Towards elementary quantum processors with Cooper pair boxes ?

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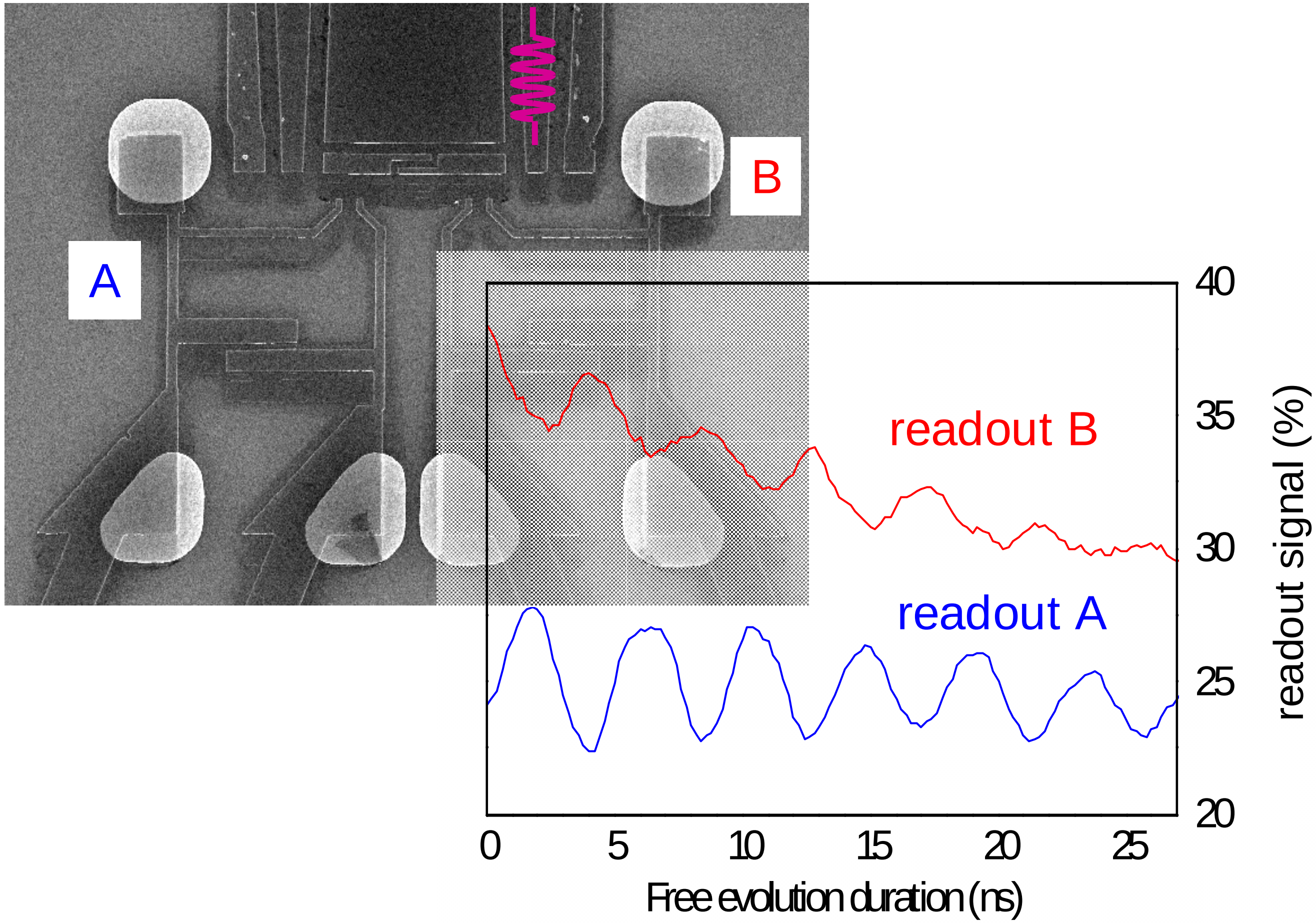


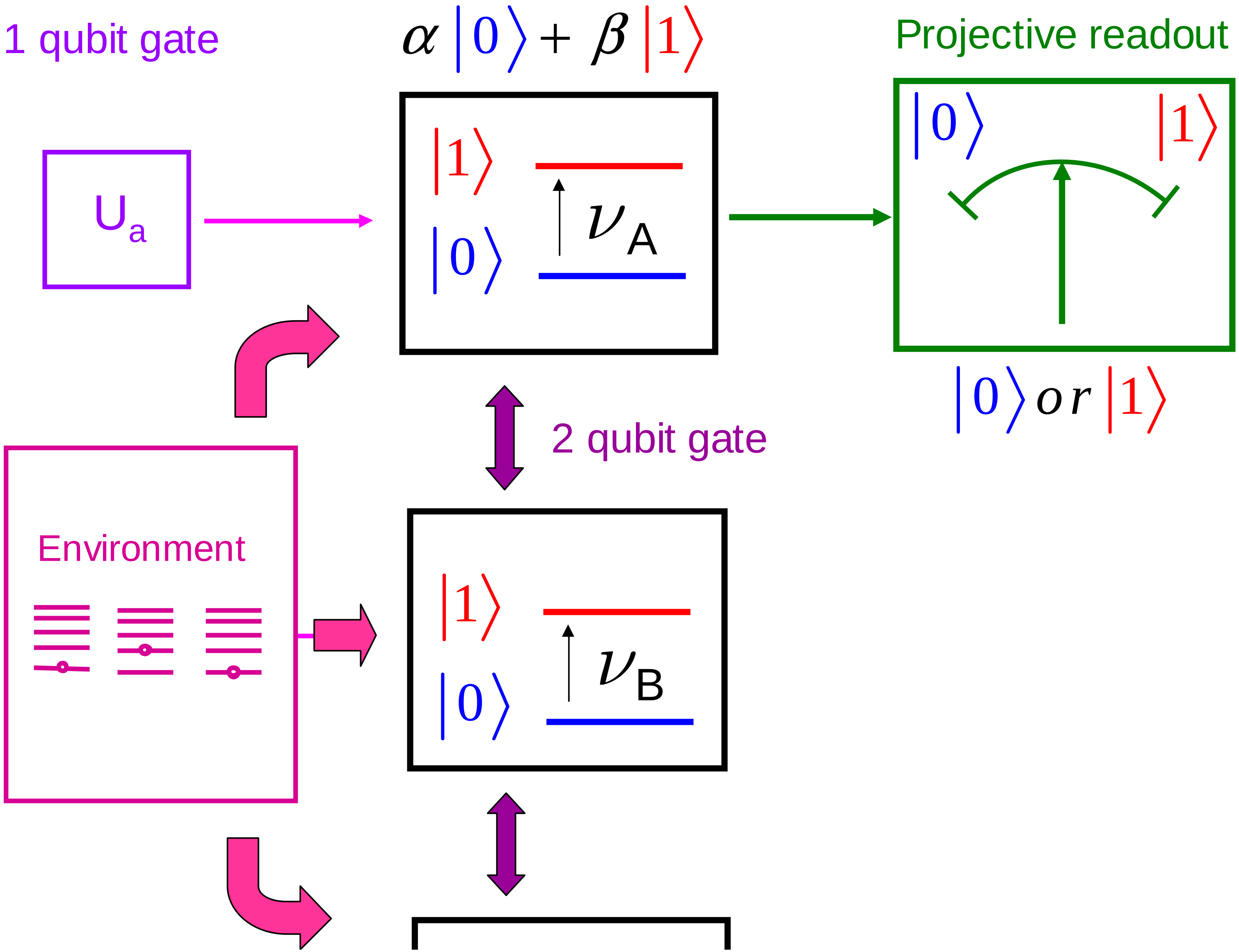
And before:

G. Ithier
A. Cottet
E. Collin
A. Aassime

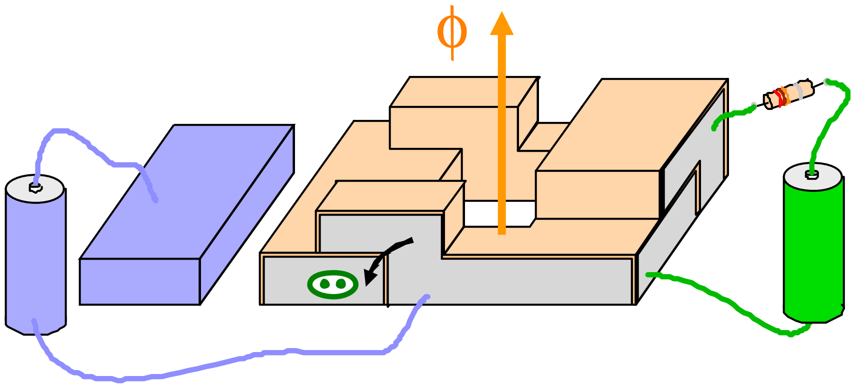
Quantronics group

Moriond 2008

An elementary quantum processor



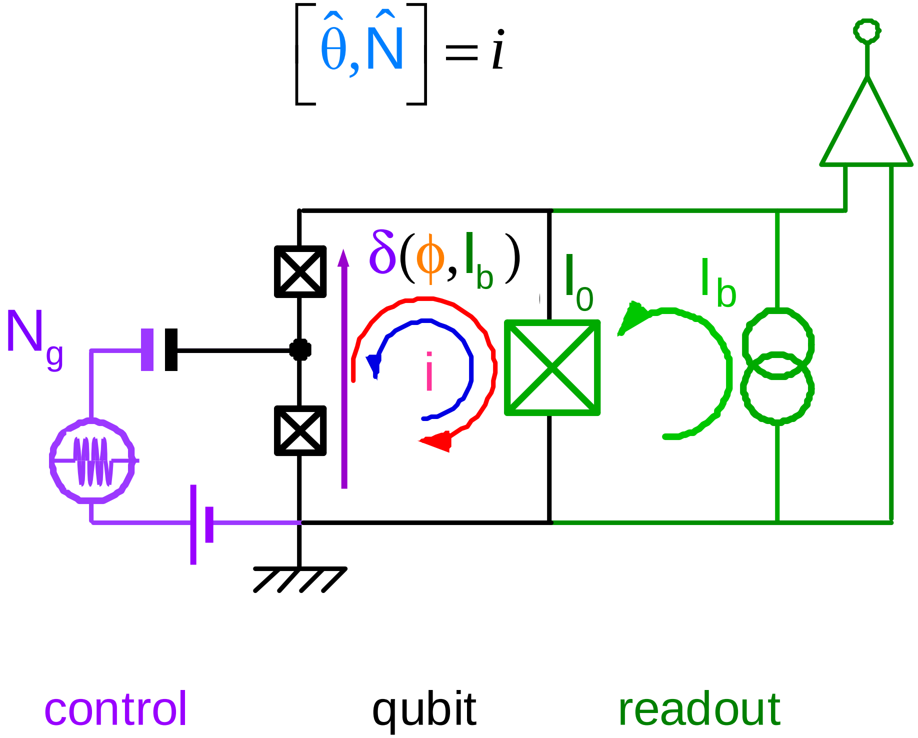
The quantronium qubit: a split Cooper pair box…

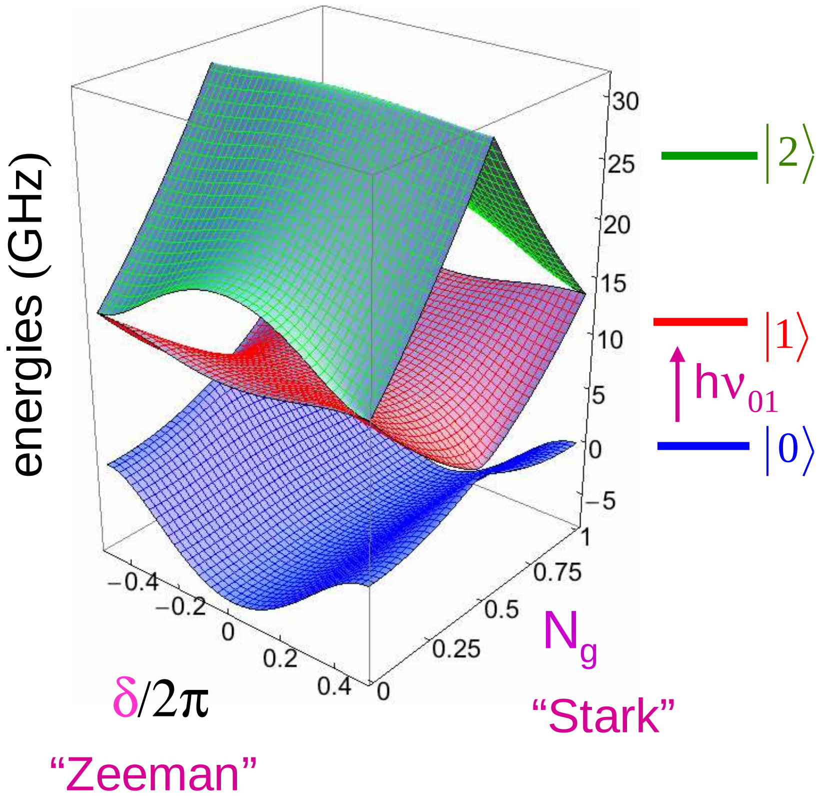


$$\hat{H}_{qubit} \approx E_C(\hat{N} - N_g)^2 - E_J \cos\frac{\delta}{2}\cos\hat{\theta}$$

$$\nu_{01}[N_g, \delta(\phi, I_b)]$$

$$\left[\hat{\theta}, \hat{N}\right] = i$$





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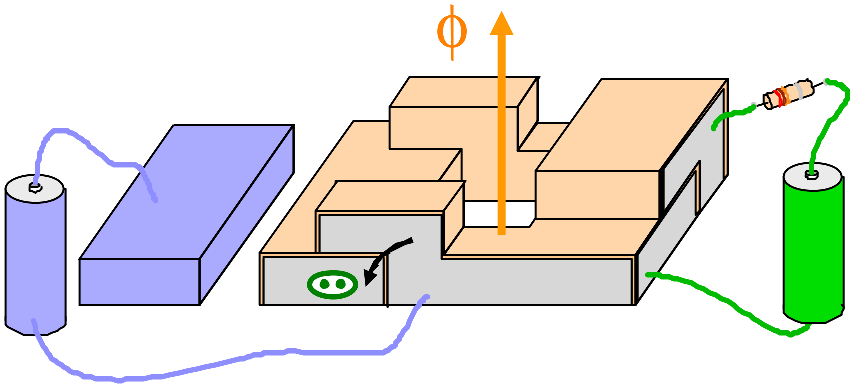

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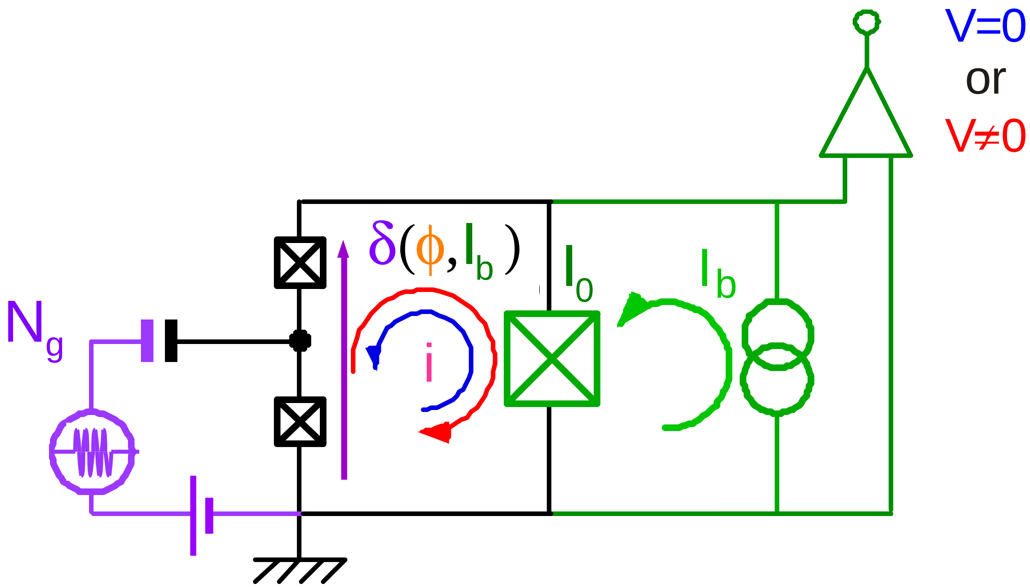
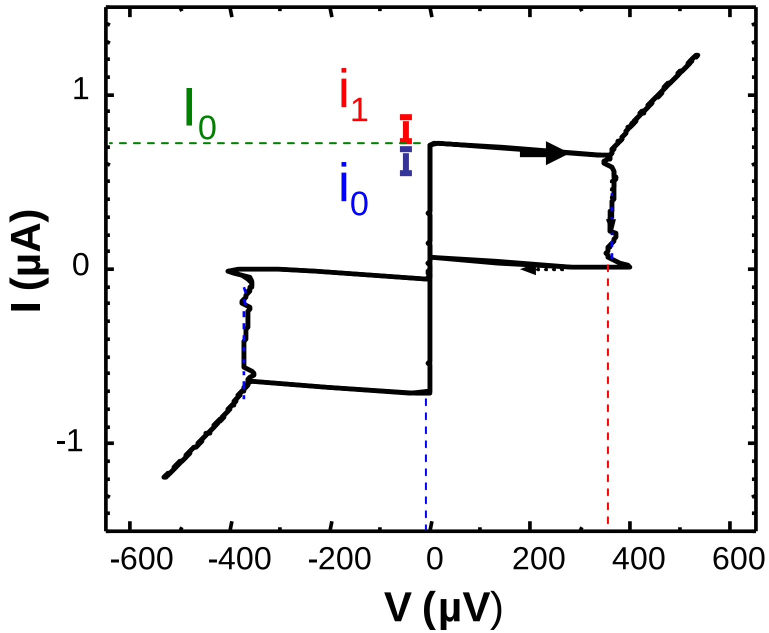
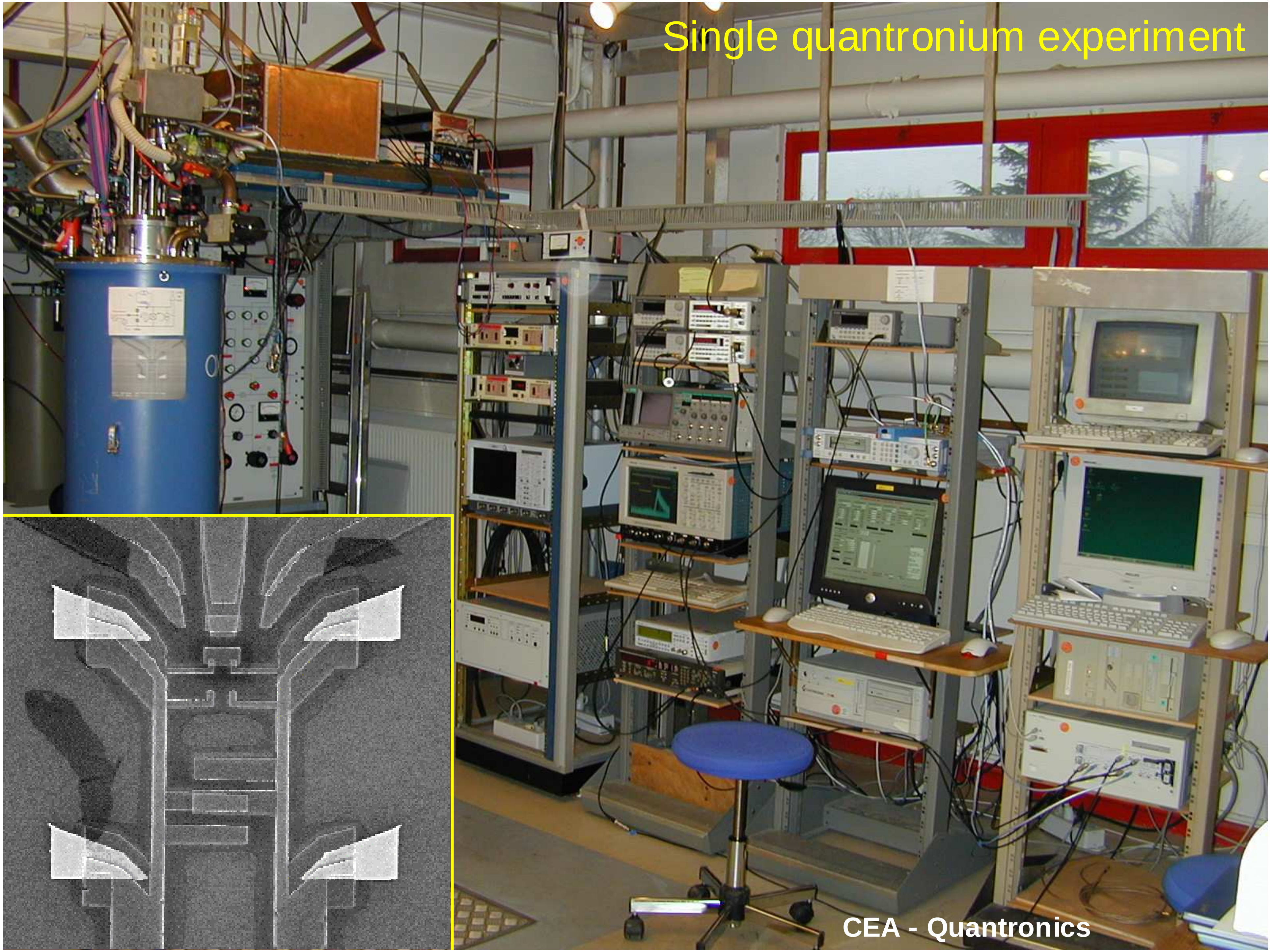




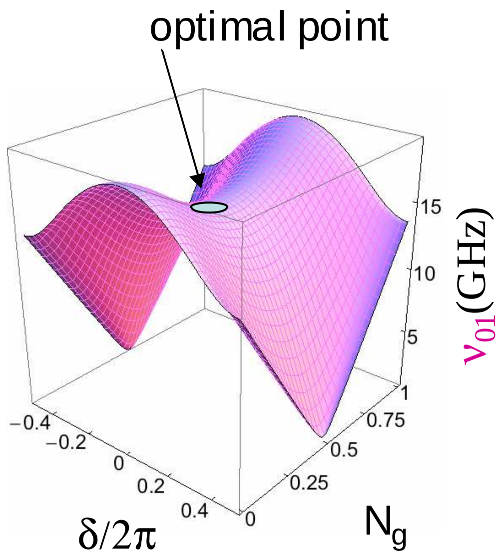
… with N_g resonant control…

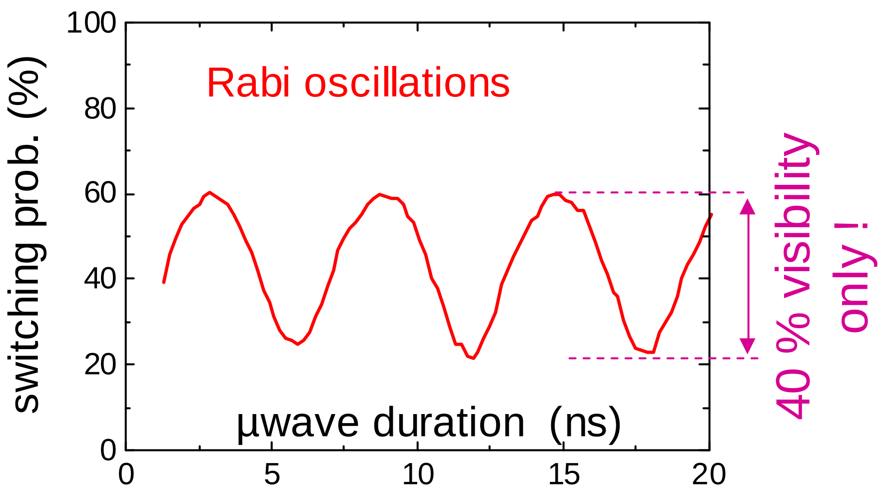
… and a JJ used as a threshold detector to read out its persistent current $i = \langle \hat{i} \rangle$

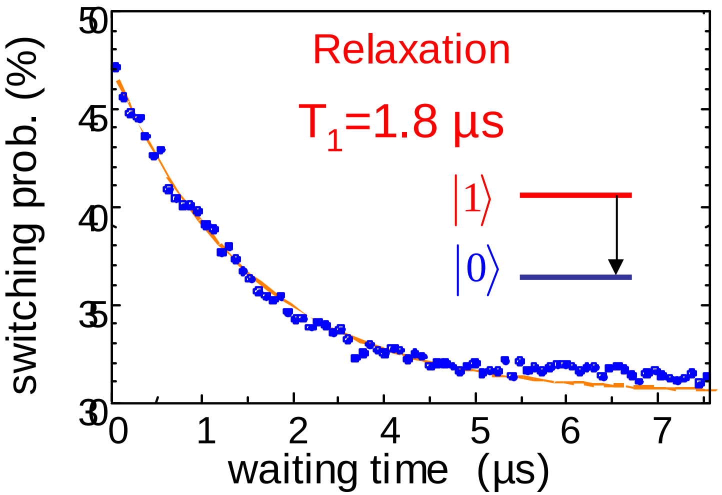

Single quantronium experiment
CEA - Quantronics

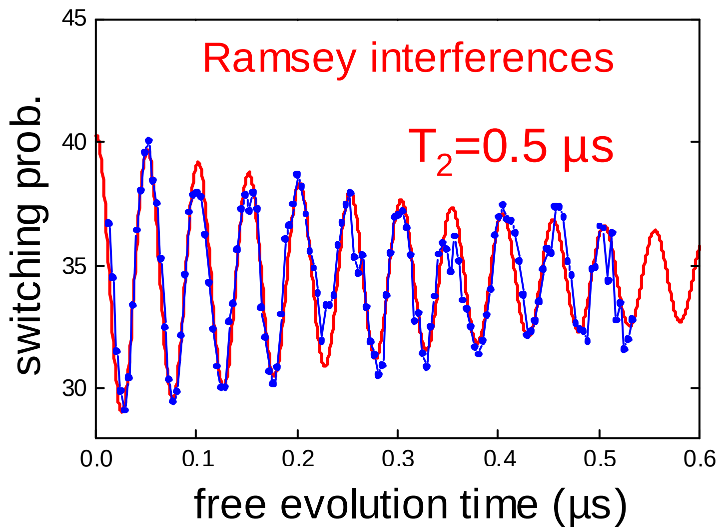
Single quantronium experiments

First demonstration (Vion *et al*., Science 2002)
NMR like manipulation (Colin *et al*., PRL 2004)
Analysis of decoherence (*Ithier et al., PRB 2005*)
QND character of the readout (Boulant *et al*., PRB 2007)



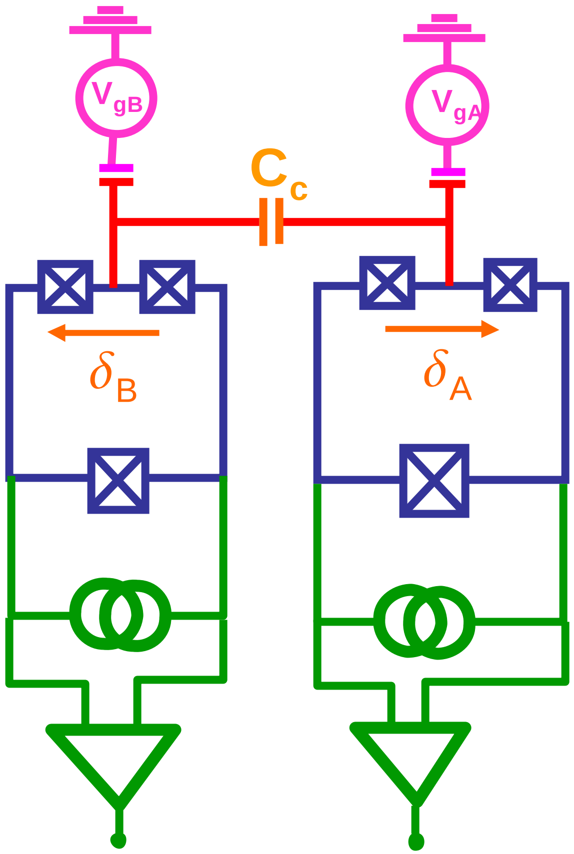






Coherence limited by charge noise
sufficient for a 2 qubit gate,
but problem with visibility

A two qubit gate with two capacitively coupled quantroniums



at $N_{gA} = N_{gB} = 1/2$

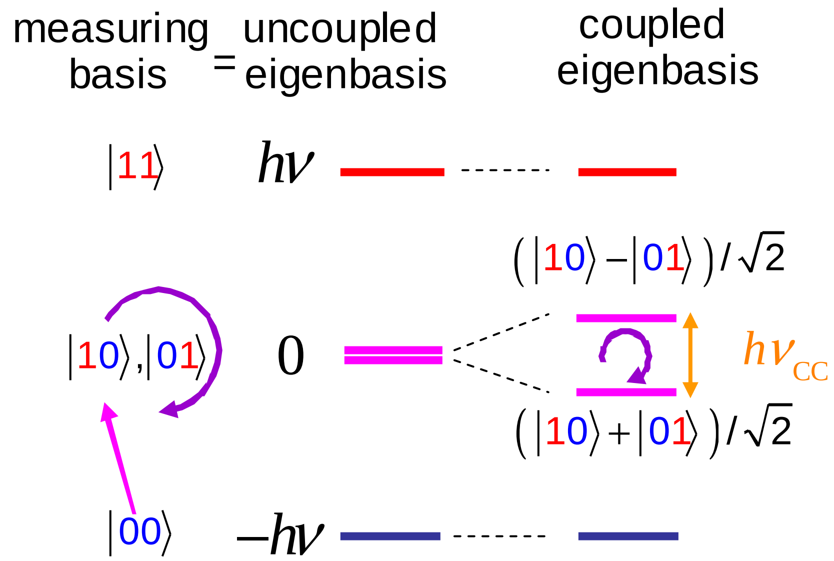
$$\frac{2}{h}\hat{H} = -\nu_A \hat{\sigma}_{zA} - \nu_B \hat{\sigma}_{zB} + \nu_{cc} \hat{\sigma}_{xA} \hat{\sigma}_{xB}$$

coupling

$$h\nu_{CC} = 2E_{cA}E_{cB}\frac{C_c}{(2e)^2}\left|\langle 1_A|\hat{N}_A|0_A\rangle\right|\left|\langle 1_B|\hat{N}_B|0_B\rangle\right|$$

At resonance

$\nu = \nu_A = \nu_B$

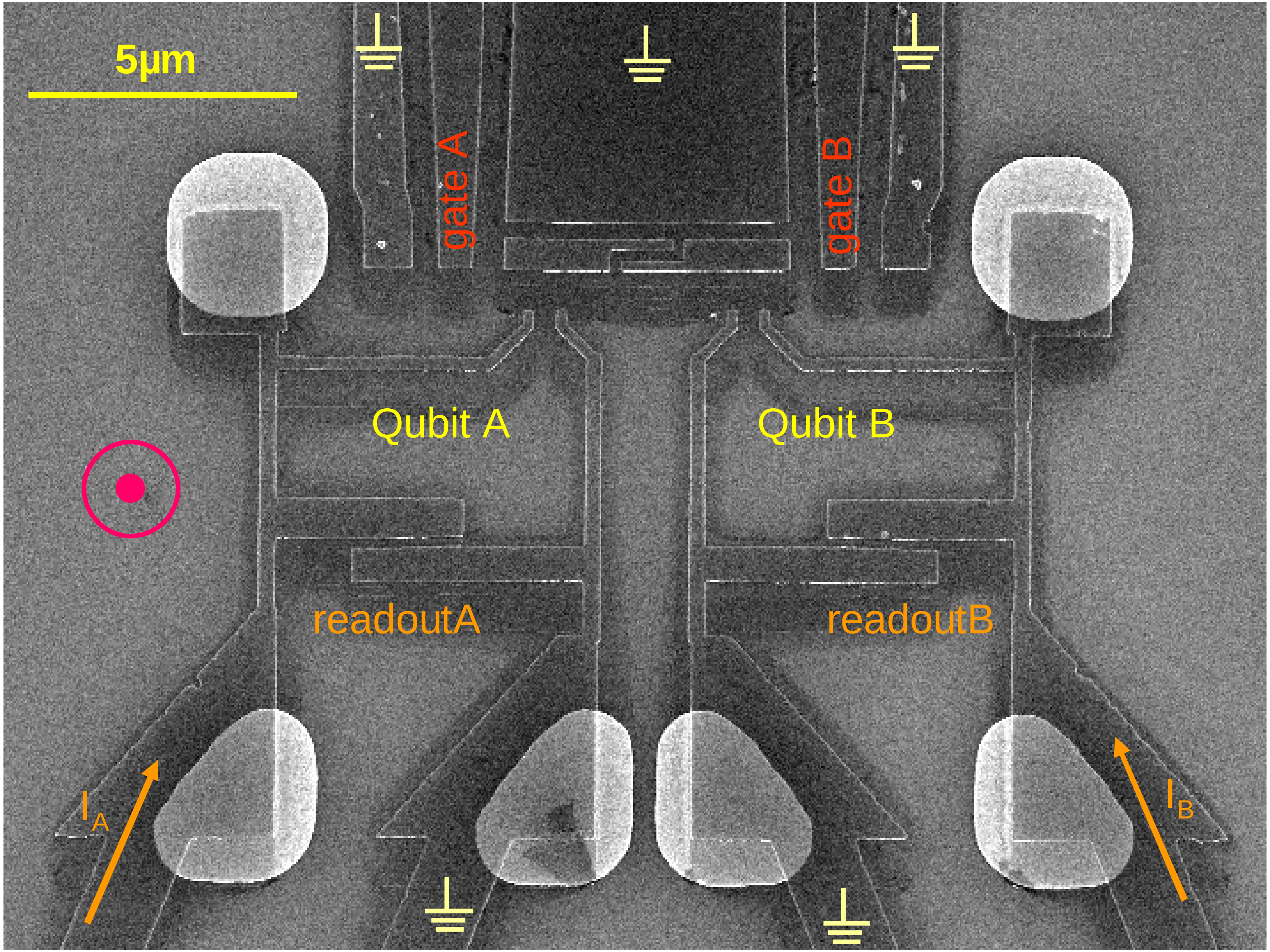


Free evolution:

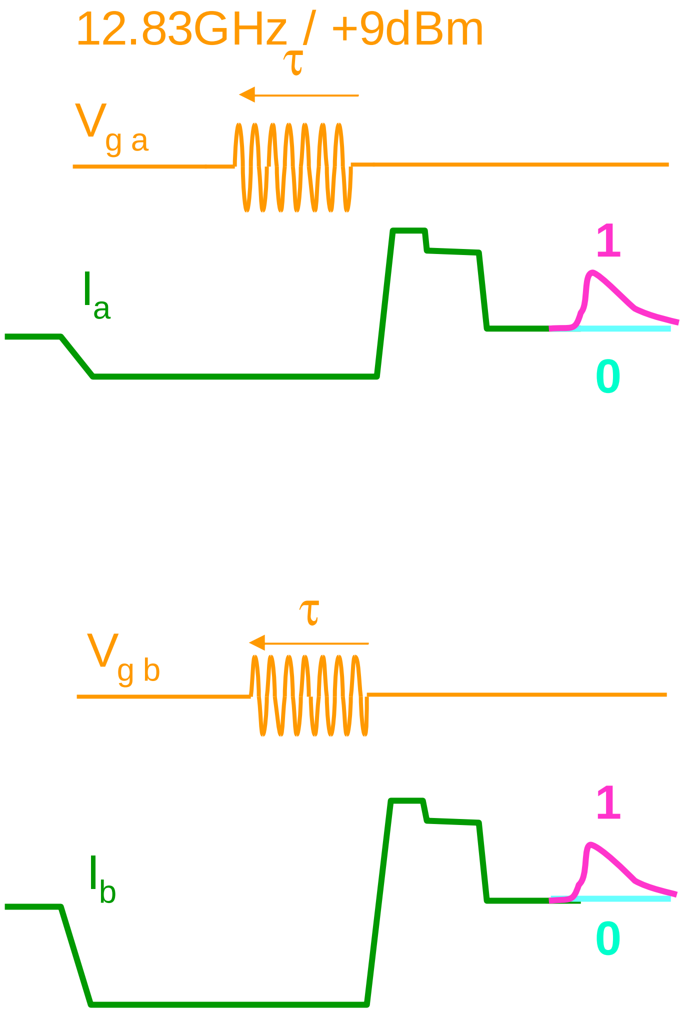
t=	0		$1/4\nu_{CC}$		$1/2\nu_{CC}$
	$\lvert 10\rangle$	$\rightarrow$	$\lvert 10\rangle - i\lvert 01\rangle$	$\rightarrow$	$-i\lvert 01\rangle$

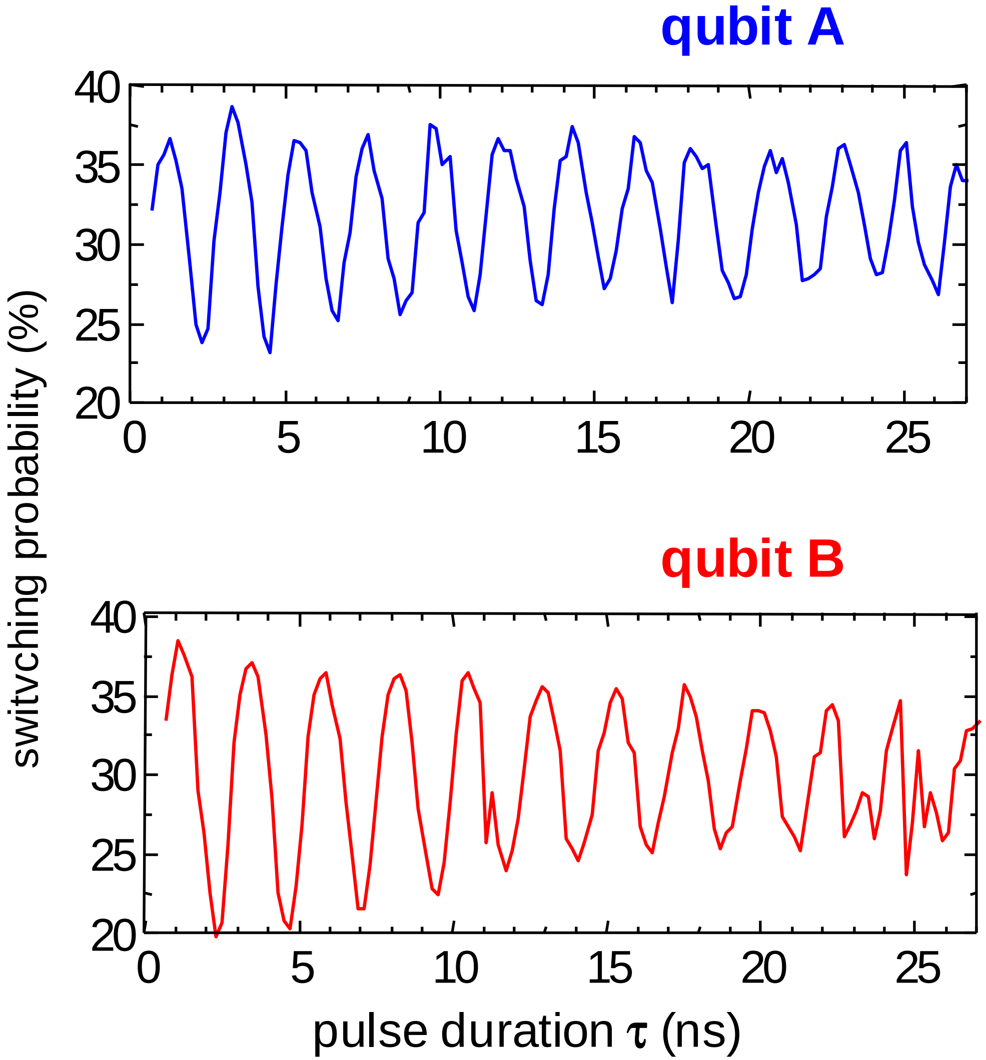
$\sqrt{iSWAP}$ universal 2-qubit gate

Two quantronium sample (version 1)



Rabi oscillations of uncoupled qubits

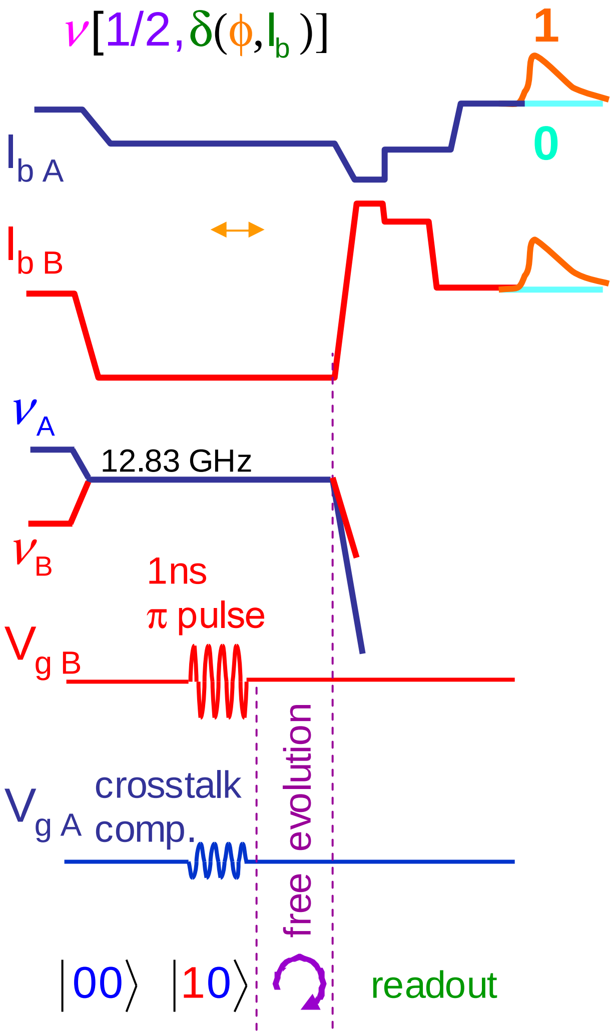


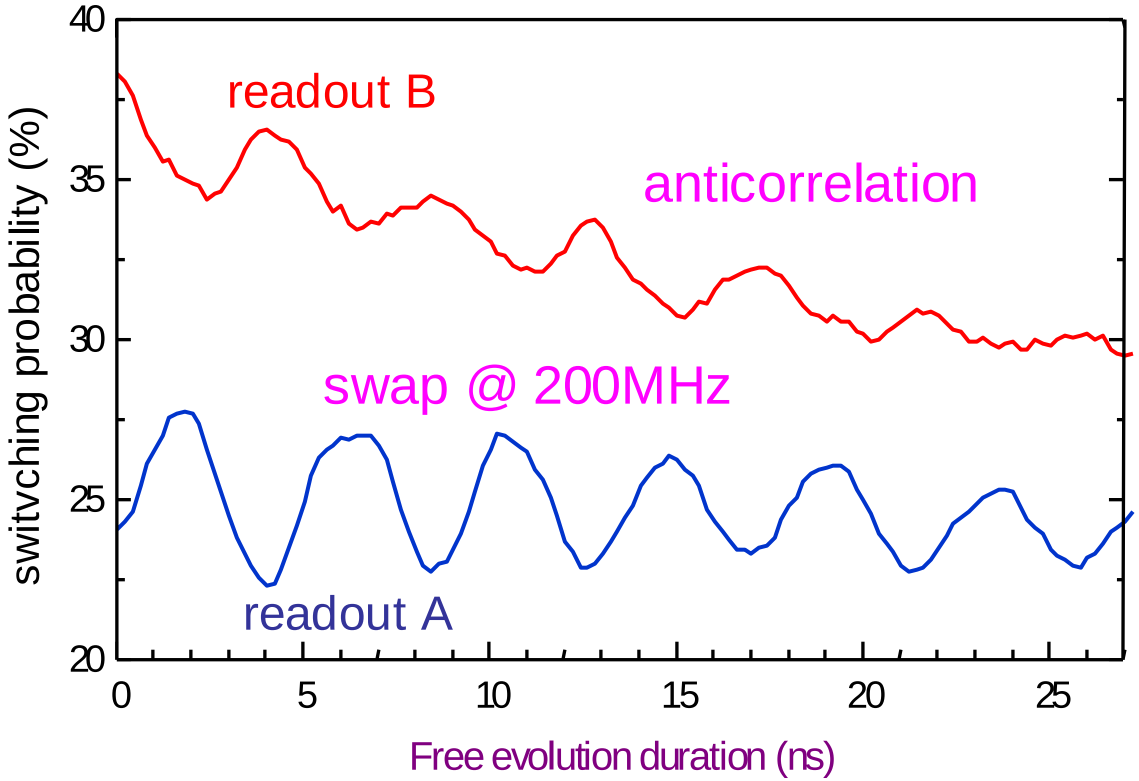


Problems : - low readout fidelity (15%-20%)

- short T1 (50ns)

Observation of two quantroniums swapping



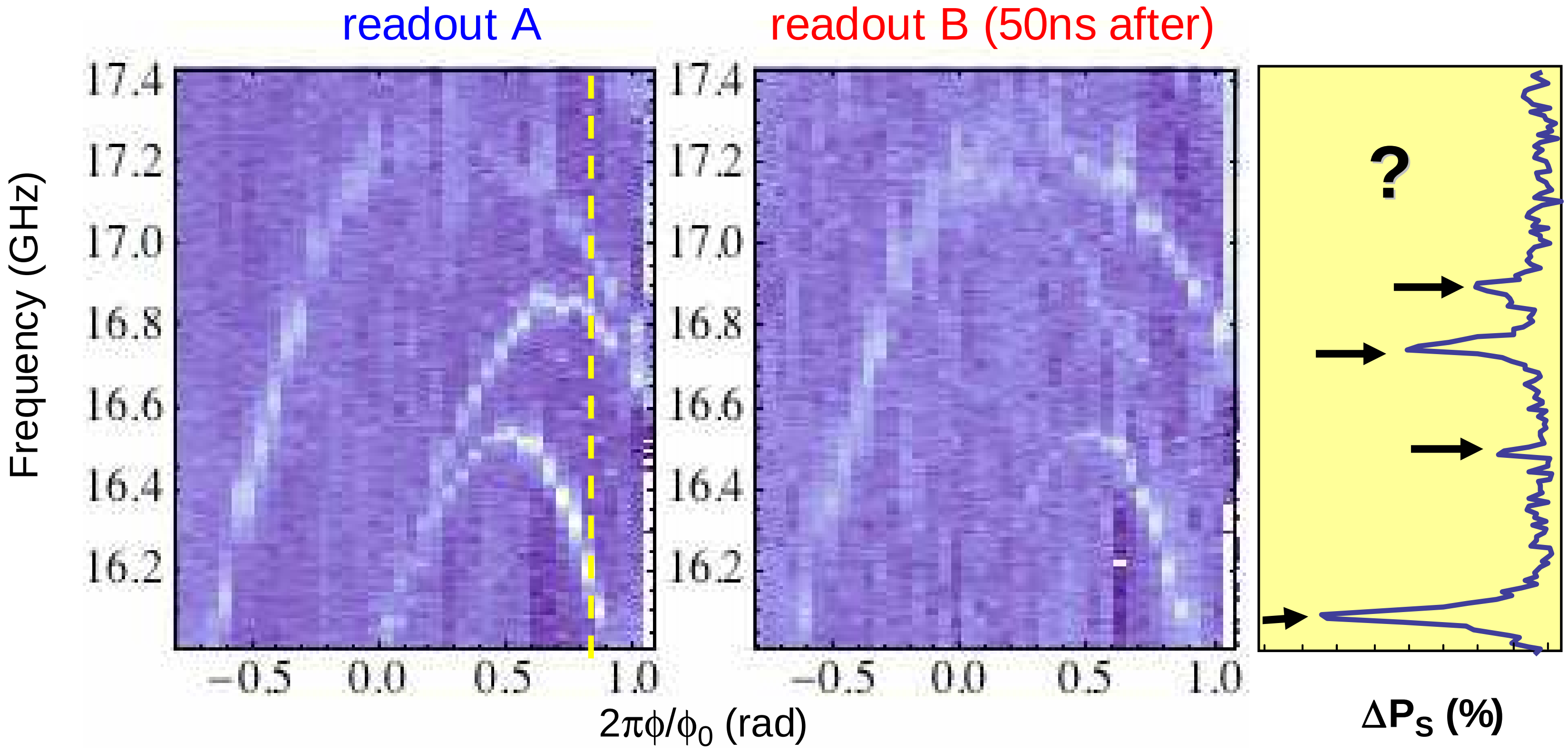


but short T_1 and visibility prevent true correlation measurements P(0 0), P(0 1), P(1 0) & P(1 1)

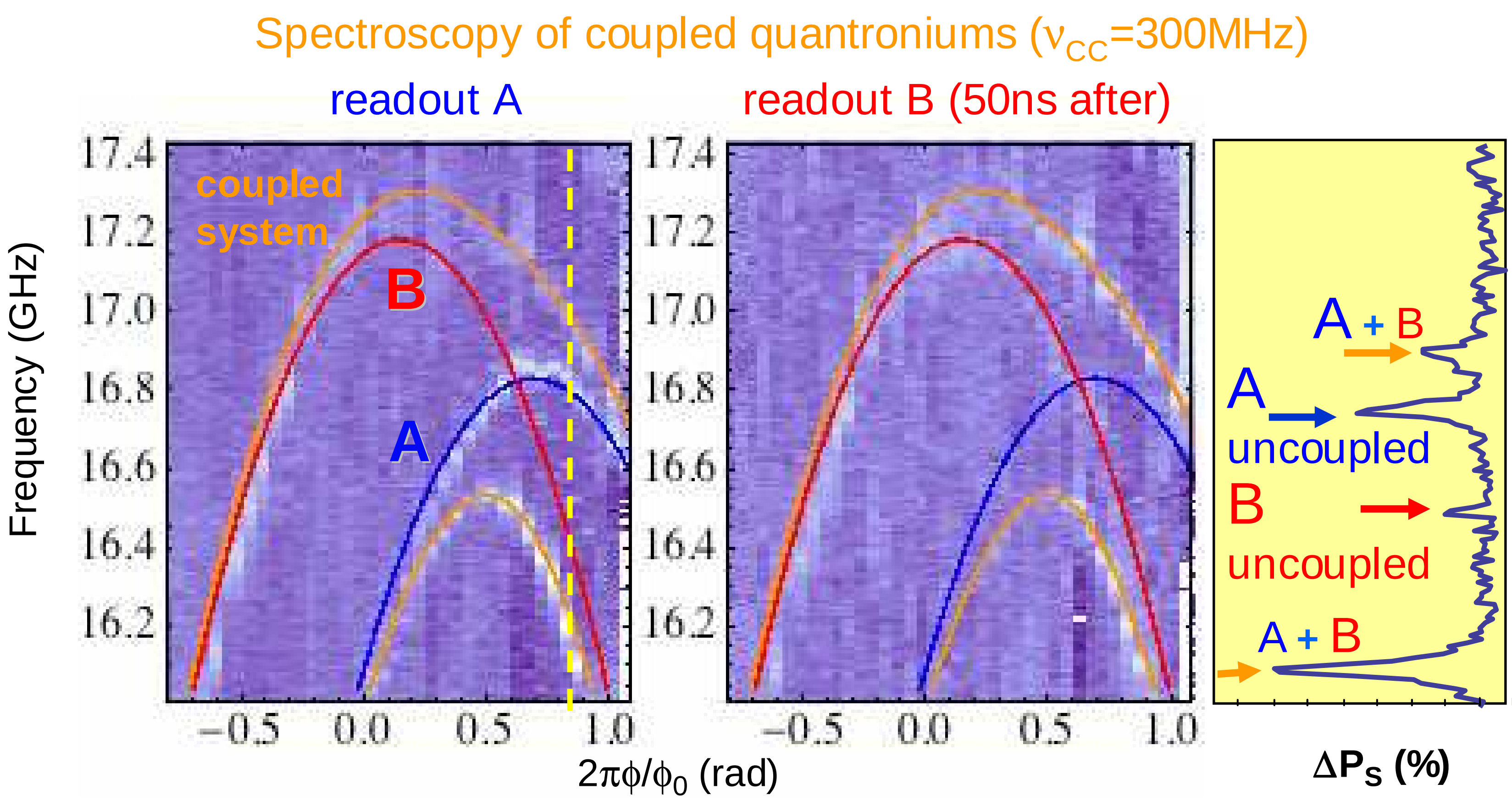
Similar visibility on 4 samples – irreproducible T1 in the 30ns – 300ns range

What's wrong ? A diagnostic

Spectroscopy of coupled quantroniums (ν_{CC}=300MHz)



What's going wrong ? A diagnosis



- A seen on readout B (and reciprocally) due to adiabatic transfer at readout (OK)
- Uncoupled lines seen: B (resp A) away part of the time !!!??

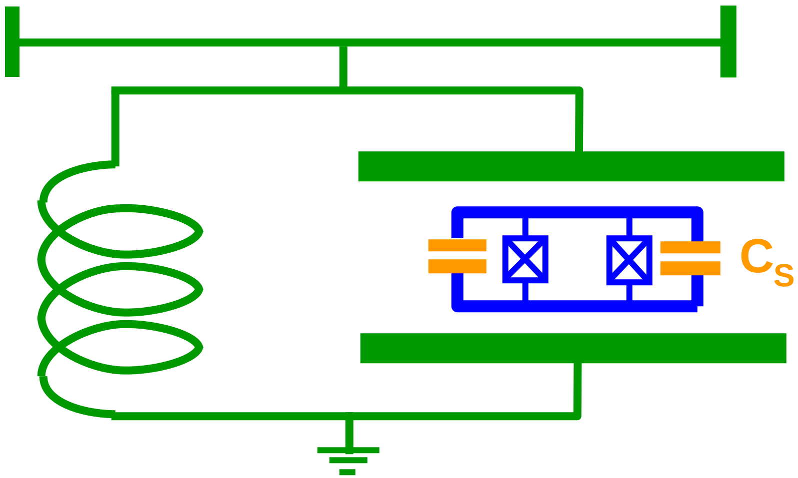
Quantronium in the intermediate charge regime does not work well !

Transmon design

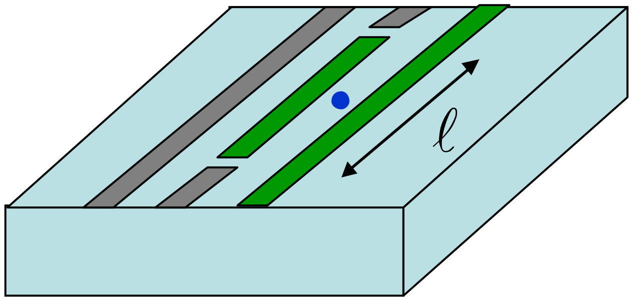
A. Walraff et al., *Nature* **431**, 162 (2004)

J. Koch et al., Phys. Rev. A **76**, 042319 (2007)

$E_J / E_C \approx 35$



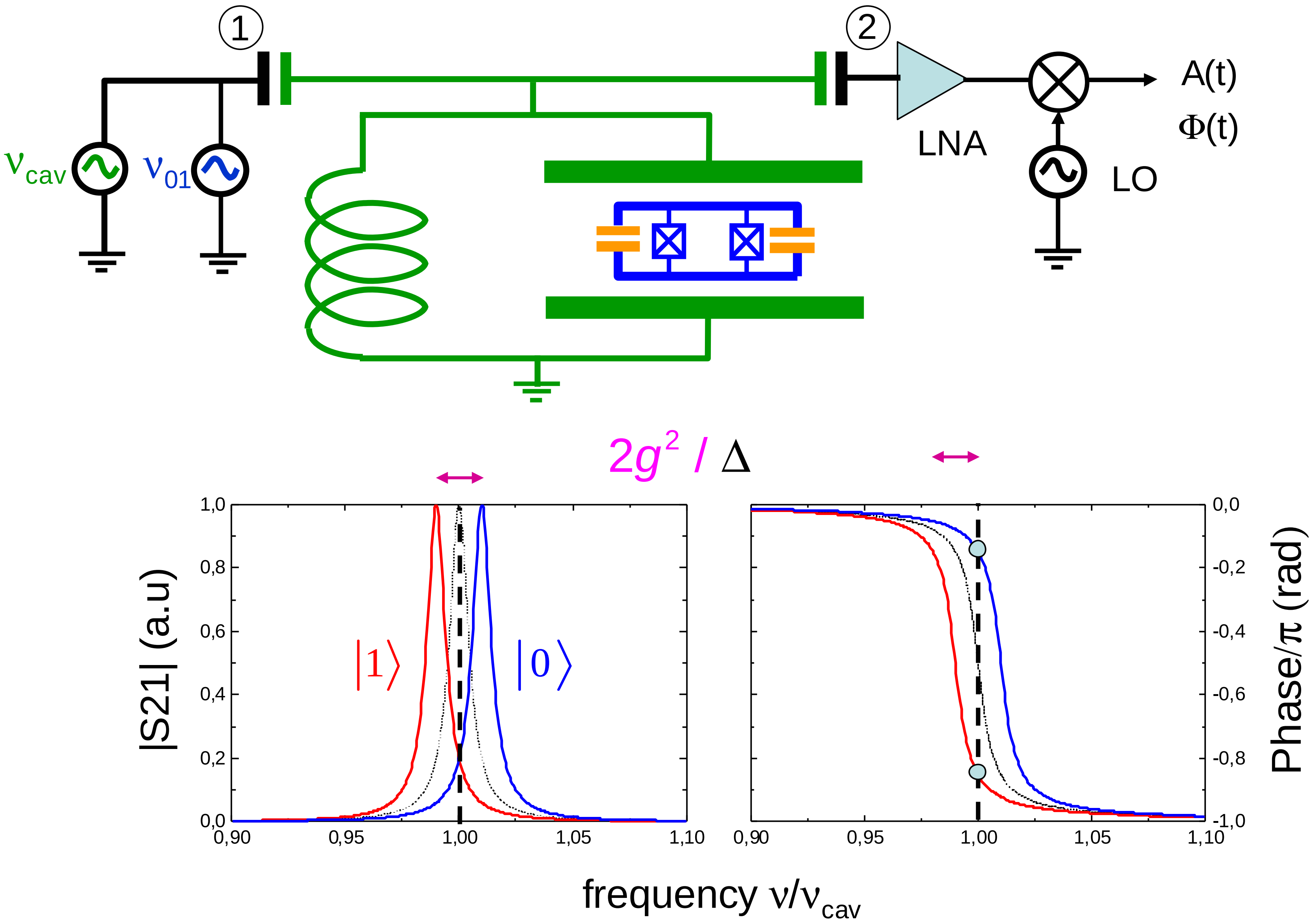
$$2\pi\nu_{cav} = \frac{1}{\sqrt{LC}} = \frac{\pi c}{\ell\sqrt{\varepsilon_r}}$$



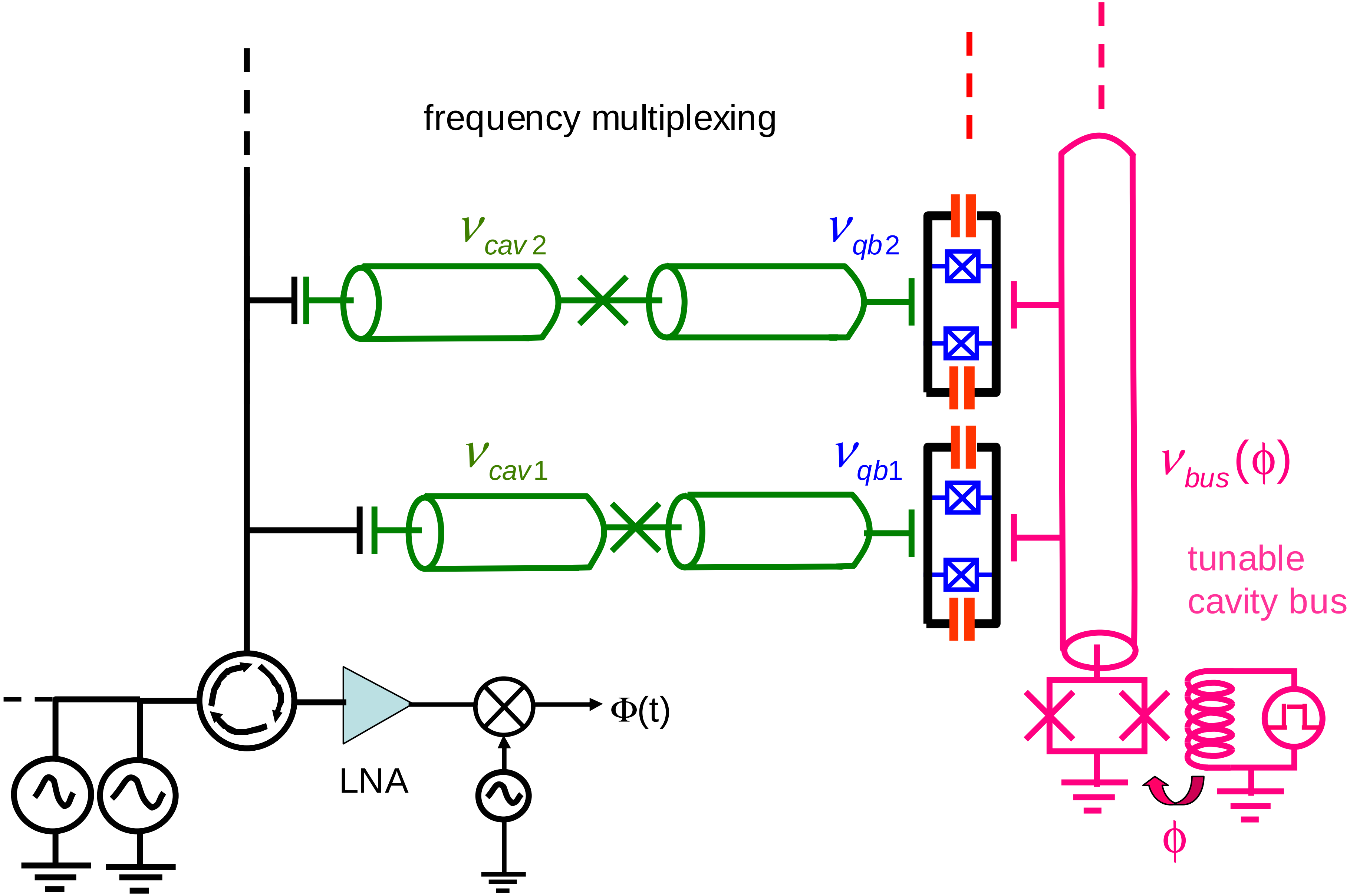
Jaynes-Cummings in the dispersive regime: coupling $g << \Delta = \nu_{01} - \nu_{cav}$

$$\hat{H}_{eff} = -\left(\frac{h\nu_{01}}{2} + \frac{g^2}{\Delta}\right)\hat{\sigma}_z + \left(h\nu_{cav} - \frac{g^2}{\Delta}\hat{\sigma}_z\right)a^+ a$$

Transmon design



Goal: a scalable architecture



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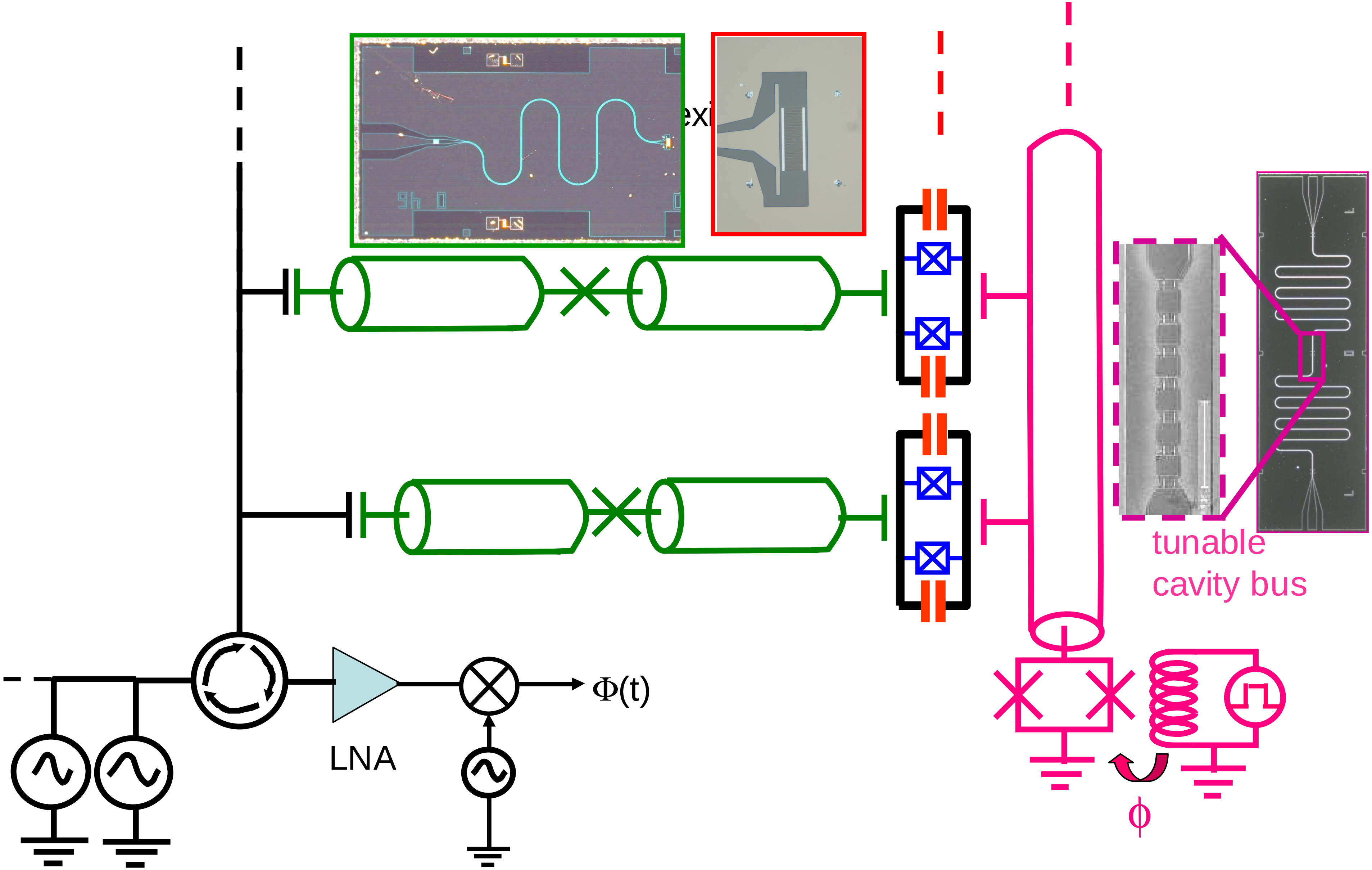
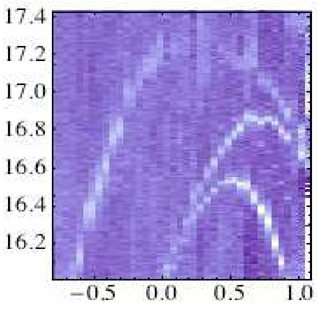
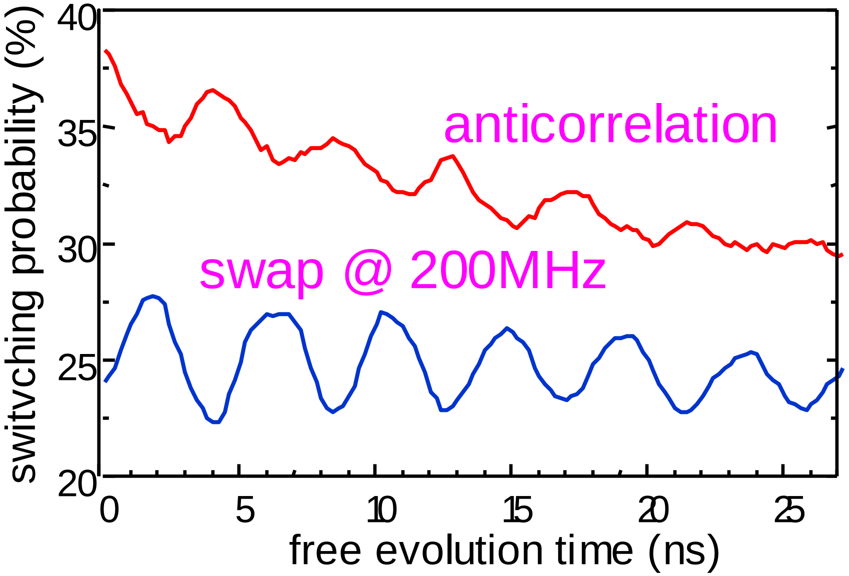


Conclusion

Swapping oscillations of 2 coupled quantroniums

But not a good gate:
- irreproducible T1
- low visibility (qubit « away »)





Switch to transmon design (à laYale) for a scalable architecture

- T_1=380ns T_2=600ns already obtained at CEA-Saclay
- a few blocks already done