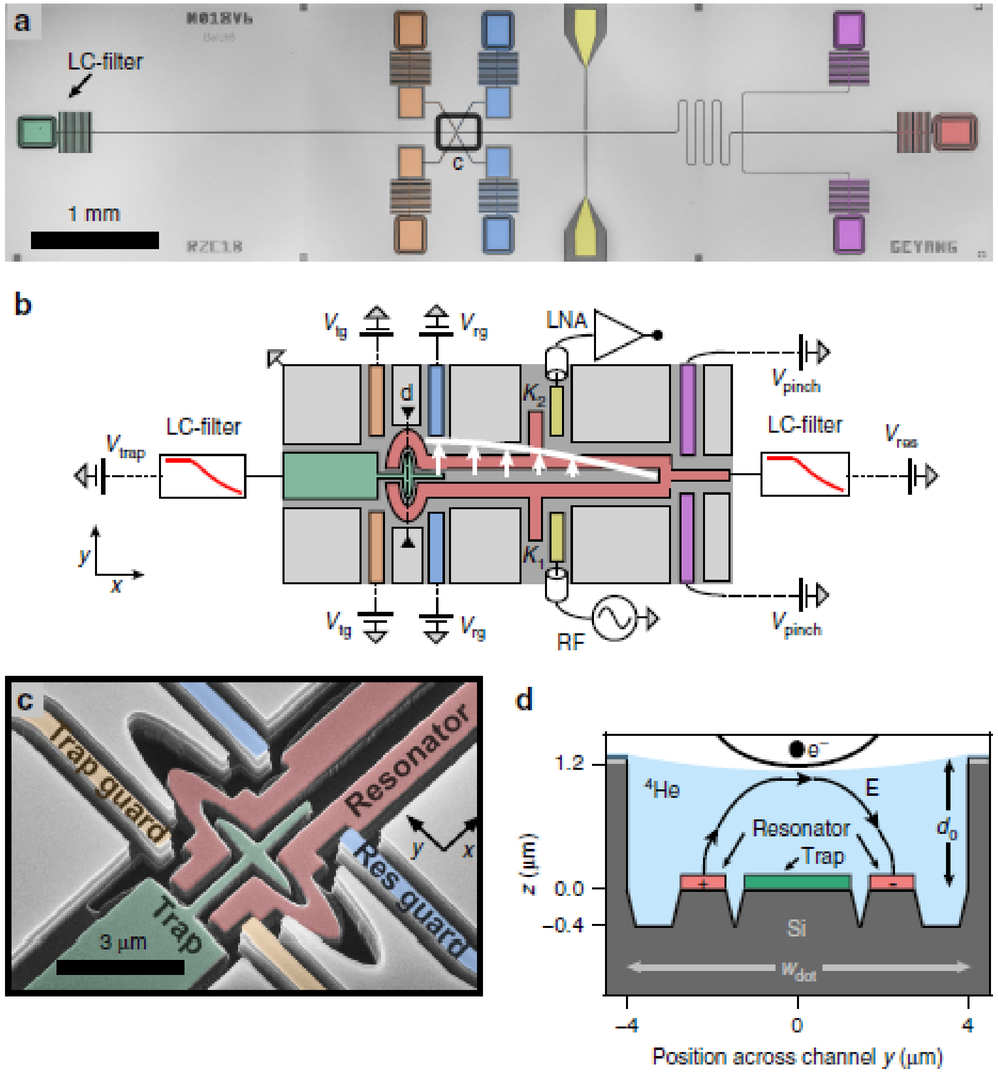
Here:
Noise limited by Helium fluctuations



Device



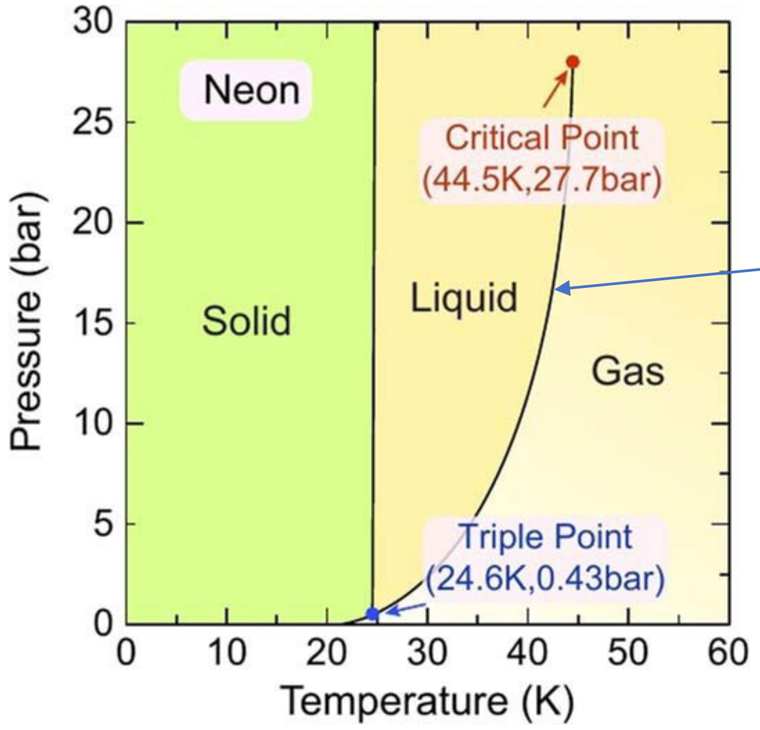
From electron on LHe paper



“Fabrication”:

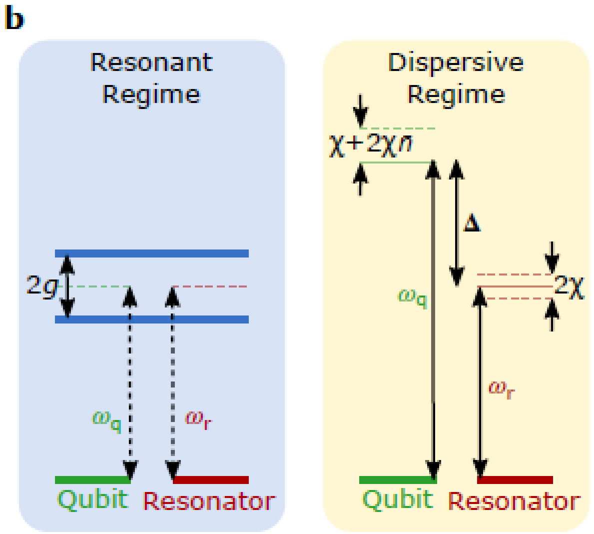
- Make chip with Nb gates/resonator on Si in “normal” fabrication
- Cool down in pressure cell with self-made regulator (“gas-handling puff system”)
- Walk through phase diagram to form best possible solid Ne in cooldown
- Electron(s) gets emitted from a tungsten filament and placed onto surface

Solid Neon



1. Fill controlled amount of Ne in cell at 26K to wet the chip
2. Cool down along liquid-gas coexisting line
3. Keep going across Triple Point at 24.6K (0.43bar) to turn into solid
4. “anneal” at 10K for 1-2h
5. Cool to base (10mK)
6. Final state: Estimate ~10s nm of Neon on top of chip

Standard cQED measurements



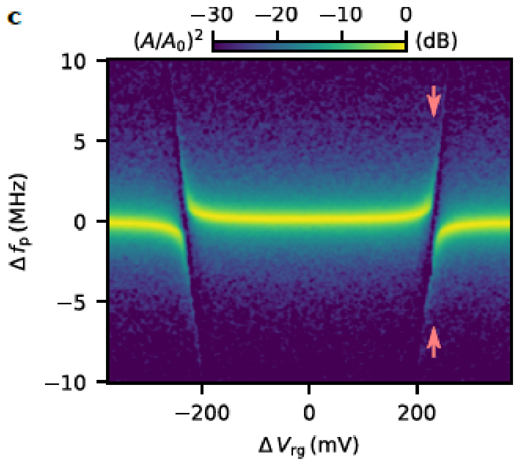
Experiments:

- Change qubit frequency with left vs right guard voltage ΔV_{rg}
- Bring on resonance and see anticrossing (c,d)
  -> extract g and losses (κ + γ)
- Fix resonator and drive qubit with second tone
  -> find charge qubit sweetspot vs detuning (e)
- Cuts across sweetspot with varying drive power show Stark-shift
  -> Find single photon limit (d)

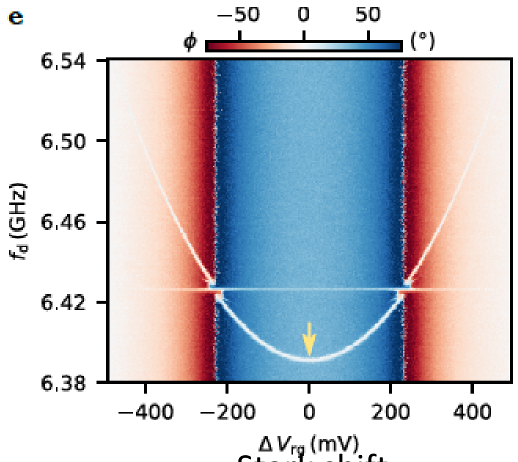
Extracted numbers*:

fr=6.4262 GHz, $\kappa/2\pi$ = 0.46 MHz, $g/2\pi$=2.3MHz, $\gamma/2\pi$=0.36MHz

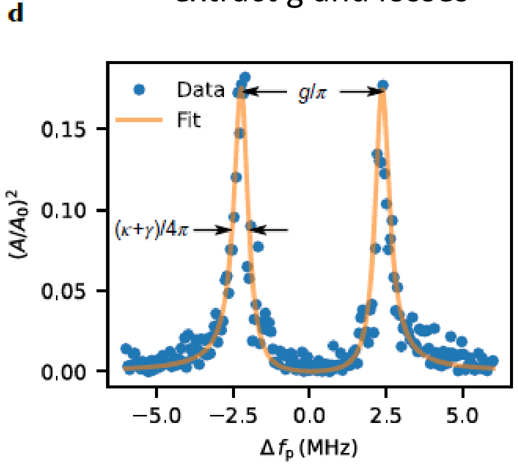
Sweep f_p close to resonance (single tone)



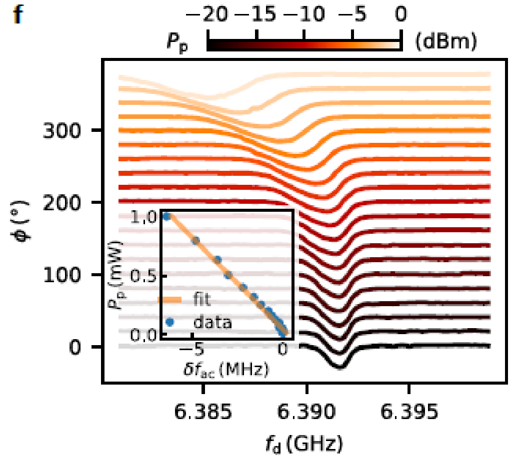
Fix f_p in dispersive regime (drive qubit in "two-tone")



Cut through (c)
-> extract g and losses

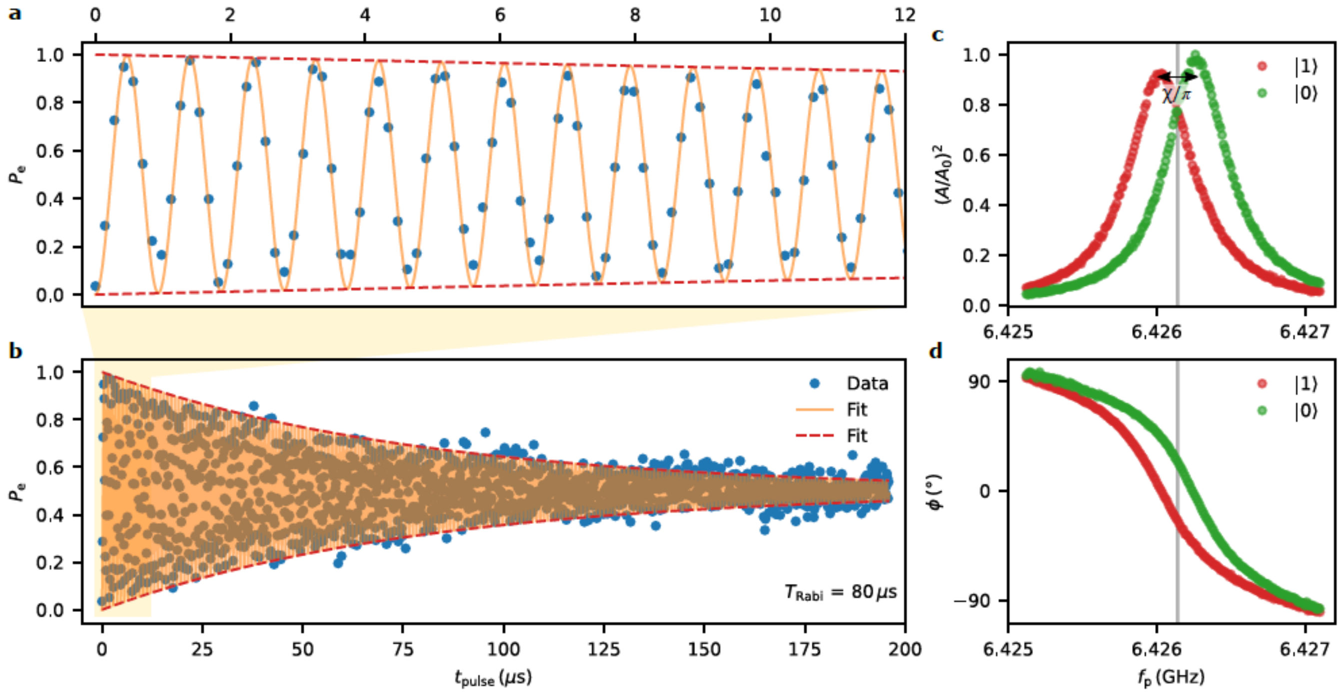


Stark shift
(two-tone with varying power)



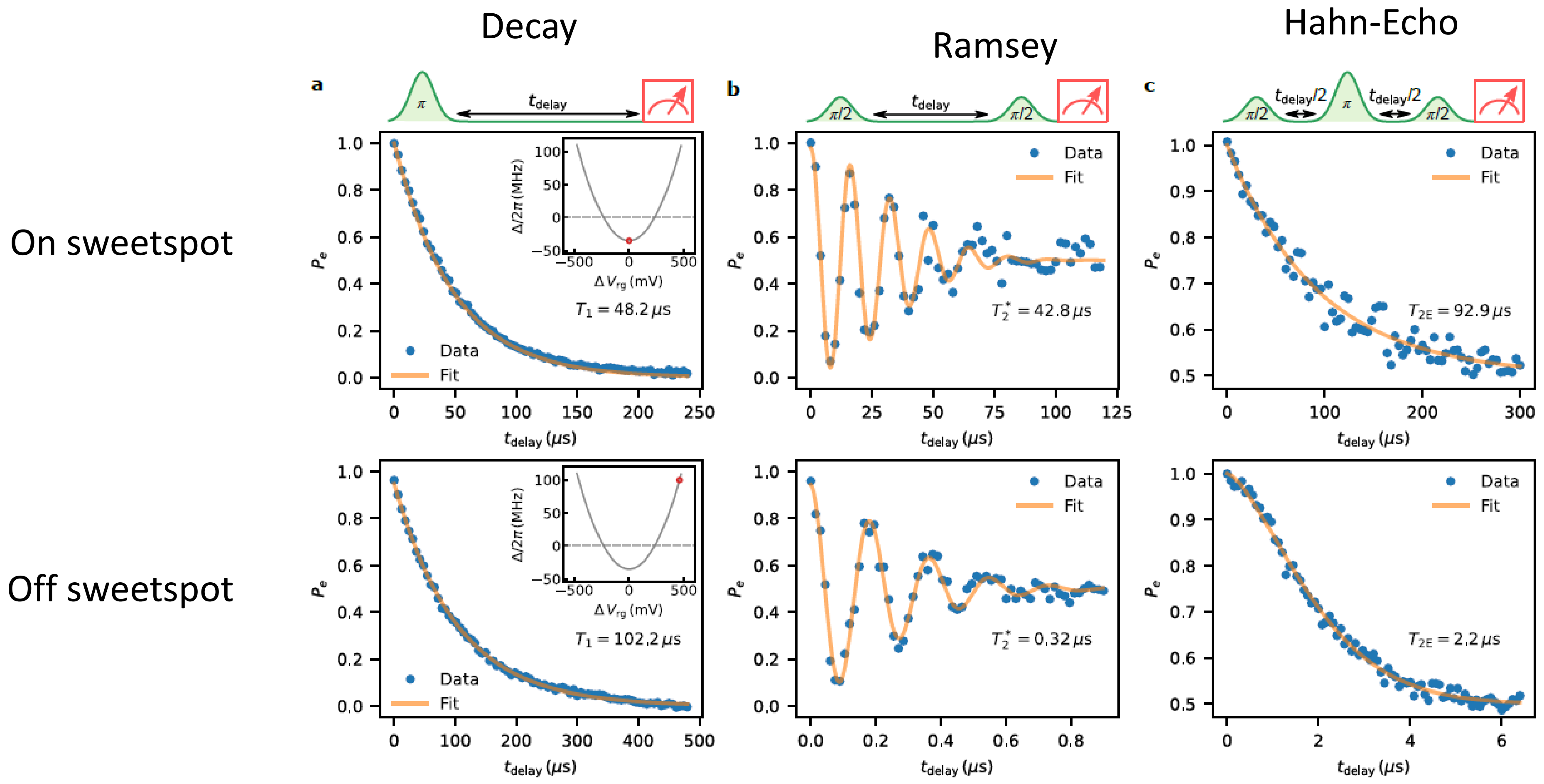
*From a first "electron"

Single qubit: Dispersive shift and Rabi



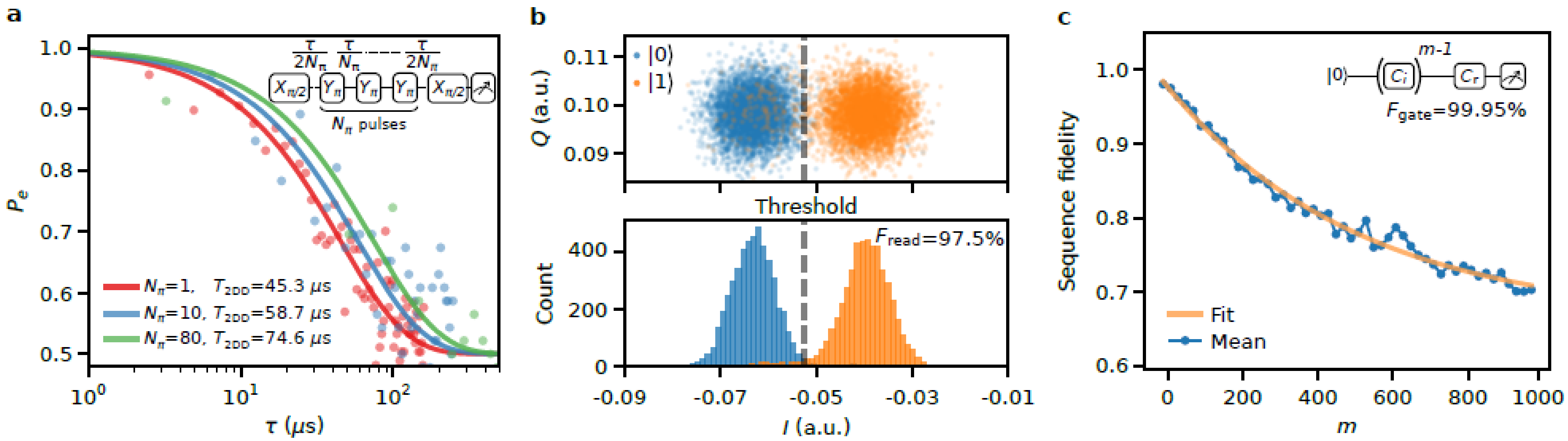
- Drive qubit using Gaussian drive tone
- On sweet spot!
- See dispersive shift (Fig c,d)
- Measure Rabi: T_{rabi}=80μs
- Dispersive shift: $\chi/2\pi$=-0.13MHz

Single qubit: On/off sweetspot



Single qubit: CPMG and fidelities

Important note: This is in another configuration using “another electron”



- In previous setting they were limited by Purcell-type decay for read-out (T_1 limit)
- In new potential the resonator is further from the qubit frequency at the sweetspot (-270MHz vs -34.7MHz)
- Here T_1=88.4µs, T^*_2=3.9µs which makes it a worse qubit but better for read-out.
- Do CPMG and recover most of previous level of T_2^{echo} with 80 CPMG pulses
- Read out fidelity (without SC amplifiers) 97.5%
- Randomized benchmarking: Gate fidelity 99.95%

$$E_\pm = \pm\frac{1}{2}\sqrt{\varepsilon^2 + (2t)^2}$$

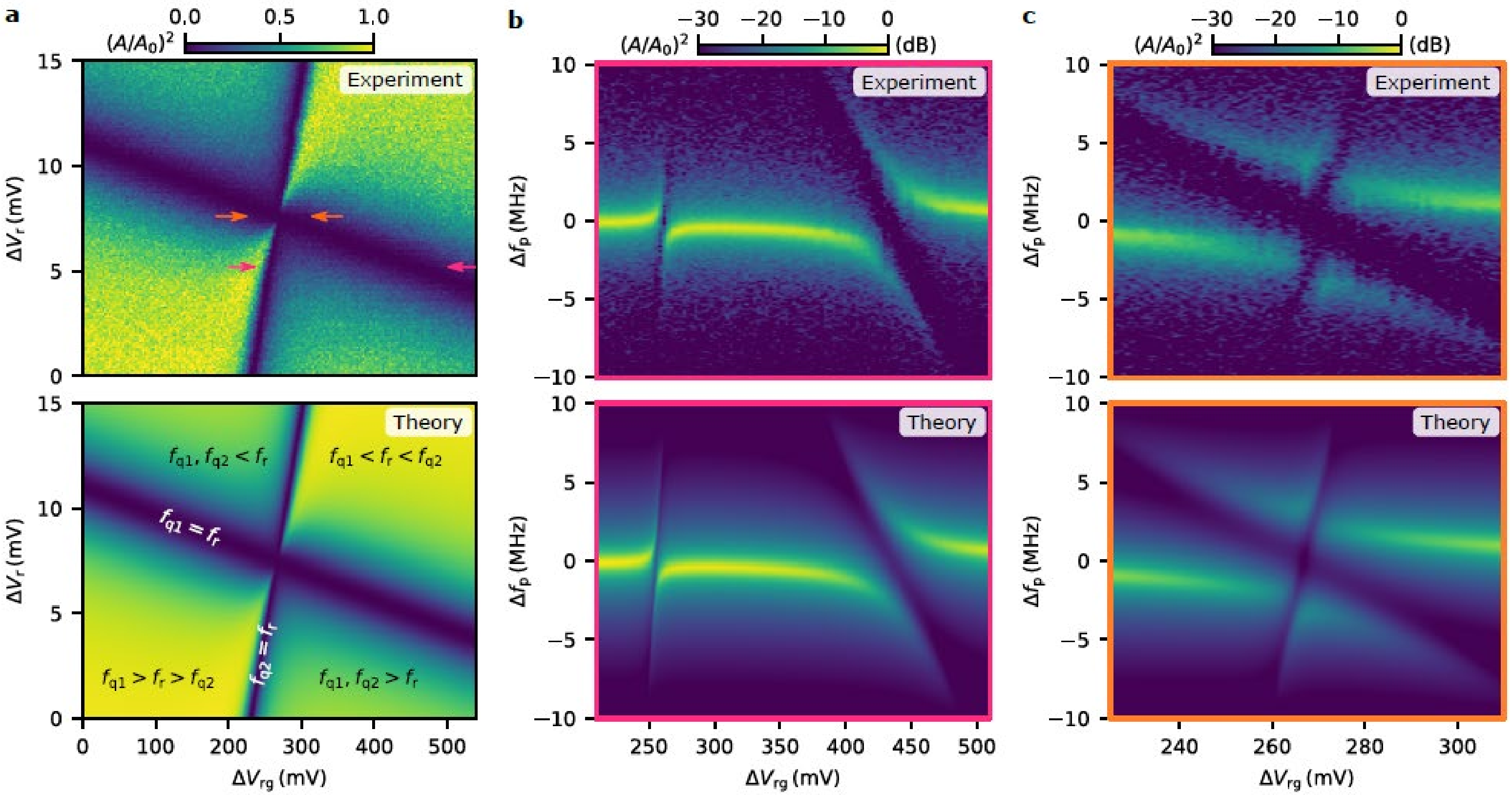
Wigner-molecule might be a bit different…

Coupling two electrons to the resonator

Tune both qubits

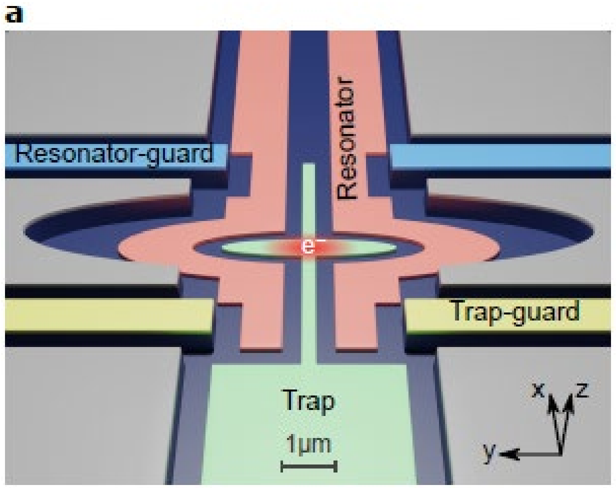
Anticrossing with qubits at diff. freq.

Anticrossing with qubits at same freq



ΔVr : "(offset) resonator voltage"
Is that the offset compared to trap?

ΔVrg: Resonator guard bias



- Two electrons in same trap (where is not clear)
- Tune with resonator offset voltage ΔV_r and trap guard voltage ΔV_{rg}
- Results matched with input-output theory
- $g_1/2\pi$=3.6MHz, $g_2/2\pi$=1.8MHz, $\gamma_1/2\pi$=1.5MHz, $\gamma_2/2\pi$=1.6MHz