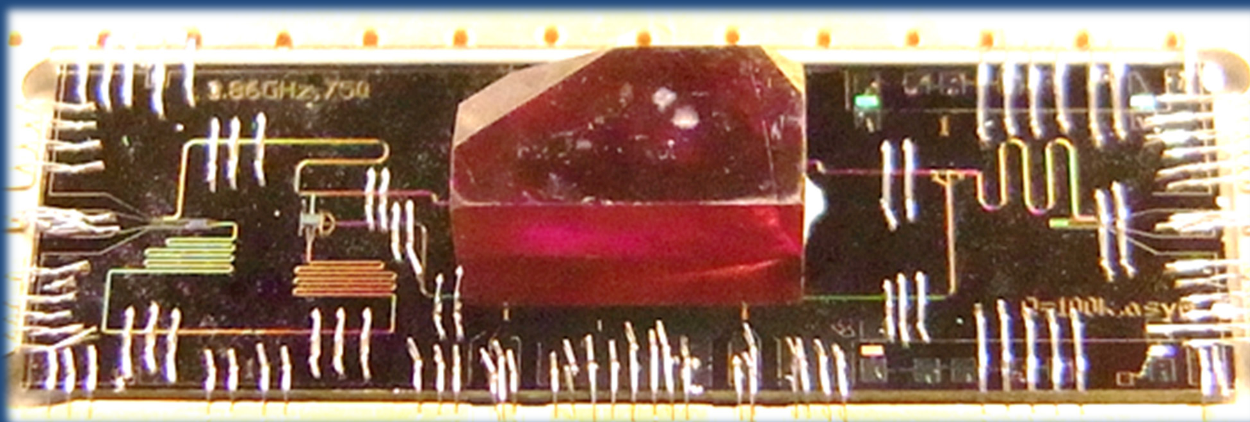
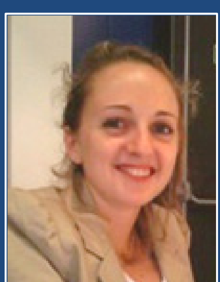
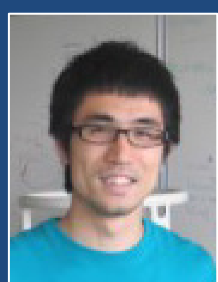
Towards a multi-qubit quantum memory based on a large ensemble of NV spins ?







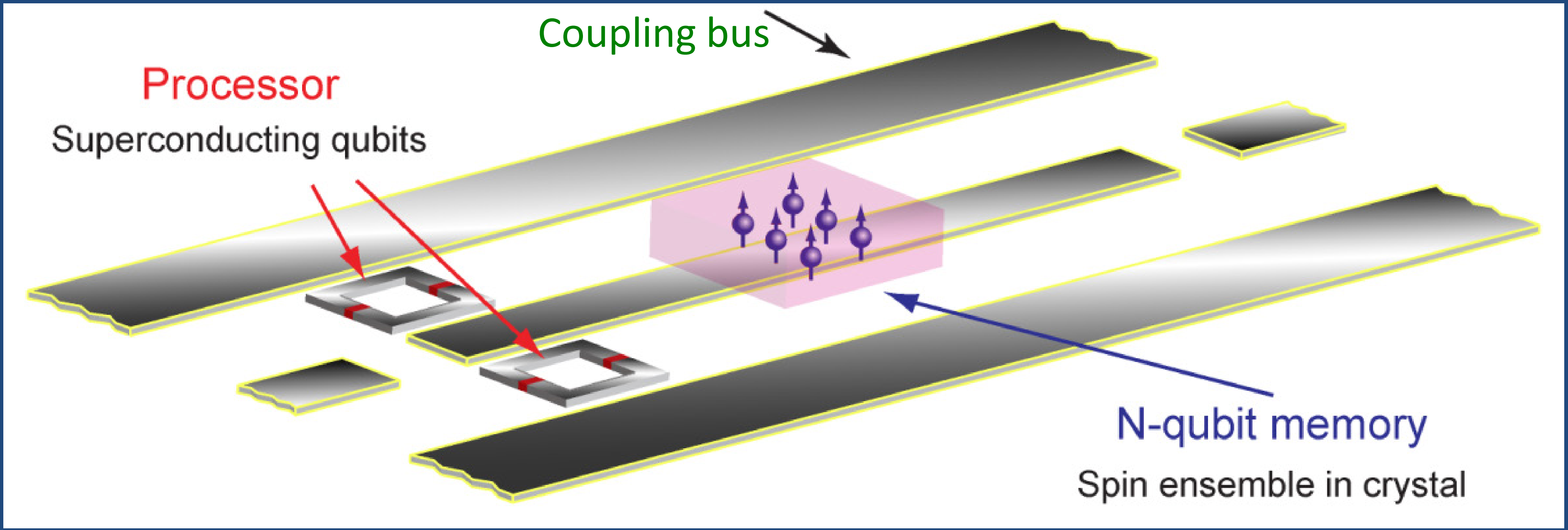
Paris
June 24
2015

QUANTUM ELECTRONICS GROUP

scaleQIT

C. Grezes, **Y. Kubo**, A. Bienfait, M. Stern, D.Vion, D. Esteve, and **P. Bertet**
B. Julsgaard, K. Mølmer, J. Isoya, V. Jacques, I. Diniz, A. Auffeves

Processing quantum information with hybrid system



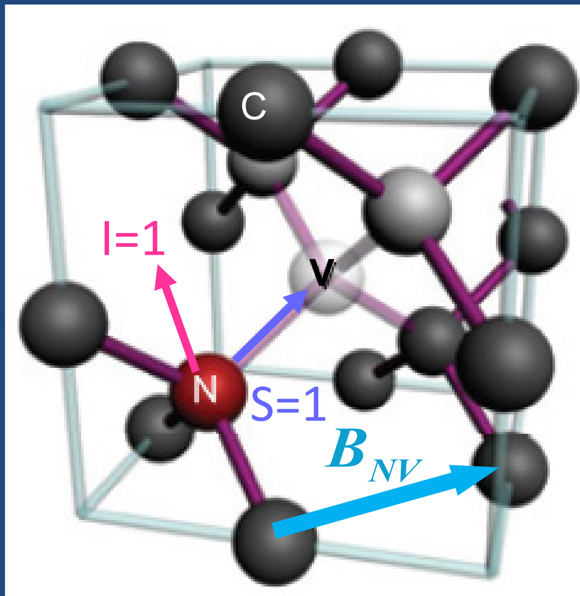
fast manipulation (10ns)
limited coherence (0.1ms)

good coherence (~s)
no fast switchable coupling

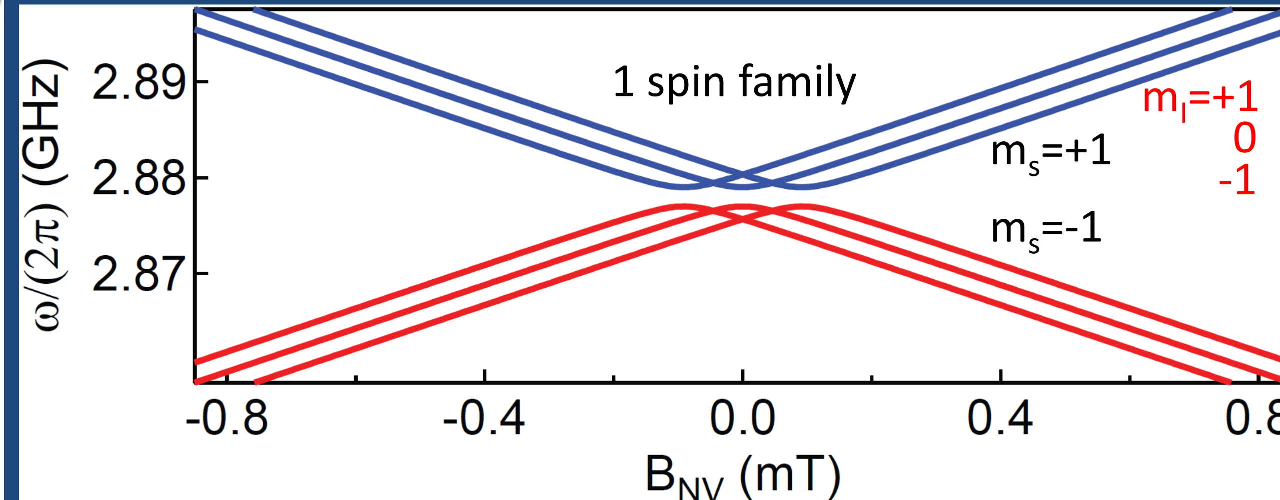
Let's dream a bit: generic rotocol is

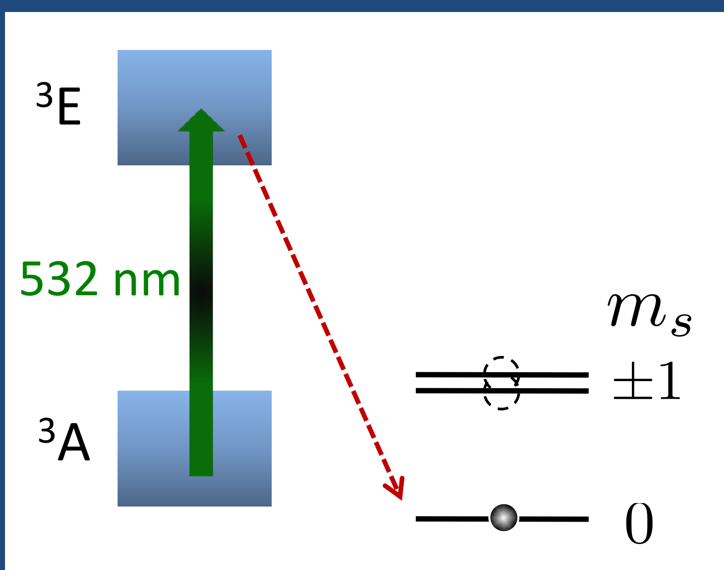
memory i to qb1
memory j to qb2
2 qb gate
qb1 to memory k
qb2 to memory l

The spin ensemble: NV^{-} centers



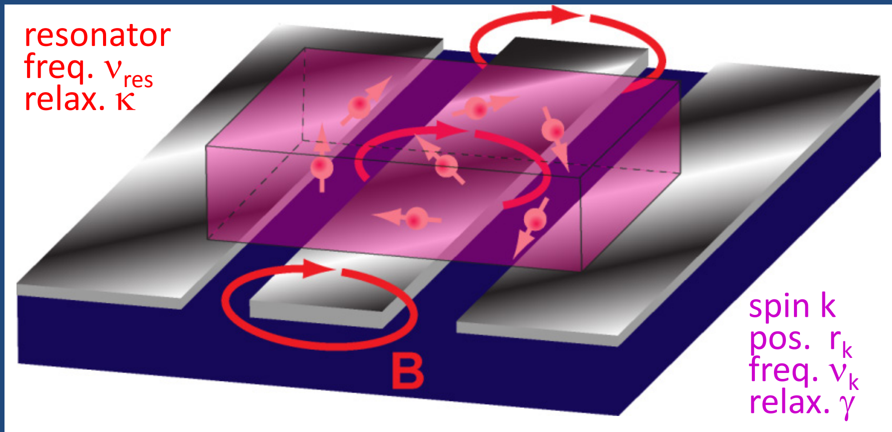
$$H = DS_z + E(S_x^2 - S_y^2) - g_e \mu_B \boldsymbol{B_{NV}} \boldsymbol{S} + \boldsymbol{S}\underline{\boldsymbol{A}}\boldsymbol{I}$$

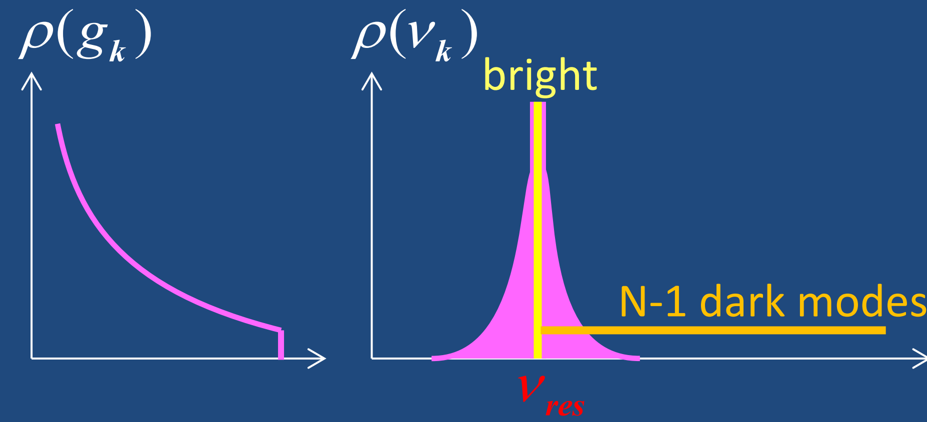




Optical repumping
(90% max)

Coupling a spin ensemble to an electrical resonator



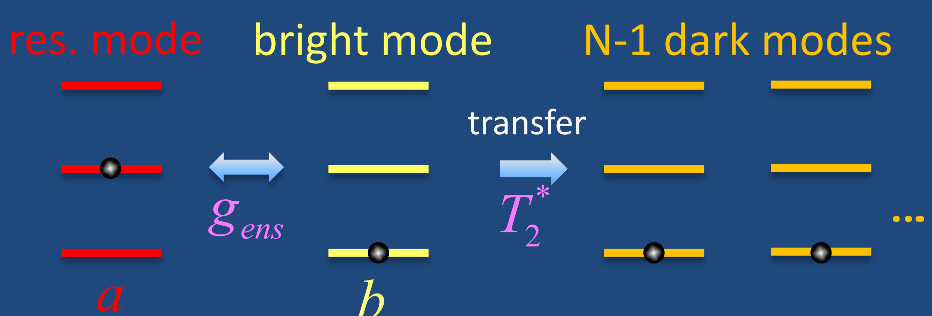


$$H_{\text{int}} = \hbar g_{ens}\left(a^\dagger b + hc\right)$$ 1 excitation in N spins

$$g_{ens} \sim \sqrt{N} g_k \gg \gamma, \kappa$$ strong coupling

$$b^\dagger \left|00...0\right\rangle = \Sigma \tilde{g}_k \left|k\right\rangle$$ Dicke spin wave

$$\Rightarrow \Sigma \tilde{g}_k e^{i\Delta\nu_k t} \left|k\right\rangle$$

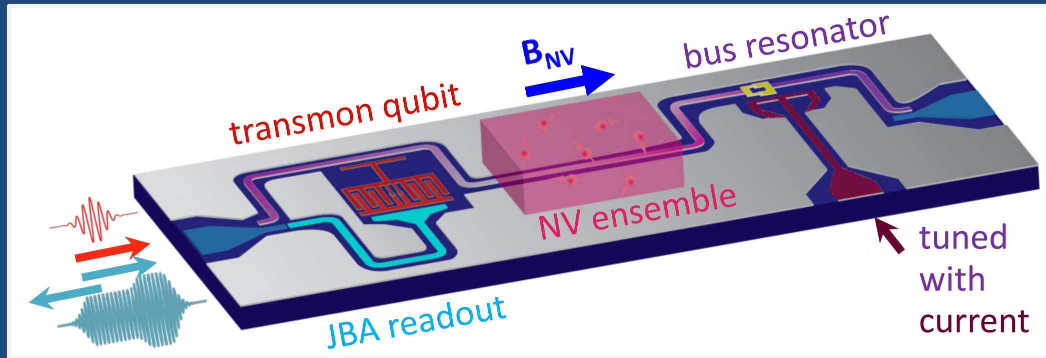


Use it as a ressource :

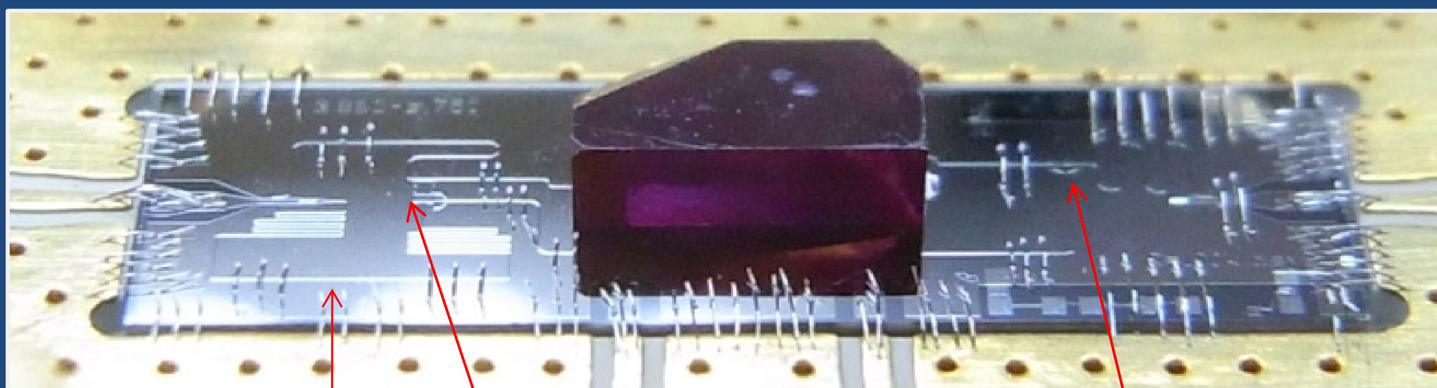
B. Julsgaard *et al.*, PRL 110 (2013)

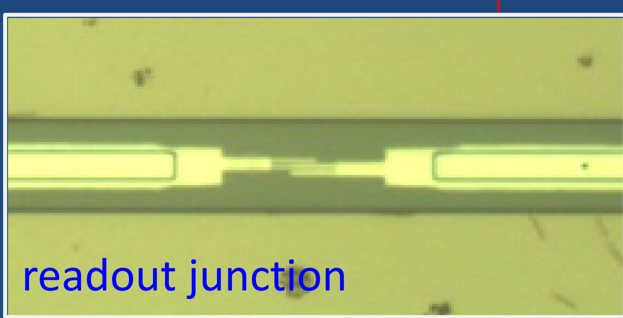
1) Multimode memory
2) Echo technique to read the memory back

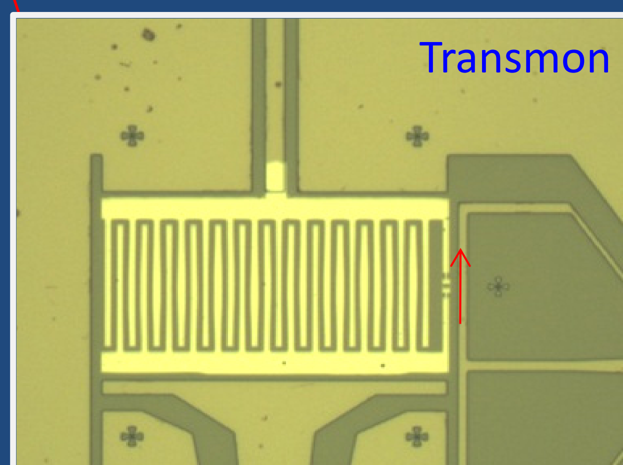
Write qubit information to spin memory: the sample

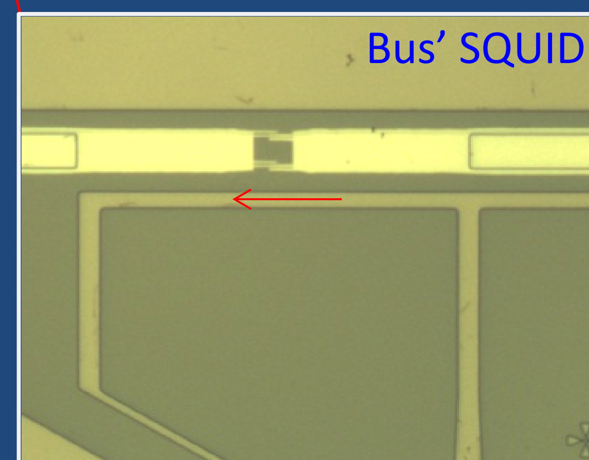


30 mK
refrigerator

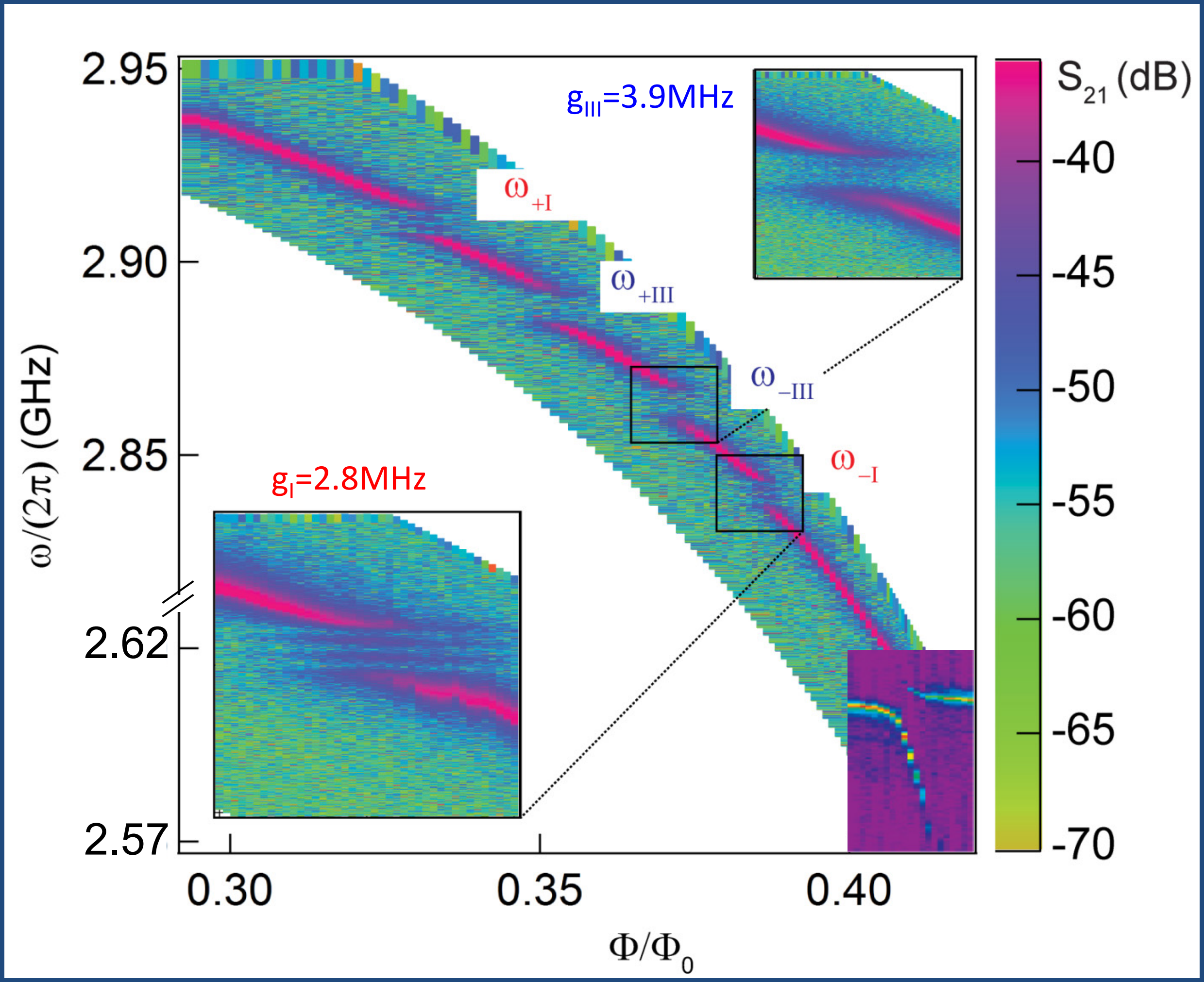


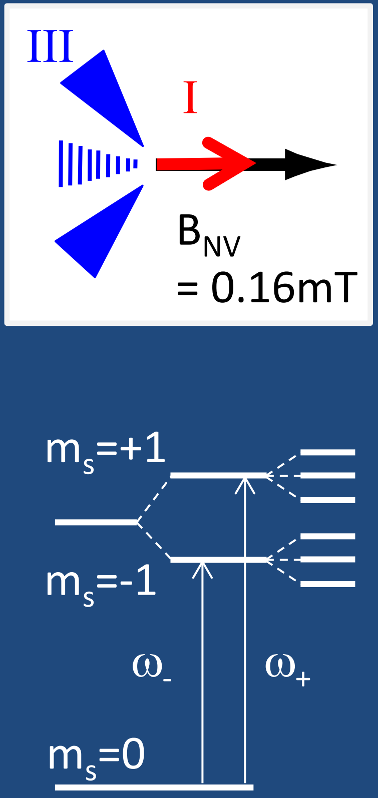






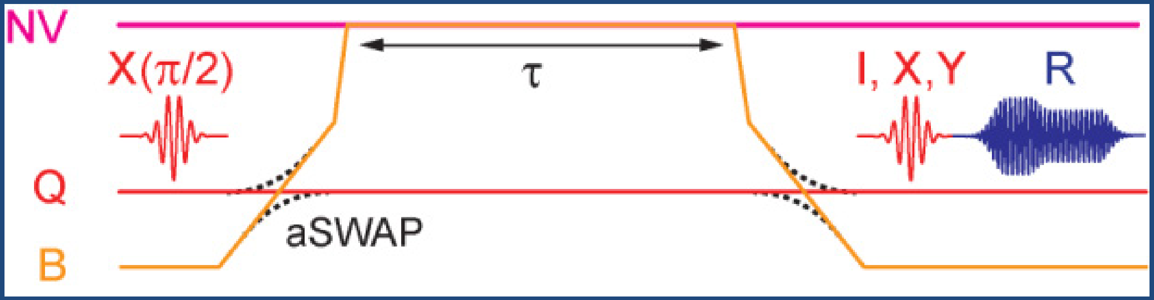
Resonator and qubit spectroscopy: strong coupling to bus

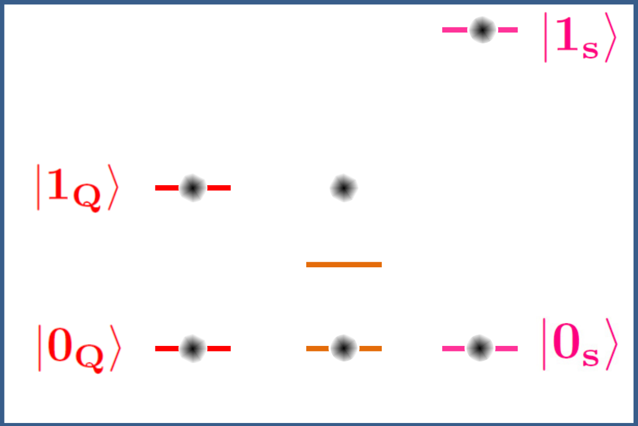


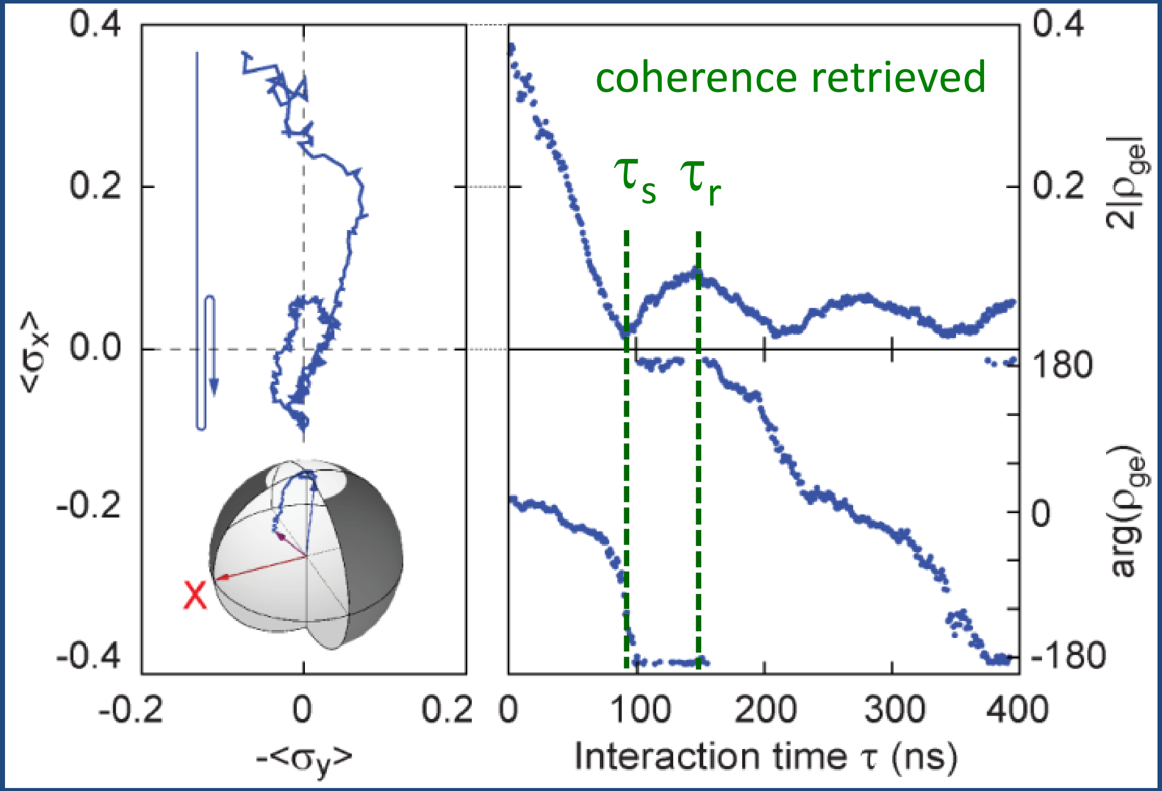


Grezes *et al.*, PRL 2011, see also Saito *et al.*, PRL 2013, Y. Tabushi *et al.*, arXiv

Write qubit information to spin memory: Demonstration



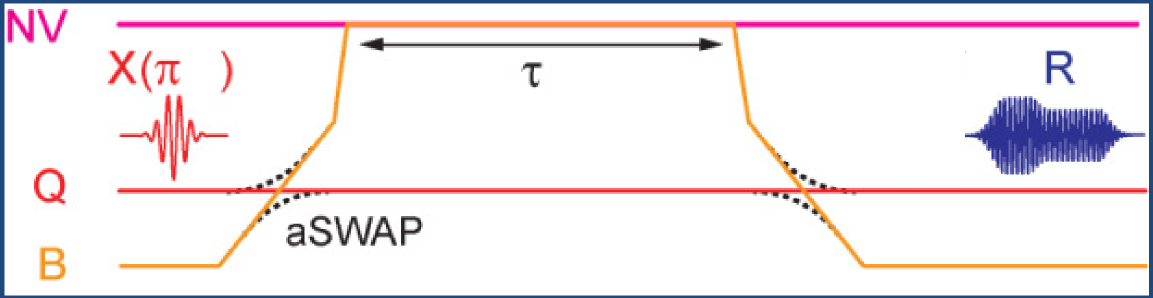


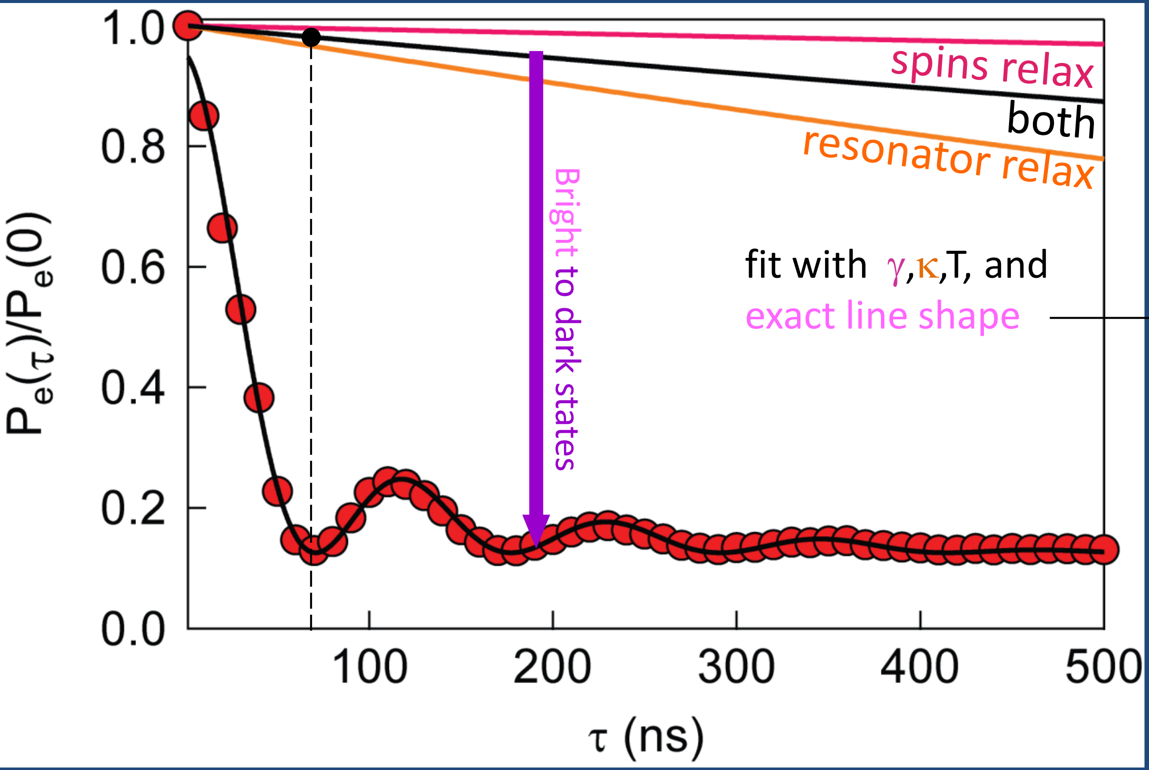


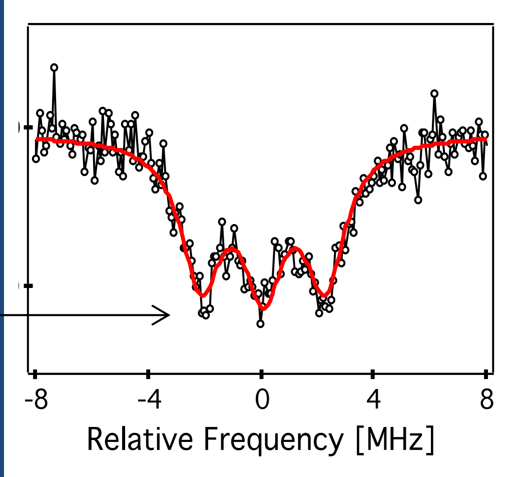
corrected for finite
readout fidelity
and qubit temperature (50 mK)

Grezes *et al.*, PRL 2011, see also Saito *et al.*, PRL 2013, Y. Tabushi *et al.*, arXiv 1410.3781

Write qubit information to spin memory: Demonstration



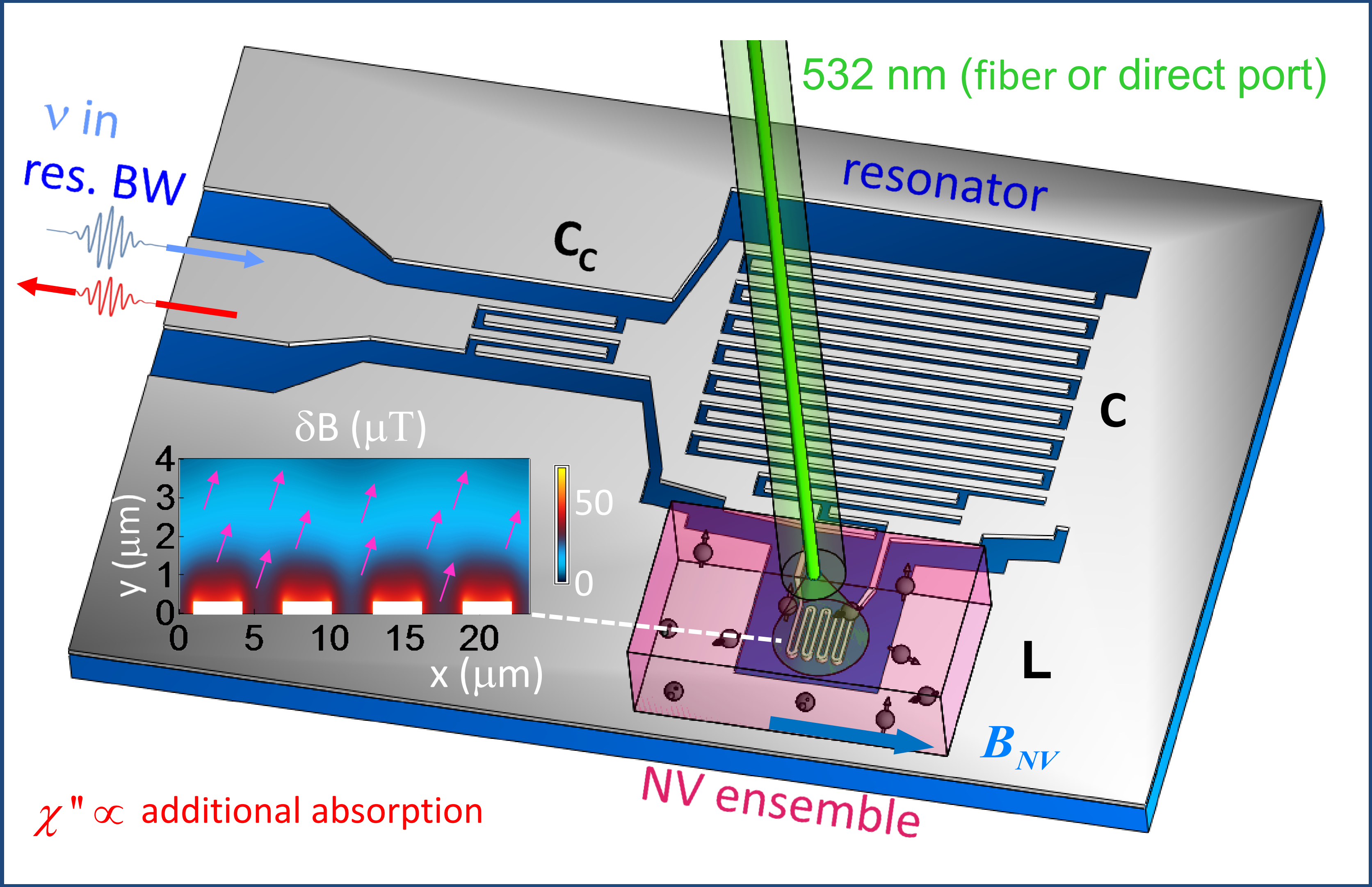




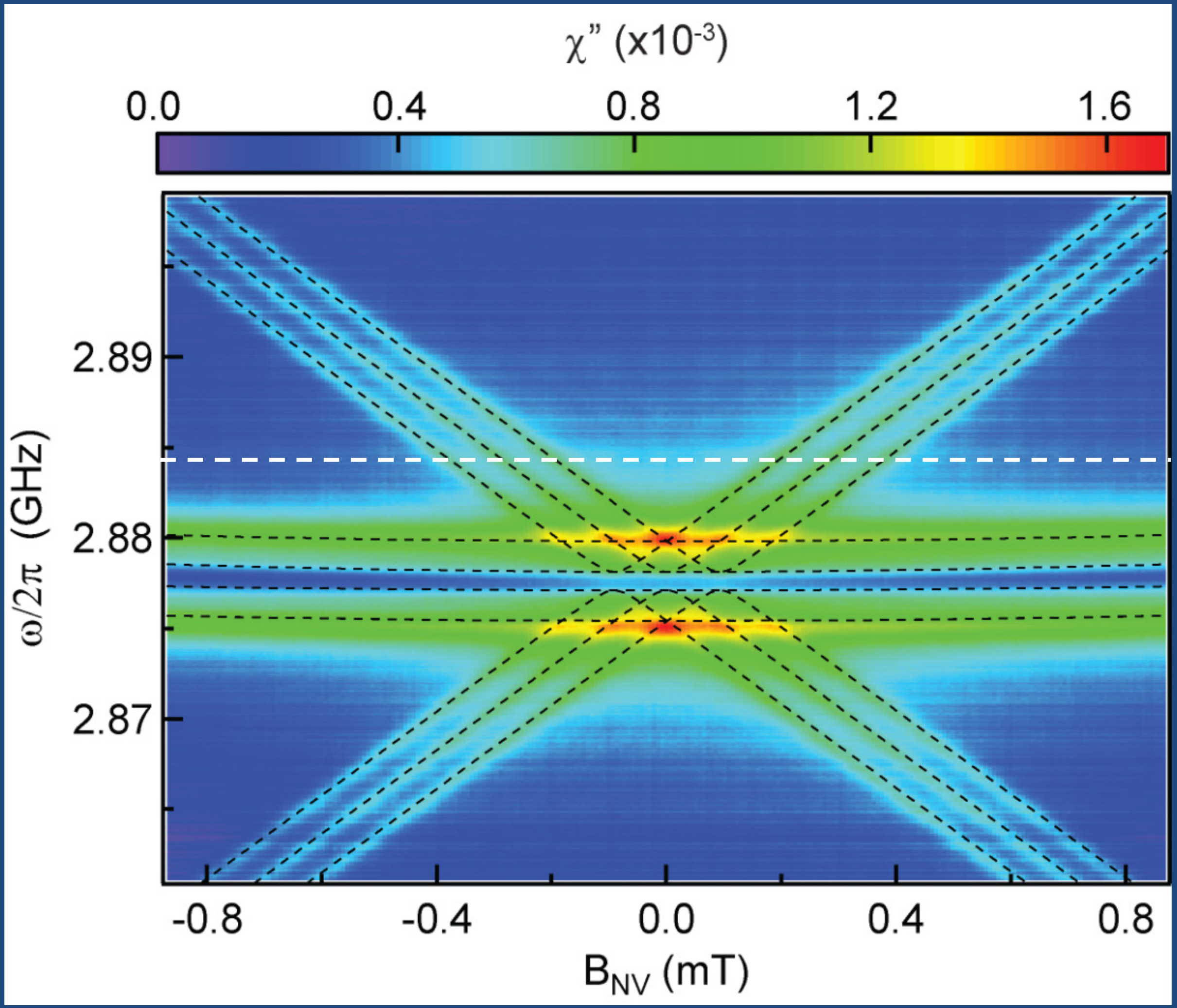
Write fidelity = 95%
limited by relaxation

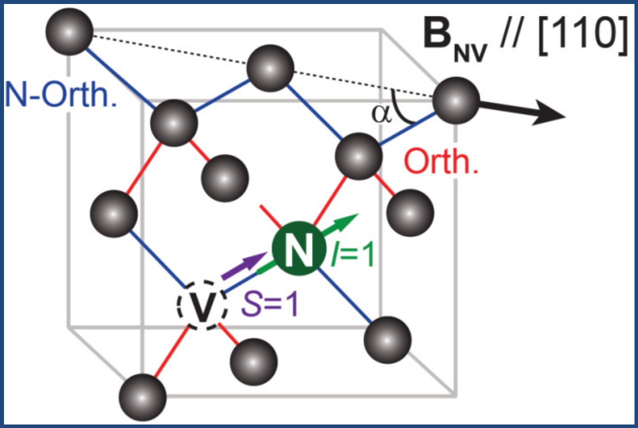
Grezes *et al.*, PRL 2011, see also Saito *et al.*, PRL 2013, Y. Tabushi *et al.*, arXiv 1410.3781

Testing the read protocol: the sample



Testing the read protocol: spectroscopy

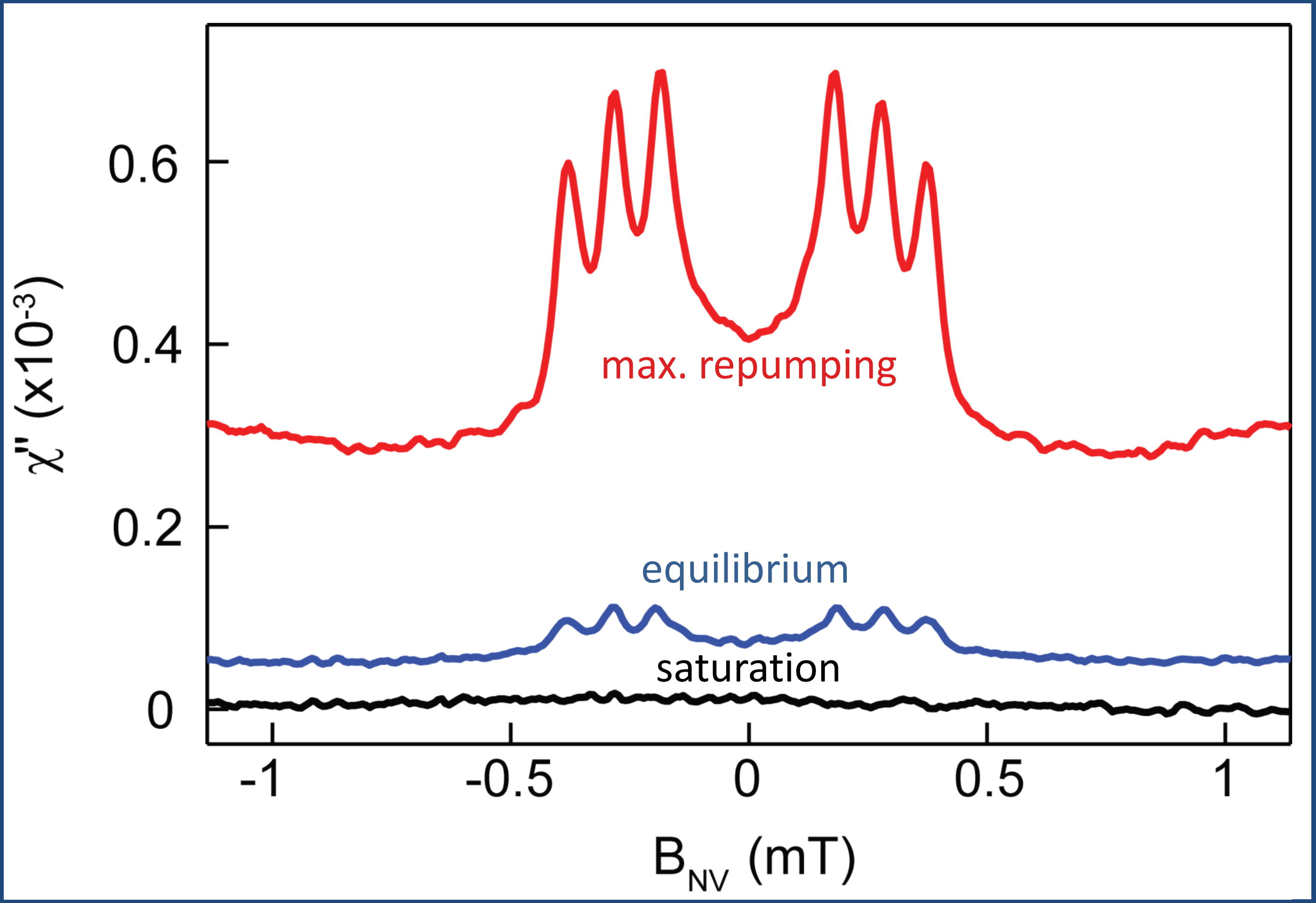




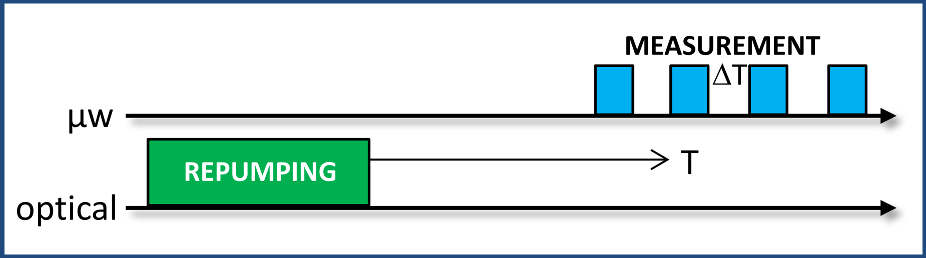
Orthogonal family

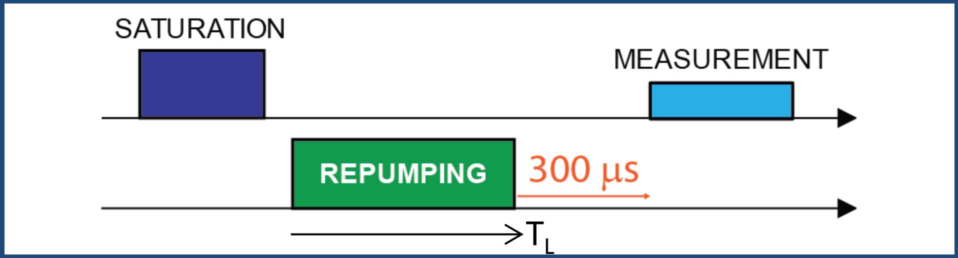
Non-Orthogonal one

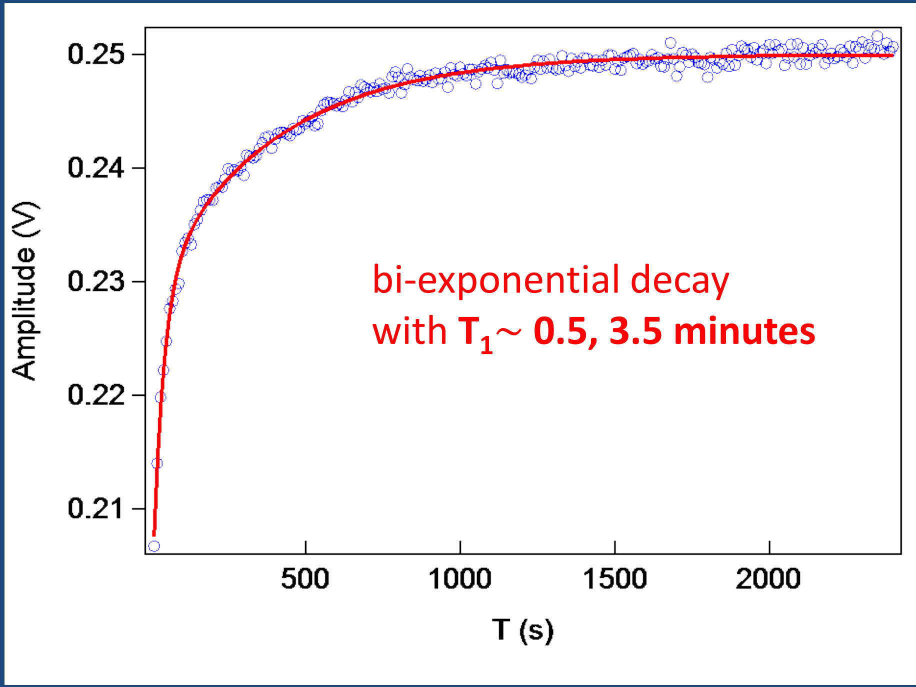
Testing the read protocol: T_1 and optical reset

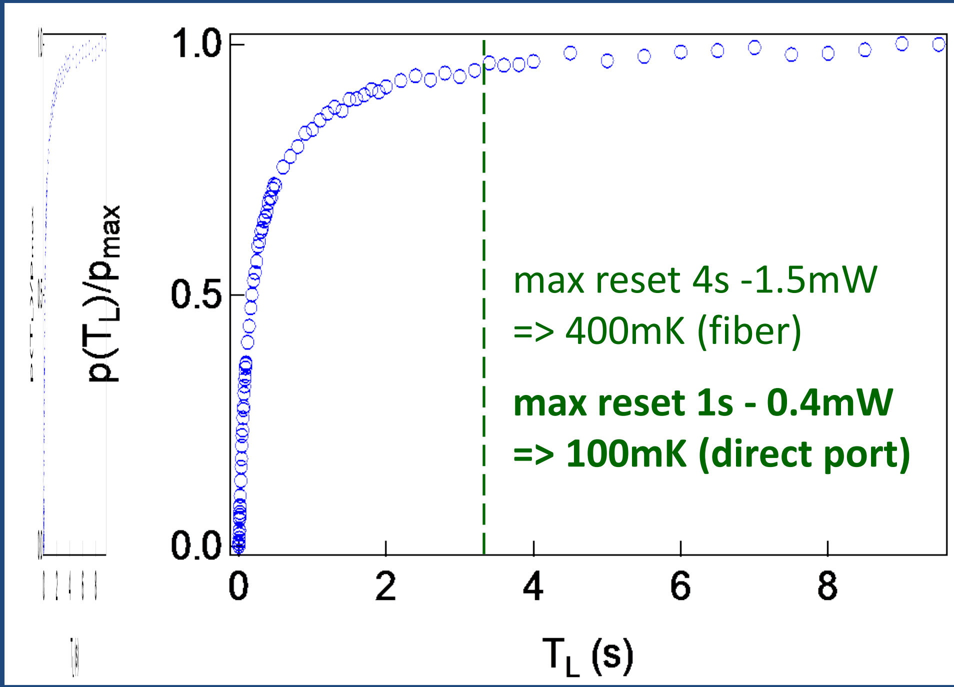


Testing the read protocol: T_1 and optical reset

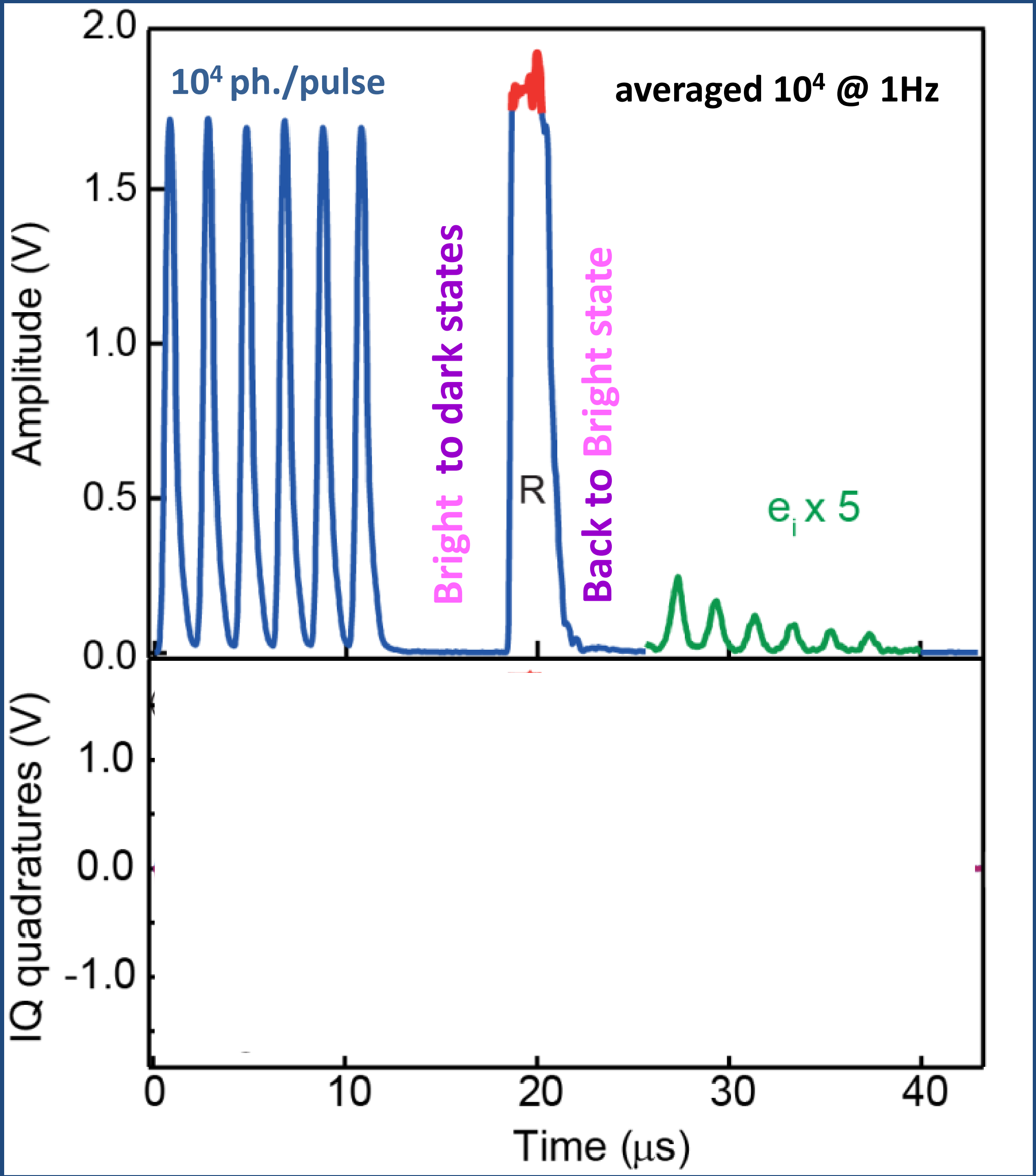








Testing the read protocol: mesoscopic regime



Strong refocussing pulse R

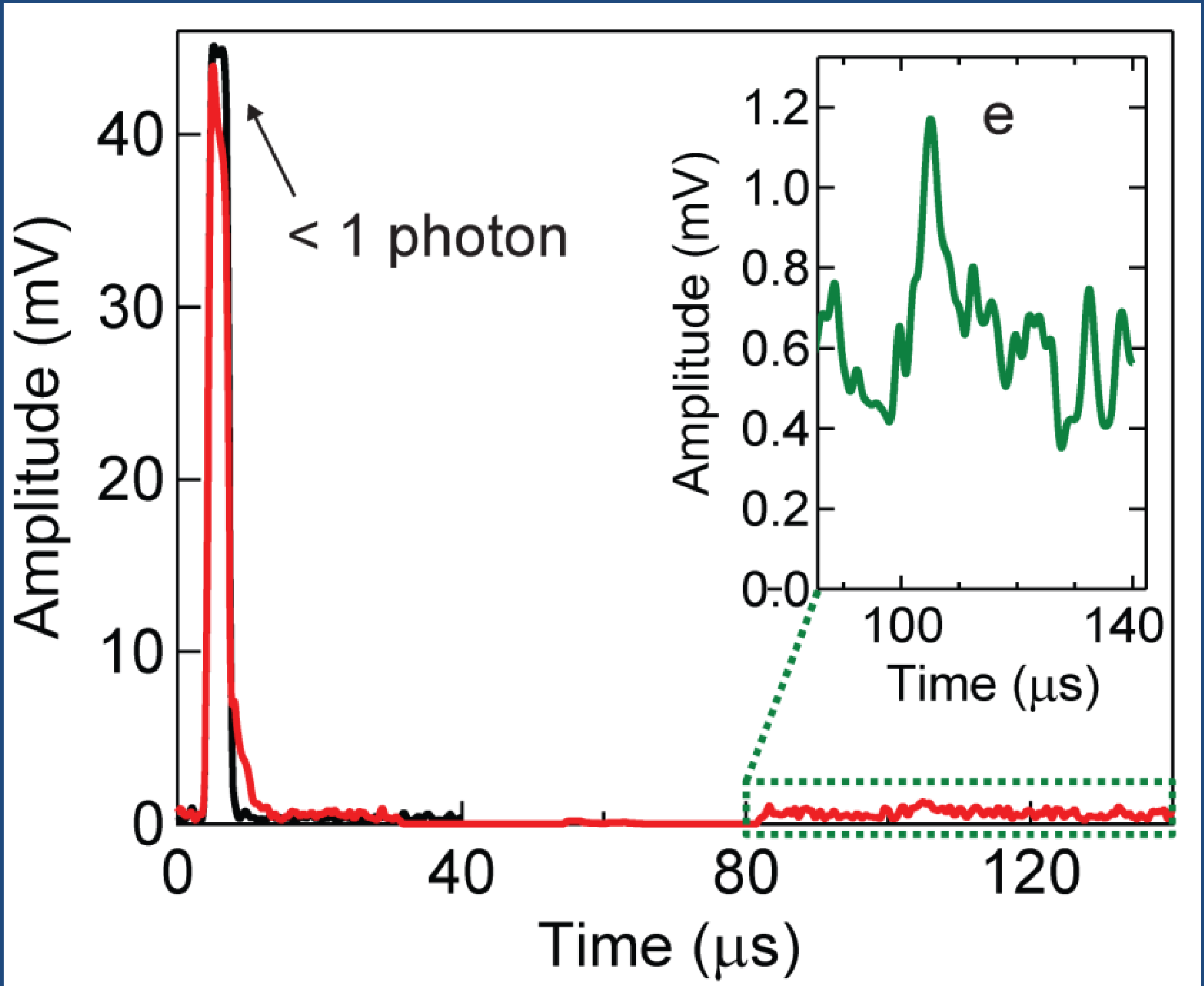
Retrieve $\mathbf{E_{echo} / E_{inc} \approx 2.\ 10^{-4}}$

with correct phase
$\varphi_e = - (\varphi_i - \varphi_R)$

Why low read efficiency?

Testing the read protocol: single photon level

^{12}C enriched sample
by J.Isoya
T_2 = 85 μs

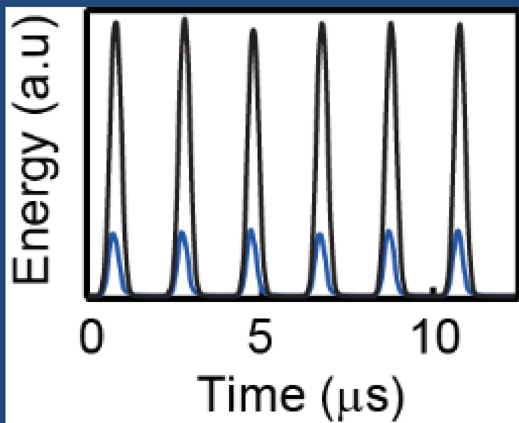


E_{echo} / E_{inc} ≈ 0.5 % after 100μs storage

Grezes *et al.* arXi: 1504.02220

Read protocol efficiency analysis

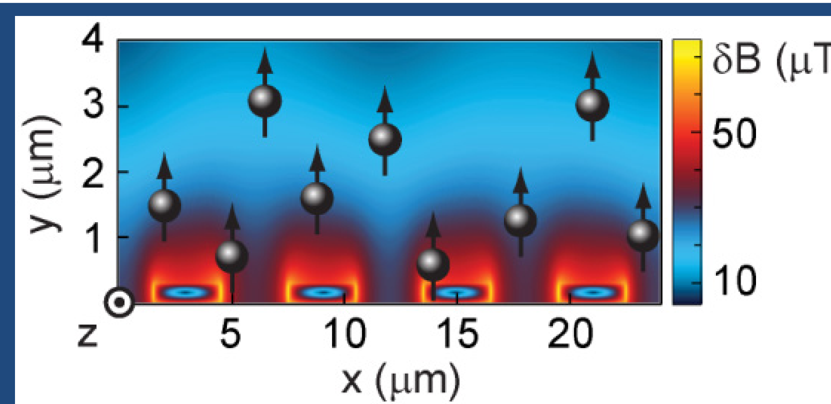
Finite ratio g_{ens} / κ_{ext}



75% absorption

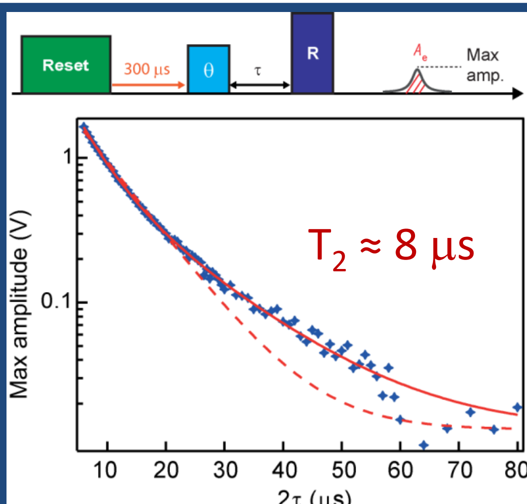
0.75^2

Imperfect π pulse



0.43

Finite coherence time T_2



10^{-3}

g_{ens} / κ_{ext} bad π T_2

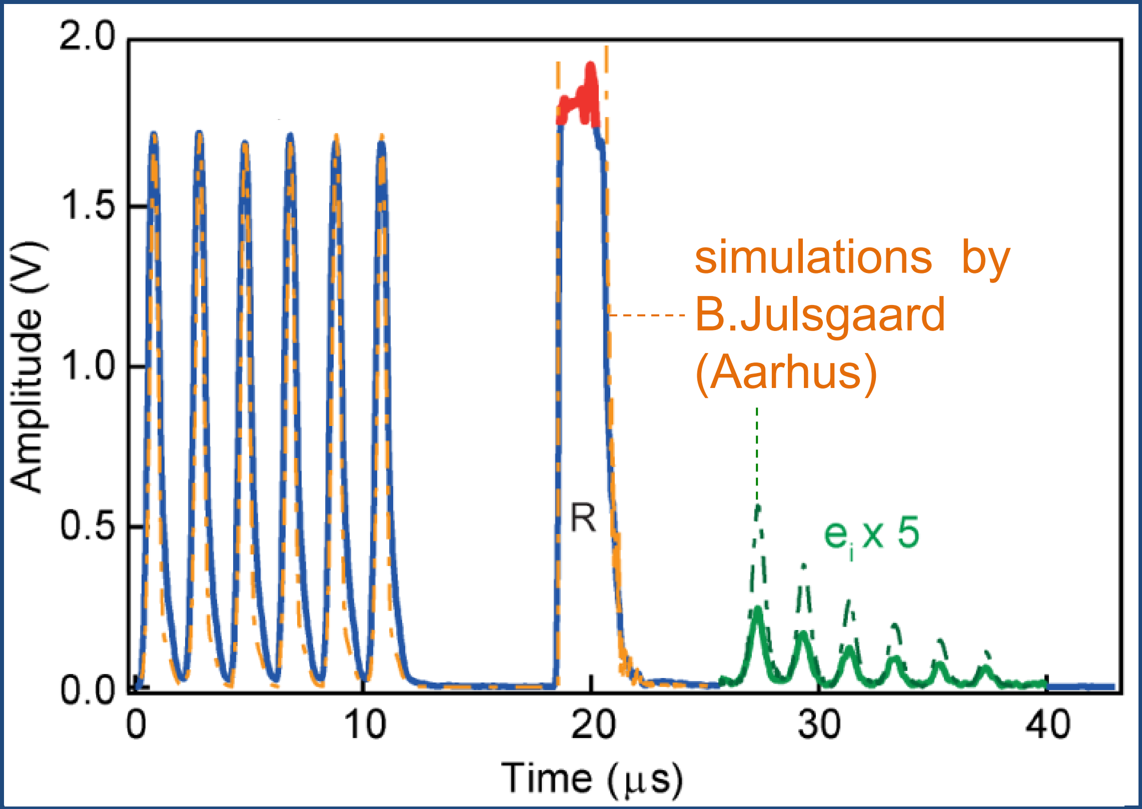
$$0.75^2 \times 0.43 \times 10^{-3} = 2.\ 10^{-4}$$

longer T_2 (C engineering)

adiabatic pulses or selective implant.

increase N or decrease κ_{ext}

Read protocol efficiency analysis



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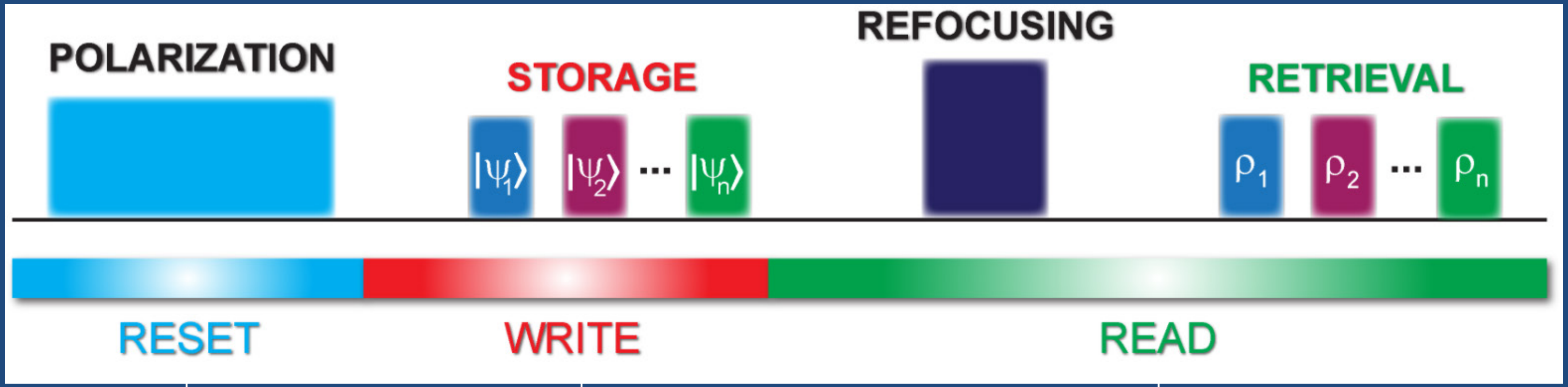
Conclusion



Optical repumping of the spins at low T	Adiabatic transfer from transmon to NV spins	Retrieval of multiple microwave pulses. Down to 1 photon
$E_{RESET} \approx 90\ \%$ in 1s	$E_{WRITE} \approx 95\ \%$	E_{READ} up to 0.5 % after 100µs for T_2 = 85µs

Margins for improvement

Alternative approach: couple superconducting qubits to single spins