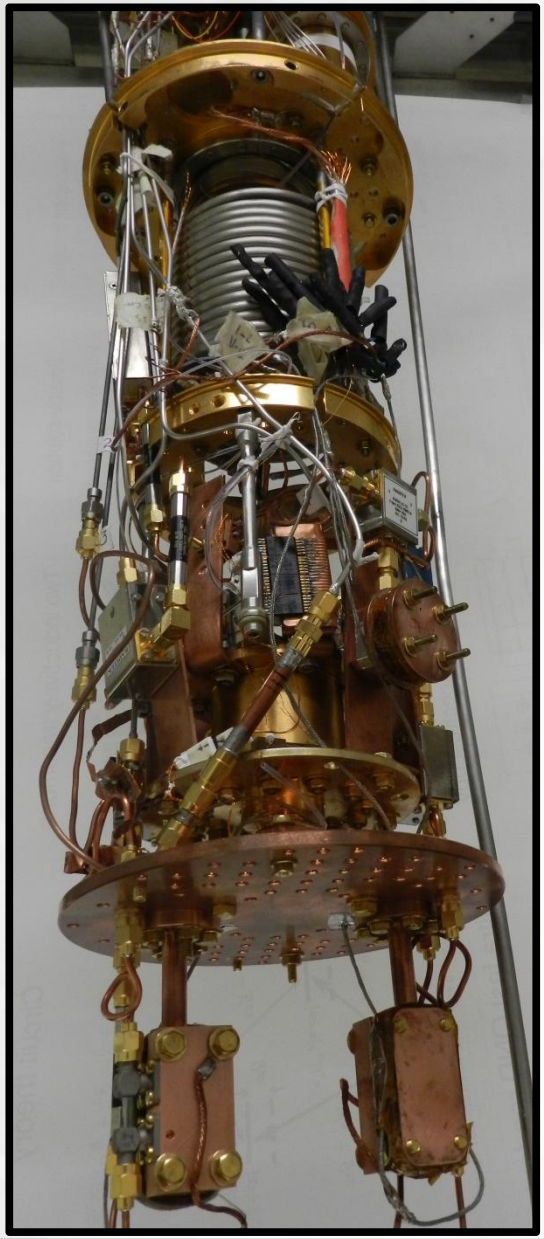


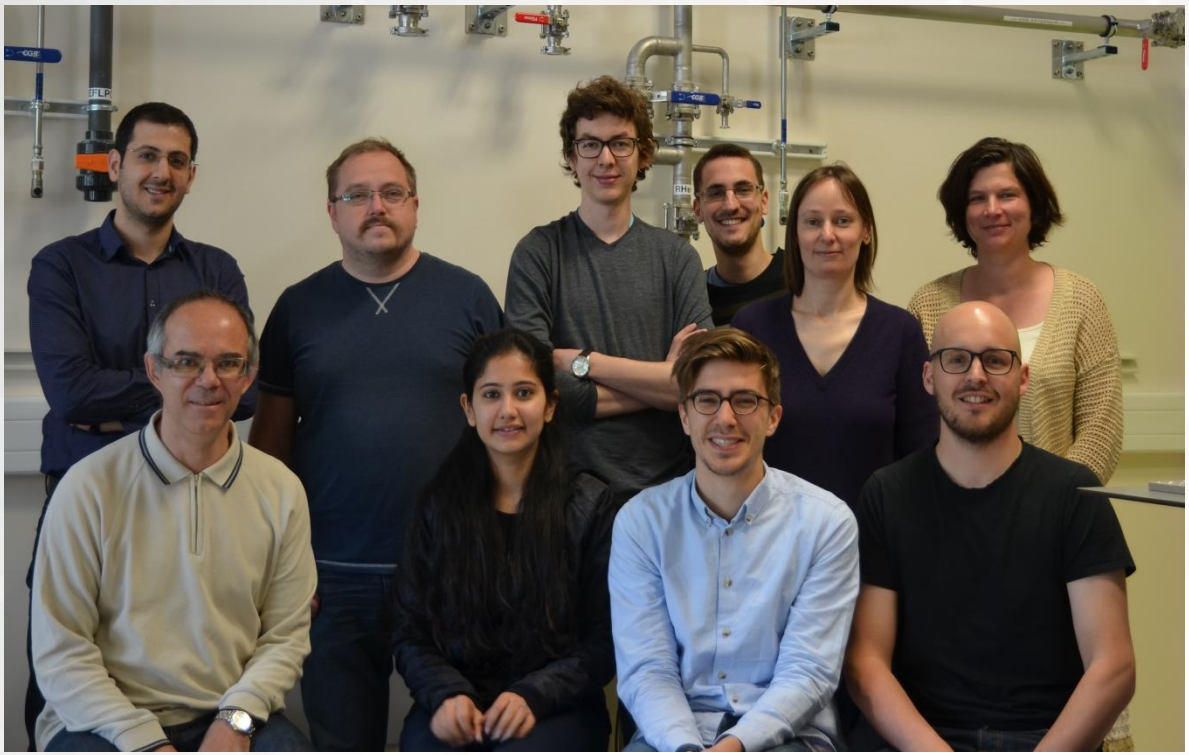
Preliminary results on superconducting V-shaped artificial atom readout

Olivier Buisson
Institut Néel, Grenoble, France

- Frank Hekking Memorial Workshop

People involved on this project

Superconducting quantum circuits team



Collaboration with theoreticians from LPMMC Grenoble

Denis Basko

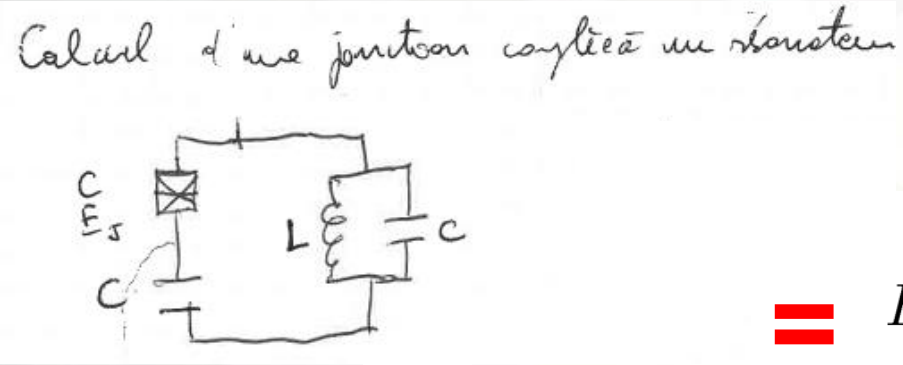
Frank Hekking

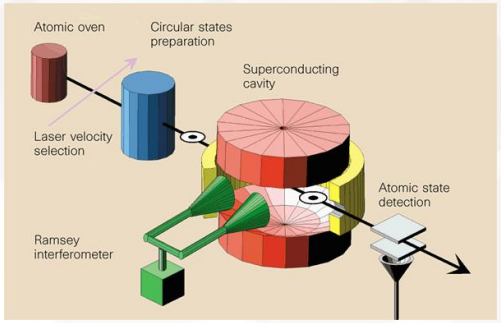
Permanents: Olivier Buisson, Cécile Naud,
Wiebke Guichard, Nicolas Roch

Non-permanents: **Rémy Dasonneville,** Luca Planat, Javier Puertas-Martinez
Yuriy Krupko, Farshad Foroughi, Sébastein Leger, Karthik Bharadwa

Frank Hekking souvenir

Summer 1999 in Grenoble…





Brune, Raimond, Haroche groupe

$$= \quad \hat{H}_c = -i\frac{E_{C,c}}{2}\sqrt{\frac{\hbar\omega_r}{E_{C,r}}}(2n - N_g)\left(a^\dagger - a\right).$$

+

Very good espresso!

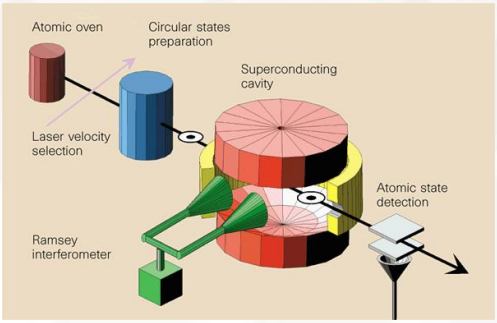
Strong coupling! $E_{coupling}$= 64MHz

arXiv008275 (2000)
Book MacroQCQC Edited 2001

…first proposal on circuit QED!

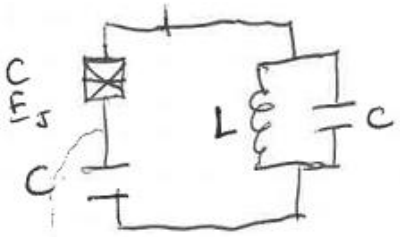
Frank Hekking souvenir

Summer 1999 in Grenoble…



Brune, Raimond, Haroche groupe

Calcul d'une jonction couplée au résonateur



=

$$\hat{H}_c = -i\frac{E_{C,c}}{2}\sqrt{\frac{\hbar\omega_r}{E_{C,r}}}(2n - N_g)\left(a^\dagger - a\right).$$

+

Strong coupling!

$E_{coupling}$= 64MHz

arXiv008275 (2000)
Book MacroQCQC Edited 2001

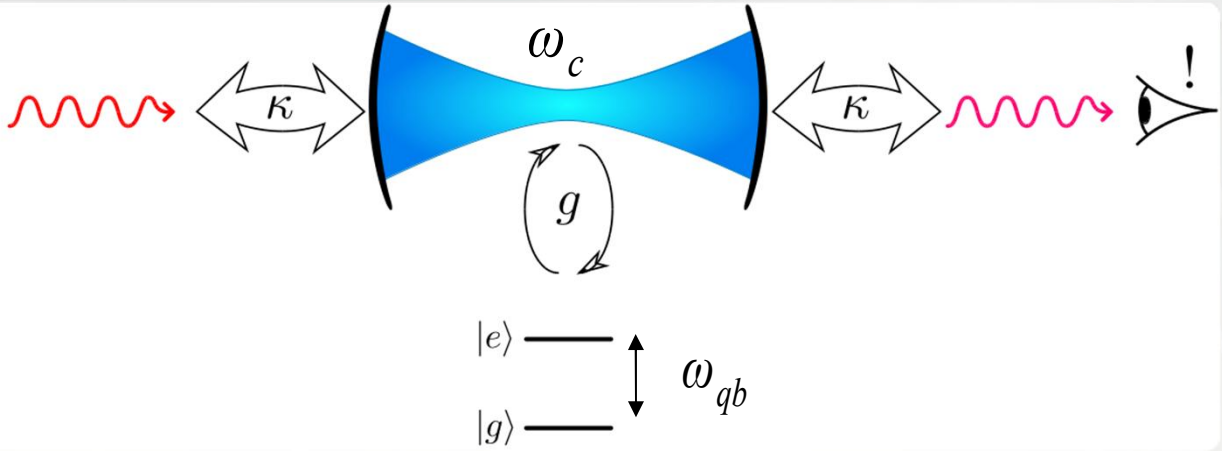
Very good espresso!

…first proposal on circuit QED!

Etienne Dumur: « Il a été le meilleur professeur que j'ai eu: il etait juste incroyable! »
« He was the best professor that I've ever had: he was just incredible! »

Motivation V-shape: quantum measurement

Two level system in a cavity:

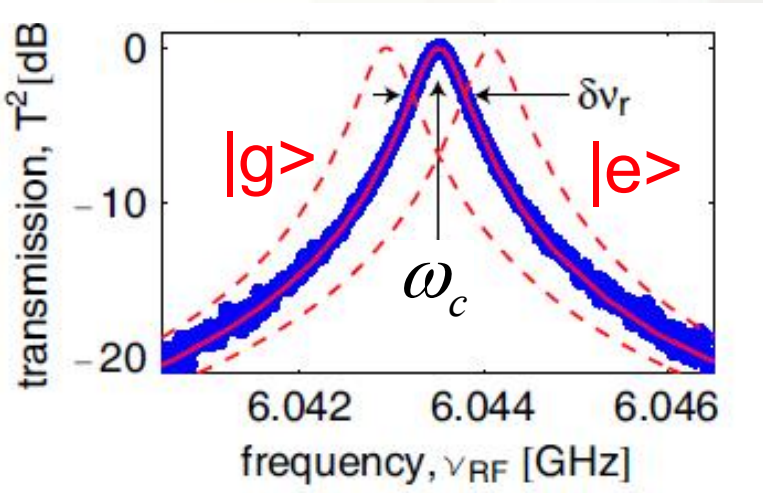


→ Janes-Cummings Hamiltonian

Dispersive limit: $\omega_c - \omega_{qb} >> g$

$$H = \eta(\omega_c + \chi\sigma_z)c^+c + \eta\tilde{\omega}_{qb}\sigma_z$$

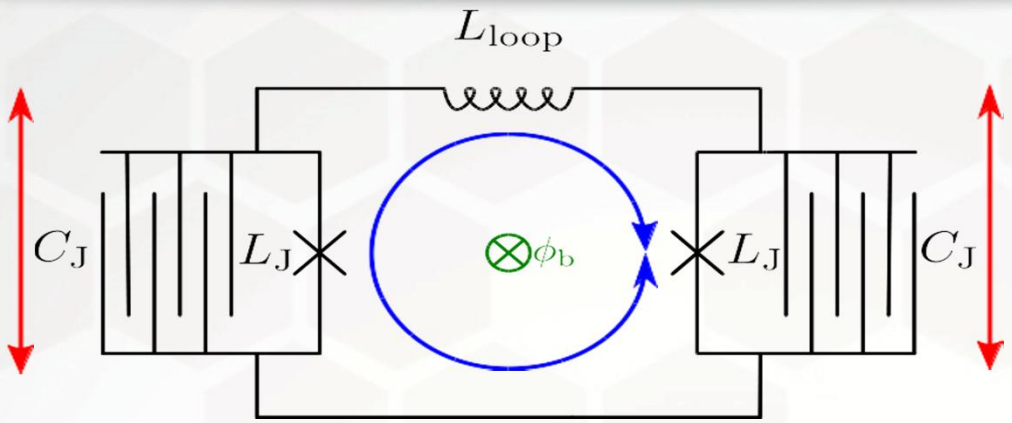
where $\chi = g^2/(\omega_c - \omega_{qb})$



Wallraff et al, Nature 2004

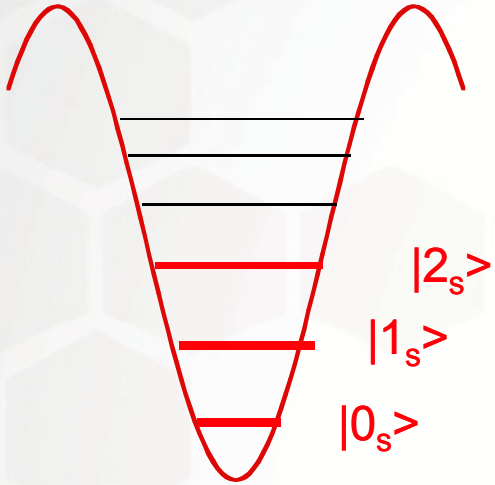
Dispersive read-out drawbacks:
- Purcell effect
- weak photon number

Motivation V-shape: quantum measurement

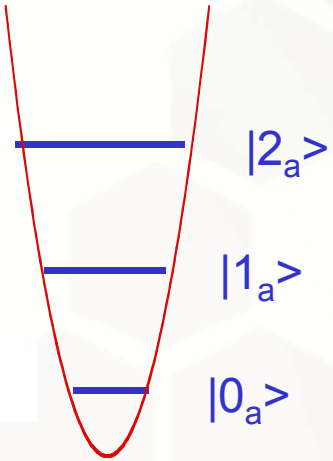


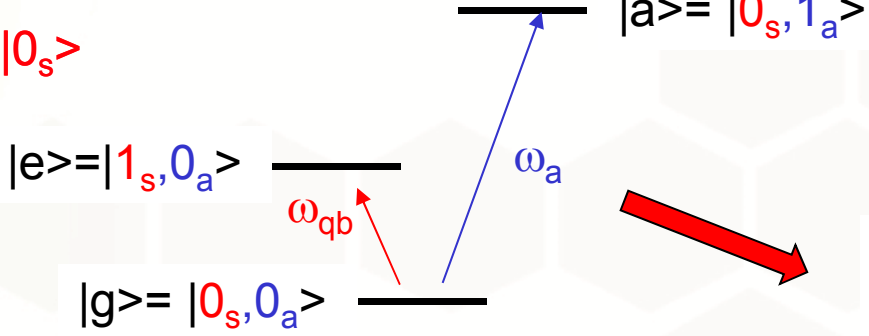
Transmon qubit mode

Ancilla mode



$\otimes$

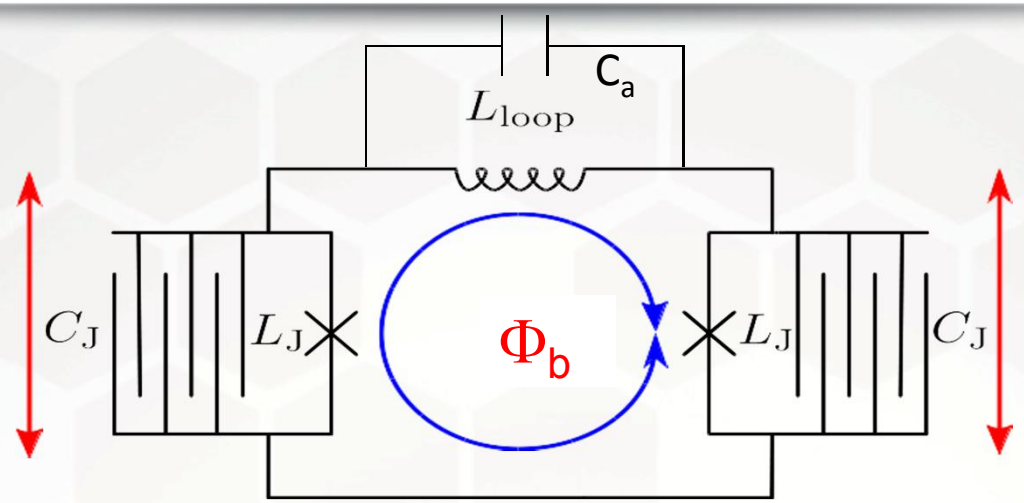




New qubit read-out using the ancilla mode

I. Diniz, E. Dumur et al., PRA 2013

Motivation V-shape: quantum measurement



$$\hat{H} = E_{c,s}\hat{q}_s^{\,2} + E_{c,a}\hat{q}_a^{\,2} - E_J\cos(\hat{x}_s)\cos(\hat{y}_a) - bE_J(\hat{y}_a)^2$$

where $\begin{cases} \hat{x}_s = (\hat{\varphi}_1 + \hat{\varphi}_2)/2 \\ \hat{y}_a = (\hat{\varphi}_1 - \hat{\varphi}_2)/2 \end{cases}$

E. Hoskinson et al., PRL (2009)

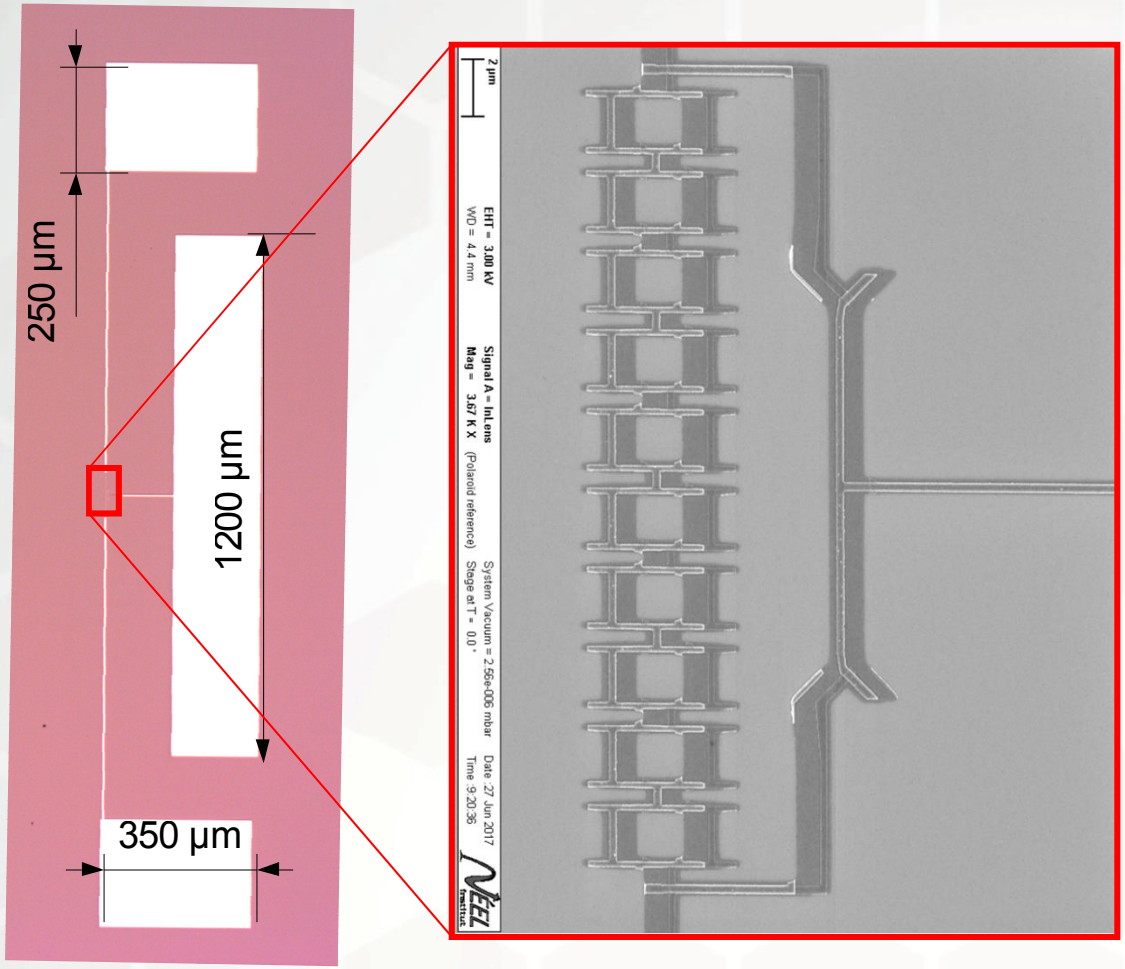
$$H_{RWA} = \tfrac{1}{2}\eta\omega_{qb}\sigma_z + \eta\omega_a(a^+a + \delta_a a^+aa^+a) + \eta g_{zz}\sigma_z a^+a$$

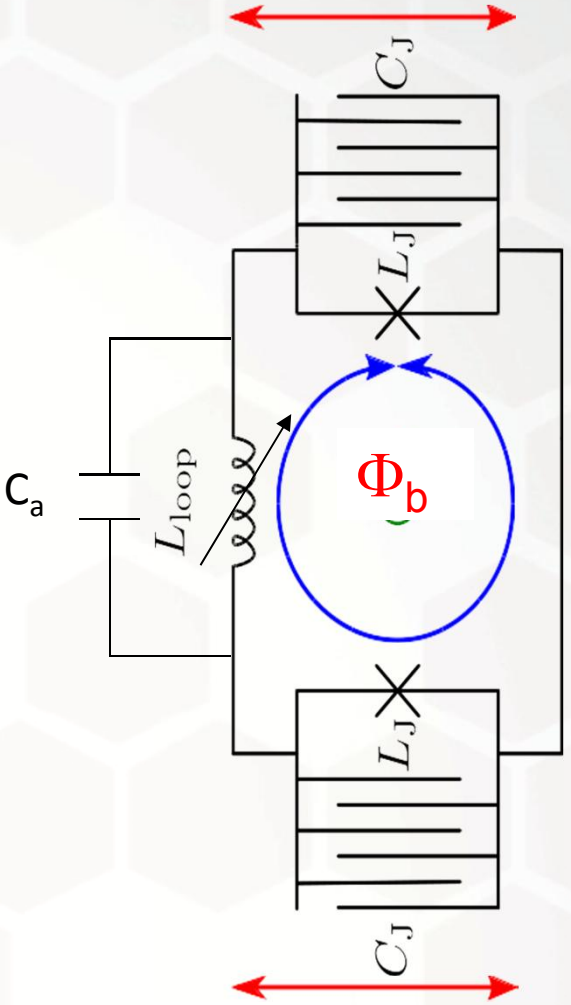
Transmon qubit Ancilla mode

Longitudinal coupling with large g_{zz} ($g_{zz}/2\pi$~60 MHz)

E. Dumur et al., PRB (2015)

The 3D V-shaped transmon

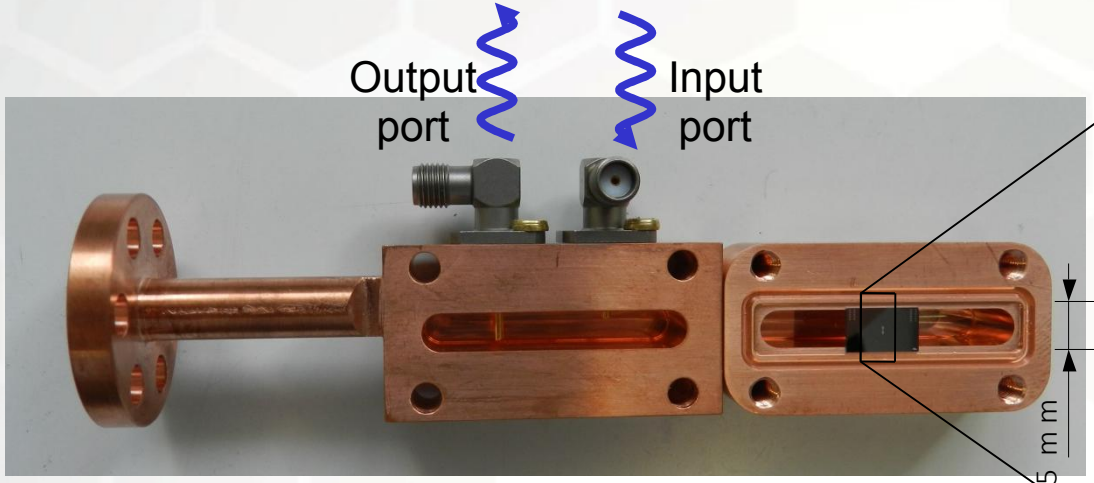


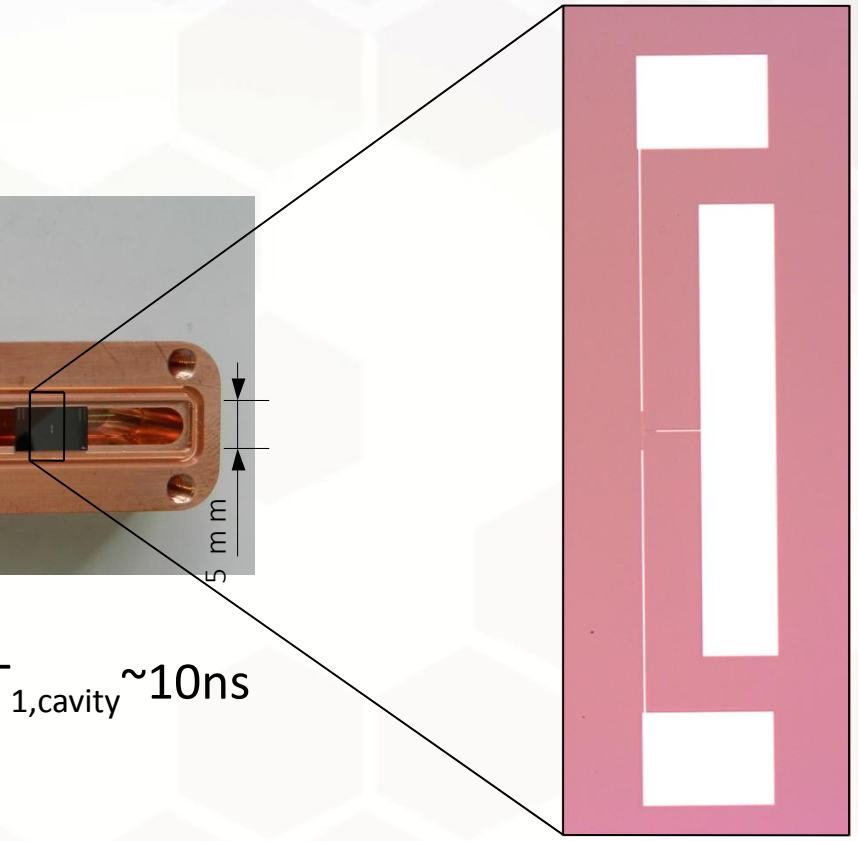


The 3D V-shaped transmon

Inserted inside a cavity:

Cavity TE_{101}	~7,1 GHz



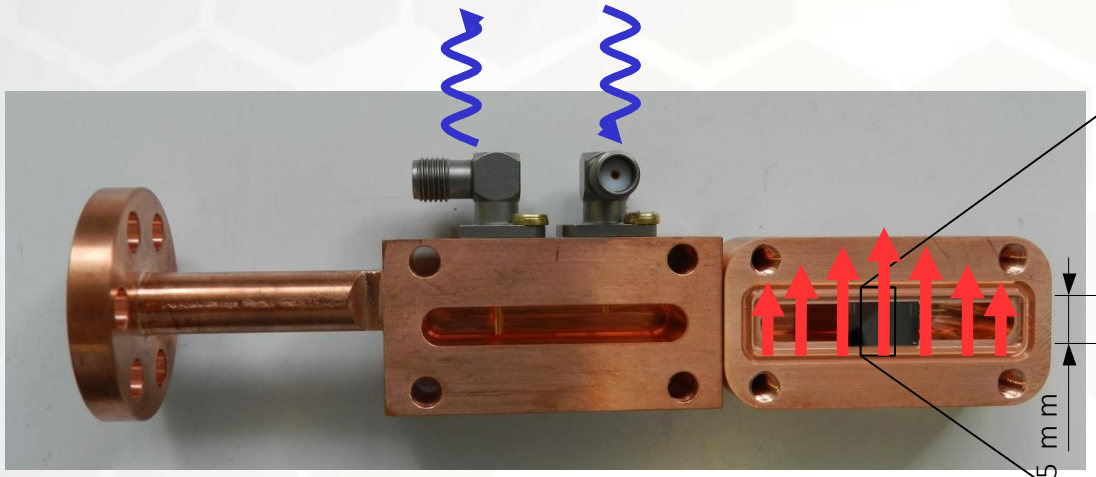


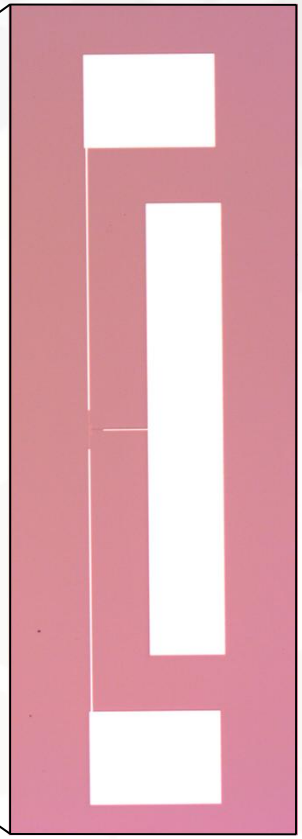
$K_{out}/2\pi$~18MHz ; $T_{photon\ life\ time}=T_{1,cavity}$~10ns

The 3D V-shaped transmon

Inserted inside a cavity:

Cavity TE_{101}	~7,1 GHz





Cavity field coupling:

$$\hat{H}_c = \eta g_{qb}(c + c^+)(\sigma_-^{qb} + \sigma_-^{qb}) + \eta g_a(c^+ + c)(a^+ + a)$$

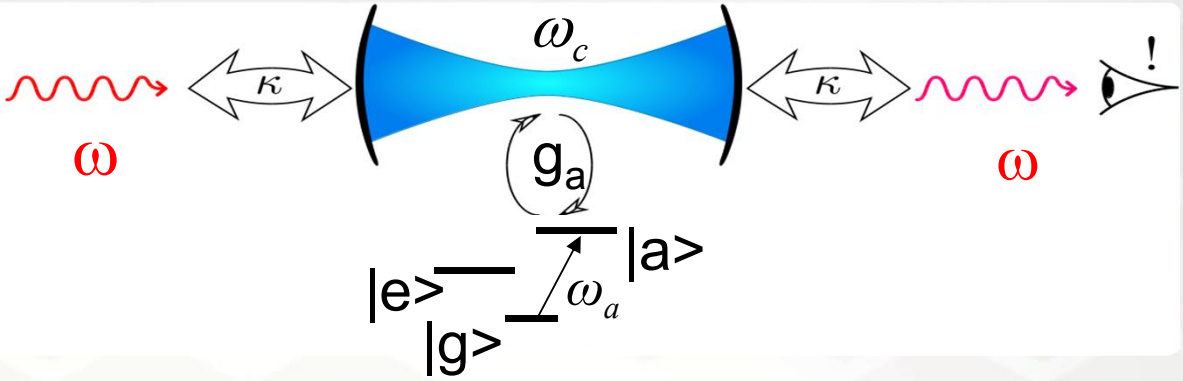
g_{qb}~0 — g_a~hundreds of MHz

$$\hat{H}_{syst} = \tfrac{1}{2}\eta\omega_{qb}\sigma_z + \eta g_{zz}\sigma_z a^+ a + \eta\omega_a(a^+ a + \delta_a a^+ a a^+ a) + \eta g_a(c^+ + c)(a^+ + a) + \eta\omega_c c^+ c$$

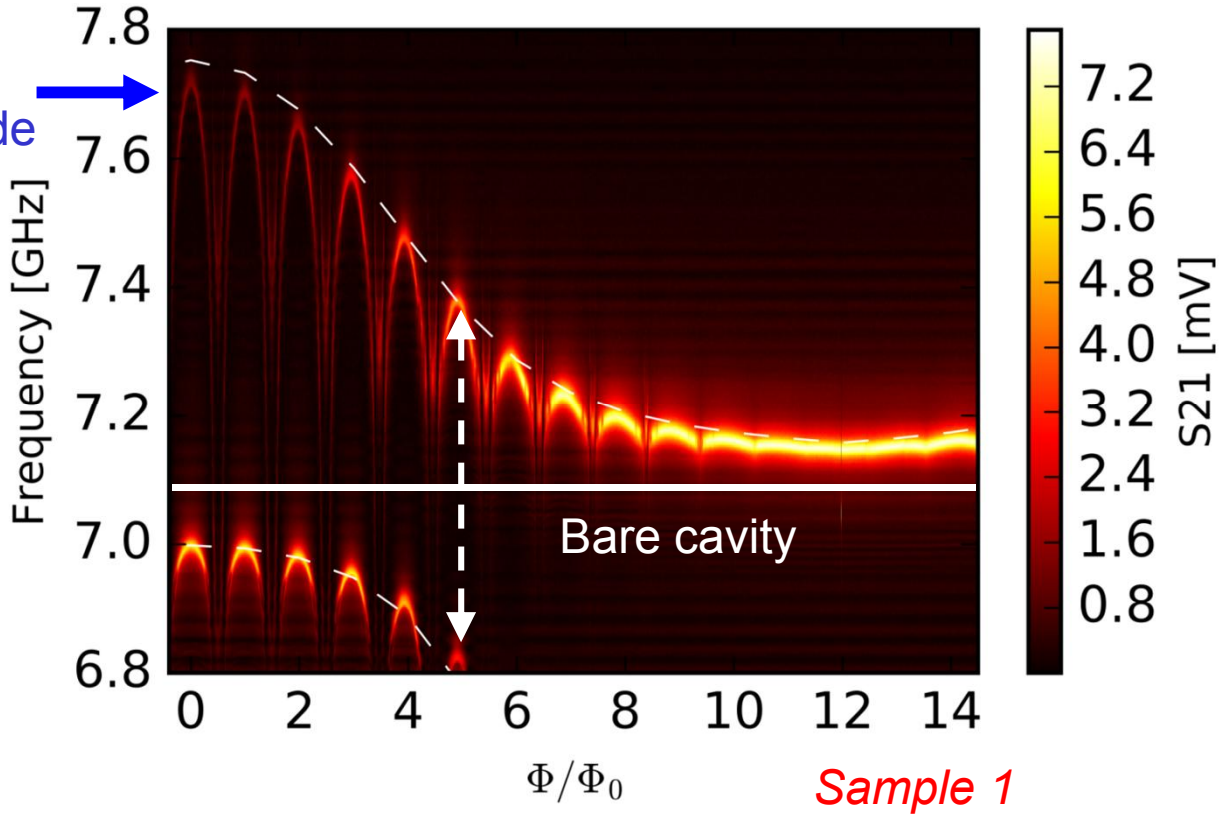
No Purcell effect for the qubit!

Cavity-Ancilla spectroscopy

Single tone spectroscopy



Zero-field ancilla mode



Sample 1

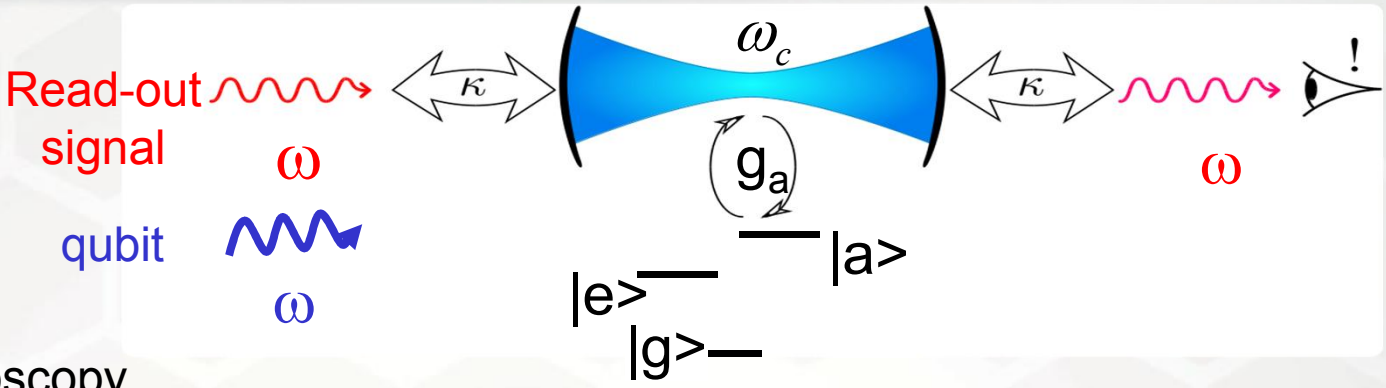
g_a~300MHz

Estimated $T_{1,ancilla}$

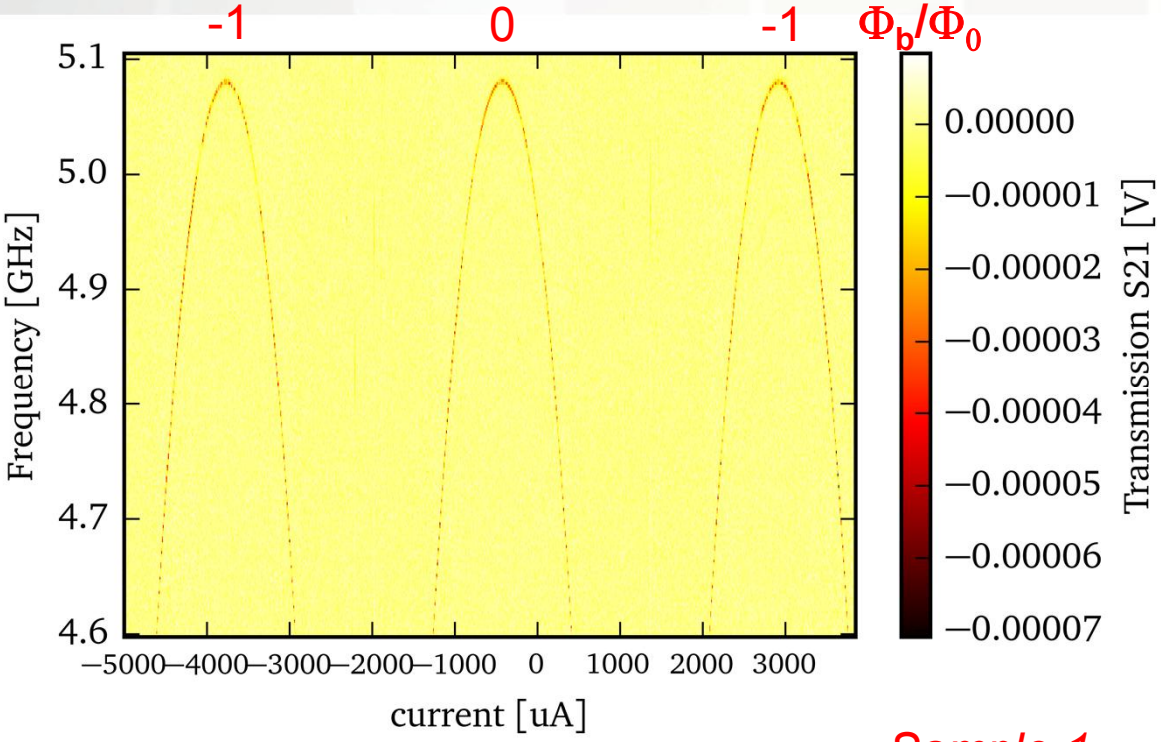
$$T_1^a = \kappa_{out}^{-1}\left(\frac{\Delta_a}{g_a}\right)^2 \approx 15ns$$

Logical Qubit properties

Two tone spectroscopy:

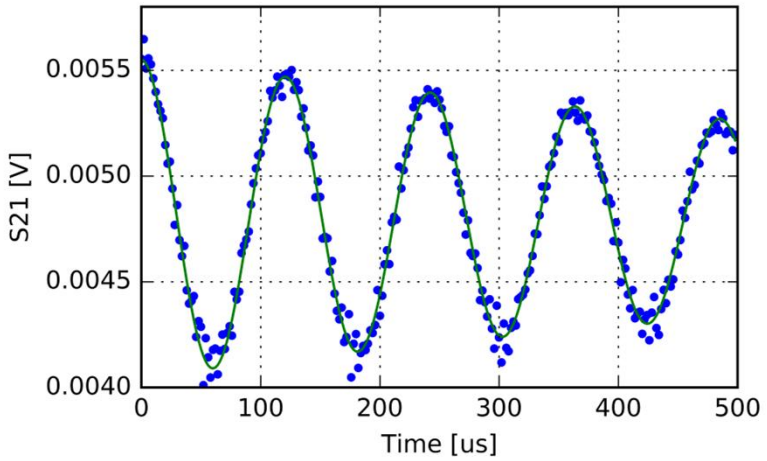


Qubit spectroscopy



Sample 1

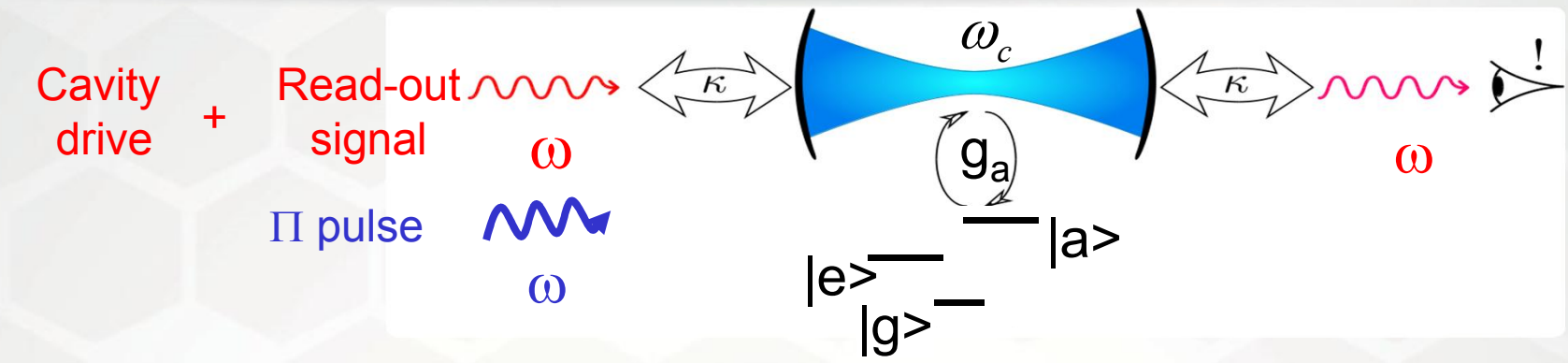
Rabi oscillation:

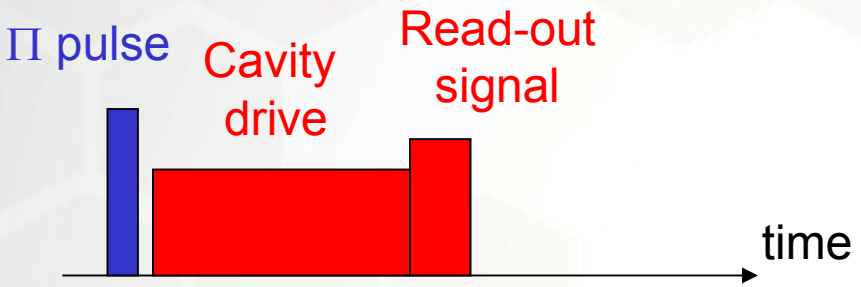


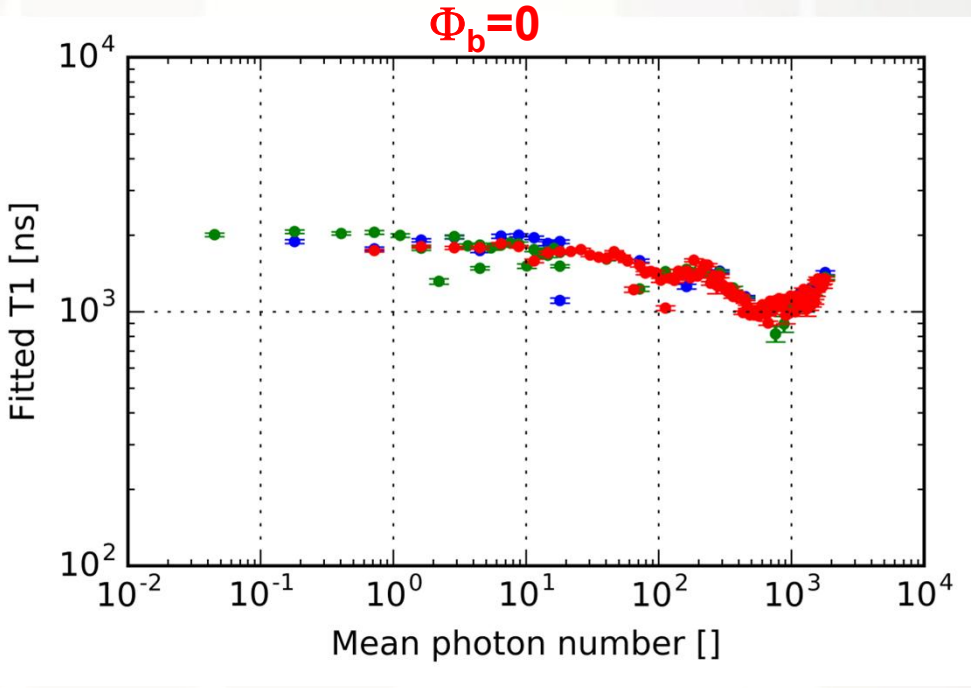
Sample 1

Relaxation time: ~2.5µs

Measurement photon induced relaxation



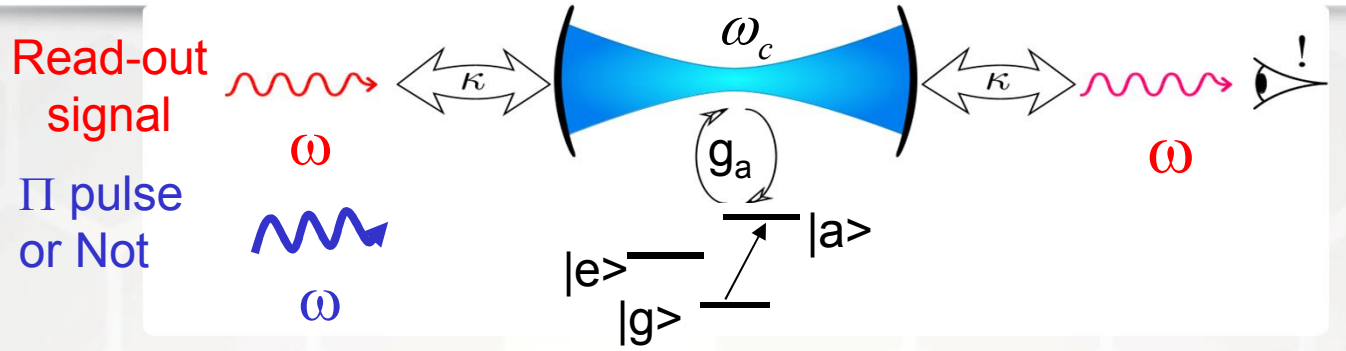




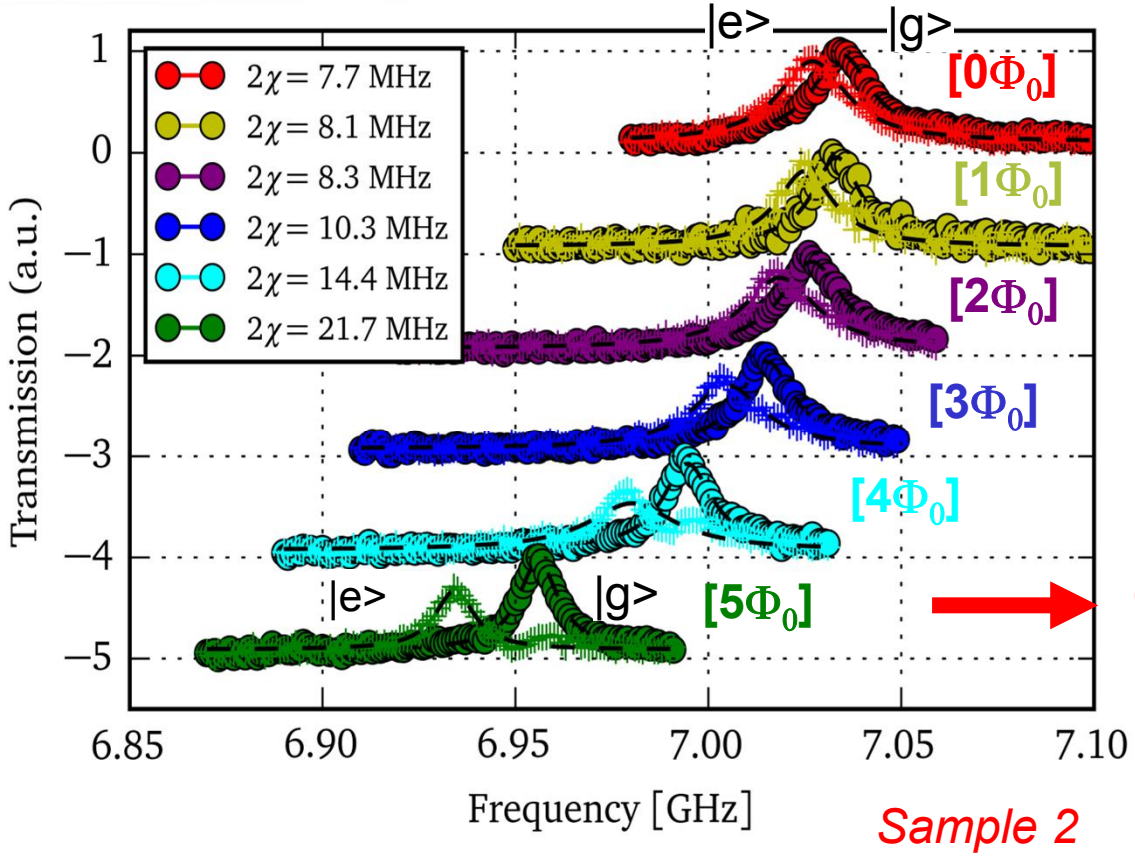
Weak qubit sensitivity on the cavity photon number

Sample 1

Effective dispersive coupling



$$H_{RWA} = \tfrac{1}{2}\eta\omega_{qb}\sigma_z + \eta\omega_a(a^+a + \delta_a a^+aa^+a) + \eta g_{zz}\sigma_z a^+a$$



Sample 2

g_{zz} ~ 40 MHz

→ Large effective dispersive shift

$$\chi_{eff}^{qb} = -g_a{}^2 \frac{g_{zz}}{\Delta_a(\Delta_a + 2g_{zz})}$$

(dispersive limit)

→ Complete separation on transmitted peak!

Qubit readout fidelity

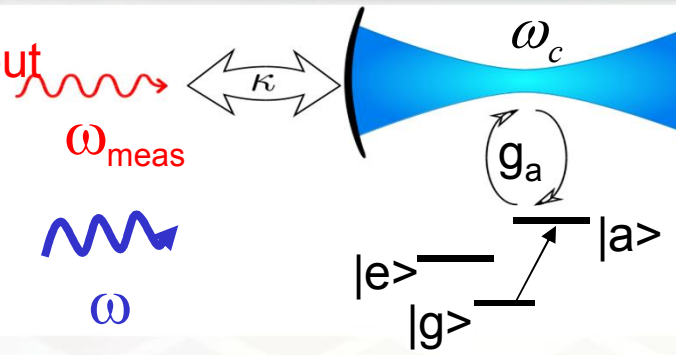
$\Phi_b=5\Phi_0$

Large read-out signal

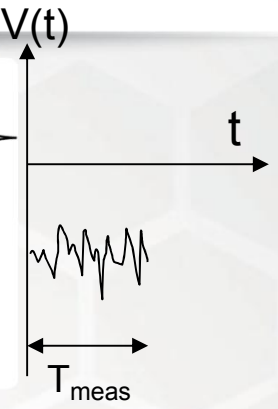
ω_{meas}

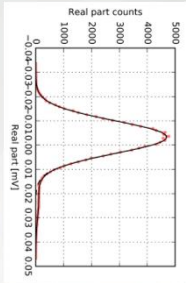
Π pulse or Not

ω

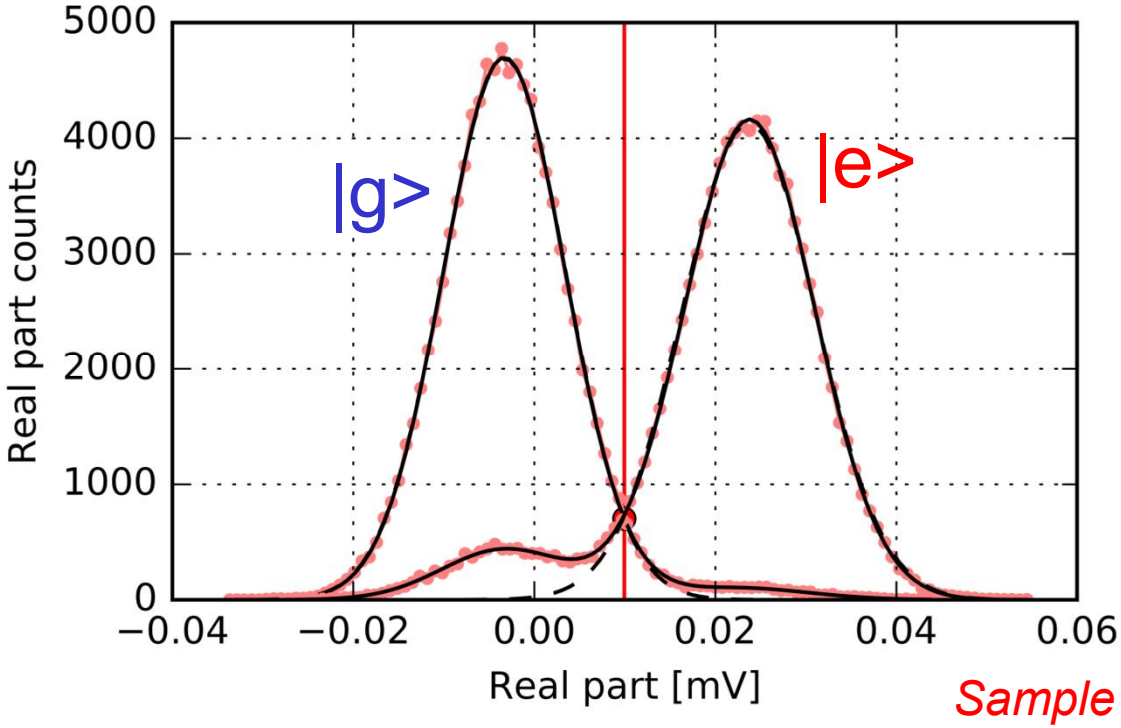


ω_{meas}

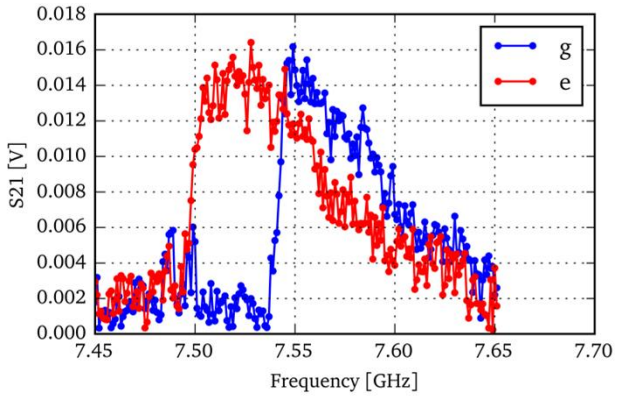




T_{meas}=500ns: $\omega_{meas}/2\pi$=7.51GHz



Sample 2



Thermalization: 2%
Relaxation: 8%

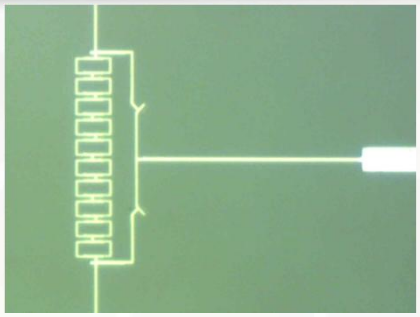
Fidelity=84%

Intrinsic fidelity=95% !

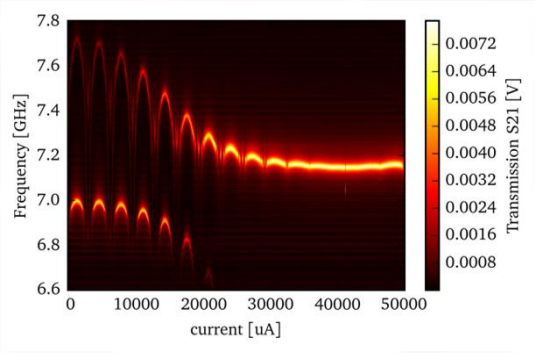
without JPA!!

Conclusion

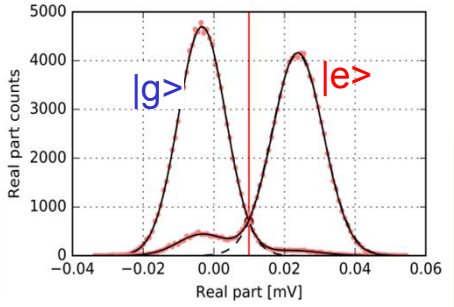
➡ Implementation of a 3D V-shape transmon



➡ Resonance condition ancilla-cavity



➡ Promissing large readout fidelity without JPA



Work in progress to reach large fidelity...