Entanglement In Hybrid Solid-State Quantum Systems

ANGELA VIVIANA GÓMEZ AZUERO

av.gomez176@uniandes.edu.co

LUIS QUIROGA

FERNEY RODRIGUEZ

GRUPO DE FÍSICA TEÓRICA DE LA MATERIA CONDENSADA[1]

DEPARTAMENTO DE FÍSICA

UNIVERSIDAD DE LOS ANDES

Universidad de los Andes

[1] http://fimaco.uniandes.edu.co

CONTENTS

MOTIVATION

We have study the concept of entanglement, applied to our interes system: The NV centers in diamond in three cases

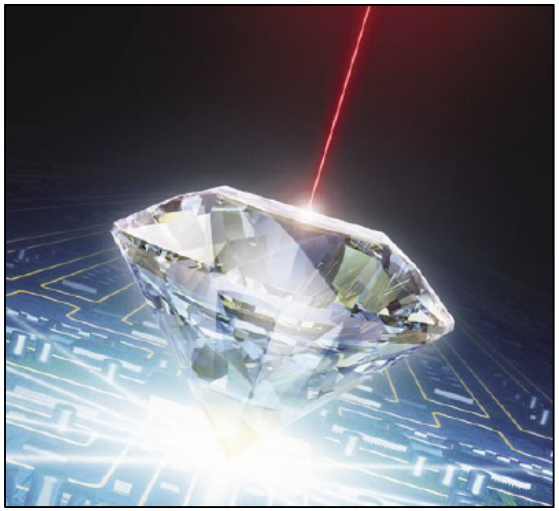
1. *Two isolated NV centers with dipolar coupling.*

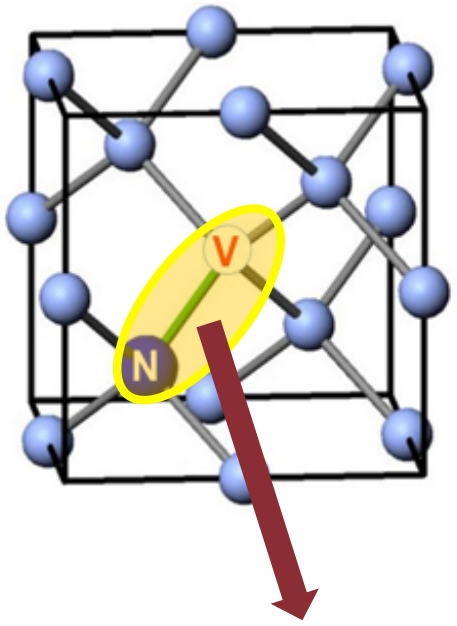
2. *Two NV centers in a ^{13}C bath.*

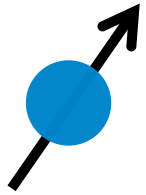
3. *To combine the NV centers with other solid state systems: superconducting qubits and photons.*

INTRODUCTION: NV centers in diamond

NV CENTERS IN DIAMOND



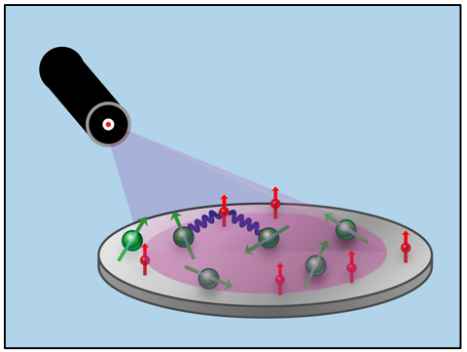


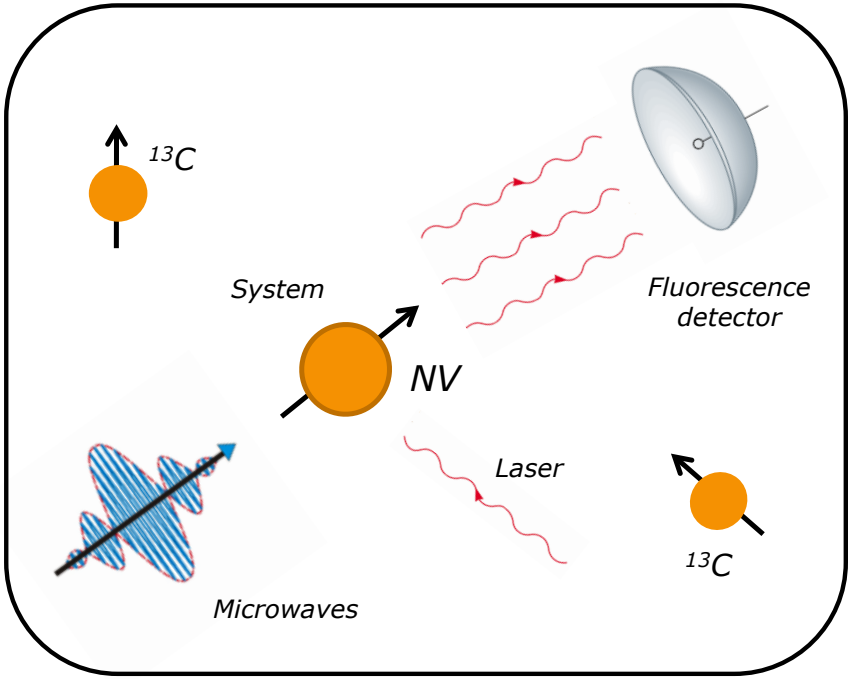


NV center

System	Spin	Natural Abundance
NV Centers	1	-------
^{12}C	0	99%
^{13}C	1/2	1%

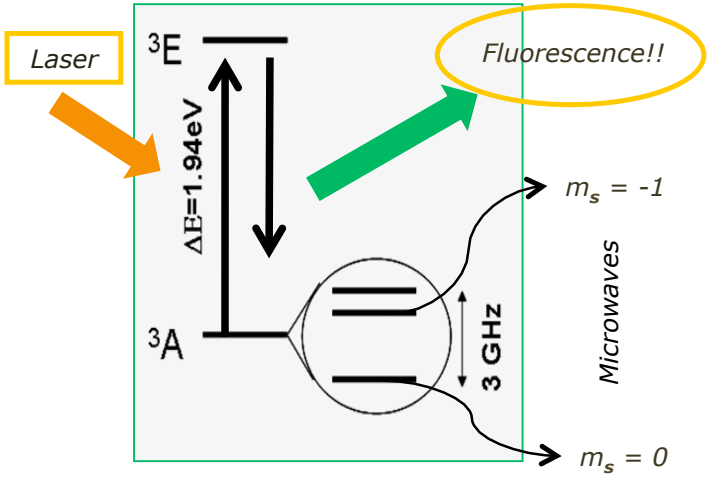
OPTICAL CONTROL OF SPIN AT ROOM TEMPERATURE





Experimental set up to control spin

Electronic structure NV center



Entanglement: two nv centers

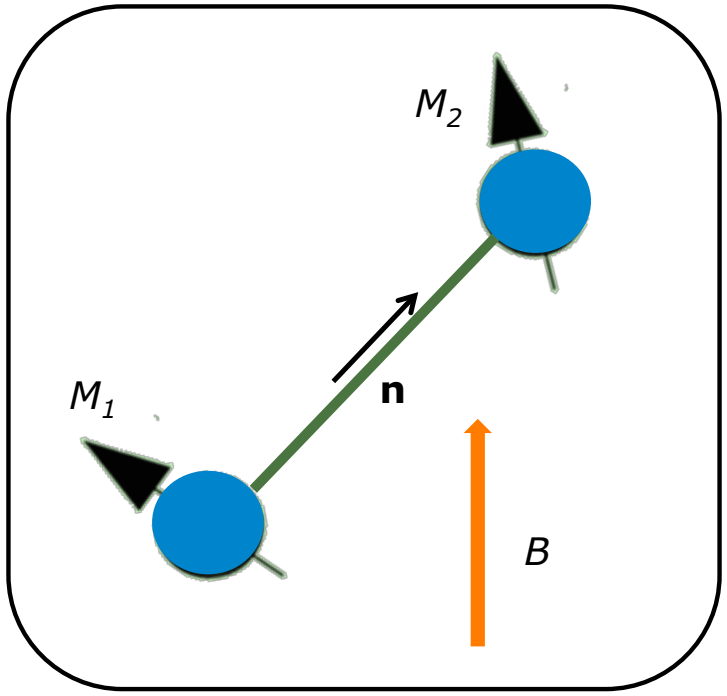
THE SYSTEM: IDEAL CASE

The Hamiltonian of the system is:

$$\hat{H} = \hat{H}_z + \hat{H}_{dd}$$

$$\hat{H}_z = \omega_0 \sum_{k=1}^{2} \hat{S}_k^z$$

$$\hat{H}_{dd} = \frac{\mu_0 \gamma_1 \gamma_2}{4\pi r^3} (\hat{S}_1 \cdot \hat{S}_2 - 3(\hat{S}_1 \cdot \mathbf{n})(\hat{S}_2 \cdot \mathbf{n}))$$



We consider that the NV centers aren't embedded in a ^{13}C bath.

How change the entanglement between the centers with the magnetic field and dipolar interaction?

CORRELATION MEASURE:

Remember that:

$$\hat{H} = \omega_0 \sum_{k=1}^{2} \hat{S}_k^z + \frac{\mu_0 \gamma_1 \gamma_2}{4\pi r^3}(\hat{S}_1 \cdot \hat{S}_2 - 3(\hat{S}_1 \cdot \hat{n})(\hat{S}_2 \cdot \hat{n}))$$

$$\hat{n} = \sin\theta\cos\phi\hat{x} + \sin\theta\sin\phi\hat{y} + \cos\theta\hat{z}$$

Parameters of interes

$$\beta = \frac{\omega_0}{k_B T}$$

Magnetic Field

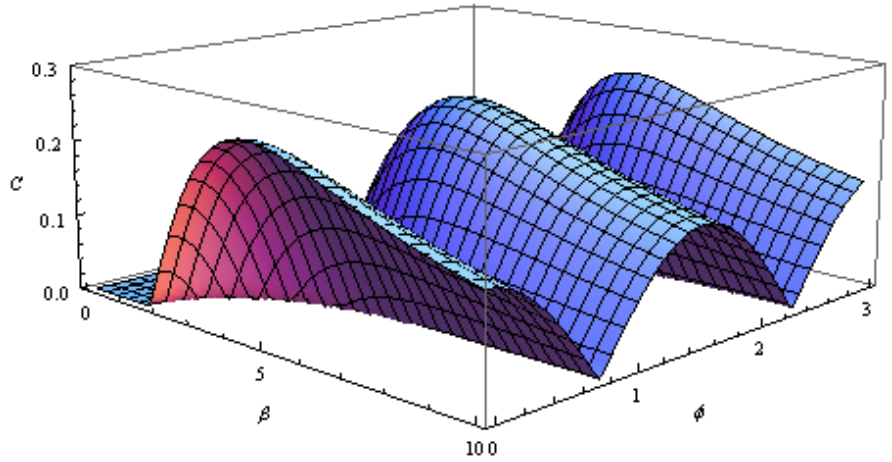
$$d = \frac{\gamma^2}{r^3 k_B T}$$

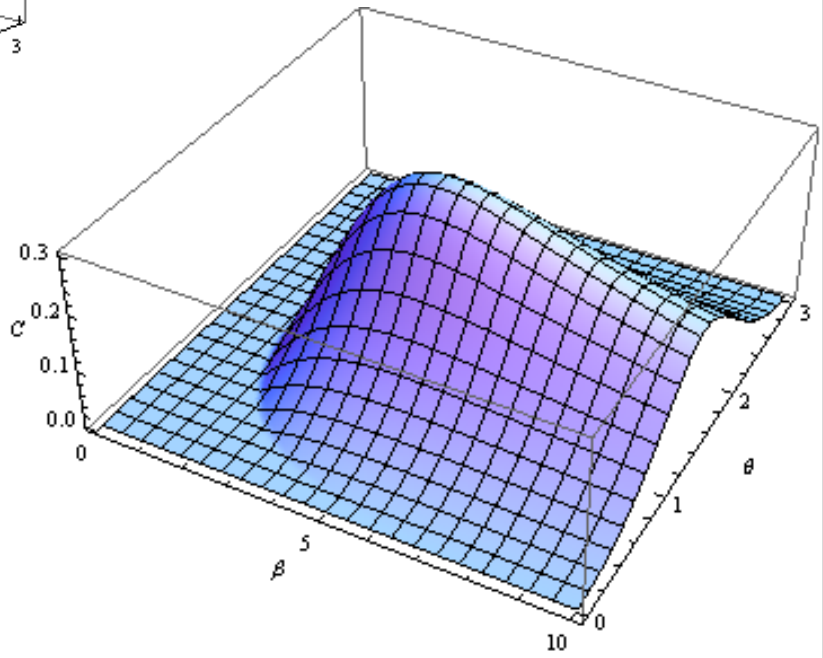
Distance

$\theta \quad , \quad \phi$

Angles

MAXIMUM VALUES OF CONCURRENCE

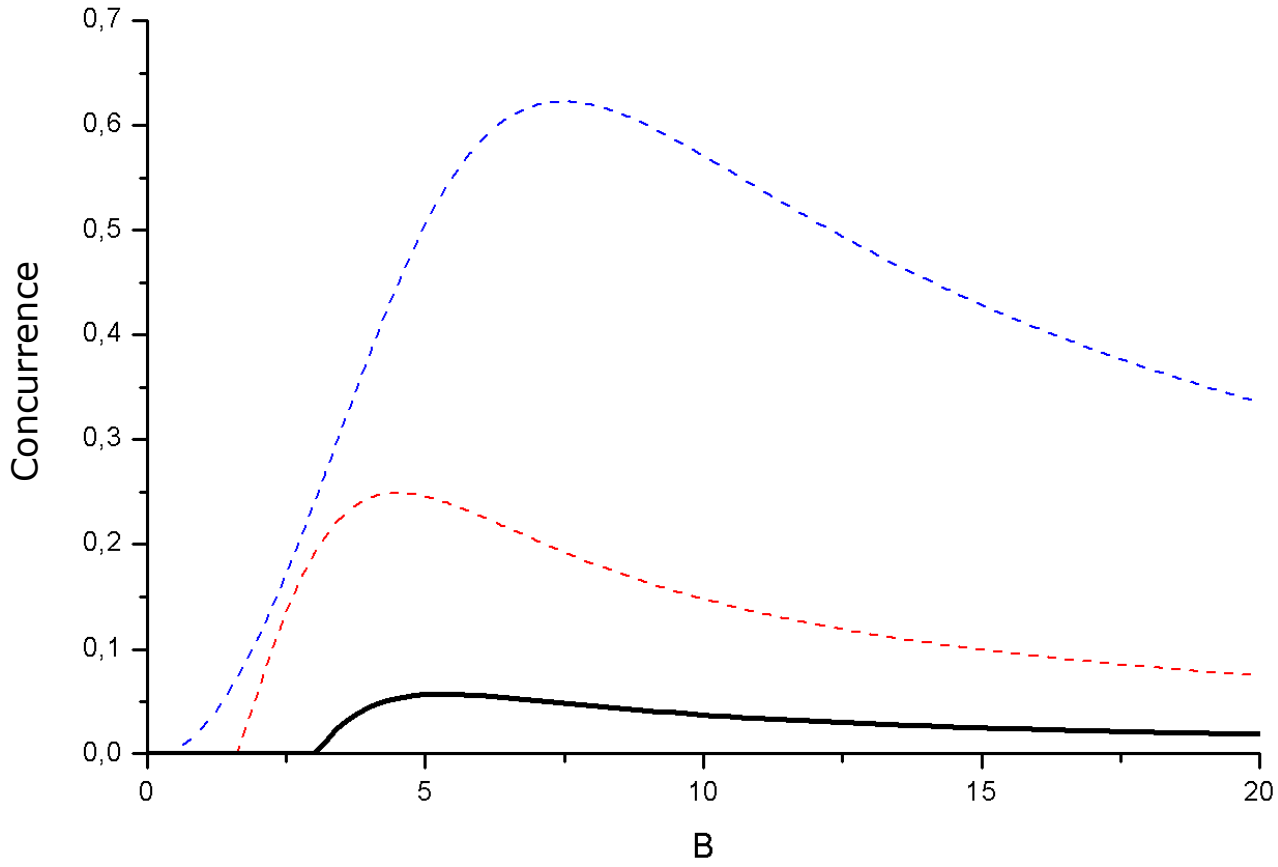




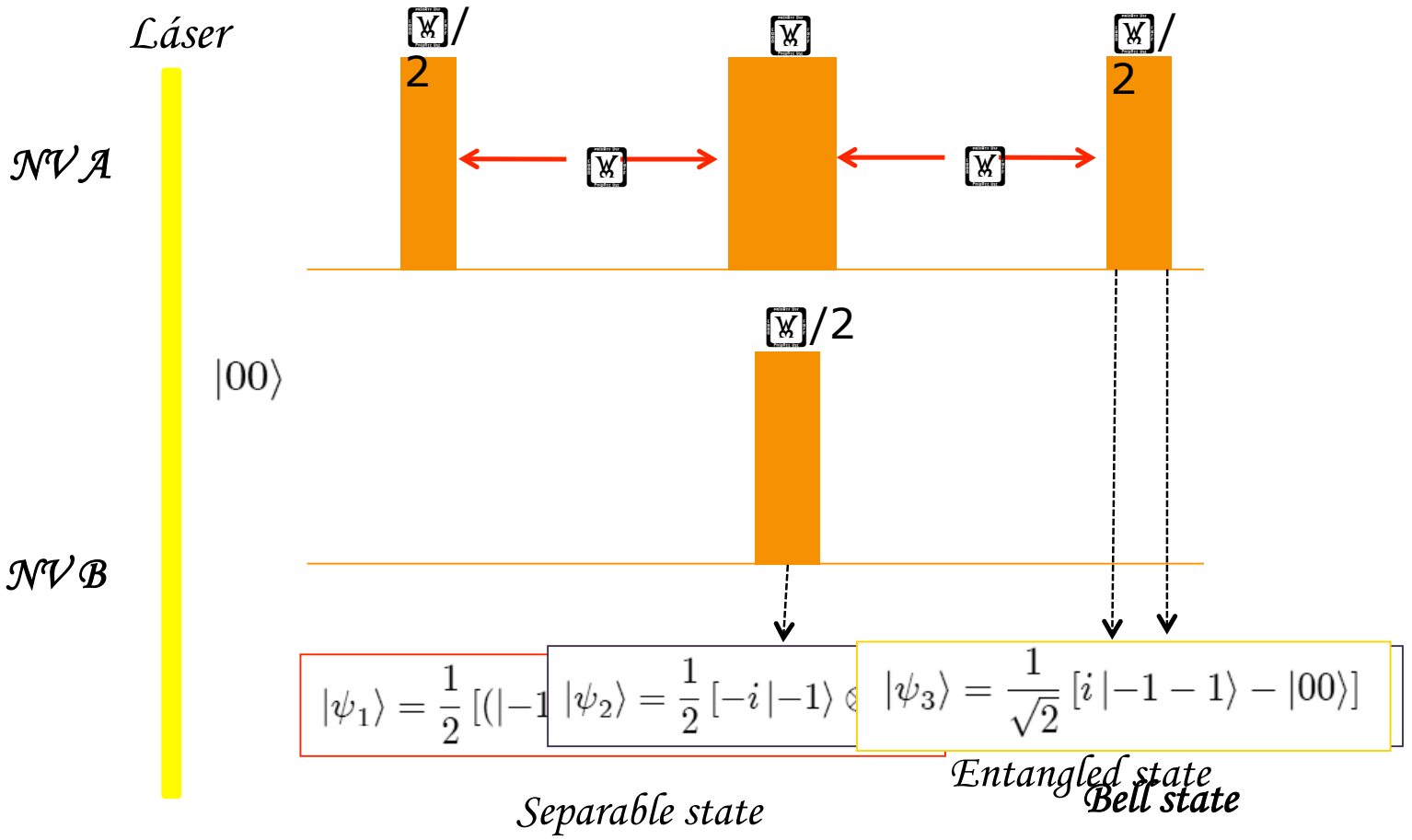
The maximum values of concurrence are for ϕ=0 θ=π/2

d=10

CONCURRENCE VS. MAGNETIC FIELD AND DIPOLAR INTERACTION



Entanglement Generation



PROBABILITY….

Initial state of the system

$$|\psi(0)\rangle = |00'\rangle$$

State of the system after sequency

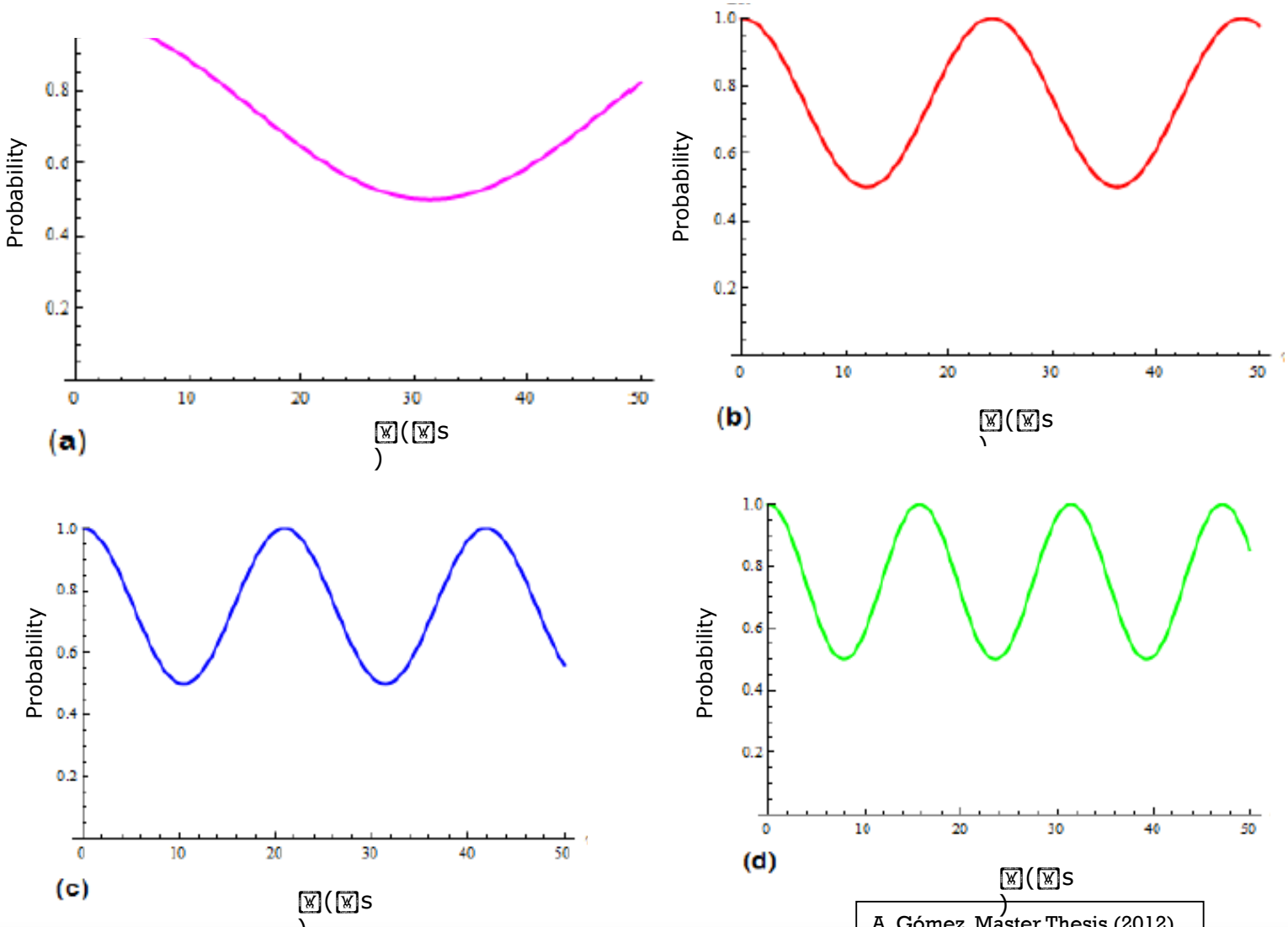
$$\psi(\tau) = R^{(A)}_{\pi/2} U(\tau) R^{(B)}_{\pi/2} R^{(A)}_{\pi} U(\tau) R^{(A)}_{\pi/2} |00'\rangle$$

The probability of recover the state is

$$P(\tau) = |\langle 00'| |\psi(\tau)\rangle|^2 + |\langle 0 - 1'| |\psi(\tau)\rangle|^2$$

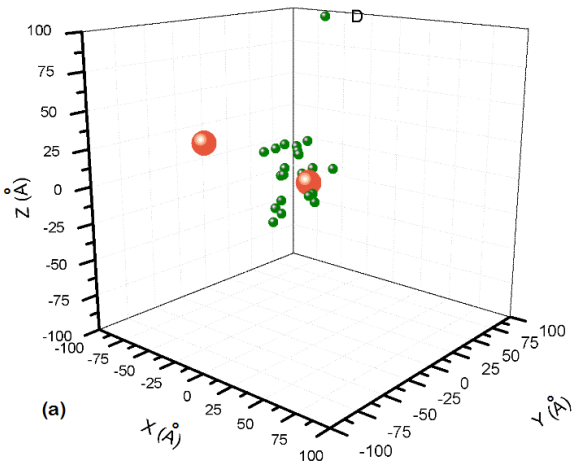
The fluorescence intensity is

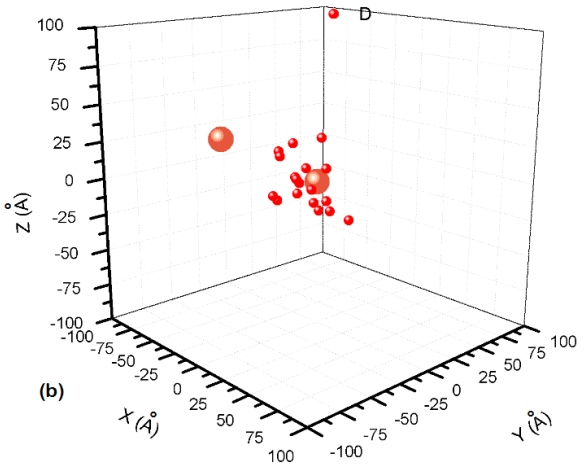
$$P(\tau) = \frac{1}{2} + \frac{1}{2}\cos^2\left[\left(\frac{\xi'' - \xi'}{2}\right)\tau\right]$$

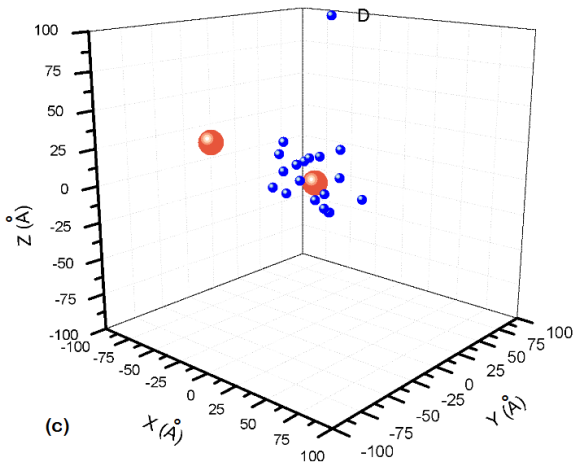


A. Gómez. Master Thesis (2012).

TWO NV CENTERS IN A BATH OF ^{13}C



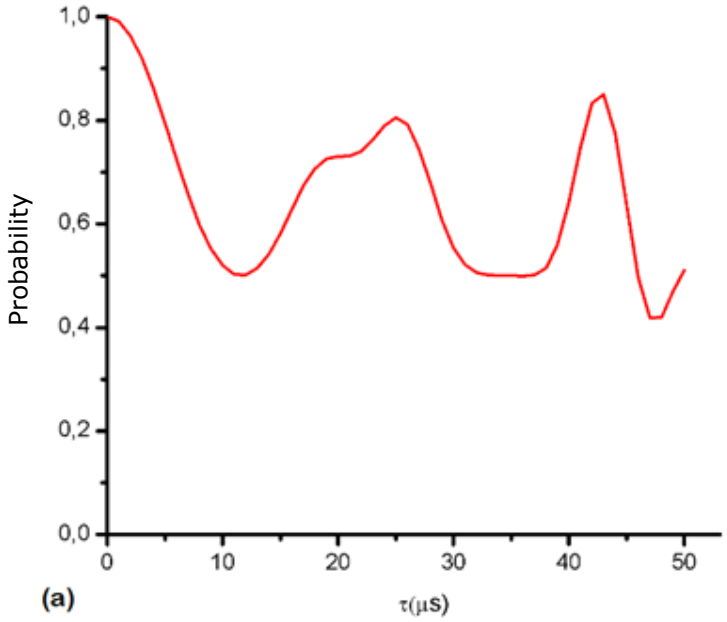




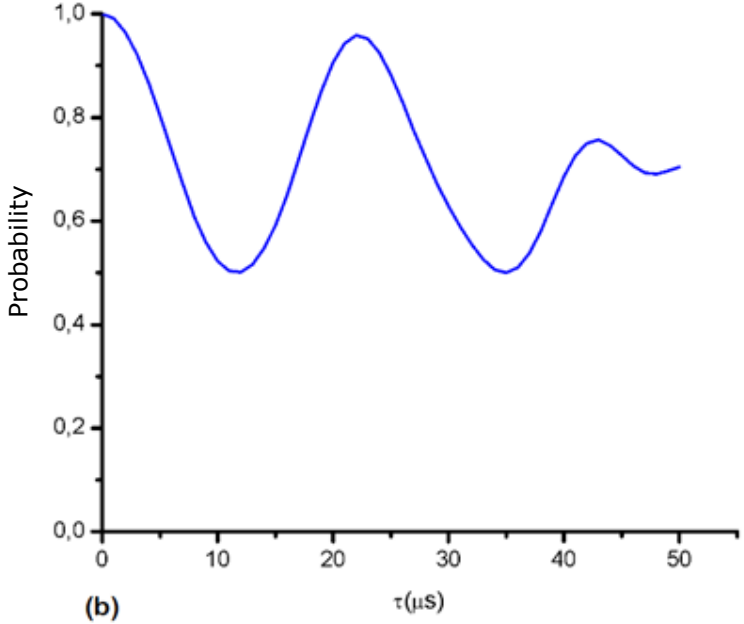
Conditions of the program

Lattice: 70 A°

^{12}C :66000
^{13}C :700

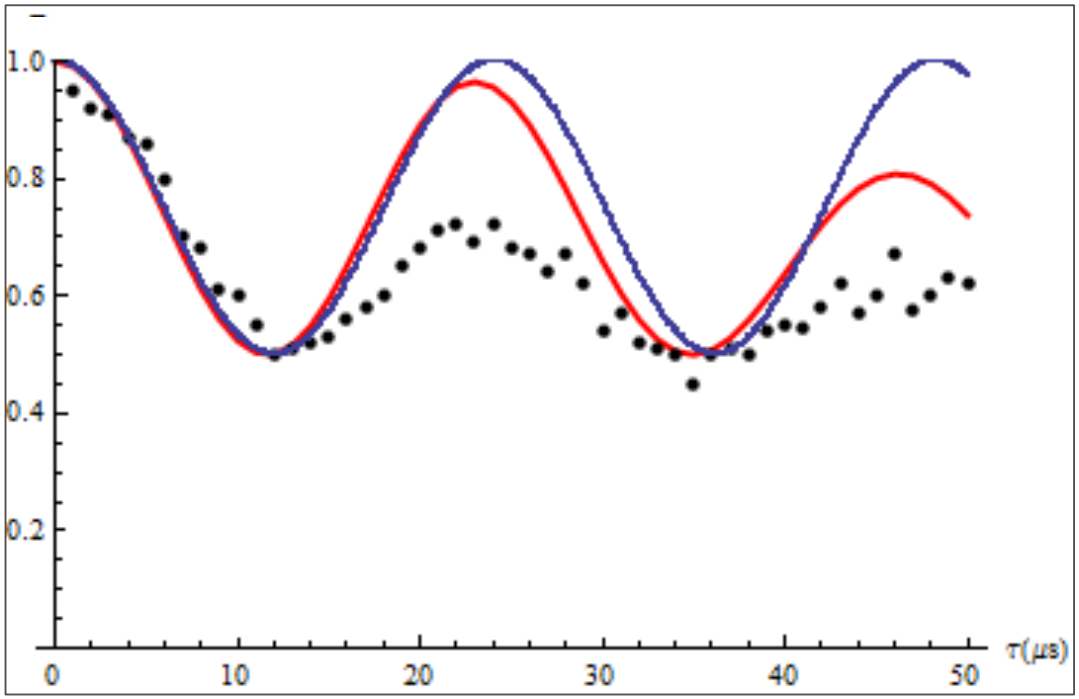

Probability
1,0
0,8
0,6
0,4
0,2
0,0
0
10
20
30
40
50
τ(μs)
(a)

$60\ ^{13}C$


Probability
1,0
0,8
0,6
0,4
0,2
0,0
0
10
20
30
40
50
τ(μs)
(b)

$40\ ^{13}C$

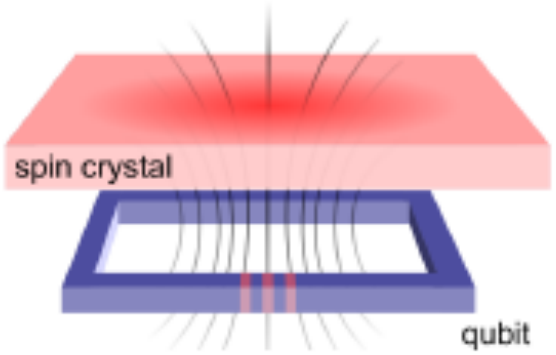
Theorical results vs. Experimental results



P. Neumann, et al., Phys. Nat. Phys. **6,**249(2010).

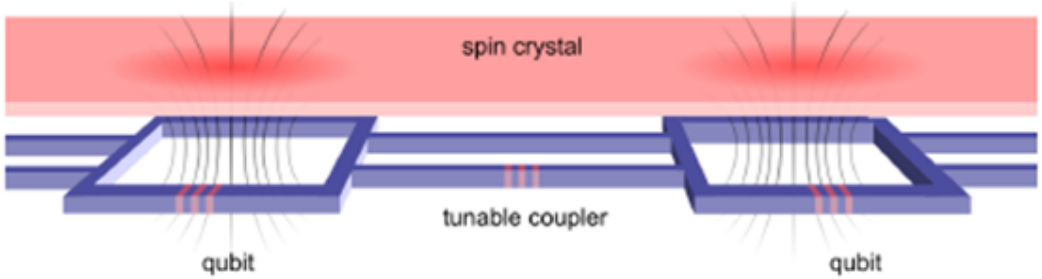
HYBRID QUANTUM SYSTEMS

MOTIVATION:FLUX QUBIT AND SPIN SYSTEMS



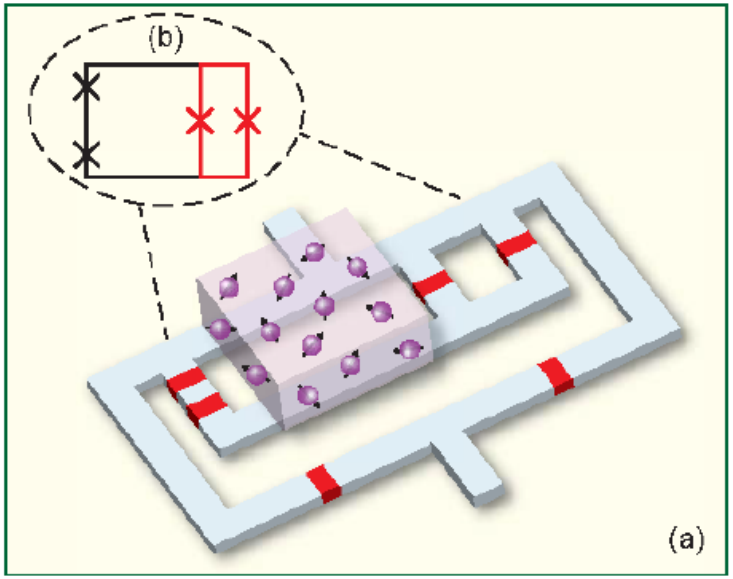
System:

A superconducting flux qubit coupled to an ensemble of NV centers in diamond



T. Hummer, et al., Phys. Rev. Lett. **108,**043604(2012).

OBJECTIVE:



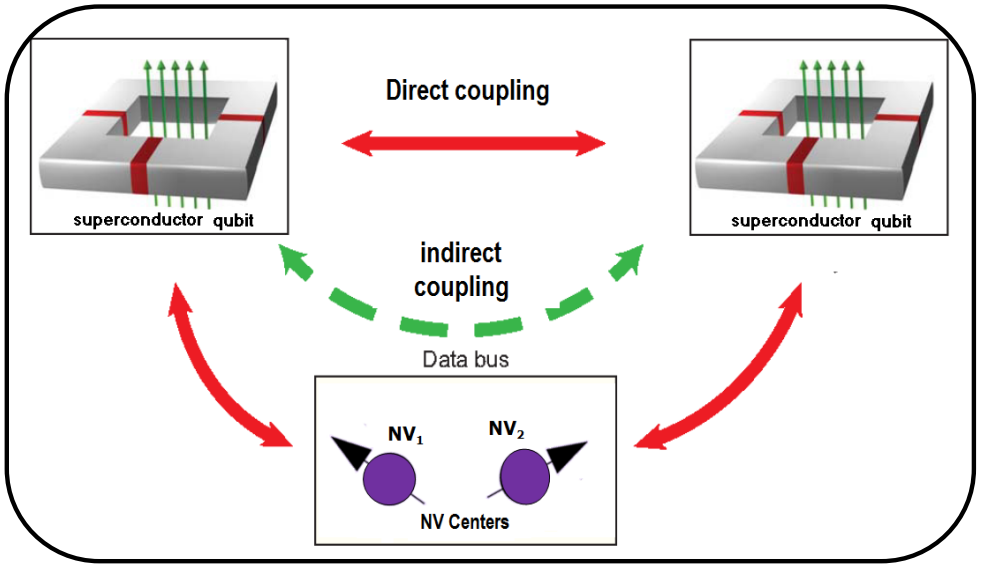
Z. Xiang et al., arxiv :1204.2137 v2 quant-ph. (2012).

To combine the NV centers with other systems with the objective of increase the interaction between them.

THE SYSTEM: SQUIDS AND NV CENTERS

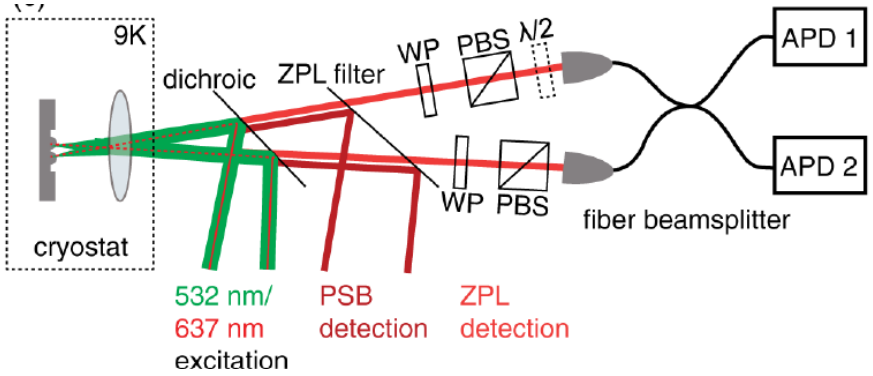
Objective:

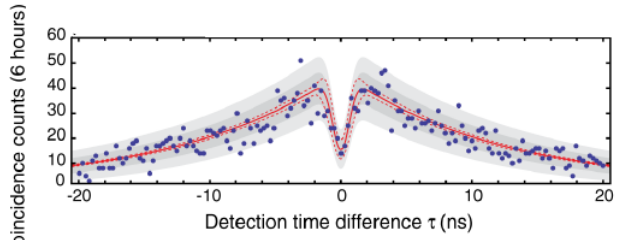
Increase the interaction of two NV centers trough of two squids and find a Hamiltonian that only depend on the NV centers operators.

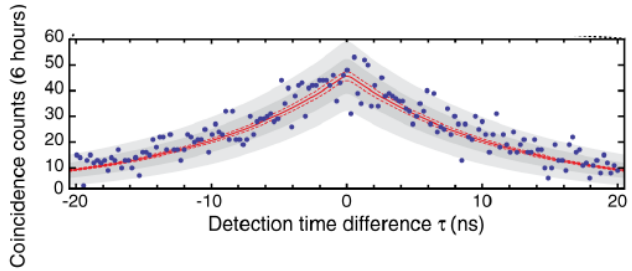


Distance between centers approximatly [illegible] m

THE SYSTEM: PHOTONS AND NV CENTERS





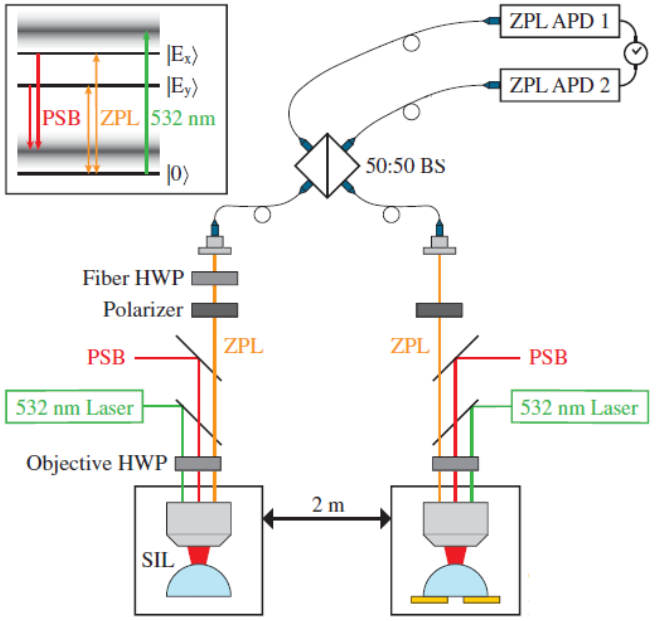


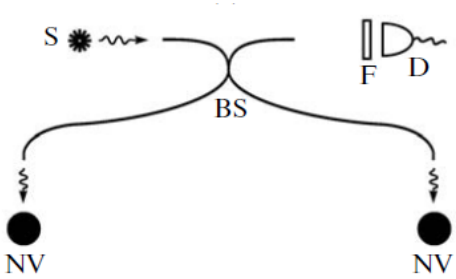
H. Bernien, et al., Phys. Rev. Lett. **108,**043604(2012).

MORE ABOUT PHOTONS

In this work is shown interference between two photons emited by two NV separated 2 meters

A. Sipahigil, et al., Phys. Rev. Lett. **108**,143601(2012).





A. Bukach et al., Optics and Spectroscopy.**108,**254(2010).

Objective:
entangle two NV centers using photons.

CONCLUSIONS

1. We show that at room temperatura two NV centers aren't entangled only due to dipolar interaction, then we show that is neccesary to apply a sequency of microwave pulses.

2. We show that the concurrence increase for larger magnetic fields and dipolar interaction.

3. We show that the probability of recover the initial state in the case of two isolated NV centers has an oscillatoy behavior.

4. We show that the effect of the ^{13}C bath in the system of two NV centers is to decrease the probability of recover the initial state of the system.