CENTRE NATIONAL
DE LA RECHERCHE
SCIENTIFIQUE

UNIVERSITE
JOSEPH FOURIER
SCIENCES. TECHNOLOGIE. MEDECINE
GRENOBLE 1

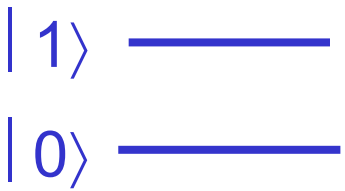
Coherent oscillations in a dc SQUID

CRTBT-CNRS-Grenoble
J. Claudon (PhD)
F. Balestro (Post Doc in TU Delft)
J. Pekola
O. Buisson
LP2MC-UJF-CNRS-Grenoble
A. Ratchov
F. Faure
F. Hekking
LCMI-CNRS-Grenoble
L. Levy
P. Lafarge

Introduction

Quantum information → Integrated quantum system

Main research : Control of a two level system



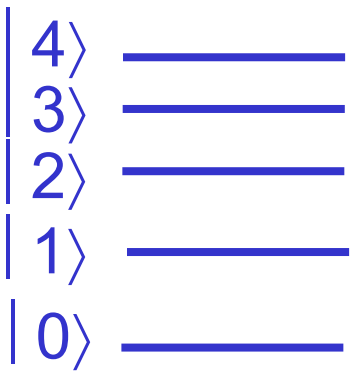
- Josephson circuits (Nakamura99, …)
- Quantum dots (Hayashi03)

⇒ Realisation and manipulation of a single qubit

Qubit+entanglement : necessar for Shor algorithm

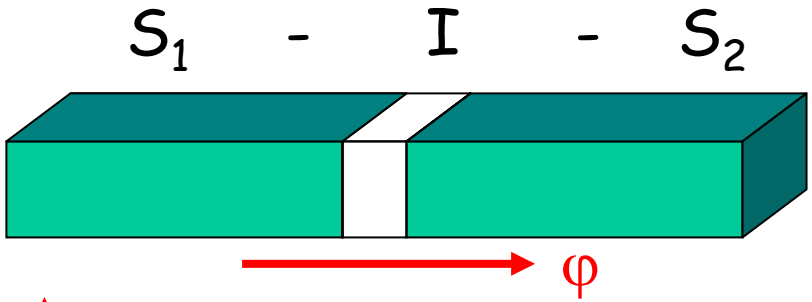
For some implementations (Grover algorithm, …) :

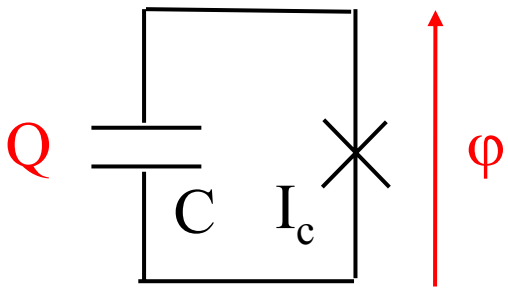
Control of a single multi-level quantum system(Lloyd99)



- Rydberg atom (Ahn00)
- Molecular magnets (Leuenberger01)
- Quantum dots (Leuenberger03)
- Current-biased dc SQUID

The Josephson junction



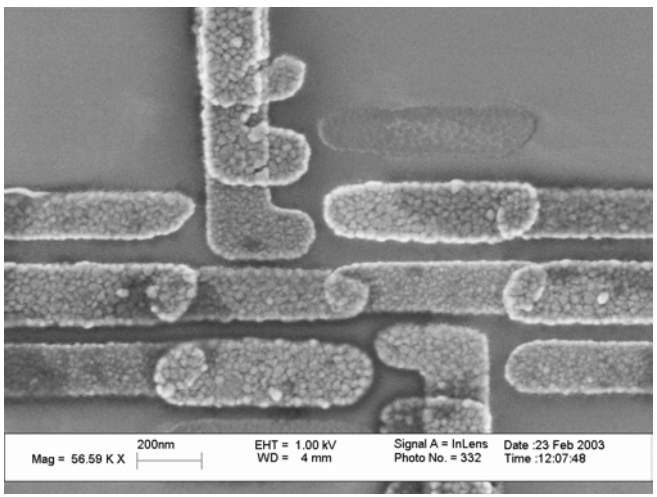


$$E_c = \frac{(2e)^2}{2C}$$

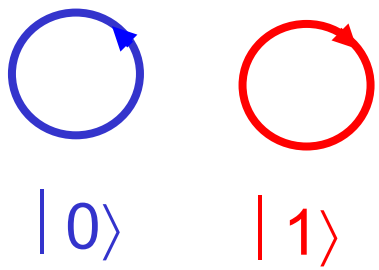
$$E_J = \frac{\Phi_0 I_c}{4\pi}$$

$E_c >> E_J$ Charge qubit

$E_c << E_J$ Flux qubit



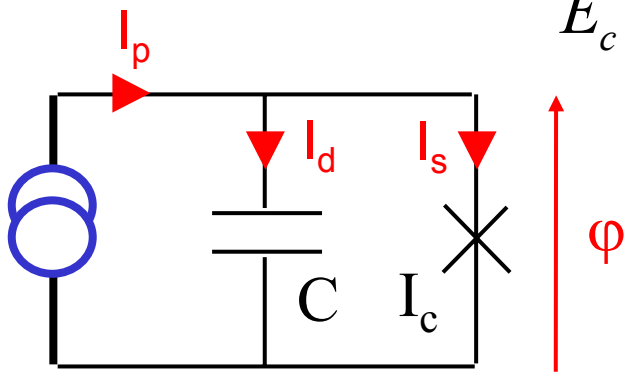
(Lafarge01)



(NEC, Saclay,Goteborg,Grenoble...)

(Delft,Stony-Brook,NTT...)

Phase qubit



$$E_c << E_J$$

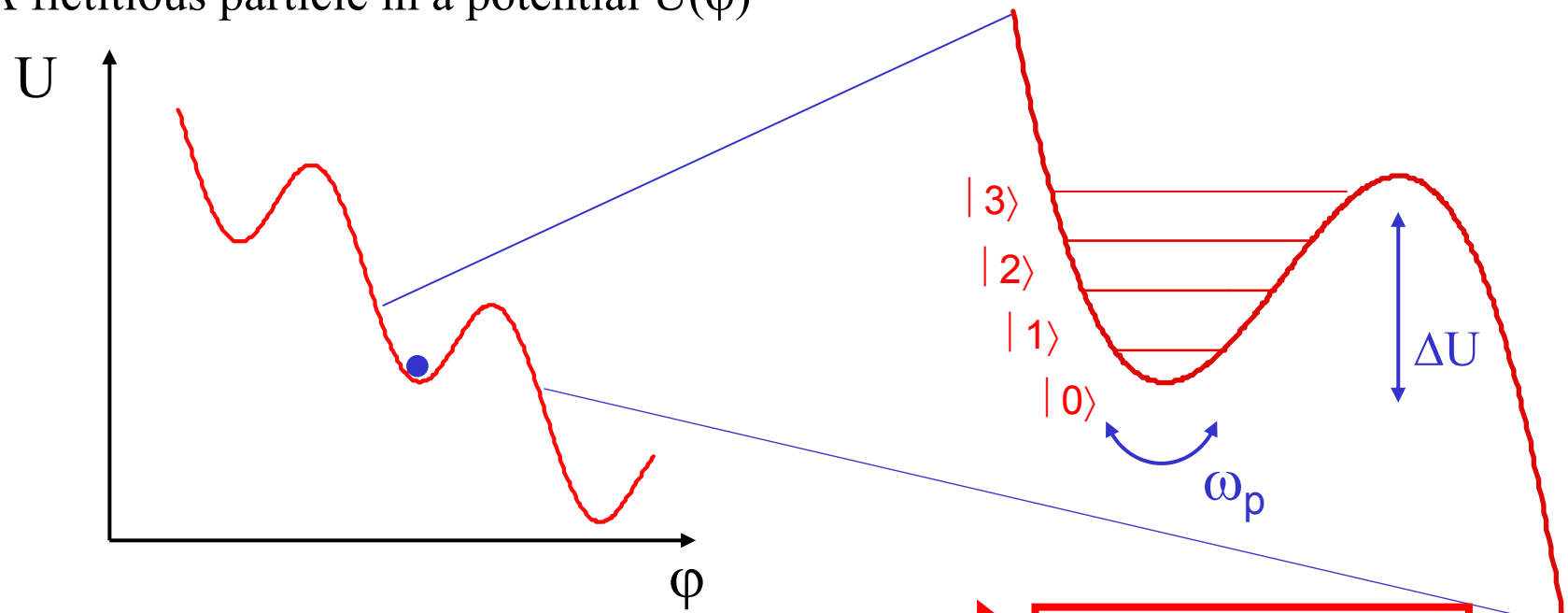
$$I_d = I_p - I_s$$

$$C\left(\frac{\phi_0}{2\pi}\right)^2 \frac{d^2\varphi}{dt^2} = \frac{\phi_0 I_c}{2\pi}\left(\frac{I_p}{I_c} - \sin\varphi\right)$$

masse m

$$-\frac{dU(\varphi)}{d\varphi}$$

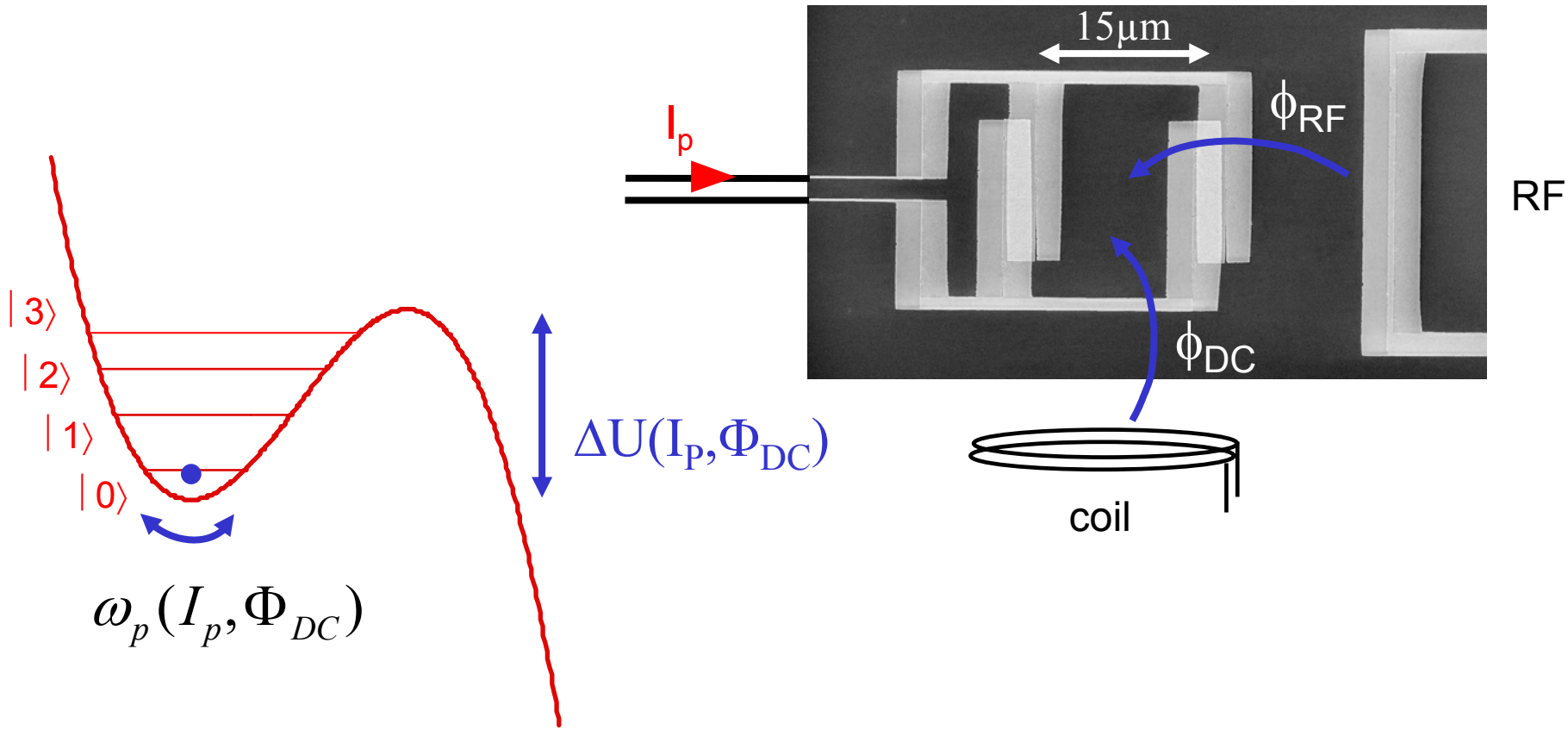
A fictitious particle in a potential U(φ)



(Berkley,Saclay80,Colorado,Arkansas,...)

Difficult control

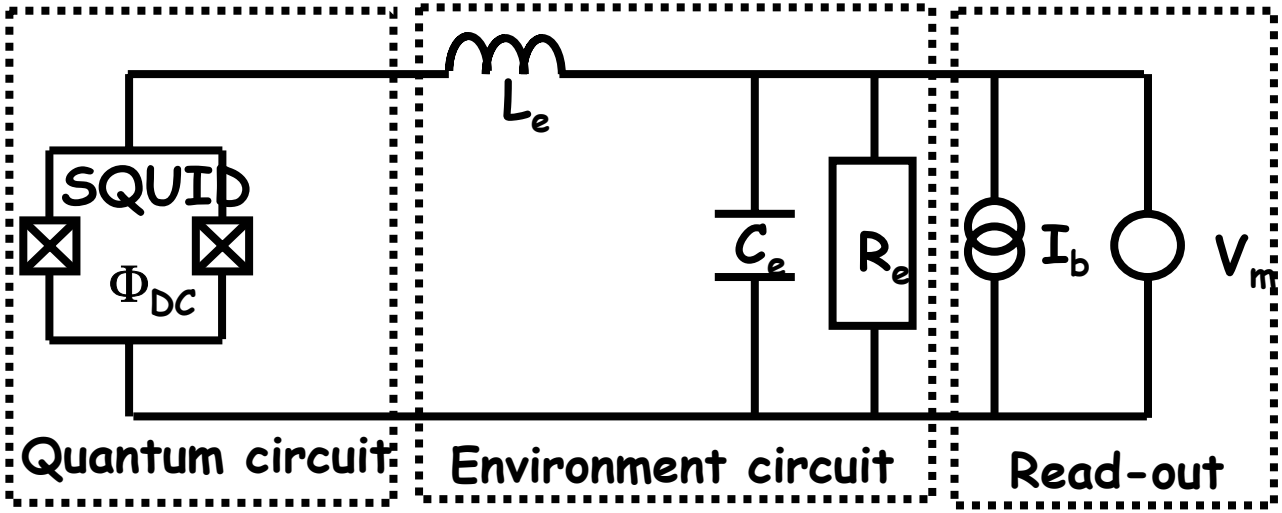
The current biased dc SQUID: a controlable anharmonic oscillator



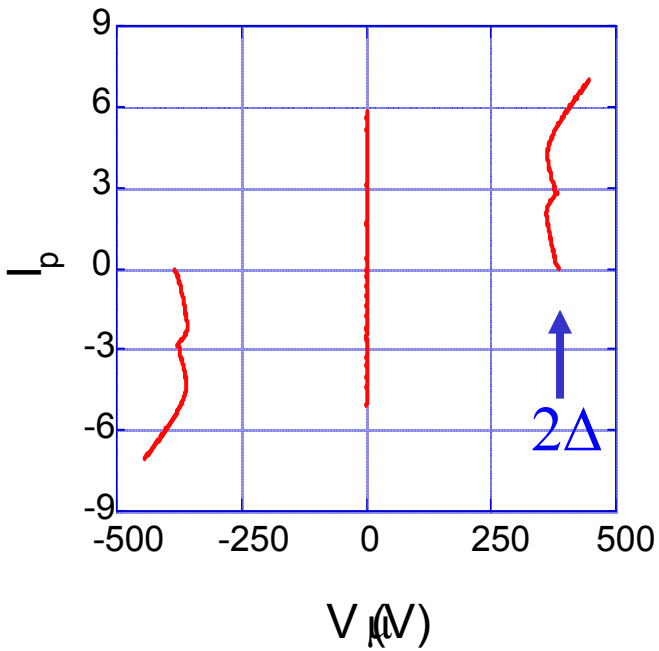
$$\hat{H}_e = \hbar\omega_p \cdot \left(\hat{P}^2 + \hat{X}^2\right) - \hbar\omega_p\sigma \cdot \hat{X}^3 + \hbar\omega_p\alpha_{RF}(t)\hat{X}$$

Out-line
- MQT for a dc SQUID
- Spectroscopic measurements
- Coherent oscillations

SQUID measurements

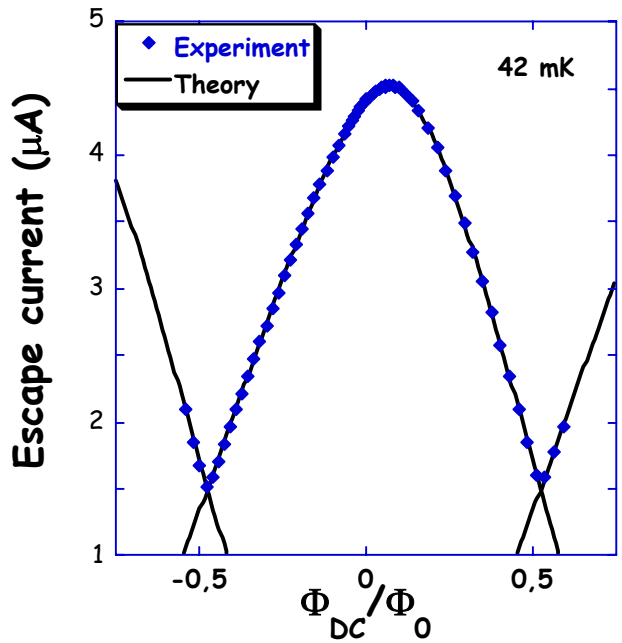


IV characteristics



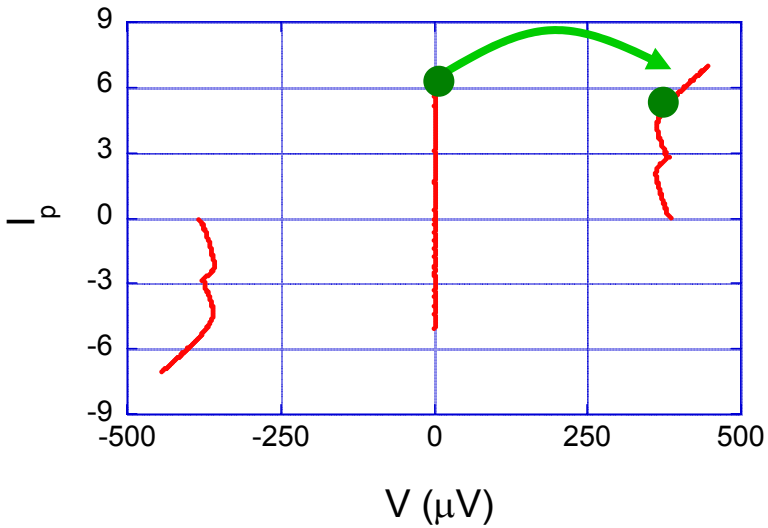
SQUID parameters:

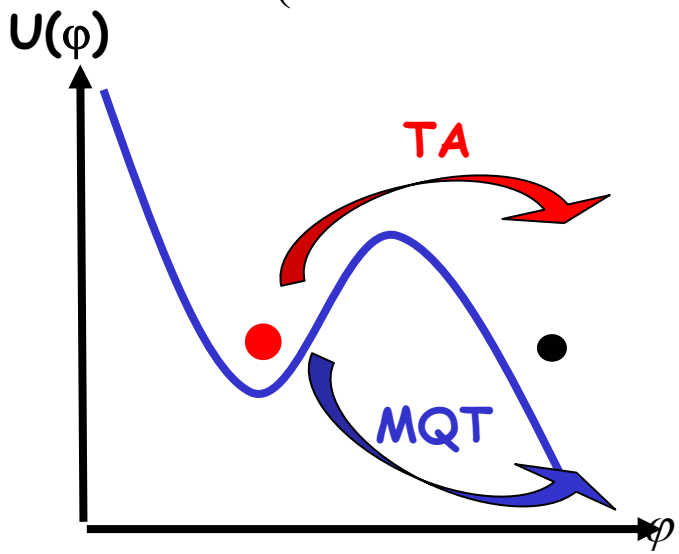
$I_0 = 2.33\mu A$
$C_0 = 0.46pF$
$L_{squid} = 244pH$
$\eta = -0.26$

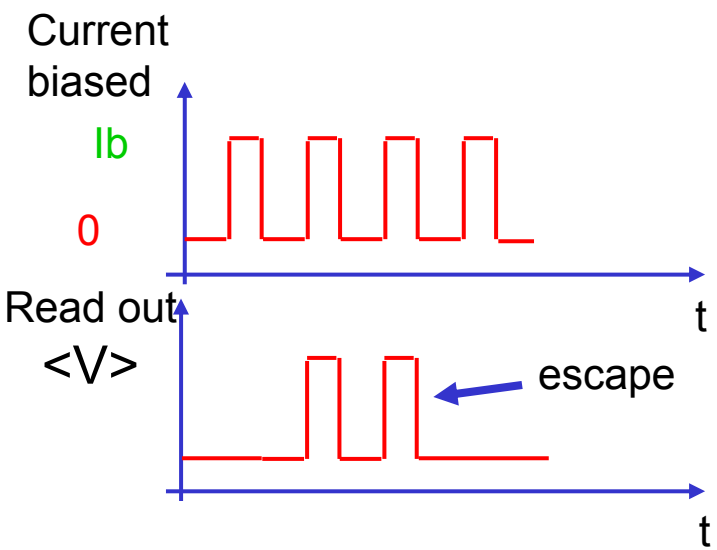


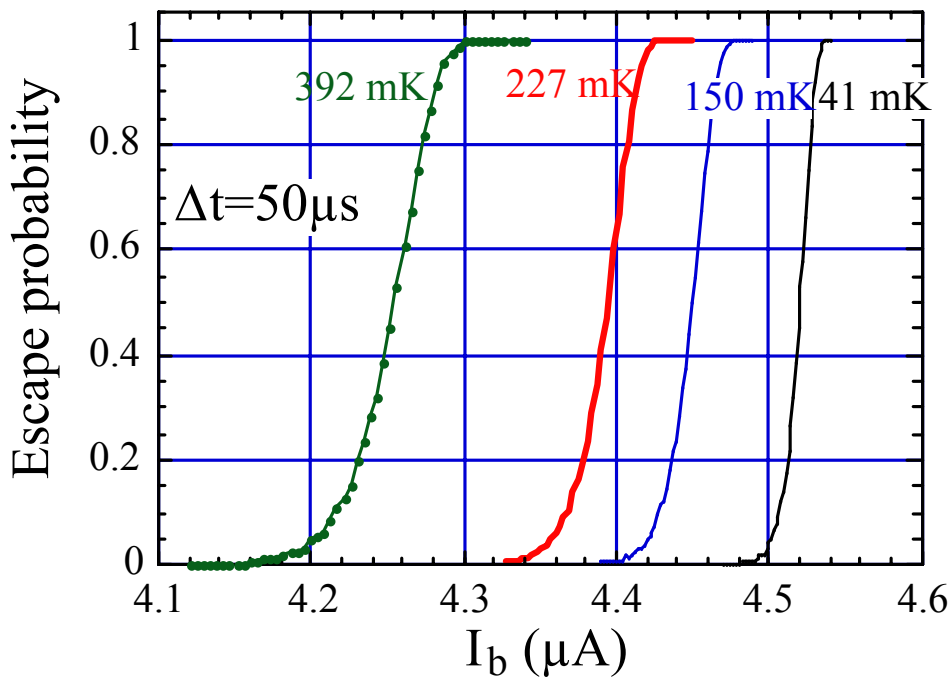
Escape measurements

(Balestro ***PhD-Thesis***)





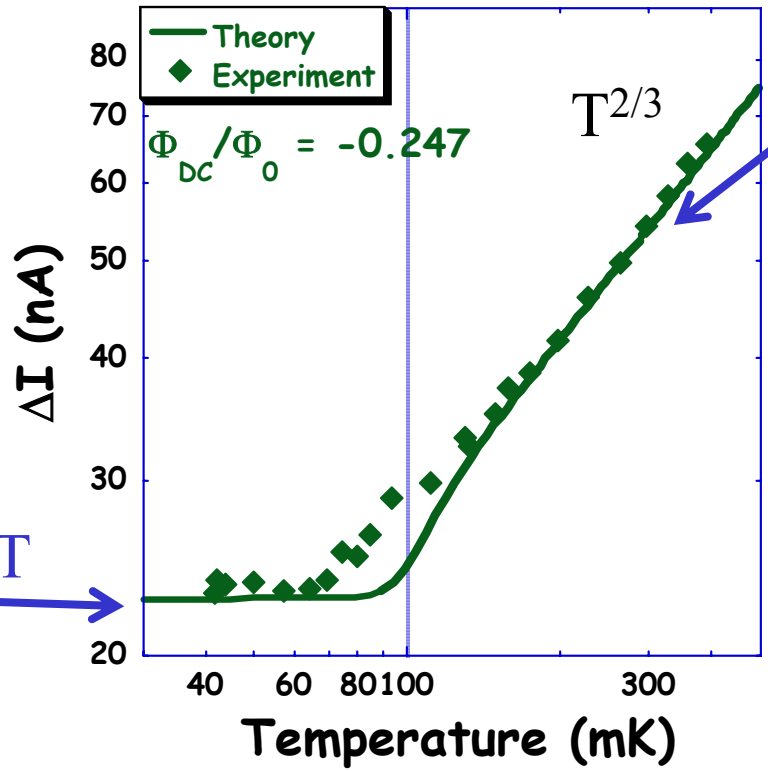




Escape regimes

Balestro ***et al*** PRL 2003

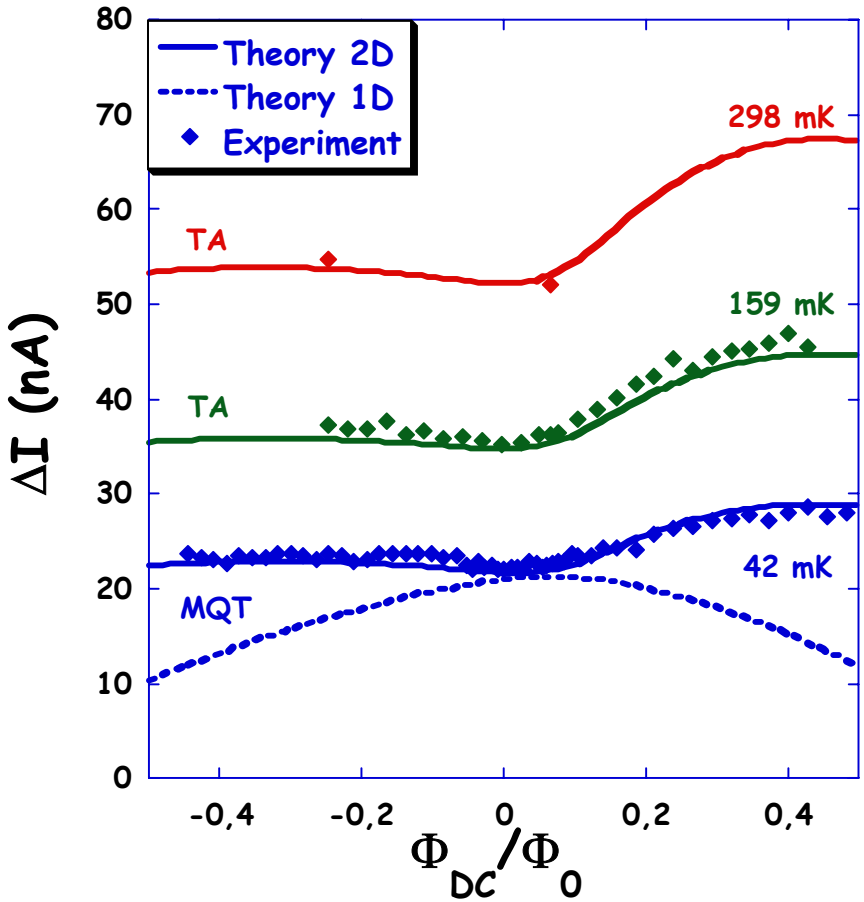
Temperature dependence



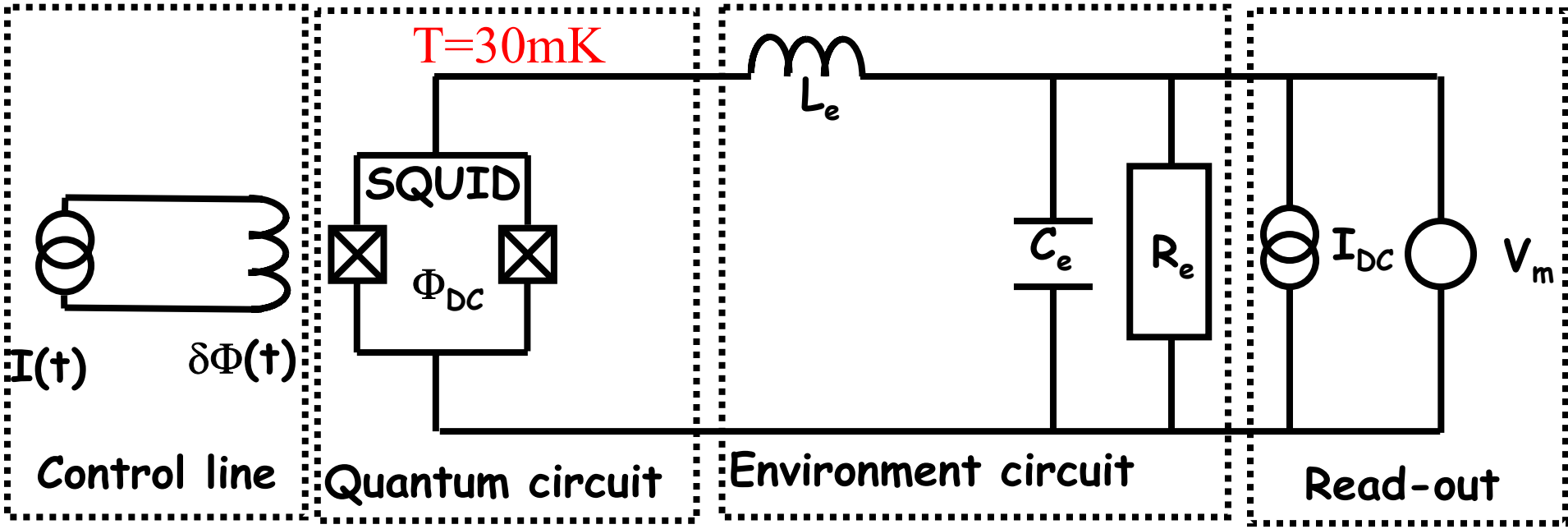
MQT

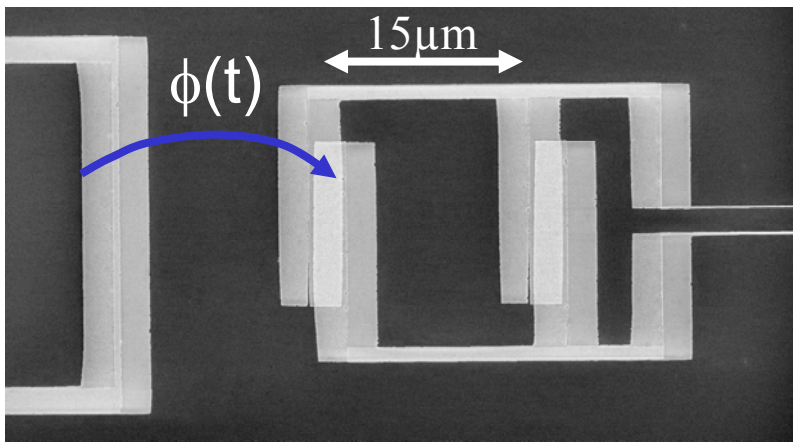
Thermal activation regime

Magnetic flux dependence



Manipulation and quantum measurements

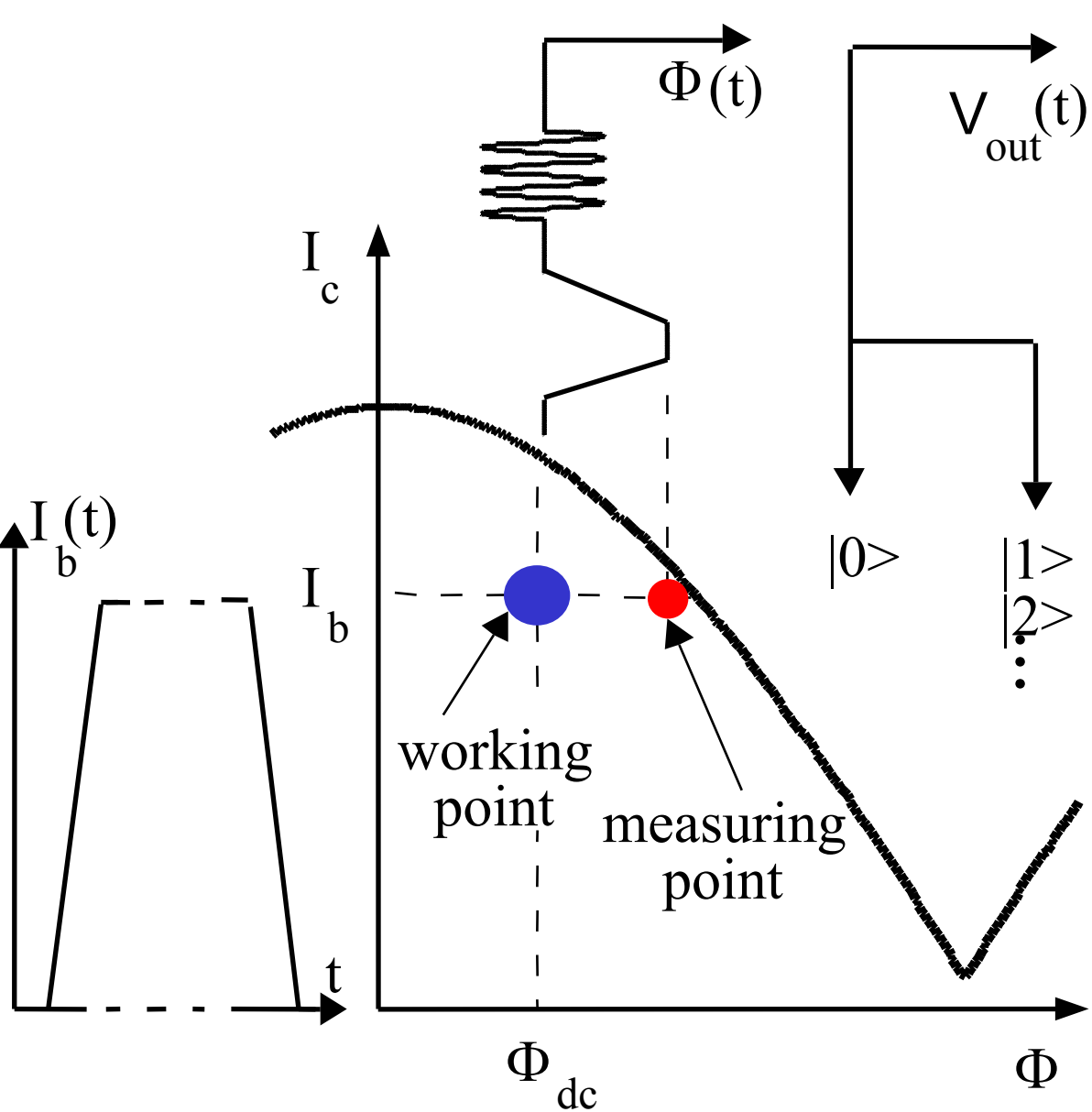


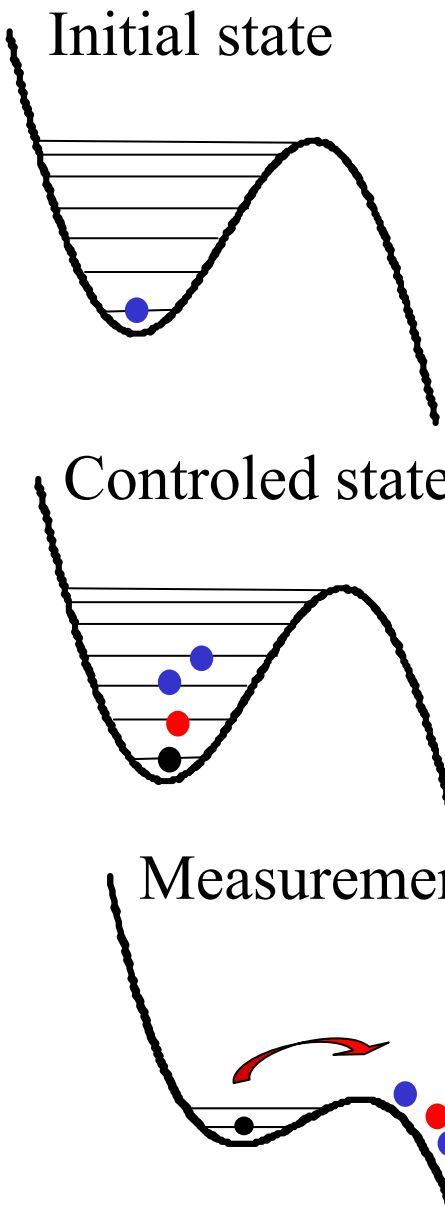


New sample:
- MQT at zero-flux
- no MQT at other flux

(Presence of flux noise…)

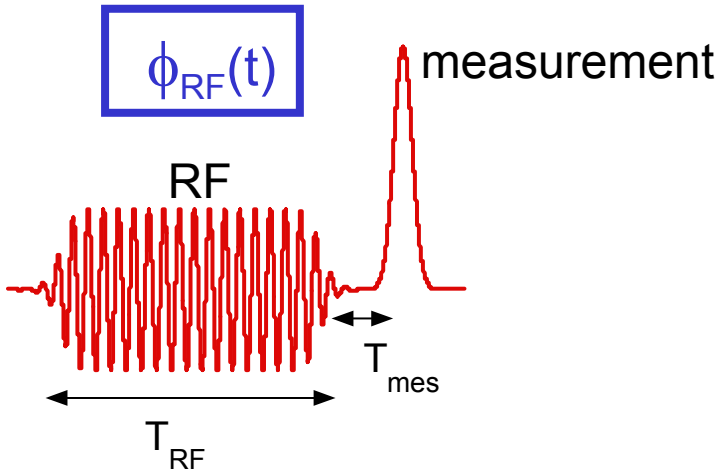
Typical experimental procedure



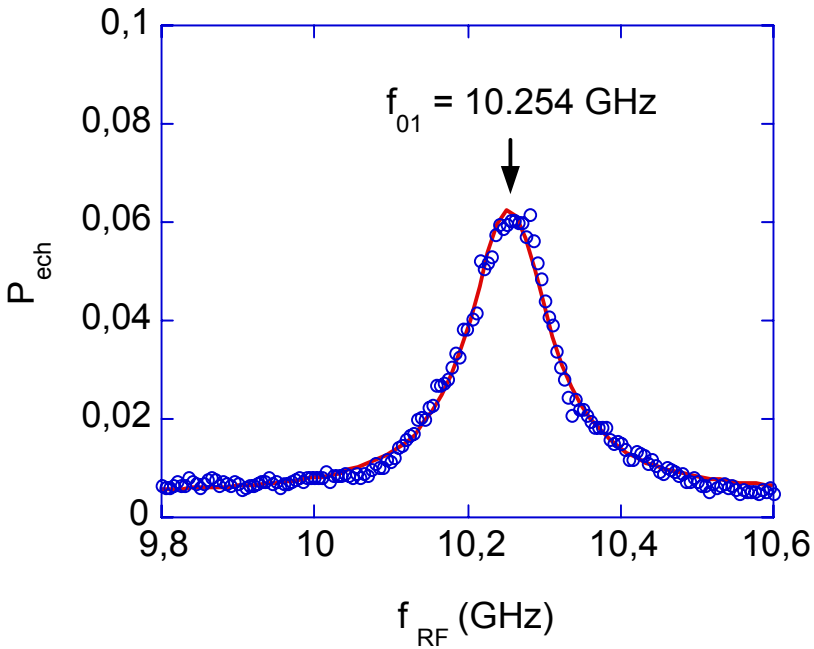


O. Buisson, ***et al*** PRL 2003

Spectroscopic measurements

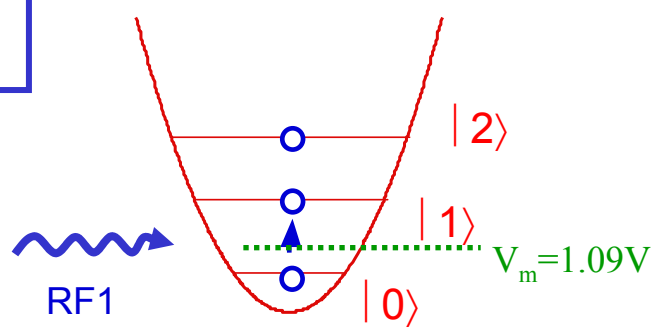


Resonant transition $|0\rangle$ - $|1\rangle$

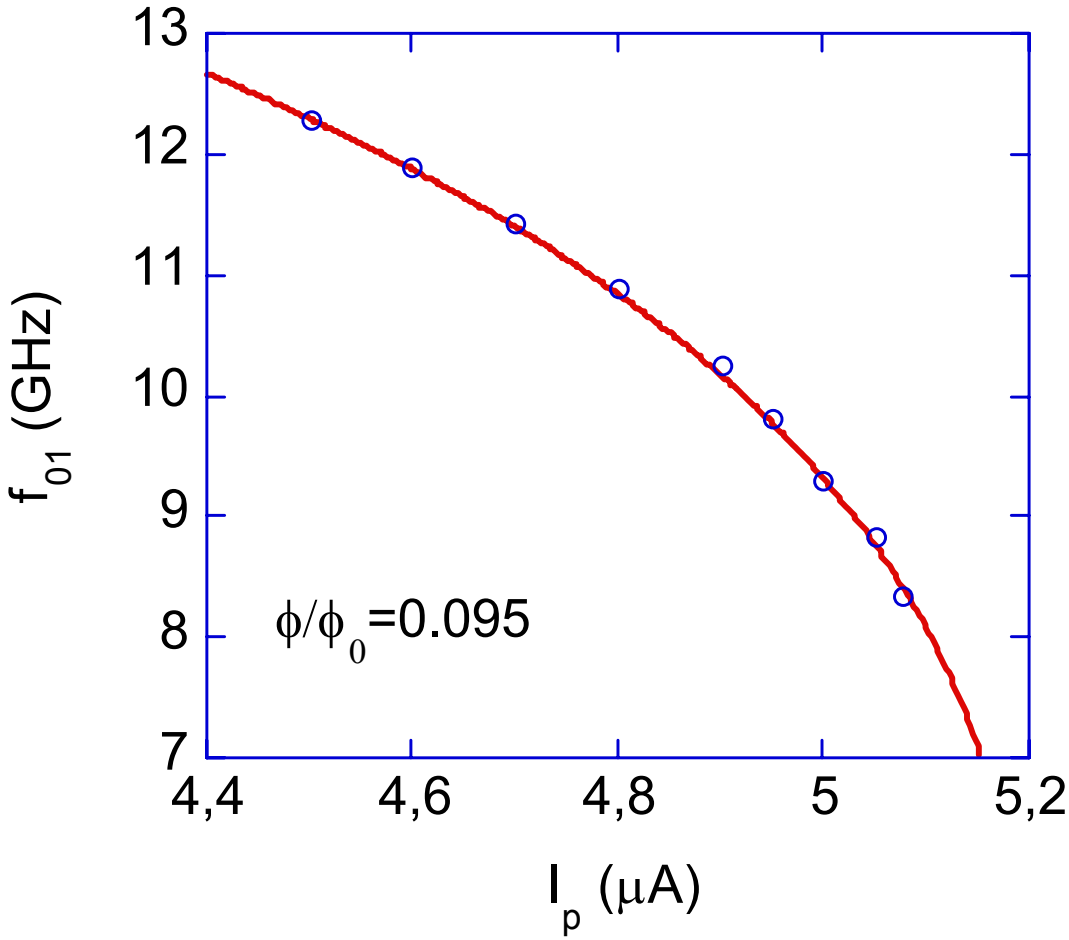


I_p =4.9 μA
ϕ_{DC}/ϕ_0=0.095

excitation $|0\rangle$ - $|1\rangle$



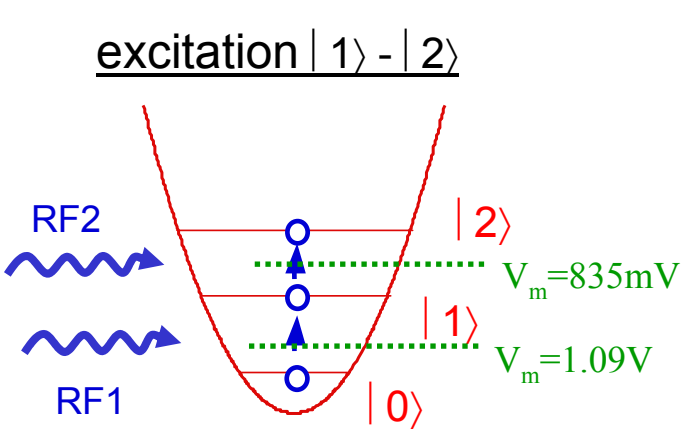
f_{01} vs bias current I_p

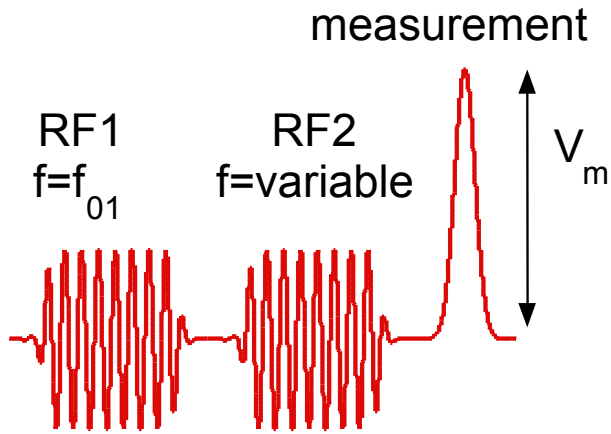


I_0 = 3.028 μA
I_p = 4.7 μA
C_0= 0.77 pF ± 1%
b = 1.15
η = 0.61
ϕ_{DC}/ϕ_0=0.095

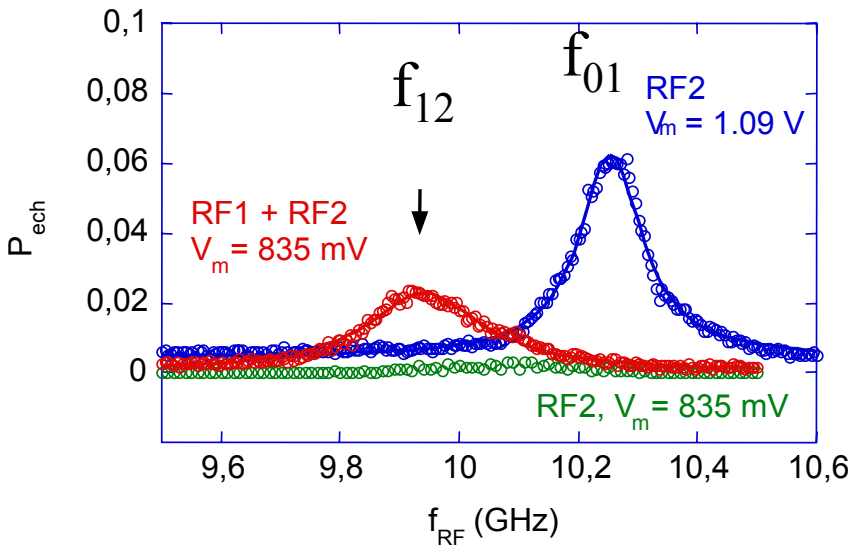
Theory : semiclassical model (Larkin86)

Two frequencies measurements





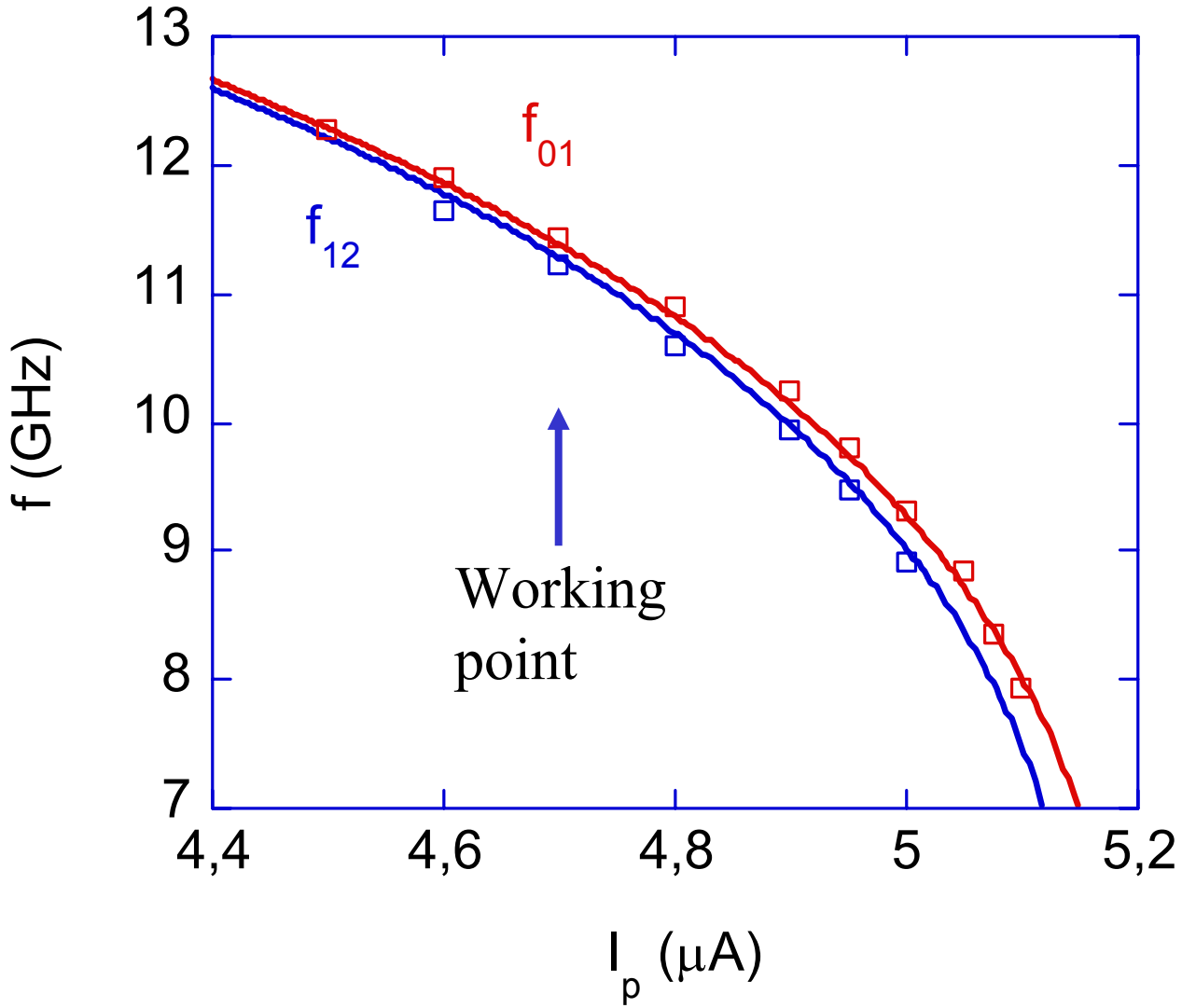
Resonant transition |1⟩ - |2⟩



I_p =4.9 μA
ϕ_{DC}/ϕ_0=0.095

f_{12} appears only when f_{01} is applied

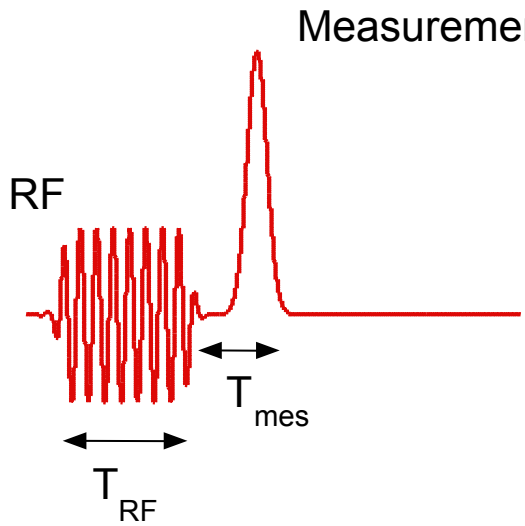
f_{01} and f_{12} vs bias current I_p



I_0 = 3.028 μA
I_p = 4.7 μA
C_0= 0.77 pF ± 1%
b = 1.15
η = 0.61
ϕ_{DC}/ϕ_0=0.095

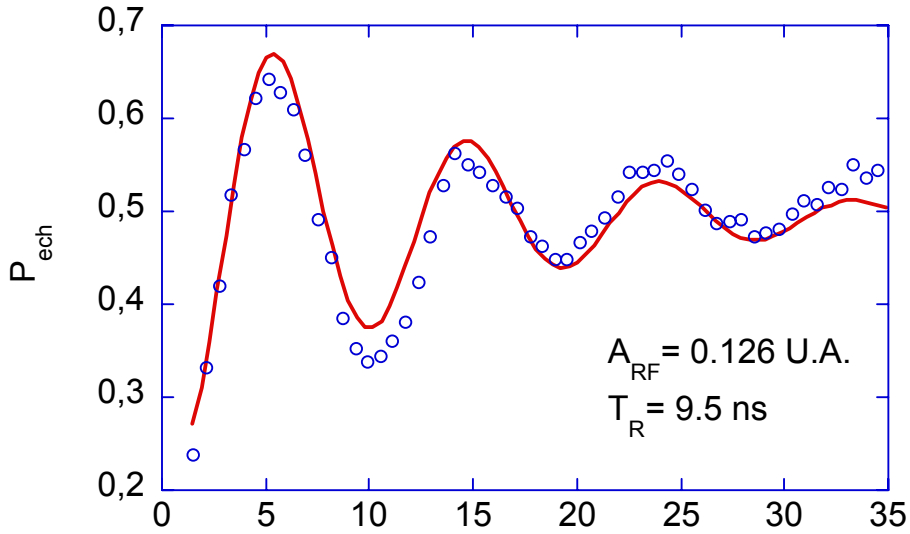
Theory : semiclassical model (Larkin86)

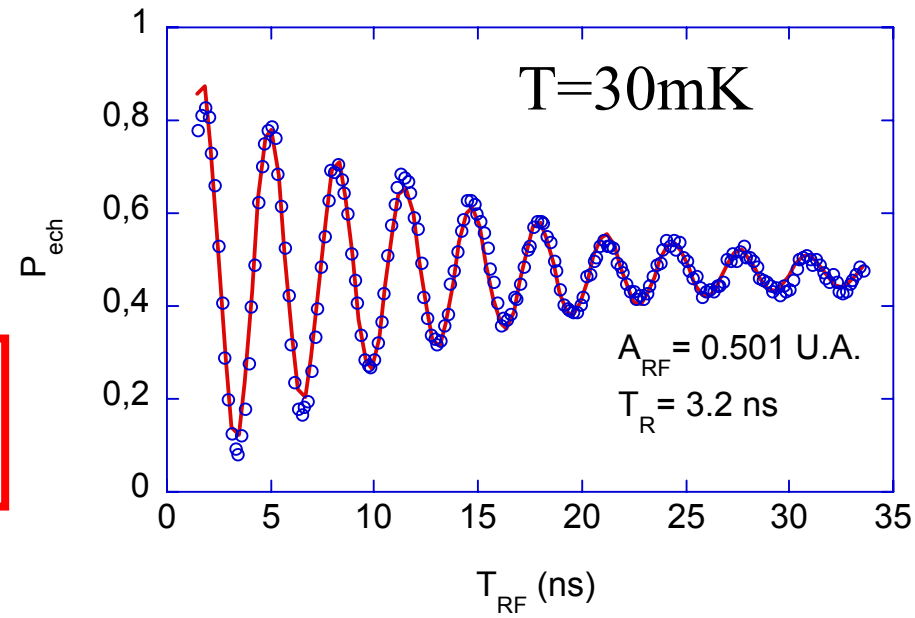
Coherent oscillations



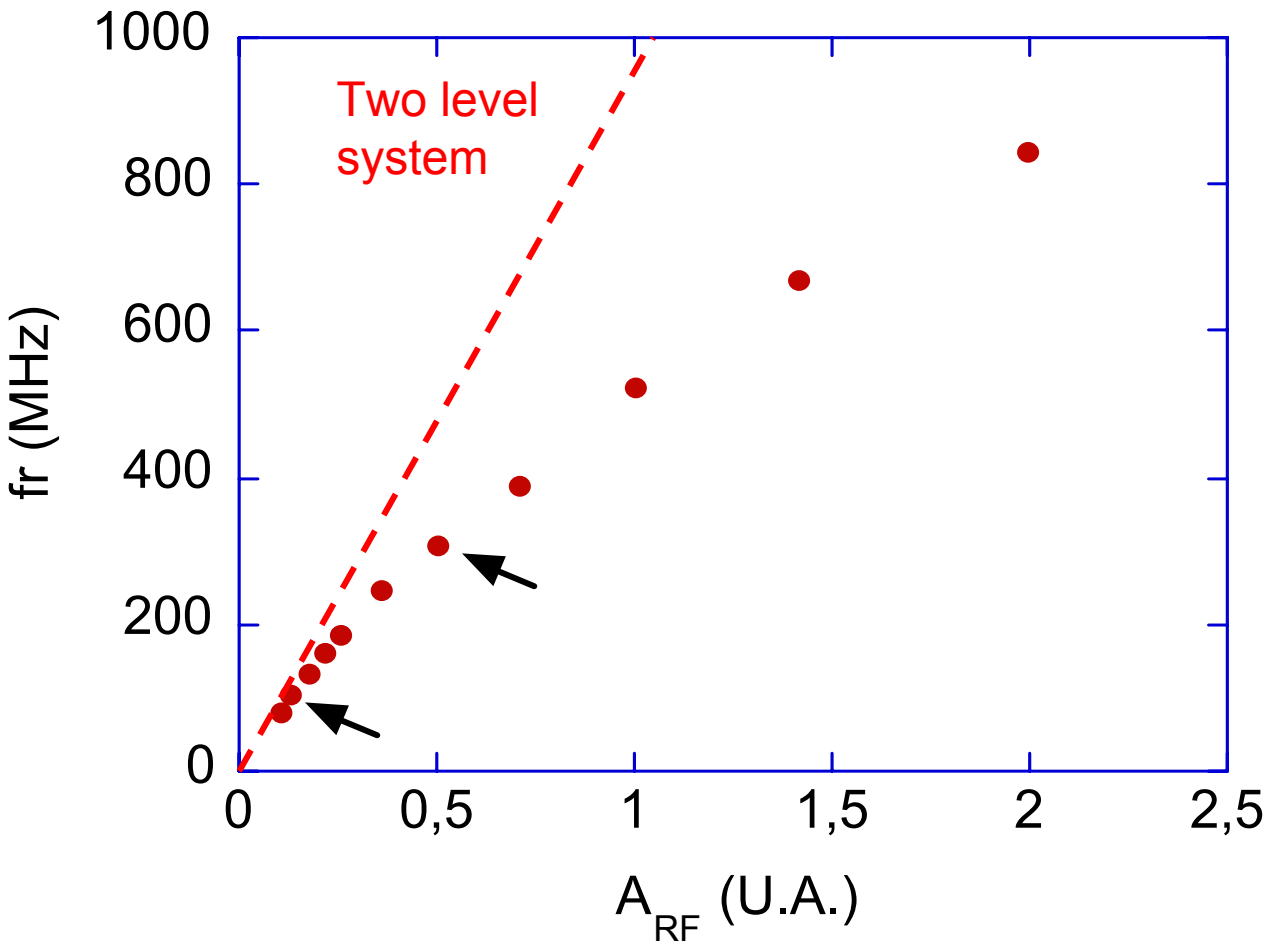
- f_{RF} matches f_{01}
- A_{RF} fixed
- T_{RF} variable, from 1 to 35 ns

- Big contraste: 80% !!
- Attenuation time = 13 ns



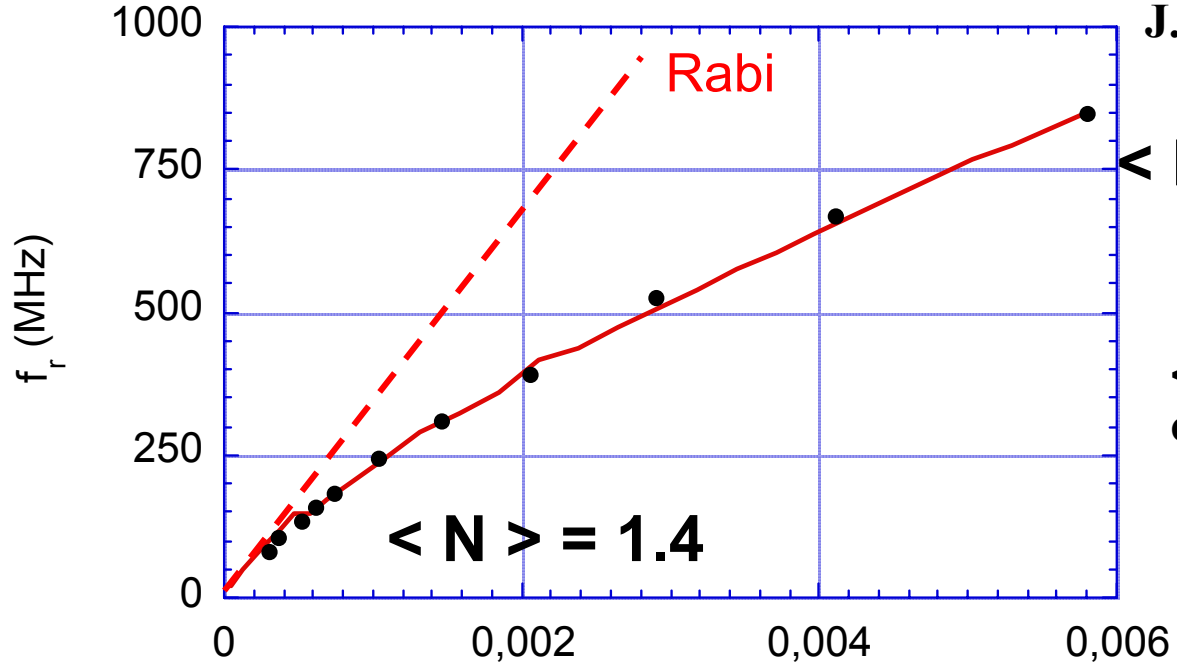


Rabi oscillations?



Strong deviation from a two level system

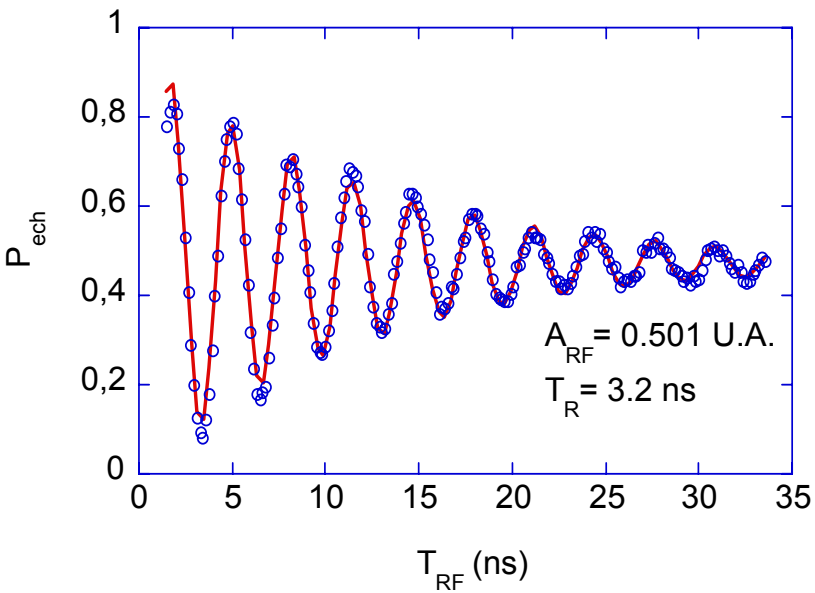
Interpretation: multi-levels oscillation

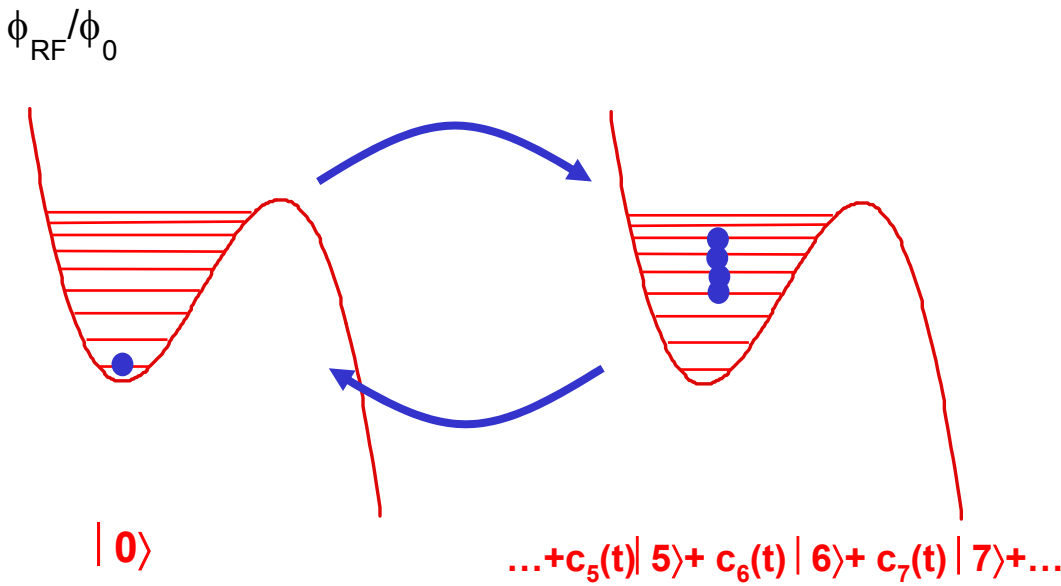


J. Claudon, submitted…

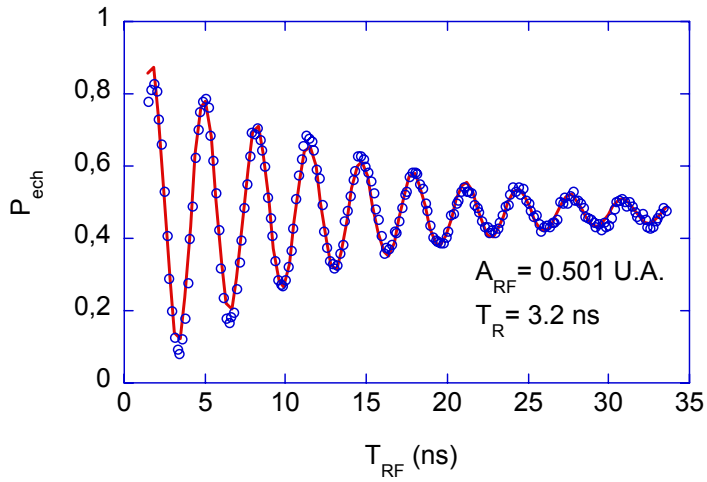
< N > = 10.4

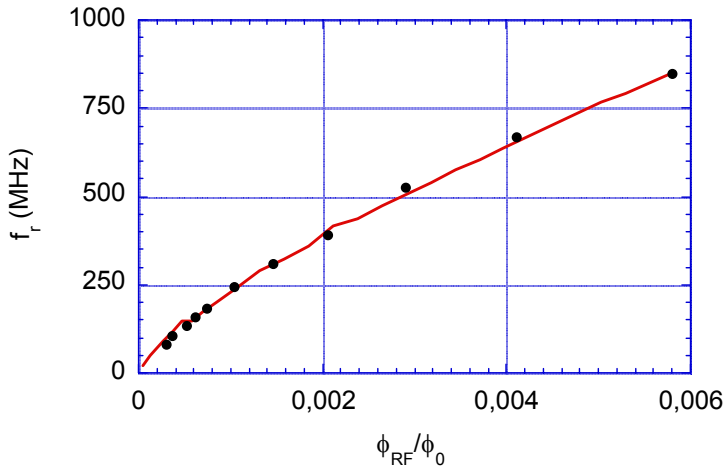
< N > = average number of states involved





Conclusion





New results in a dc SQUID

- MQT and TA from a 2D potential
- Observation of quantized levels
- Nanosecond measurements procedure
- Observation of coherent oscillations in a multi level quantum system