Coherently manipulating quantum states using Landau-Zener transition

Yang Yu, Nanjing University

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Acknowledgement

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J. Chen (陈健),
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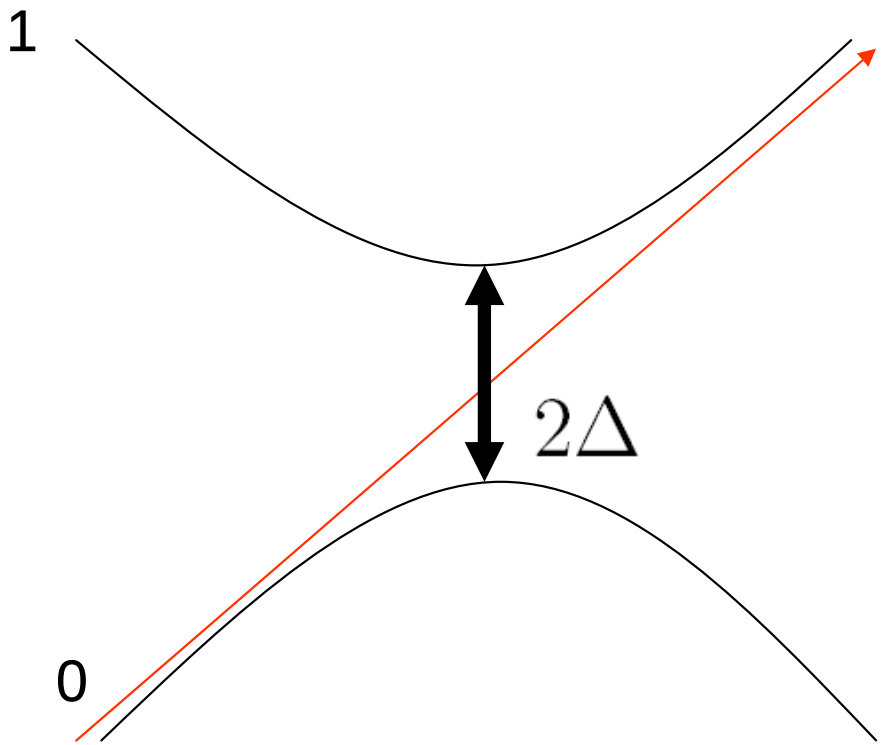
Motivation

- Coherent control of multi-qubit is very important for implementation of quantum processor.

- Due to short decoherence time and limitation of the control method，coherent control of quantum states is hard to realize in multi-qubit system, especially in solid-state qubits including superconducting qubits.

Landau-Zener Transition



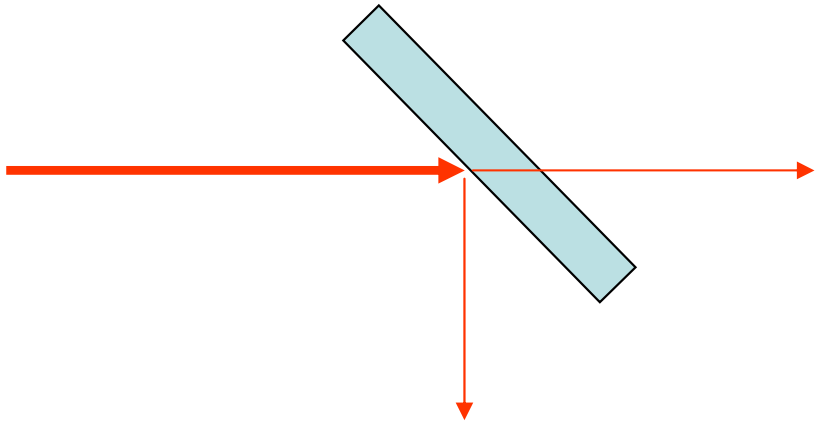
$\nu \equiv dE/dt$

$$P_{LZ} = \exp\left(-2\pi \frac{\Delta^2}{\hbar \nu}\right)$$

$\Delta >> \nu$ T = 0

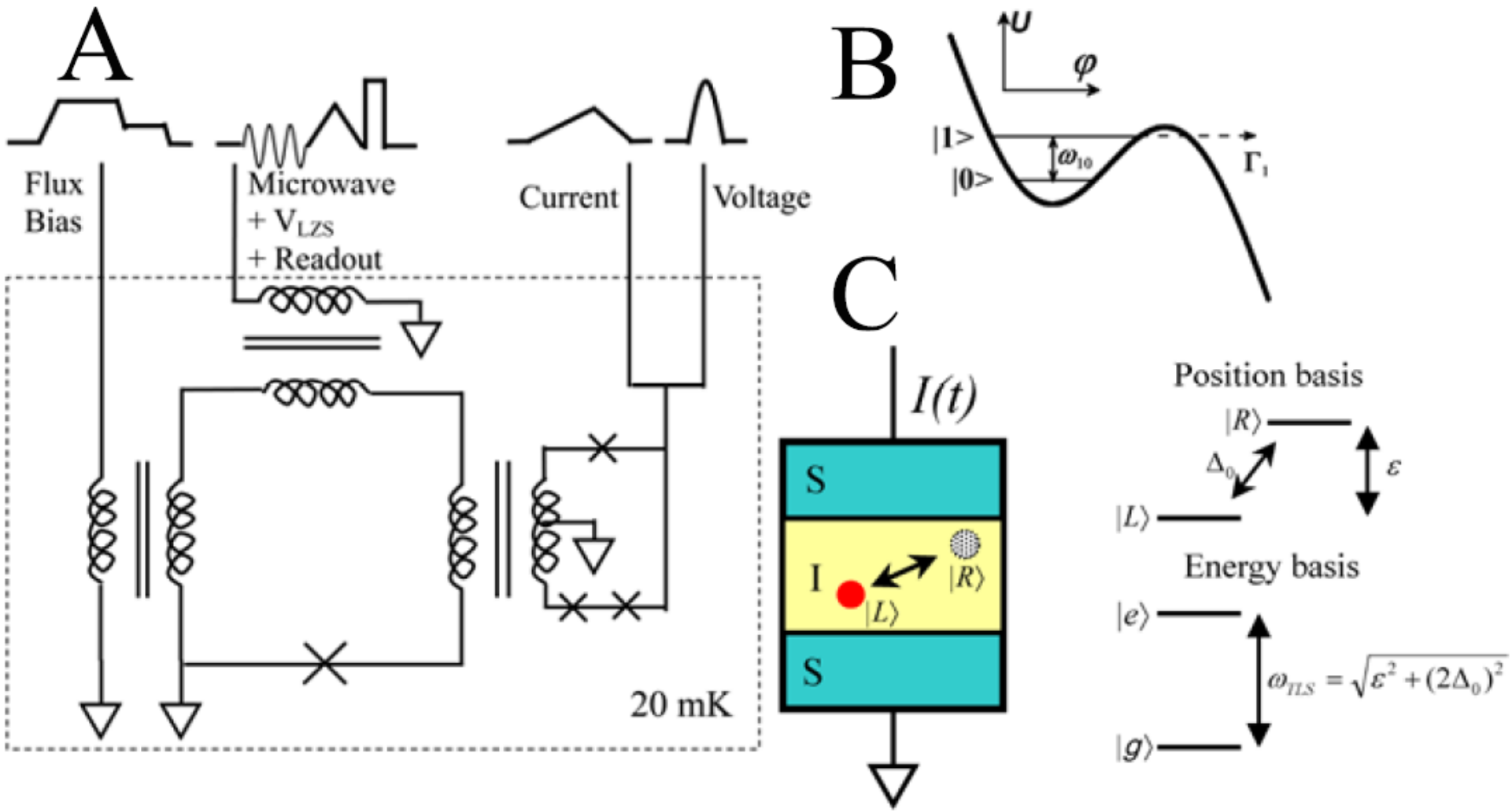
$\Delta << \nu$ T = 1

$\Delta \sim \nu$ T ~ 0.5



Shevchenko, Ashhab, Nori, Physics Report, 2010

Superconducting Qubit

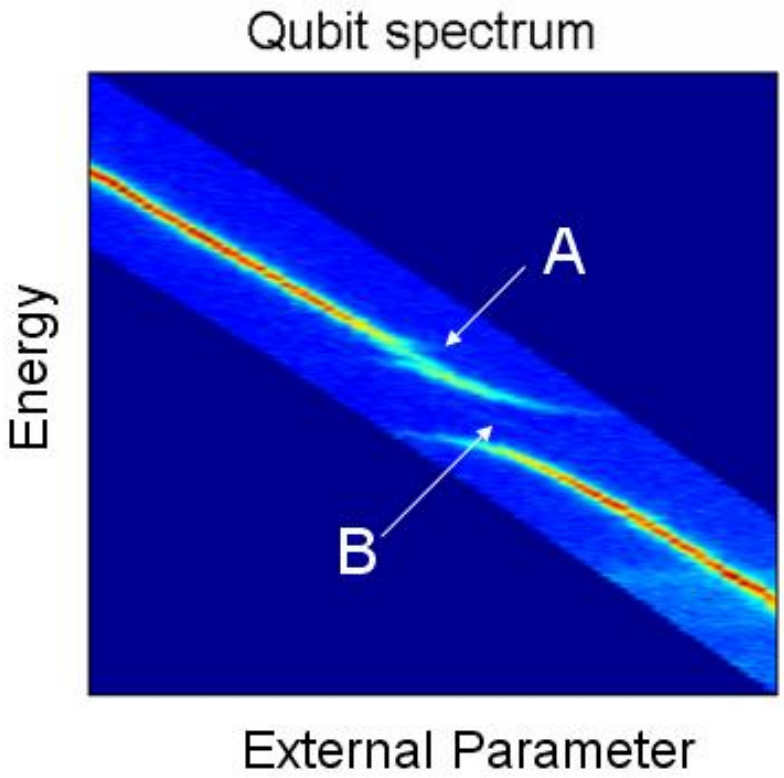


Simmonds et al., Quantum inf. Process, 2009

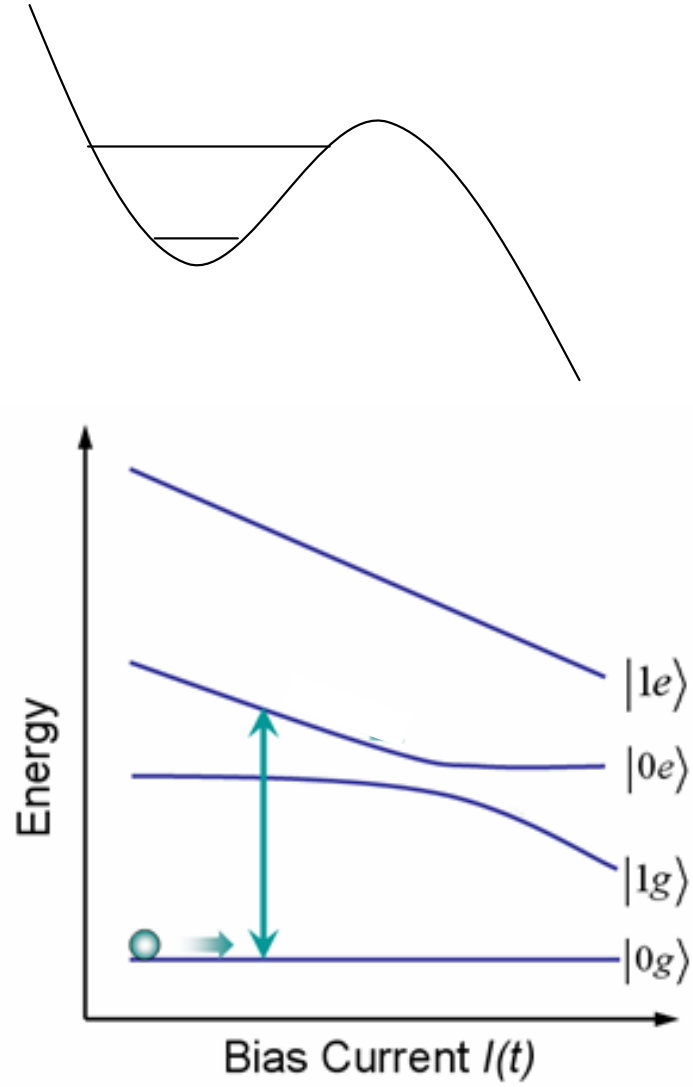
Zegoskin, Ashhab, Johansson, Nori, PRL 2006

Neeley et. al., Nature Physics, 2009

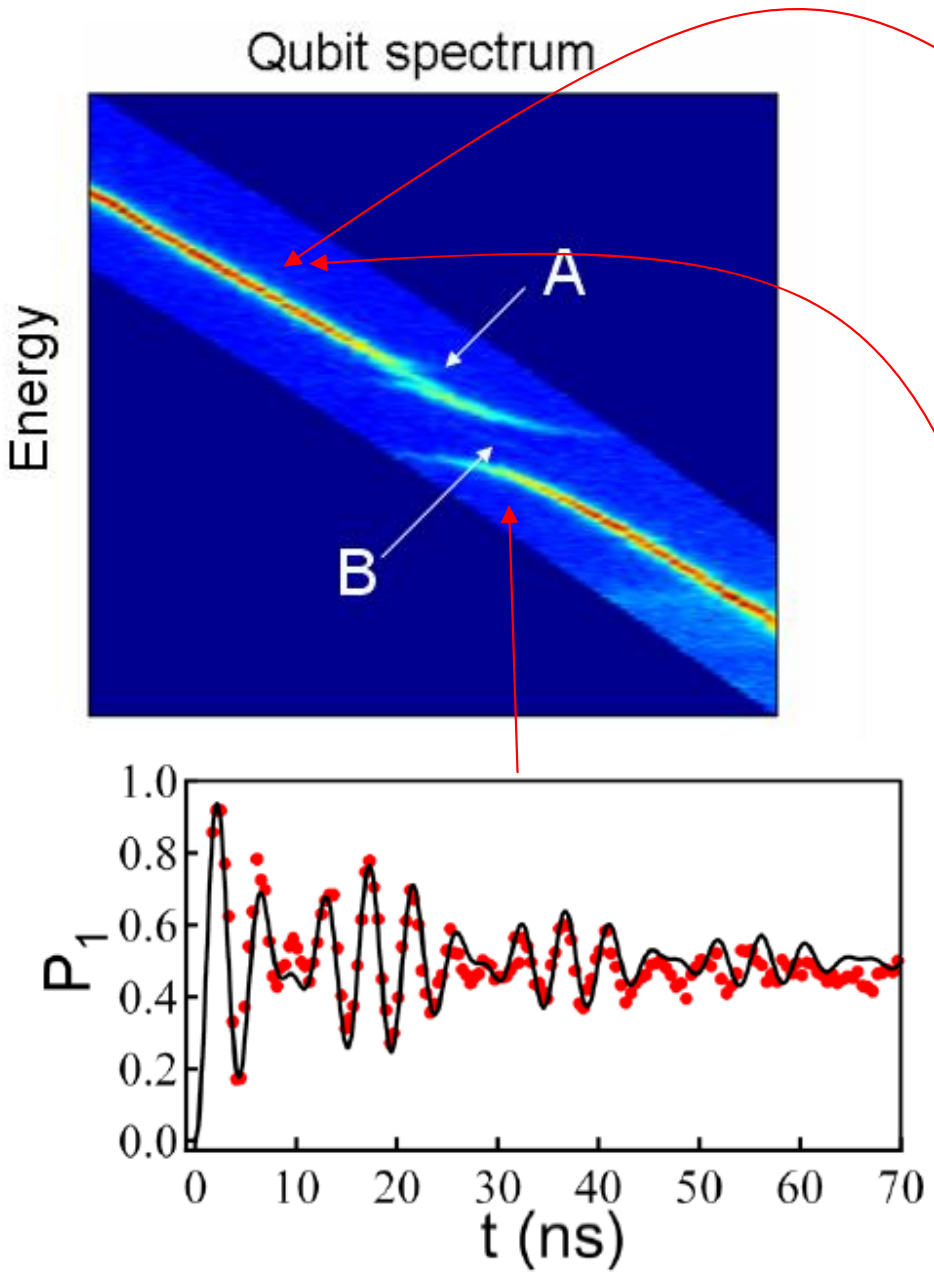
Spectroscopy

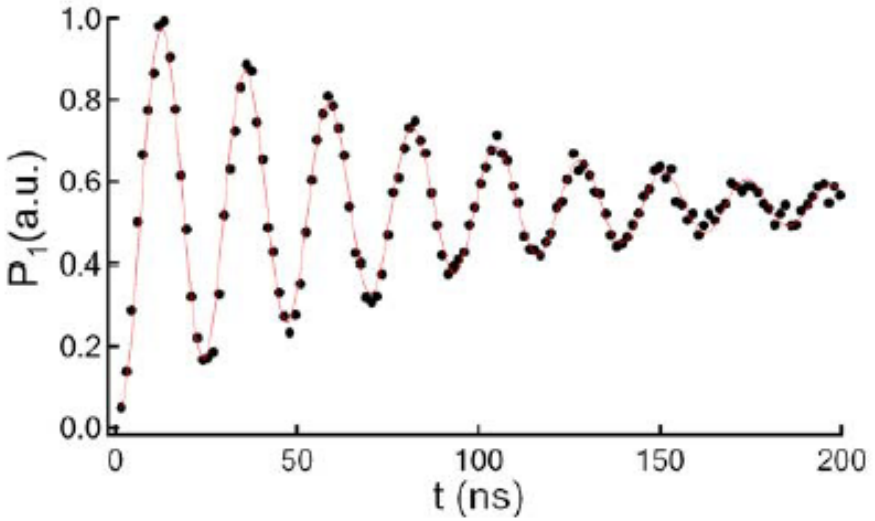


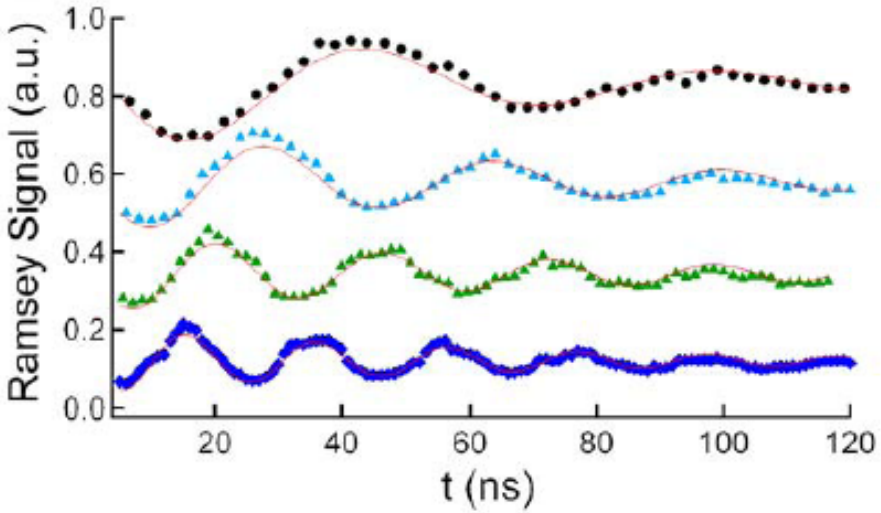
(a)



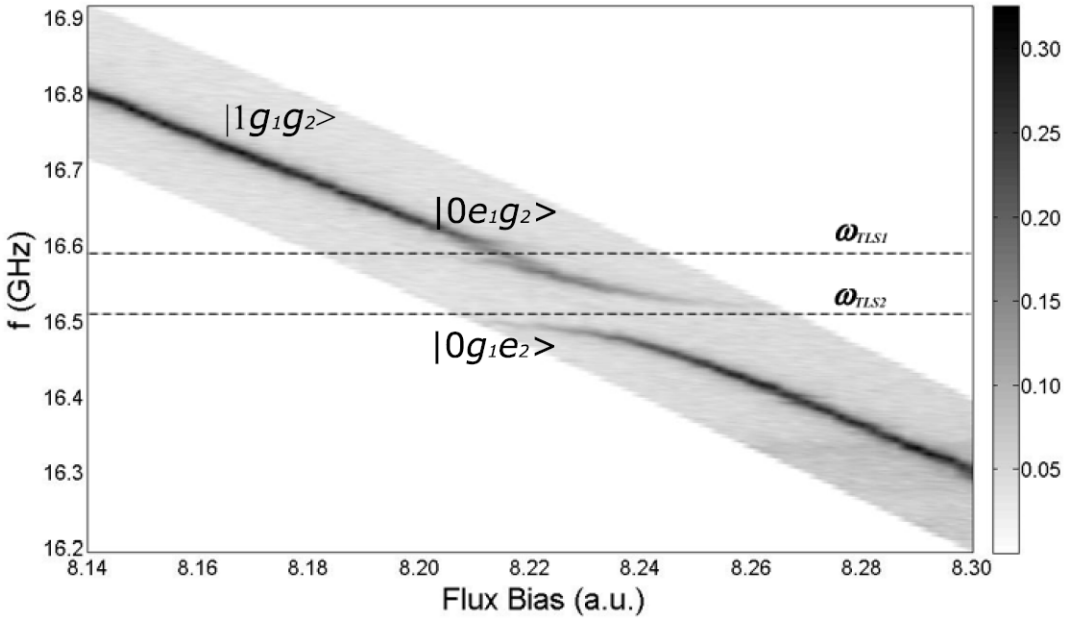
Coherent Oscillations

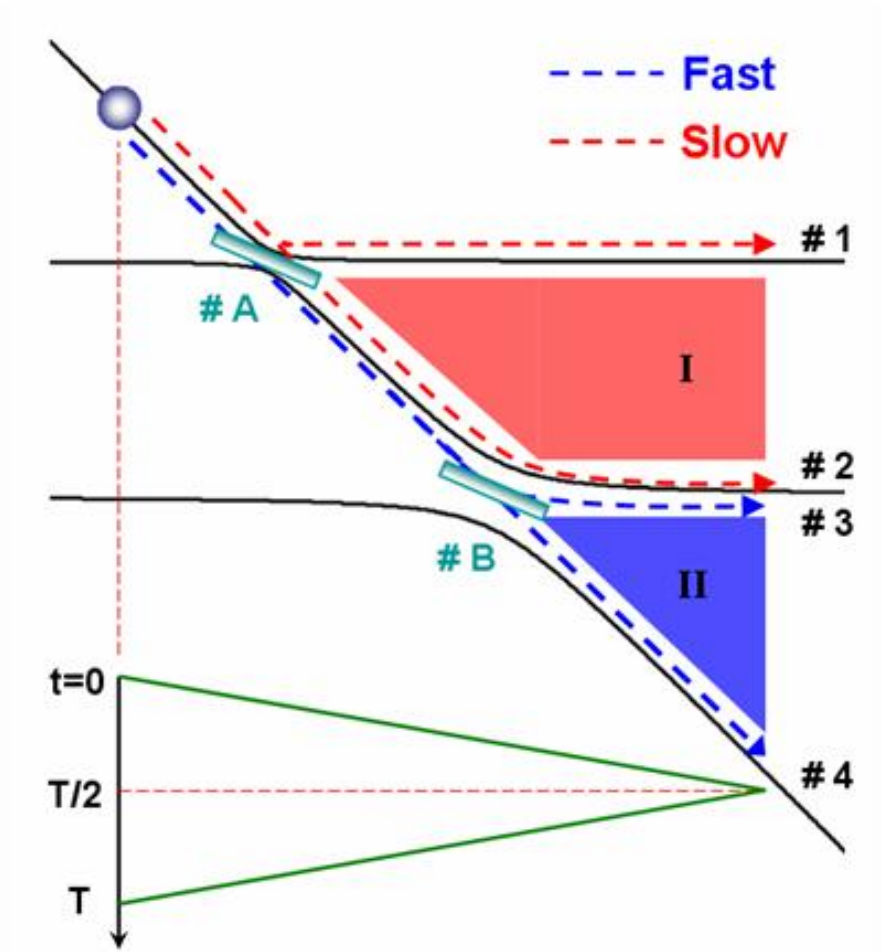




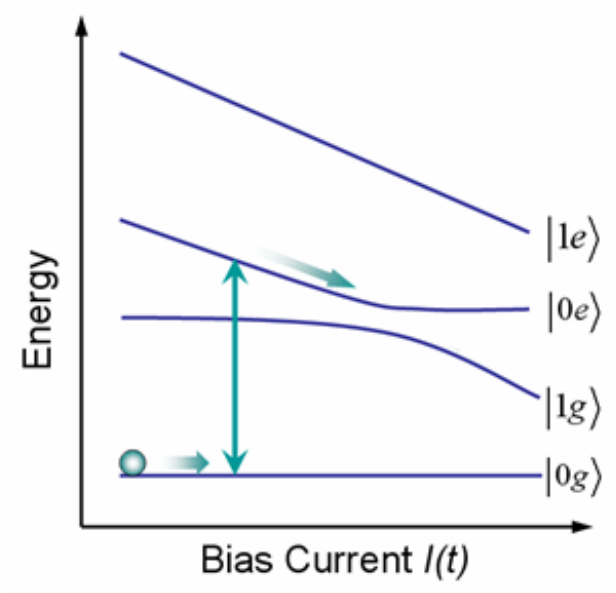


Dc Manipulation



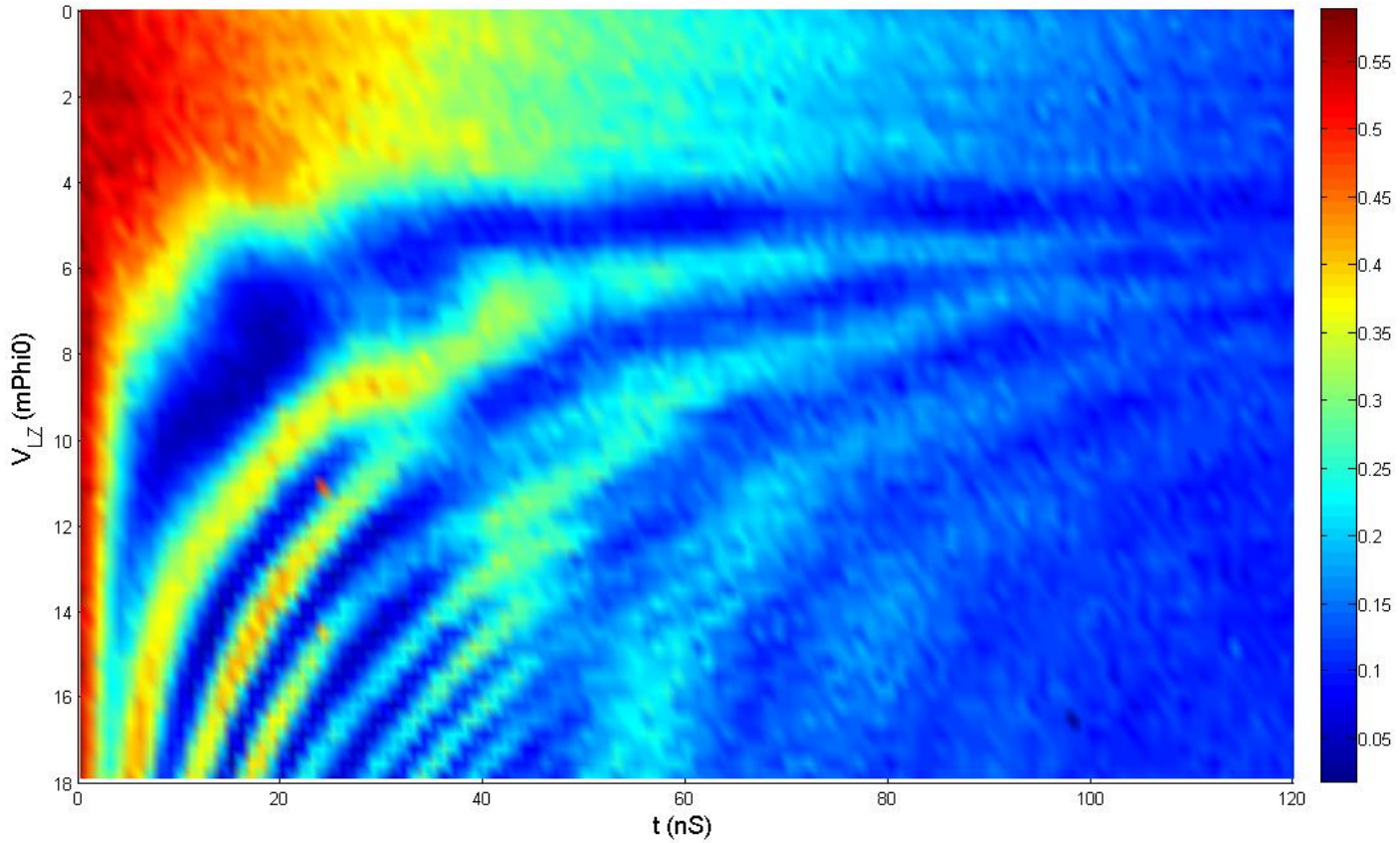


(b)



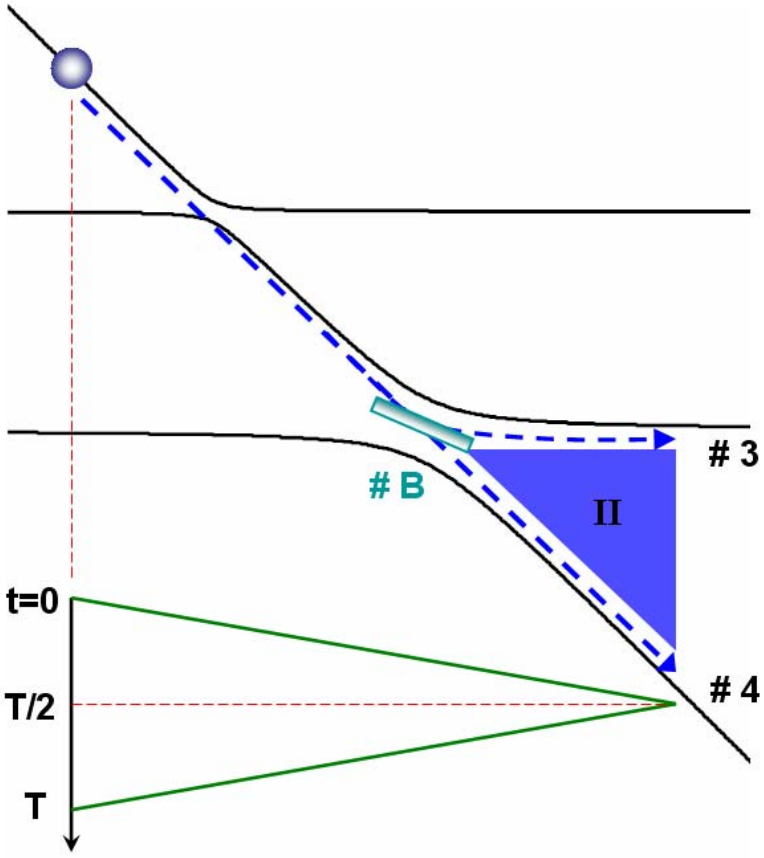
Population vs. Amp. and Width

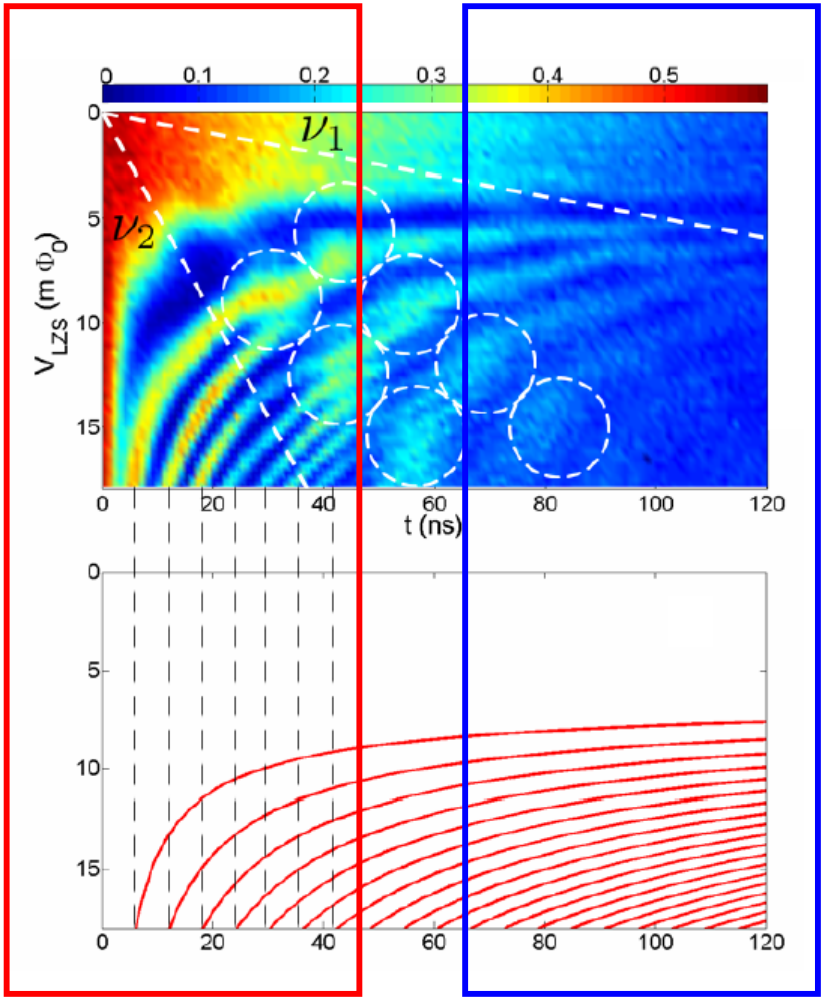
Amplitude



Width

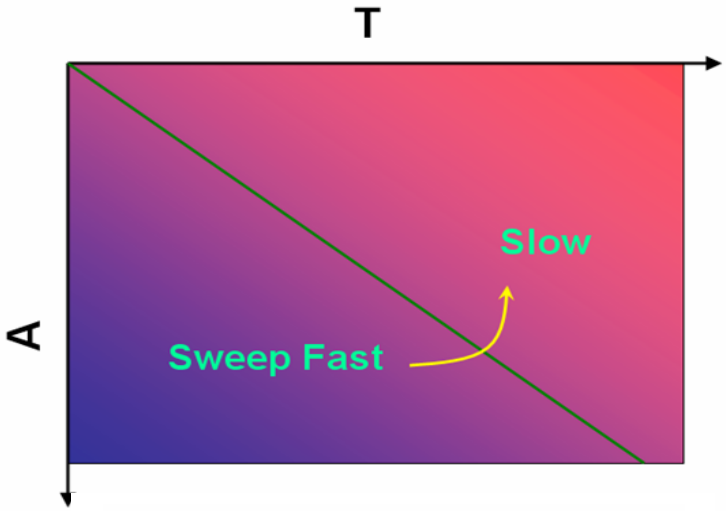
Analytical Calculation

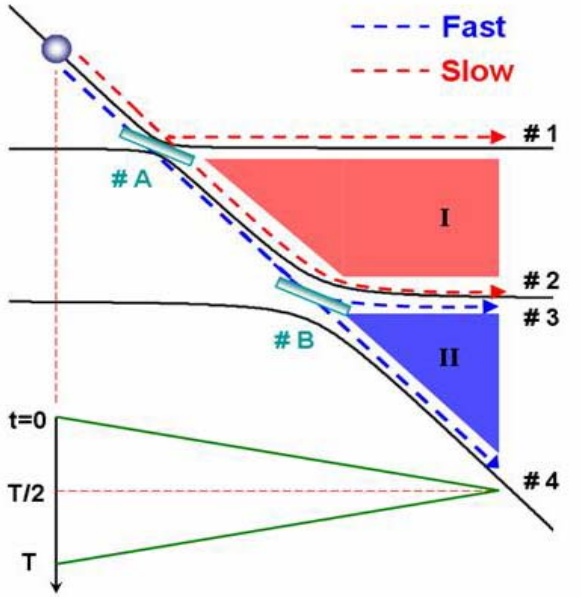


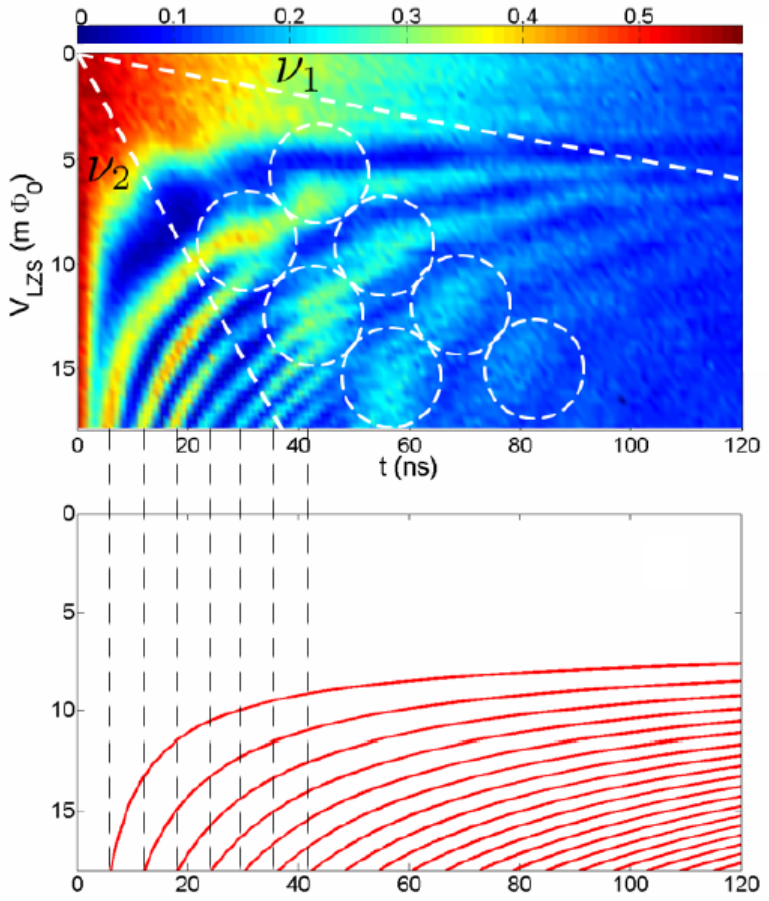


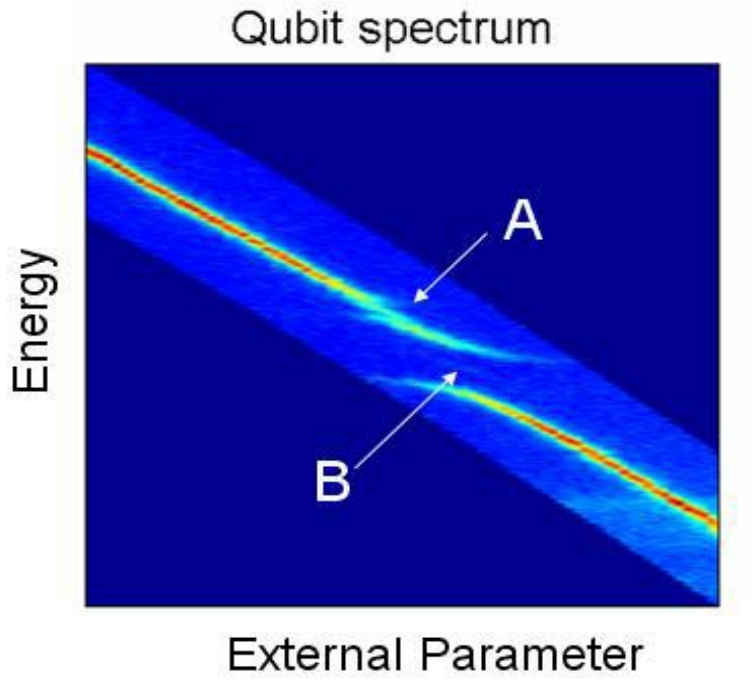
☺ ☹

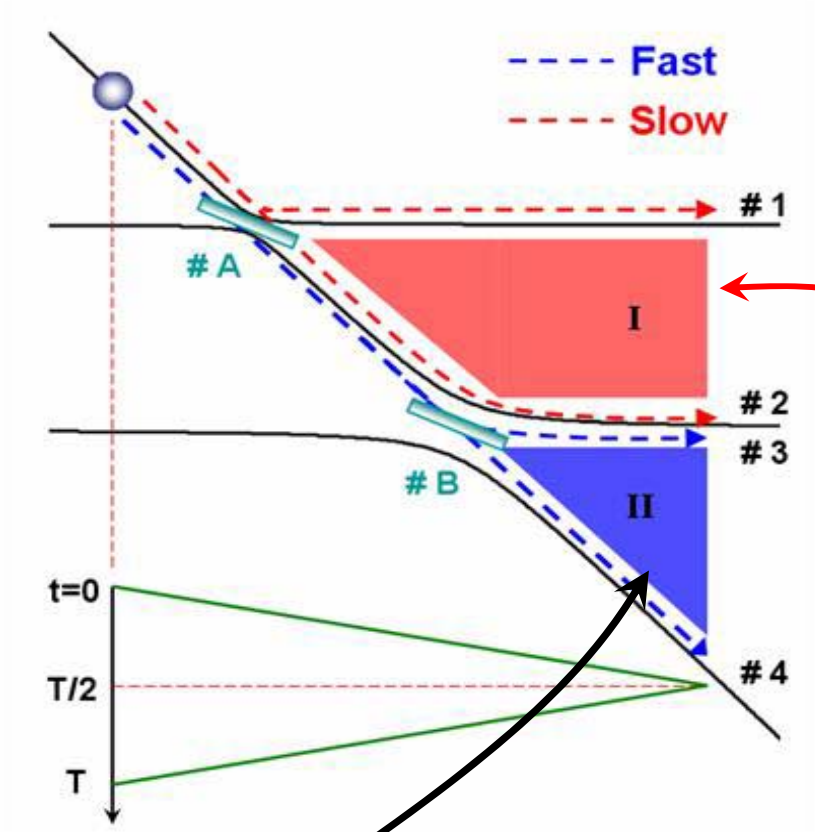
Why?

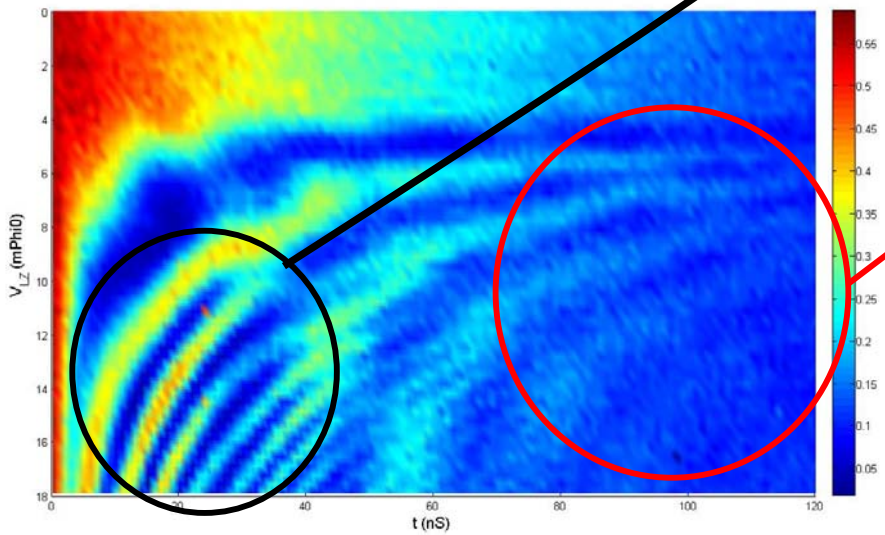

T
A
Slow
Sweep Fast

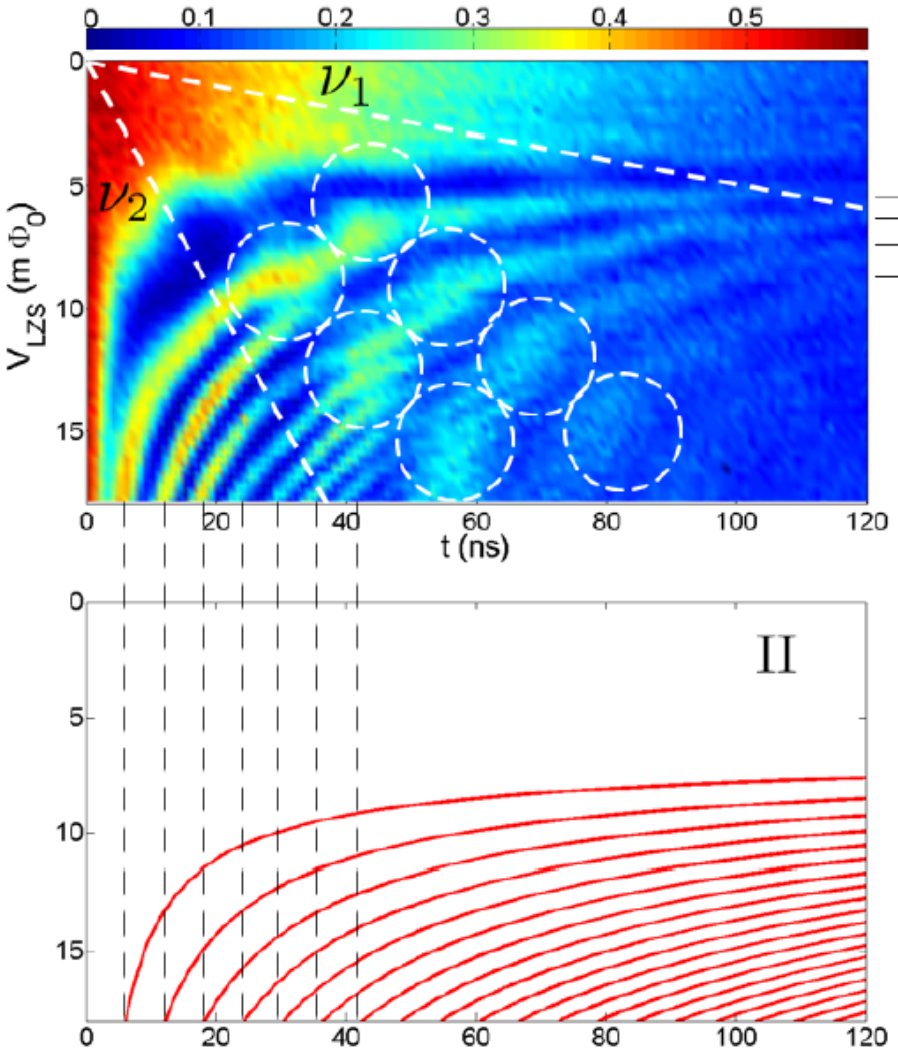

Fast
Slow
#1
#A
I
#2
#3
#B
II
t=0
T/2
T
#4

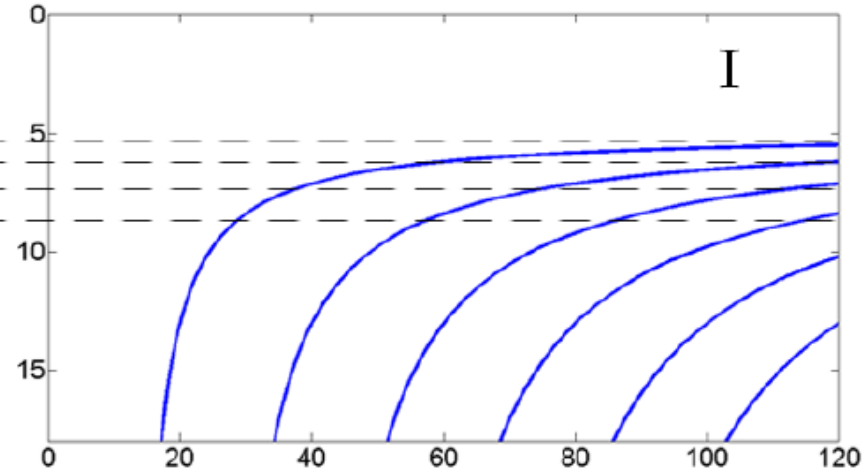

0
0.1
0.2
0.3
0.4
0.5
ν_1
ν_2
V_{LZS} (m Φ_0)
t (ns)
0
5
10
15
20
40
60
80
100
120


Qubit spectrum
Energy
A
B
External Parameter


Fast
Slow
1
A
I
2
3
B
II
t=0
T/2
T
4


V_LZ (mPhi0)
t (nS)

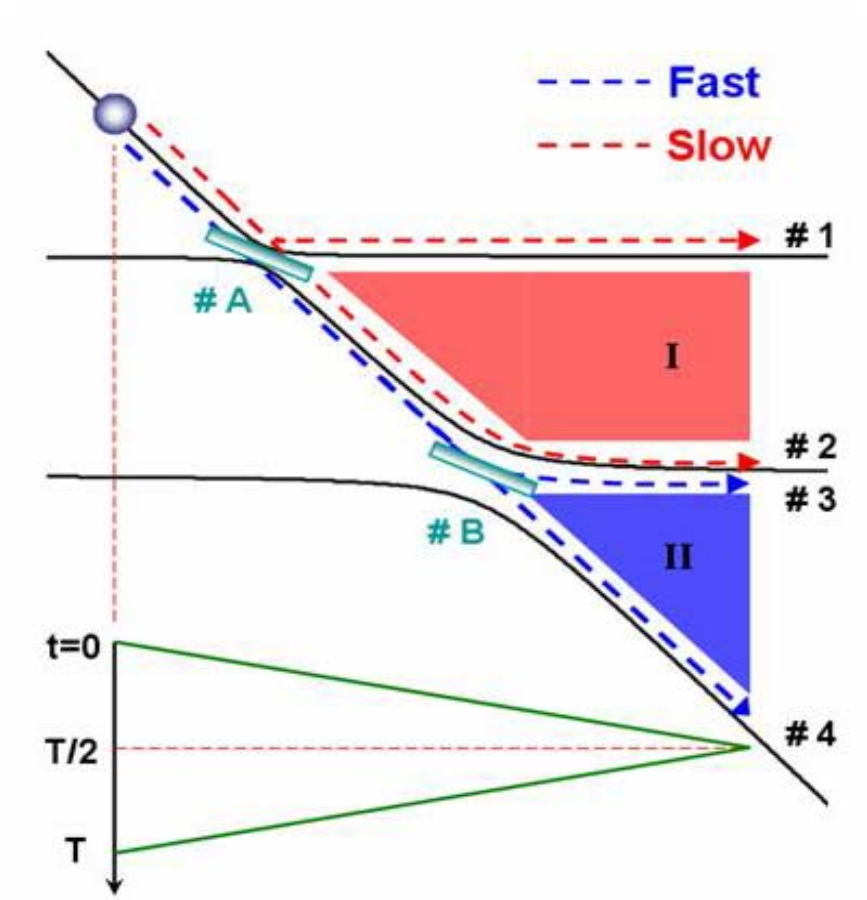




$$\begin{cases} sV_{LZS}\left(1-\frac{\delta_1}{sV_{LZS}}\right)^2 T = 4n\pi, & \delta_1 < sV_{LZS} < \delta_2 \\ \left[\frac{\delta_{12}^2}{sV_{LZS}} + 2\left(1-\frac{\delta_2}{sV_{LZS}}\right)\delta_{12}\right] T = 4n\pi, & sV_{LZS} > \delta_2 \end{cases}$$

$$sV_{LZS}\left(1-\frac{\delta_2}{sV_{LZS}}\right)^2 T = 4n\pi$$

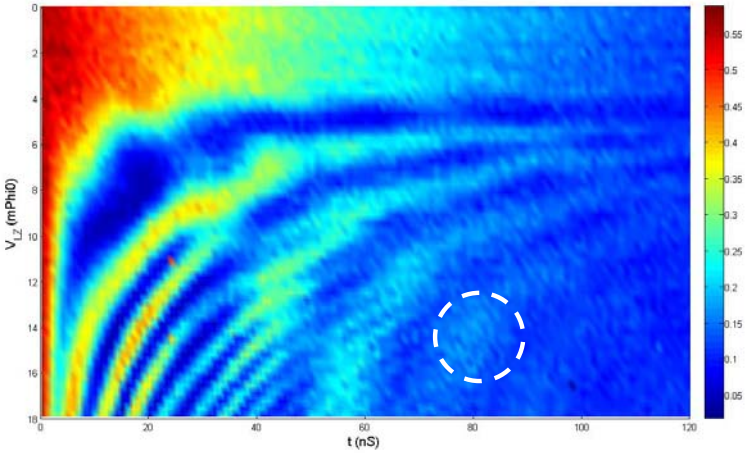
Large amplitude approximation

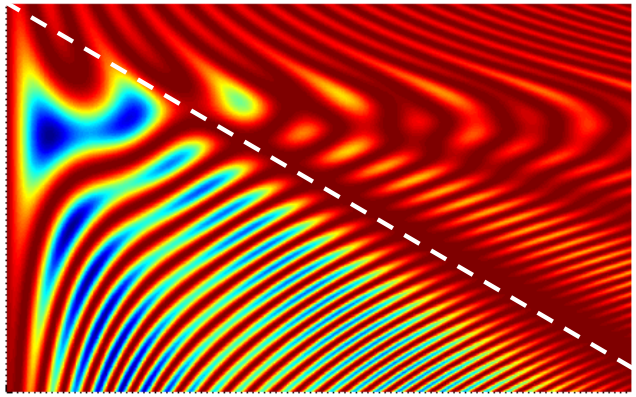


$$\delta_{12}T = 2n\pi$$

$$sV_{LZS}T = 4n\pi$$

The last confusion:



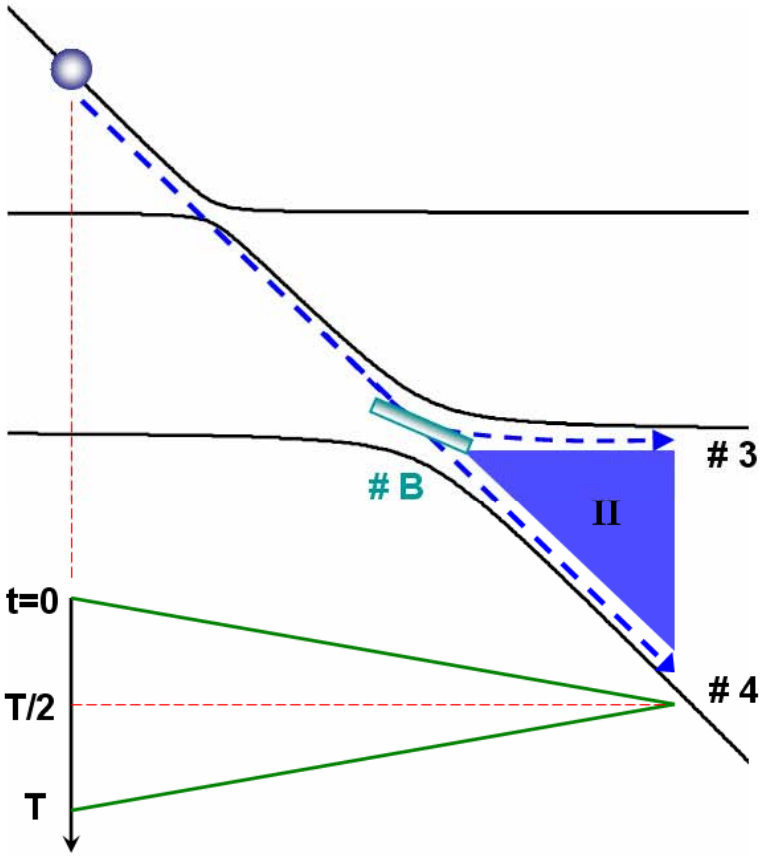


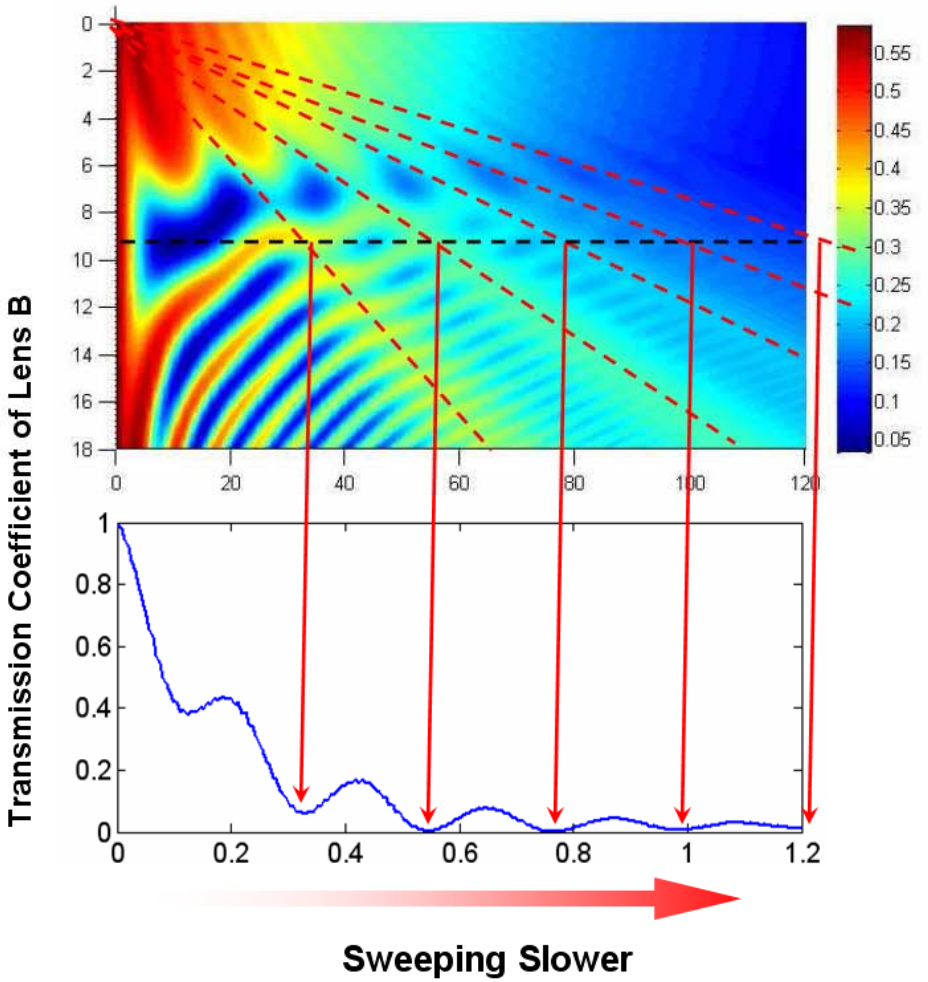
No interference!

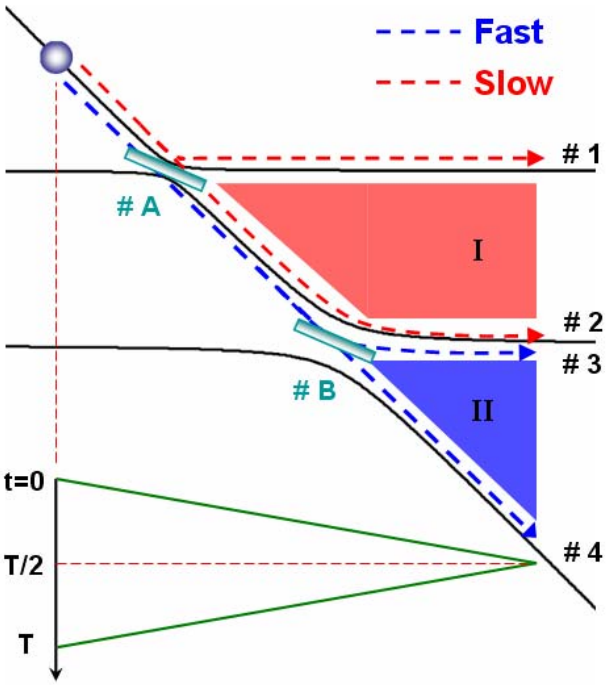
Two factors affecting interference:

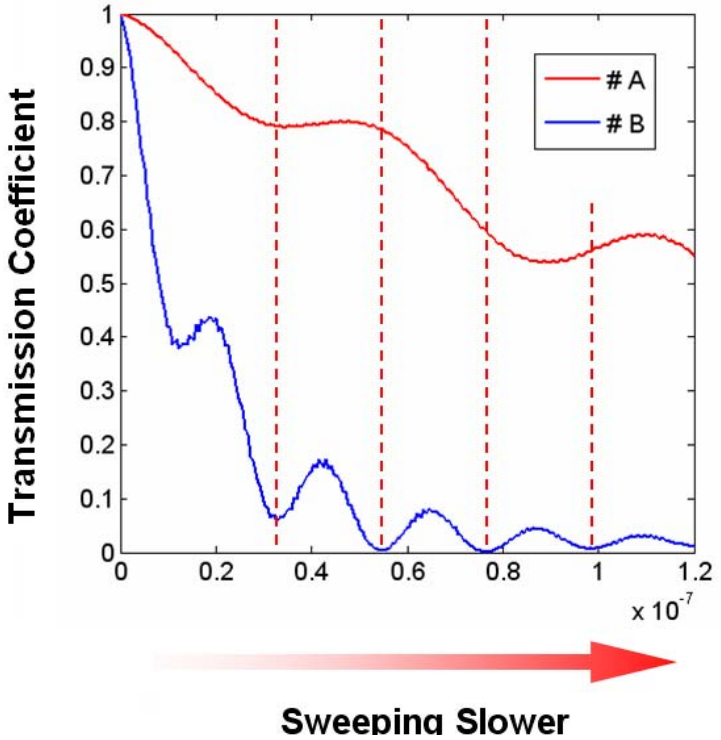
(1)Phase (2) Amplitude

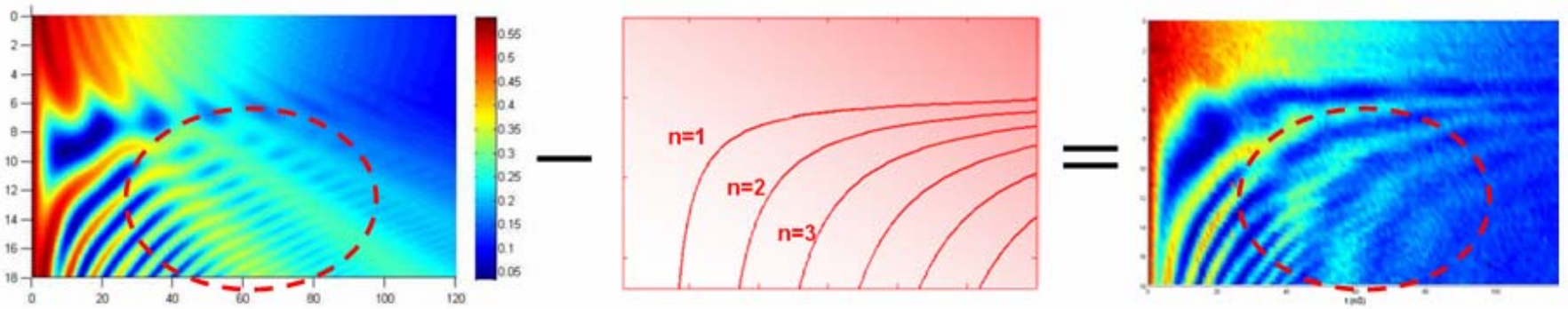
Effect of Amplitude





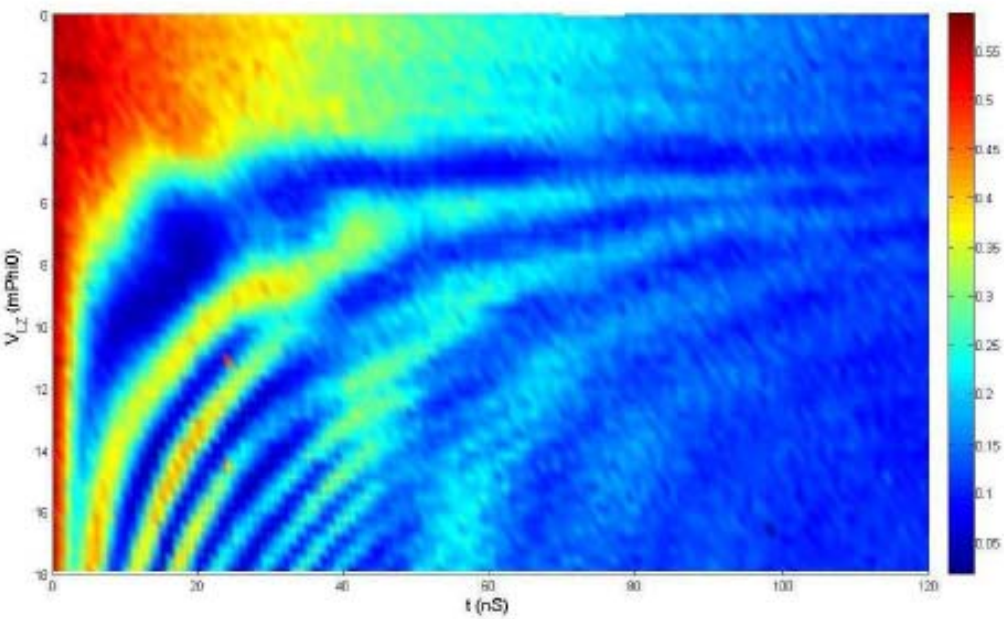




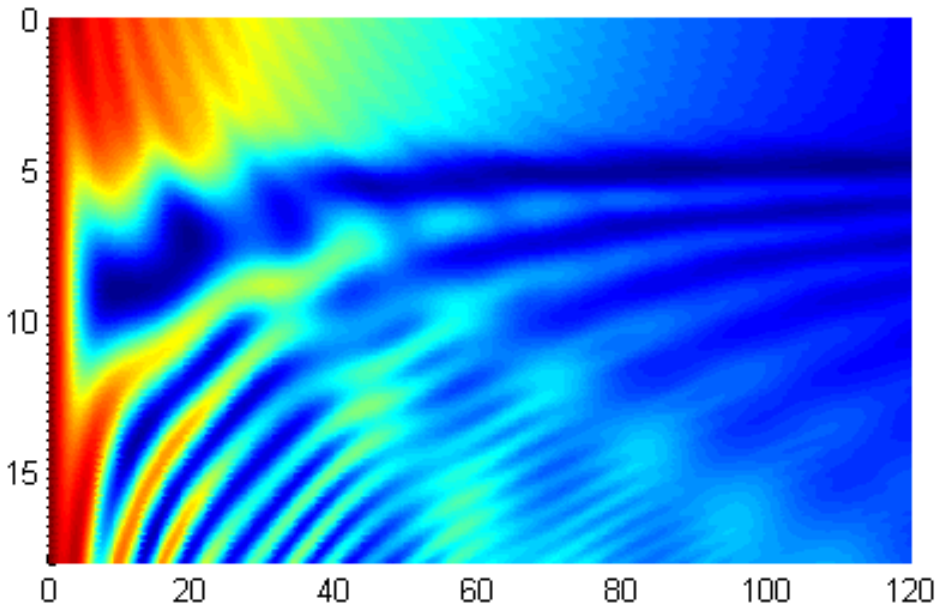


—— All confusions have been resolved !

Perfect !



Experiment

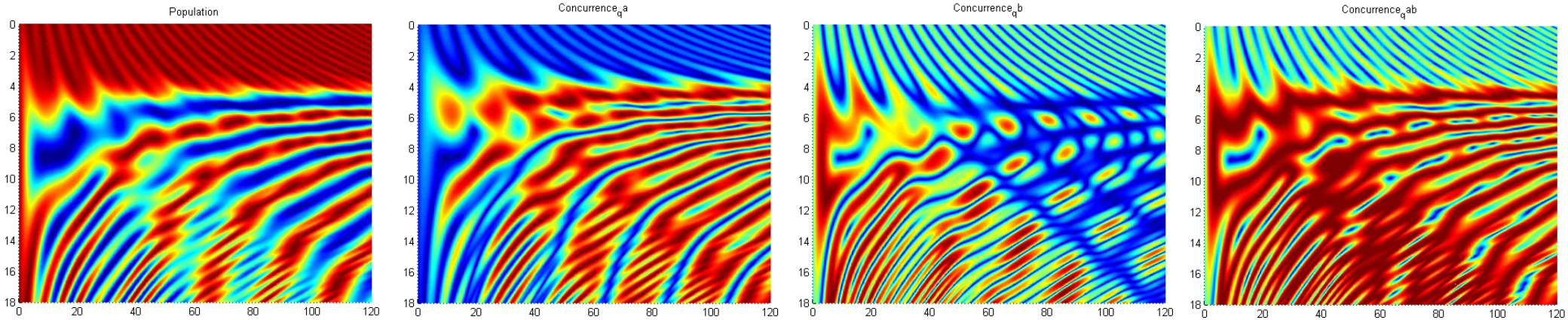


Simulation

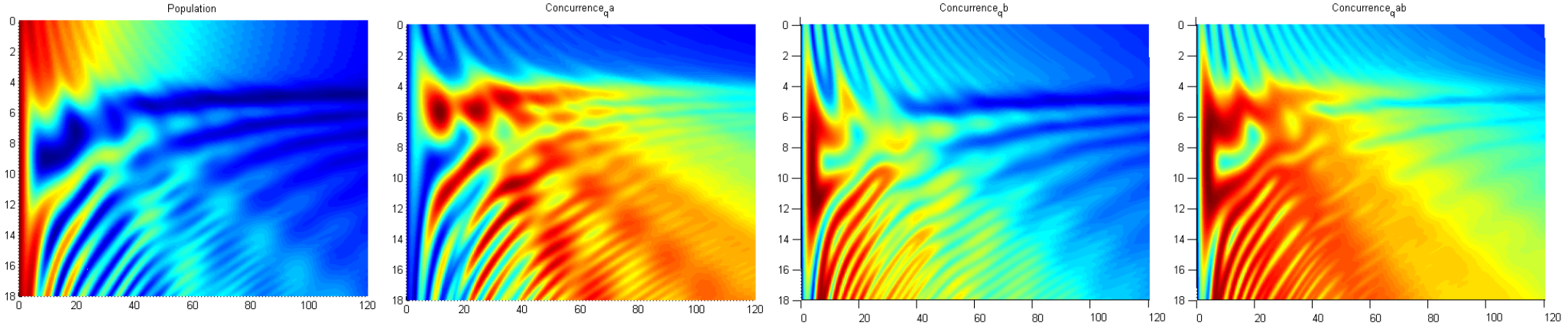
Numerical Simulation

Three-Body Entanglement

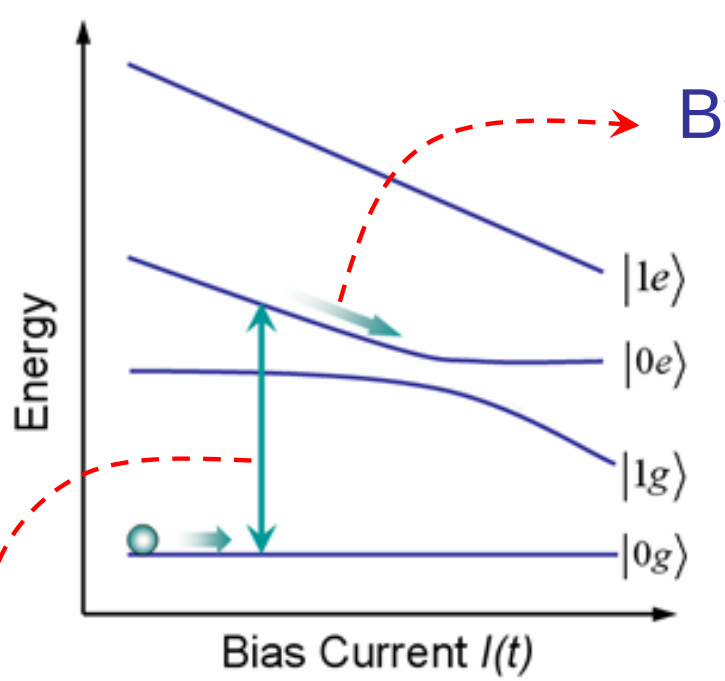
Pure State



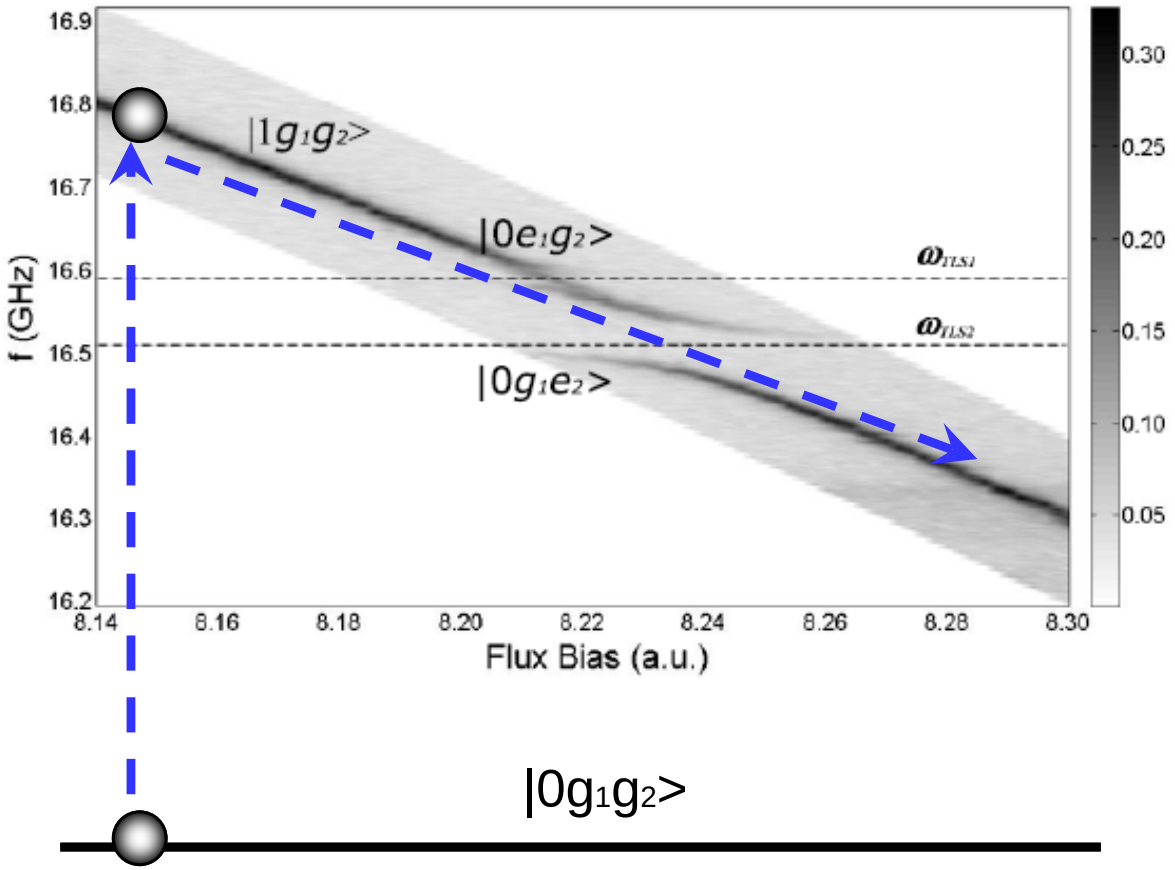
Mixed State



Two Methods to Manipulate the hybrid System



Scheme to generate W state and GHZ (cat) state



$$|\psi\rangle = \alpha|1g_1g_2\rangle + \beta|0e_1g_2\rangle + \gamma|0g_1e_2\rangle$$

W-state $\alpha = \beta = \gamma = 1/\sqrt{3}$

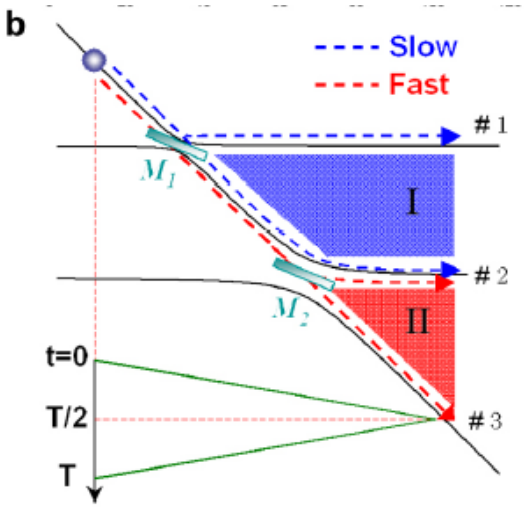
GHZ (cat) state $|0e_1g_2\rangle + |1g_1e_2\rangle)/\sqrt{2}$

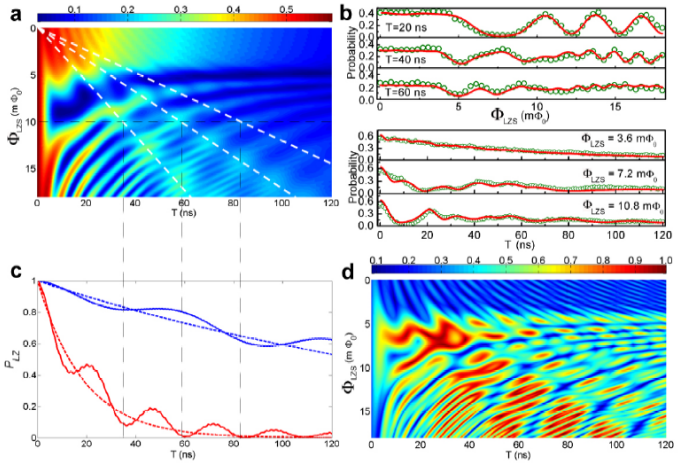
Summary

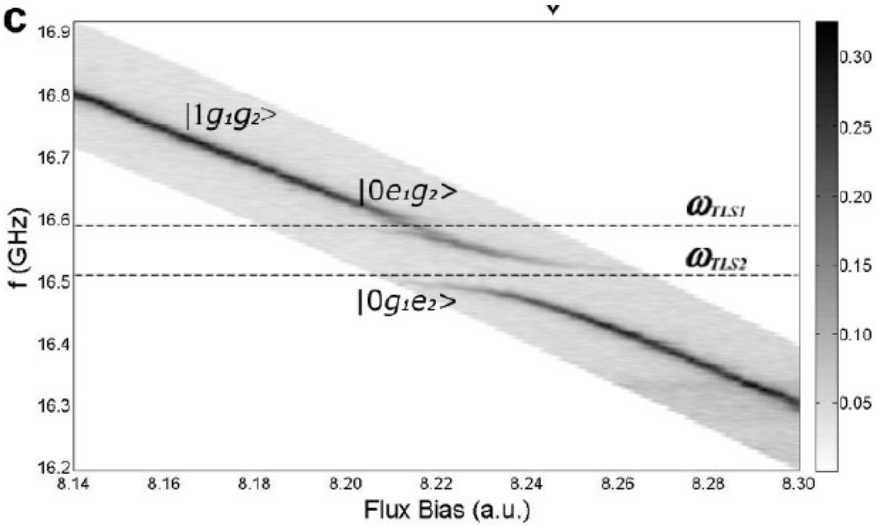
Tunable quantum beam splitters for coherent manipulation of a solid-state tripartite qubit system

Guozhu Sun[1,2,3], Xueda Wen[3], Bo Mao[2], Jian Chen[1,3], Yang Yu[3], Peiheng Wu[1,3] & Siyuan Han[1,2]

Nat. Commun. 1:51 doi: 10.1038/ncomms1050 (2010).



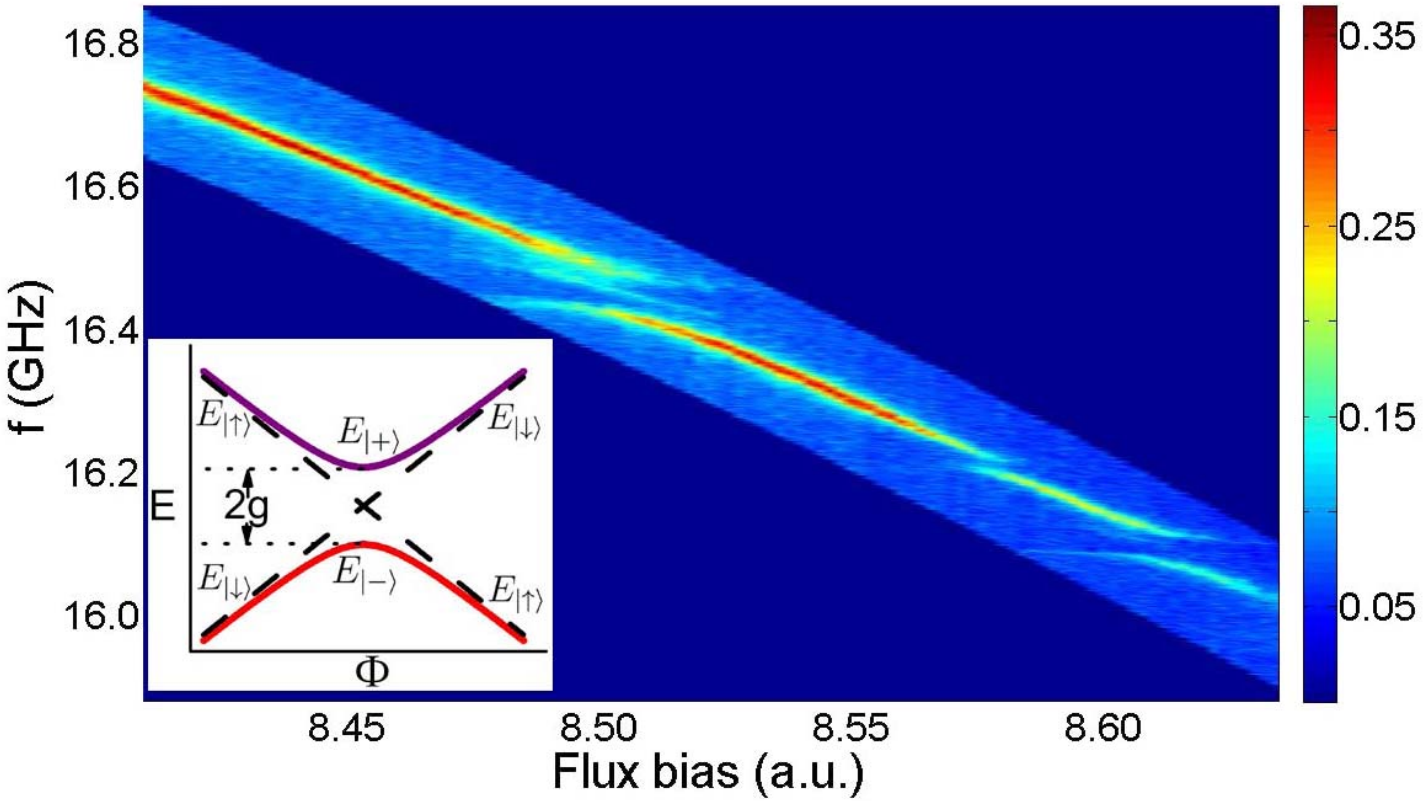




- Use tunable Landau-Zener tansition to coherently control multiple qubits.
- Demonstrate coherent control of tripartite solid-state qubits and generation of W-state.

$$|\psi\rangle = \alpha|1g_1g_2\rangle + \beta|0e_1g_2\rangle + \gamma|0g_1e_2\rangle$$

Microwave Assisted LZS



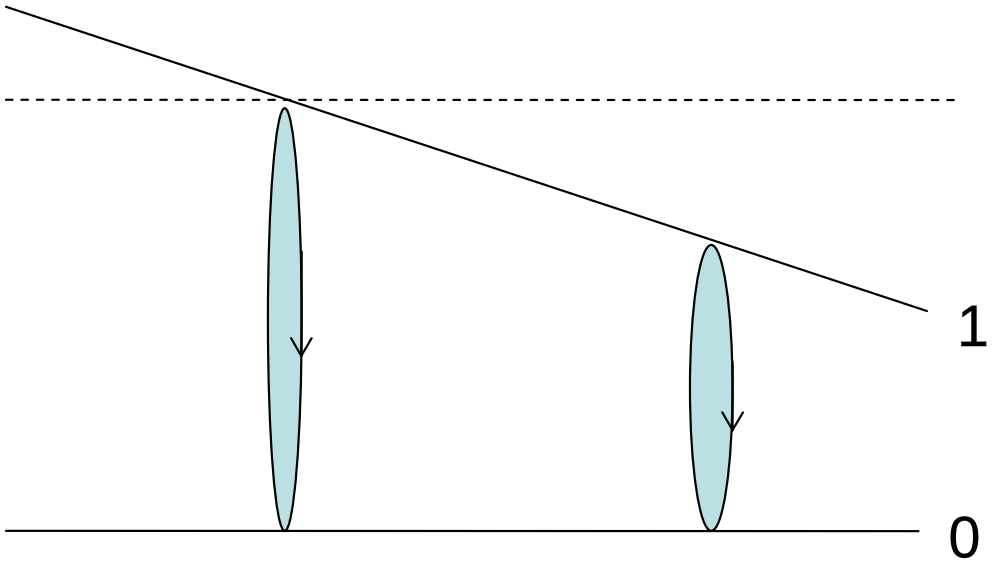
1. Landau-Zener tunneling requires an anticrossing.

2. The position and magnitude of the anticrossing are fixed during fabrication. Some system even have no anticrossing.

3. Microwave can open anticrossing in situ.

Guozhu Sun et al. PHYS. REV. B 83, 180507(R) (2011)

Principle



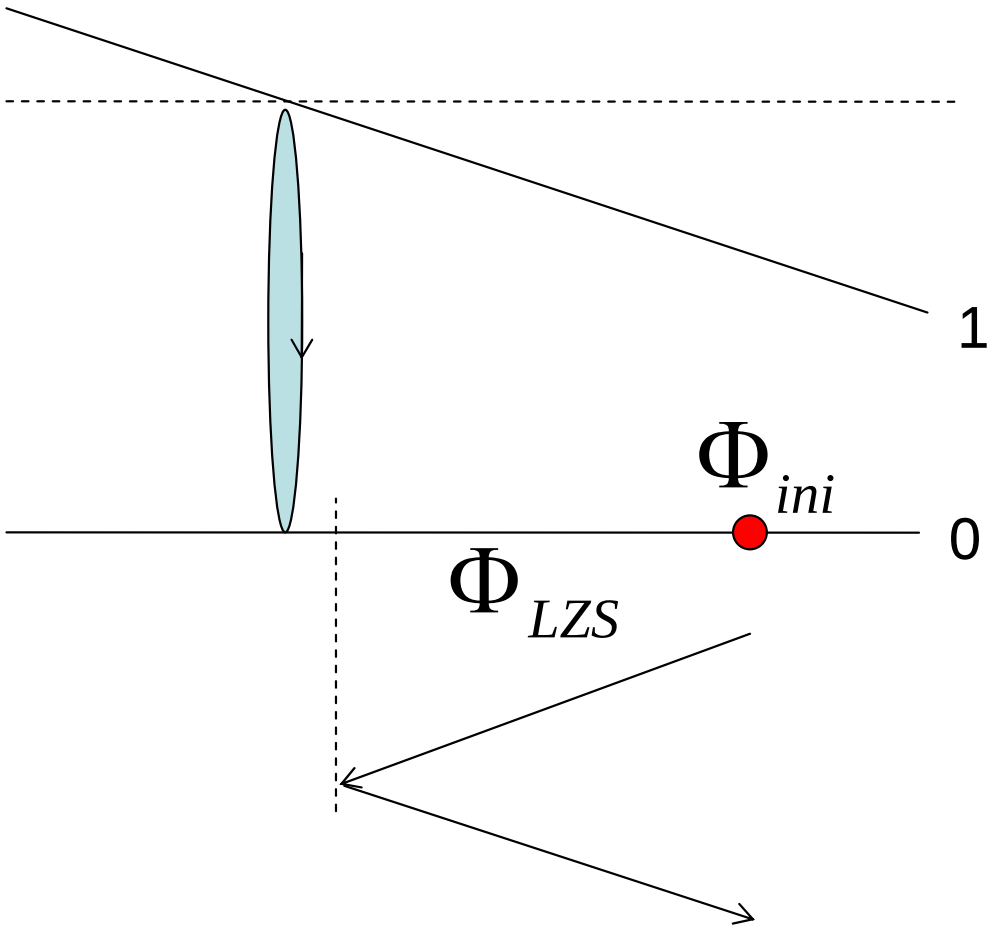
$$\omega_{10} = E_1 - E_0$$

$$I_{rf} = I_A \sin \omega t$$

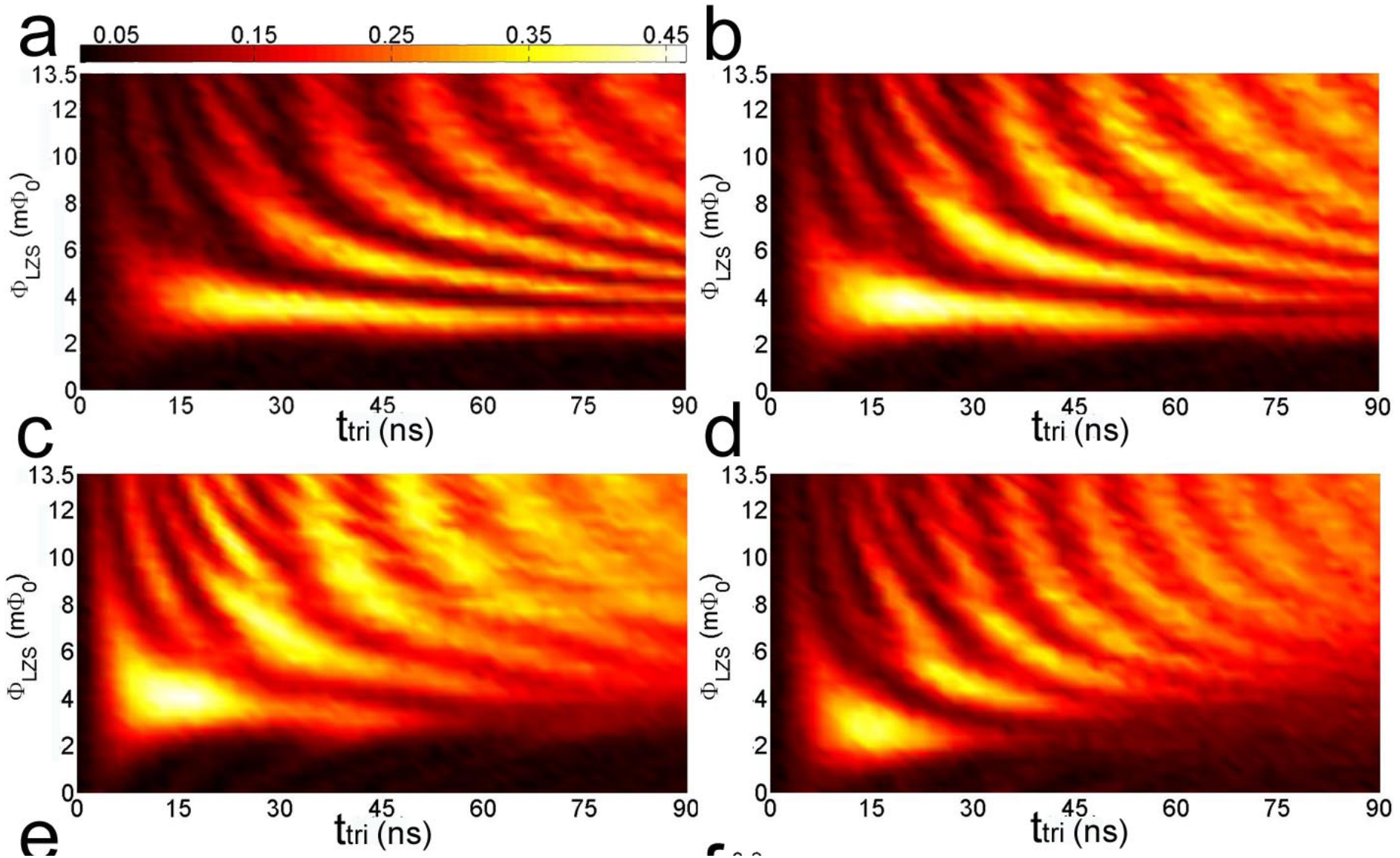
$$H = \begin{pmatrix} 0 & \Omega_R \\ \Omega_R & 0 \end{pmatrix}$$

$$\Omega_R \propto \langle 1 | I_A | 0 \rangle$$

Experimental procedure



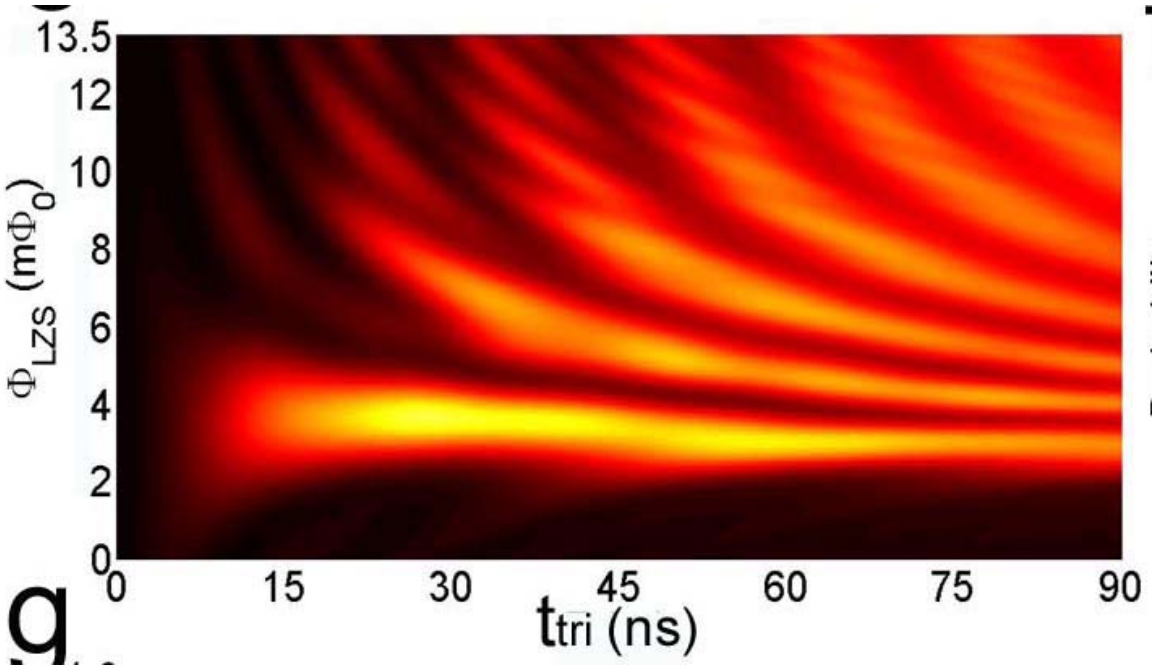
Interference patterns

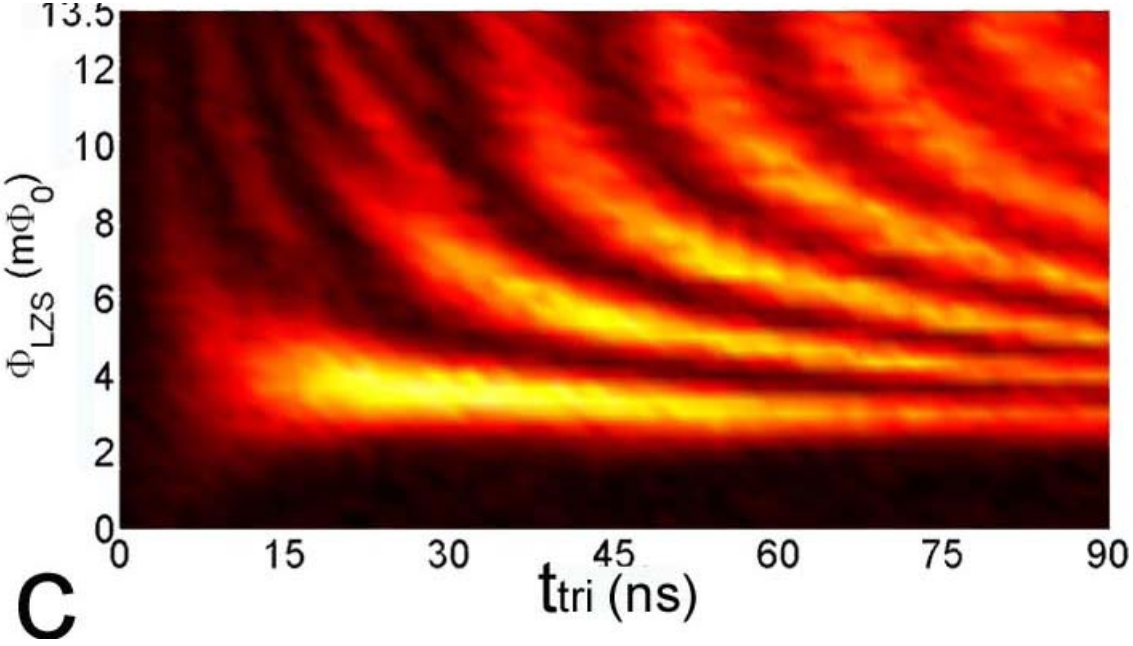


$a,b,c: \omega/2\pi = 16.345\ \ GHz,\ \ \Omega_{Ra} = 19.6MHz,\ \ \Omega_{Rb} = 27.8MHz,\ \ \Omega_{Rc} = 41.7MHz$

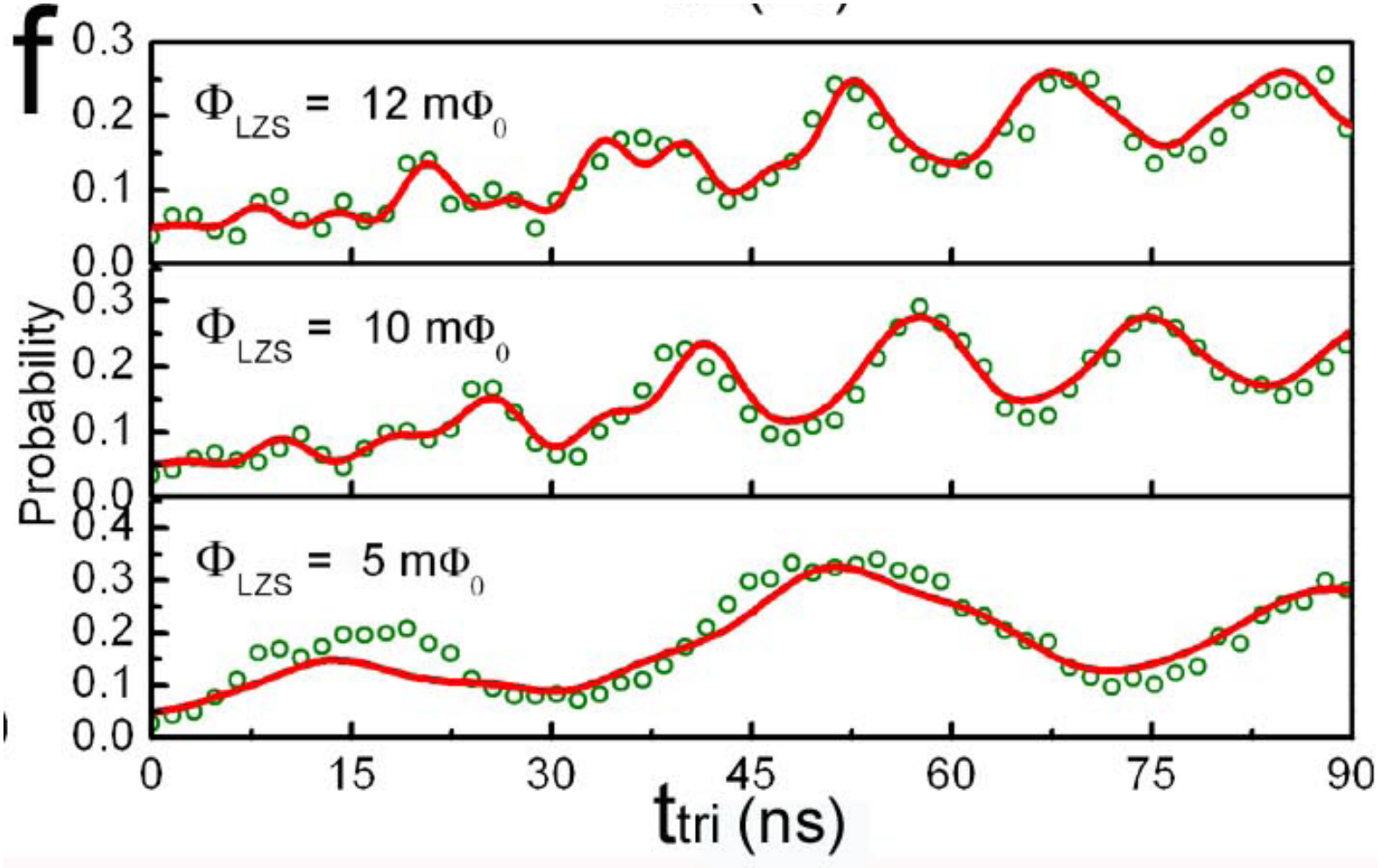
$d: \omega/2\pi = 16.315\ \ GHz,\ \ \Omega_{Rd} = 30.9MHz,$

Calculated results

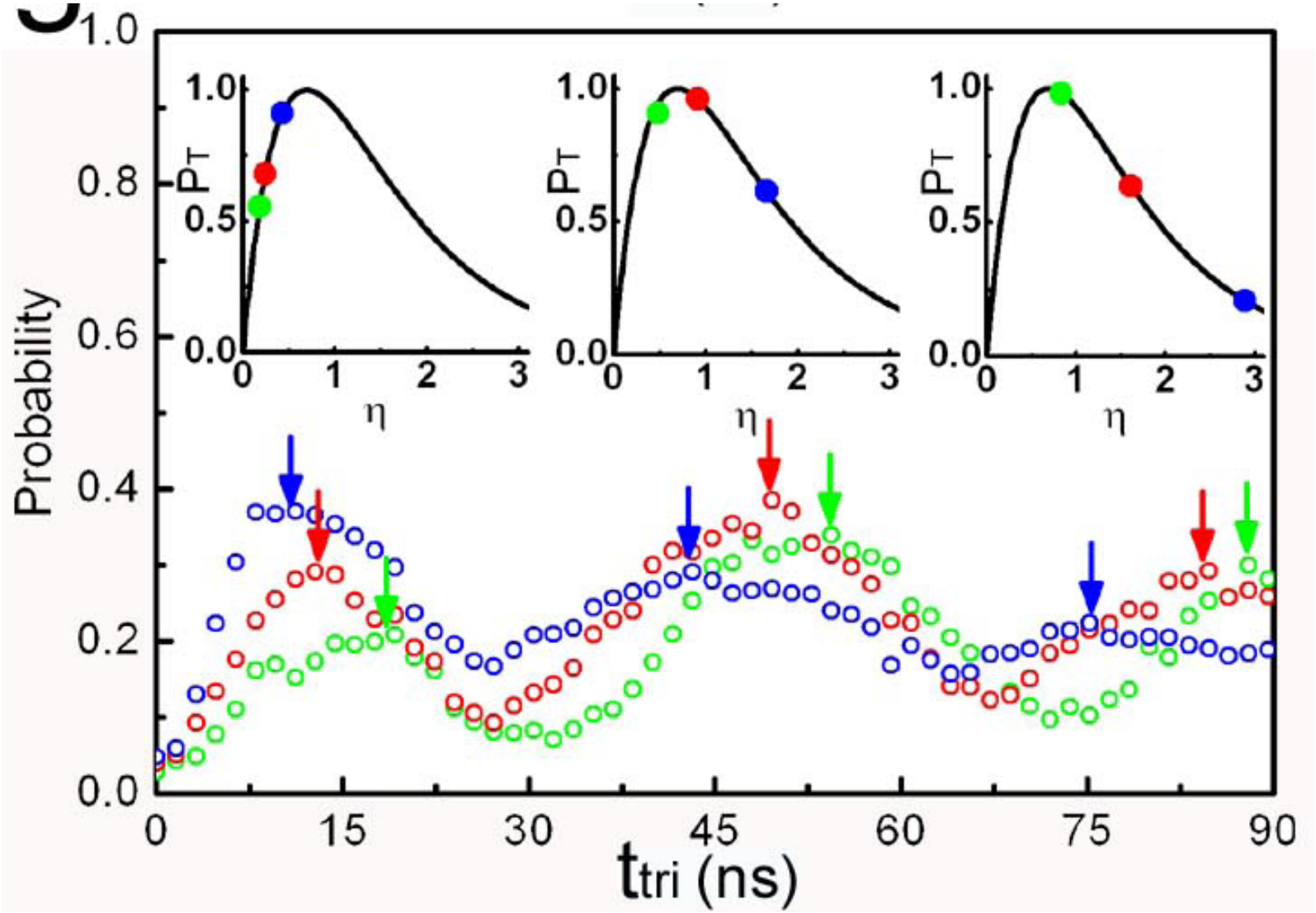




Oscillations of the population



Detail agreement between theory and experiments



$$P_T = 4P_{LZ}(1-P_{LZ}) \qquad P_{LZ} = \exp\left(-2\pi\frac{\Delta^2}{\hbar\nu}\right)$$

Thank you for your attention !

谢谢!

$$C_{AB} = 2|\alpha\beta|,\ C_{AC} = 2|\alpha\gamma|,\ \text{and}\ C_{A(BC)} = 2|\alpha|\sqrt{|\beta|^2 + |\gamma|^2}.$$

V. Coffman, J. Kundu, and W. K. Wootters, Phys. Rev. A **61**, 052306 (2000).