Surface Enhanced Quantum Control:
State Preparation and Purification

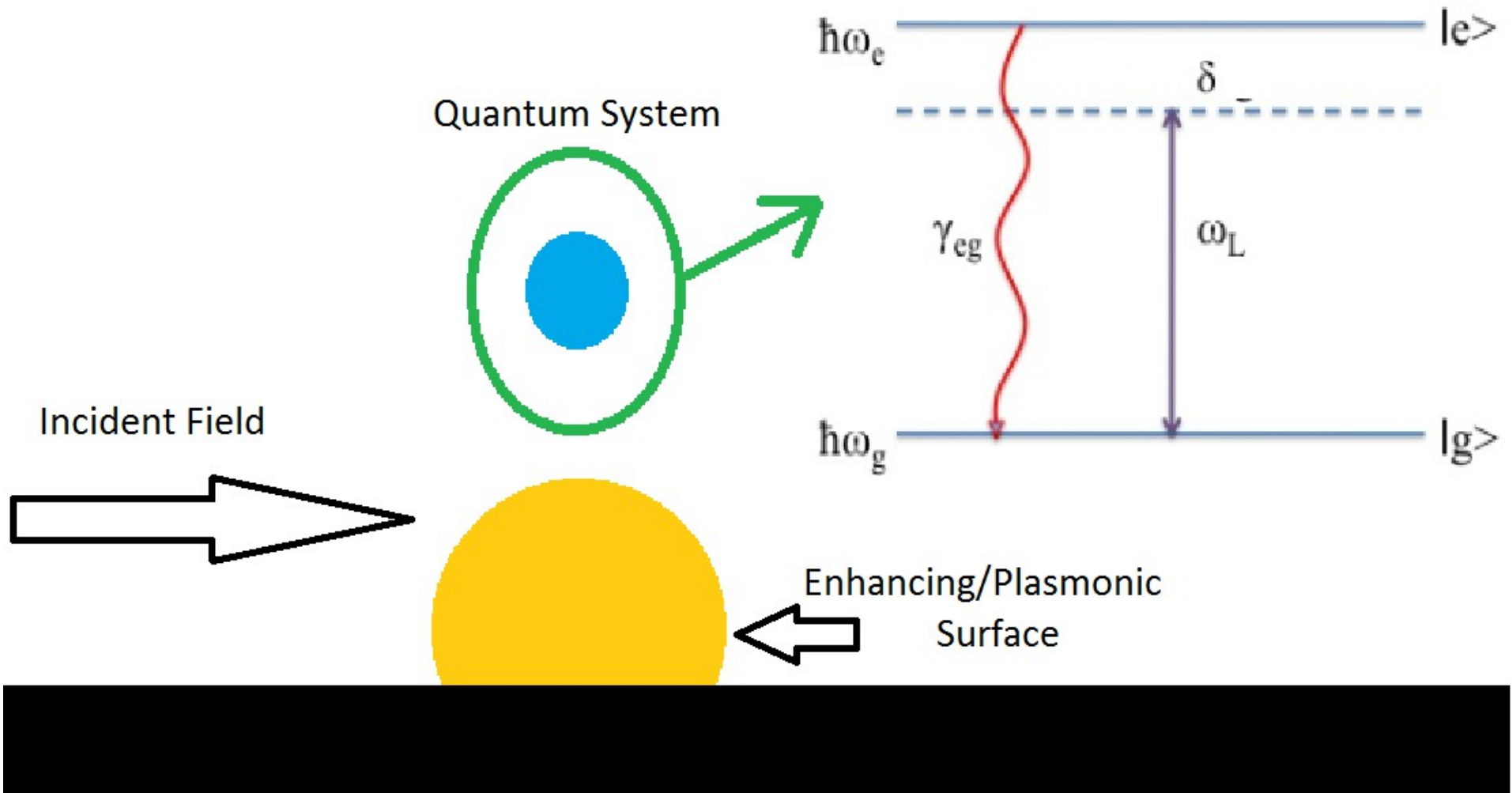Christopher DiLoreto, Somayeh Mirzaee*, Chitra Rangan

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Outline

- What is surface-enhanced quantum control (SEQC)?

- How surface enhancement can be used to enhance qubit preparation and purification?

- Future extensions of this research
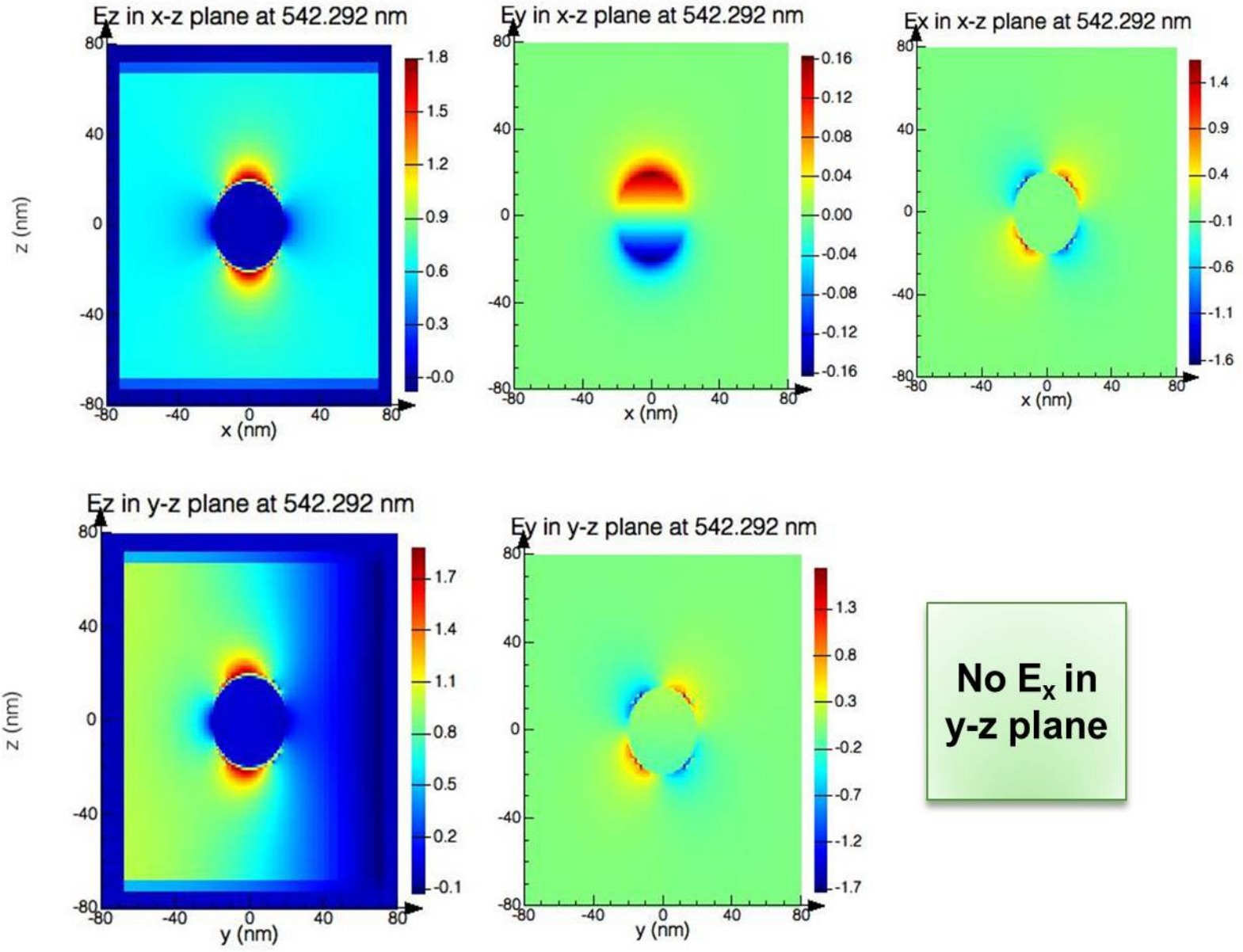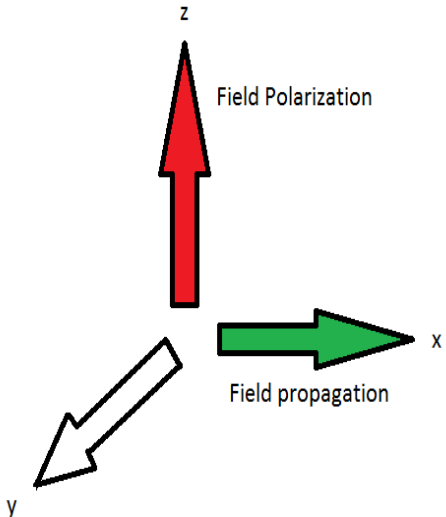
Surface-Enhanced System

Plasmonic Nanostructures

- Incident field causes a collective oscillation in metals on the enhancing surface that have a resonance wavelength
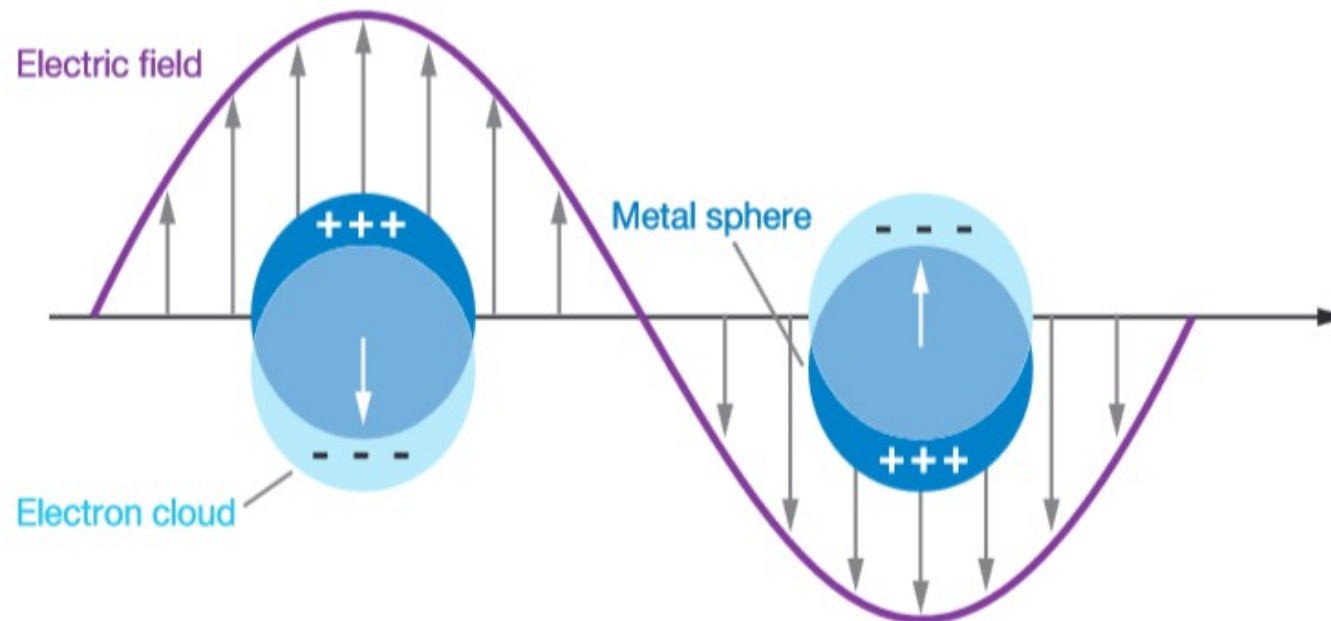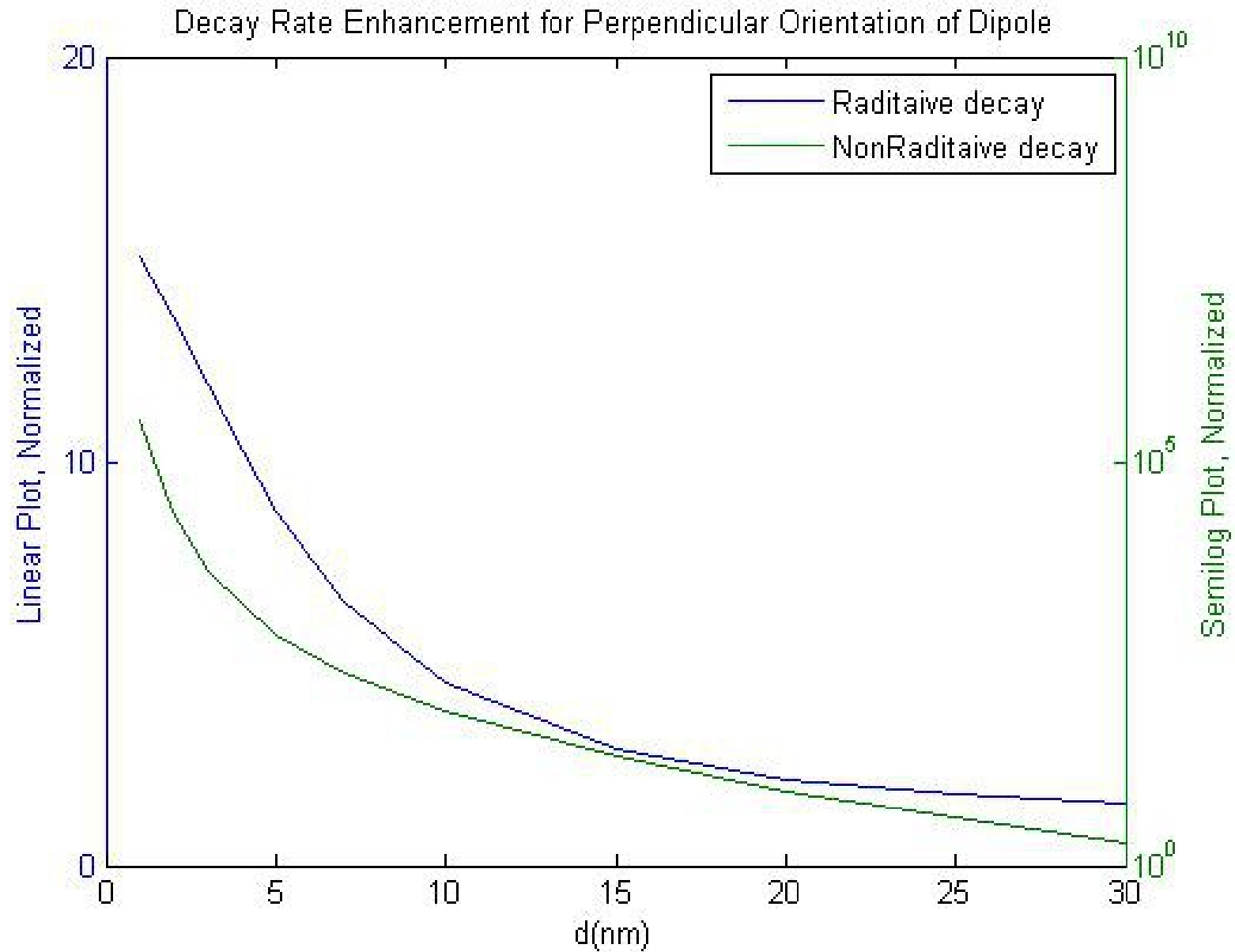

Willets, K. A., & Van Duyne, R. P. Annual Review of Physical Chemistry, 58, 267-297 (2007)

Electric Field Modification

Decay Rate Modification

Decay Rate Enhancement for Perpendicular Orientation of Dipole

Effect of Surface Enhancement

- Enhances local electromagnetic fields

- Enhances decay rate

- Promising combination of high driving frequencies with high decay

Qubit preparation and purification

- How can surface enhancement affect the preparation of a qubit in a desired steady-state

- How can surface enhancement affect the purification of a particular state

- 2 level system

Two-Level System
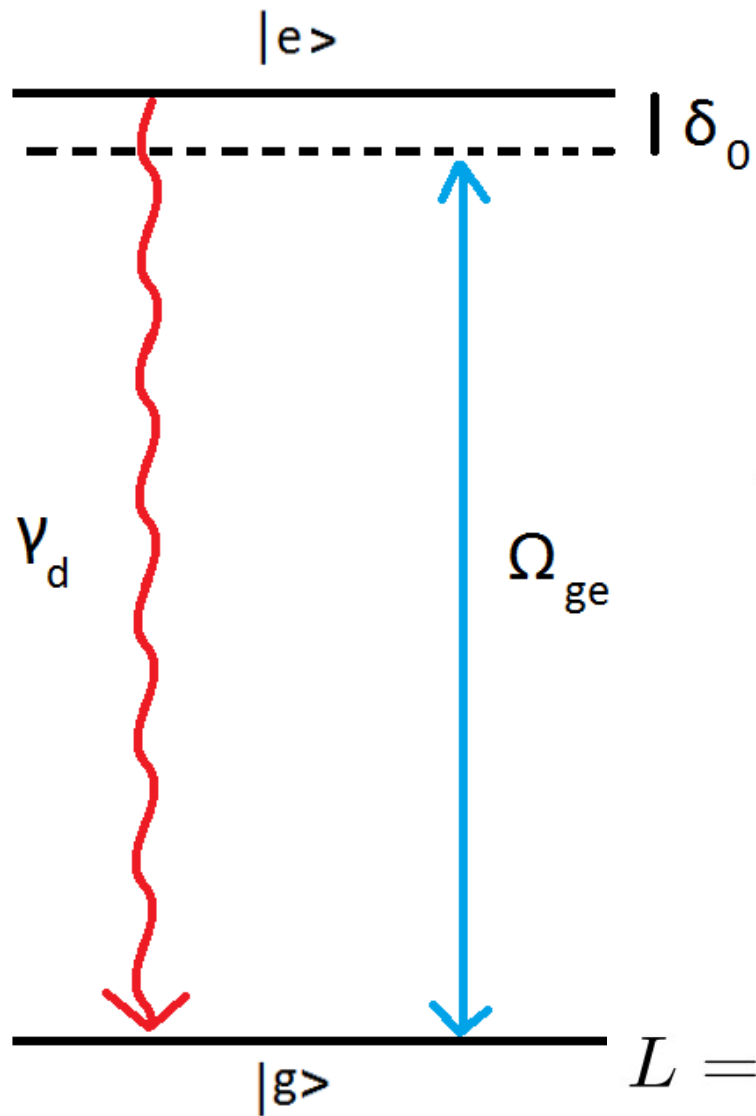
$$\rho = \begin{pmatrix} \rho_{gg} & \rho_{ge} \\ \rho_{eg} & \rho_{ee} \end{pmatrix}$$

$$H_{RWA} = \begin{pmatrix} 0 & -\frac{\hbar\Omega_{ge}}{2} \\ -\frac{\hbar\Omega_{ge}^*}{2} & -\hbar\delta_0 \end{pmatrix}$$

$$\dot{\rho} = -\frac{i}{\hbar}[H_{RWA}, \rho] - L$$

$$L = \sum_d \frac{M_d\gamma_d}{2}(\sigma_d^\dagger\sigma_d\rho + \rho\sigma_d^\dagger\sigma_d - 2\sigma_d\rho\sigma_d^\dagger)$$

Qubit preparation

- Simulated a two-level system with $\Delta E = 2.38$ eV at various distances around a single gold nanoparticle

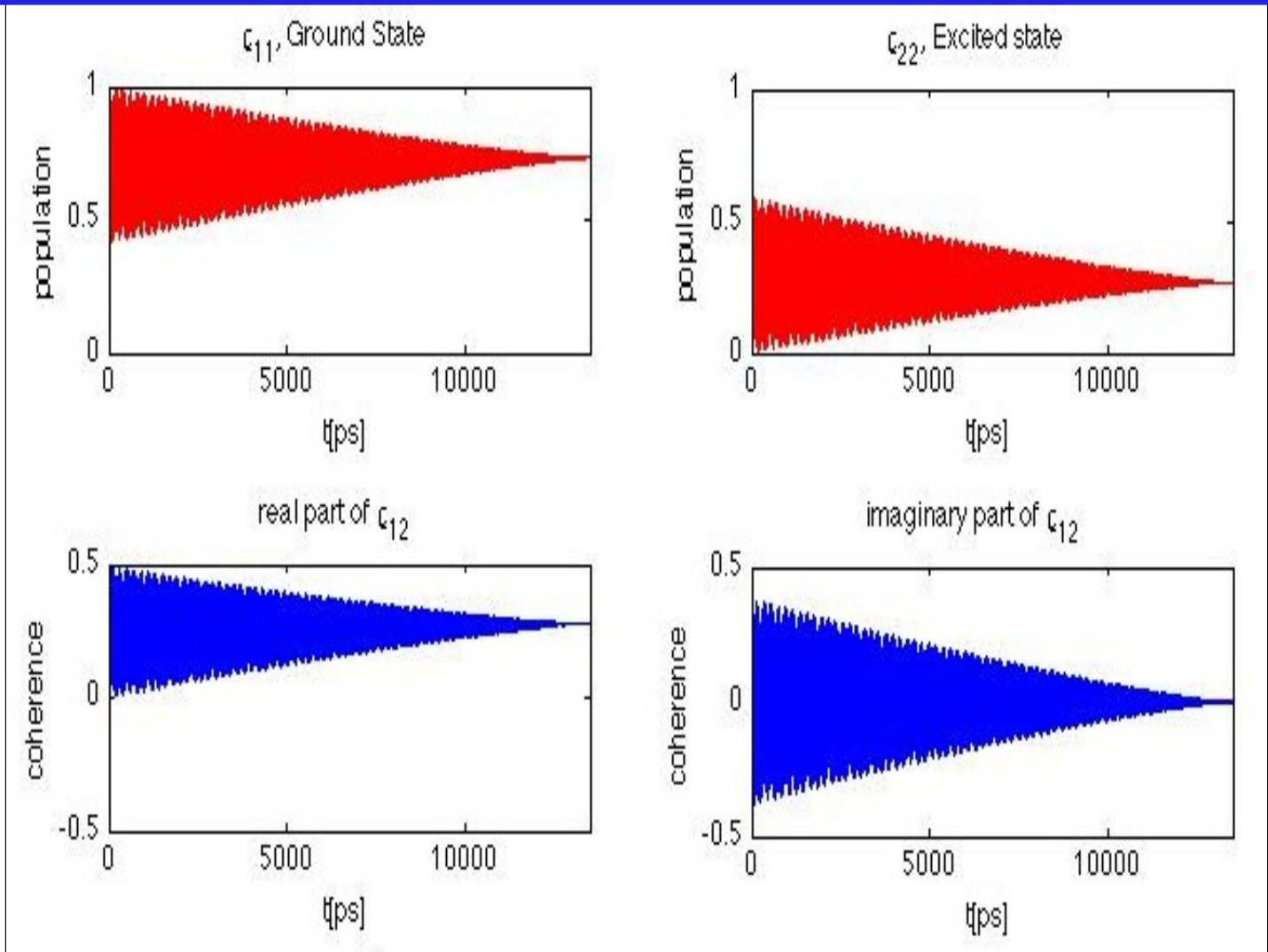- Prepare qubit in a desired target density matrix:

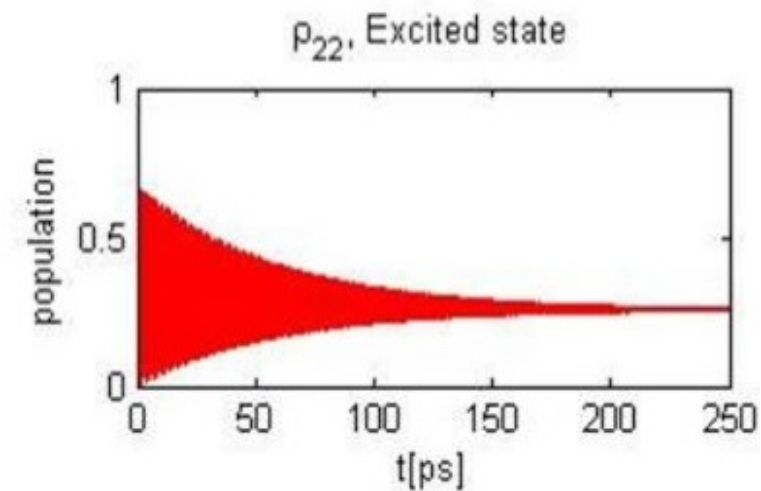$$\rho_i = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \qquad \rho_t = \begin{pmatrix} \frac{3}{4} & \frac{\sqrt{3}}{4} \\ \frac{\sqrt{3}}{4} & \frac{1}{4} \end{pmatrix}$$

- Optimal purification rate

Without Surface Enhancement

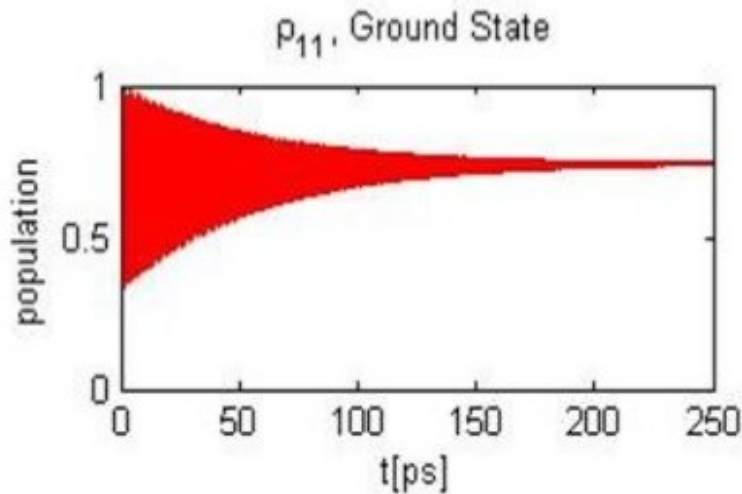$$\rho_i = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$$

$$\rho_t = \begin{pmatrix} \dfrac{3}{4} & \dfrac{\sqrt{3}}{4} \\ \dfrac{\sqrt{3}}{4} & \dfrac{1}{4} \end{pmatrix}$$
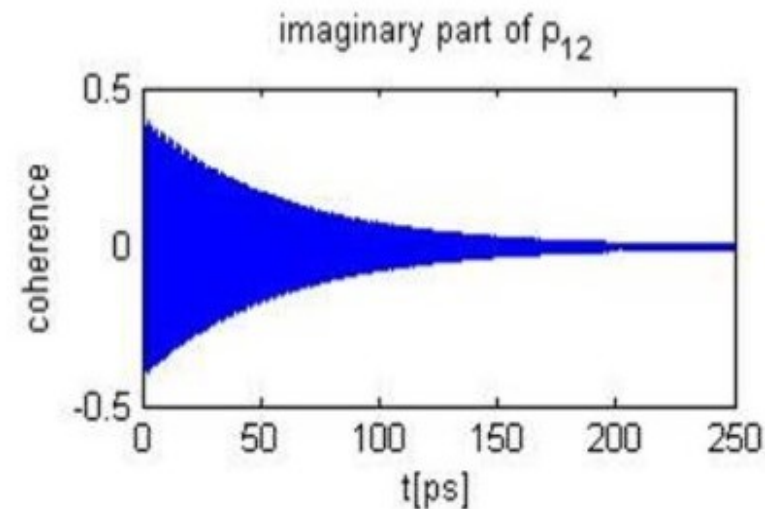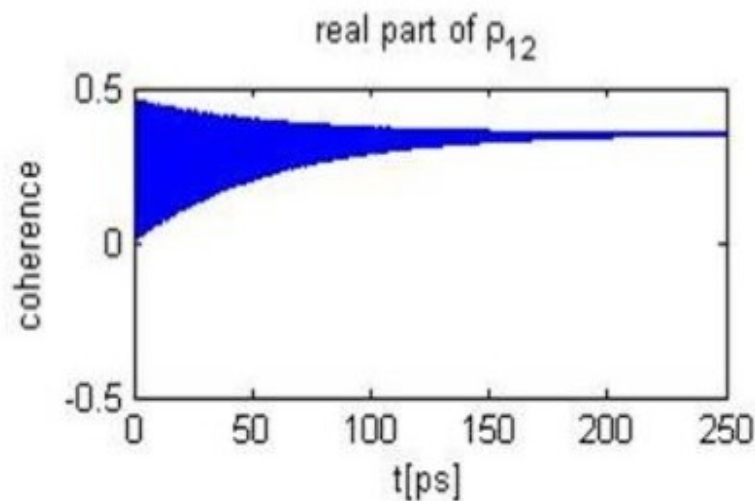

Without GNP
$E_L = 1.22e9$ V/m
$t_s \cong 140$ ns

With Surface Enhancement

$$\rho_i = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$$

$$\rho_t = \begin{pmatrix} \dfrac{3}{4} & \dfrac{\sqrt{3}}{4} \\ \dfrac{\sqrt{3}}{4} & \dfrac{1}{4} \end{pmatrix}$$

ρ_{11}, Ground State

ρ_{22}, Excited state

real part of ρ_{12}

imaginary part of ρ_{12}

d= 15nm $\hat{z}$
E_L = 5.1e8 V/m
$t_s \cong$ 250 ps

With Surface Enhancement

$$\rho_i = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$$

$$\rho_t = \begin{pmatrix} \dfrac{3}{4} & \dfrac{\sqrt{3}}{4} \\ \dfrac{\sqrt{3}}{4} & \dfrac{1}{4} \end{pmatrix}$$
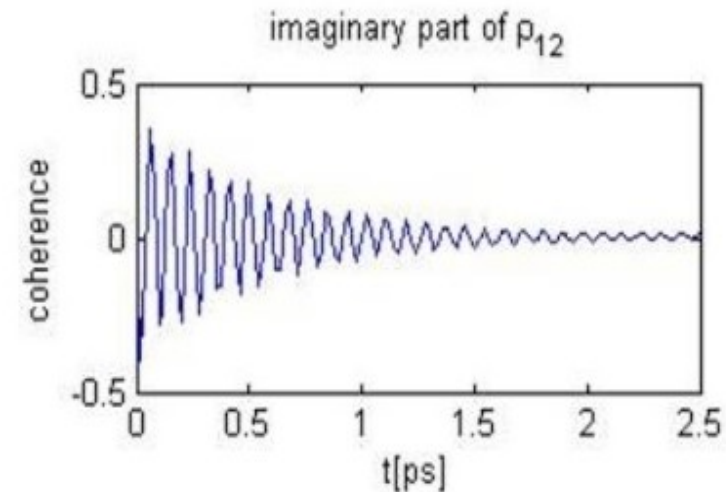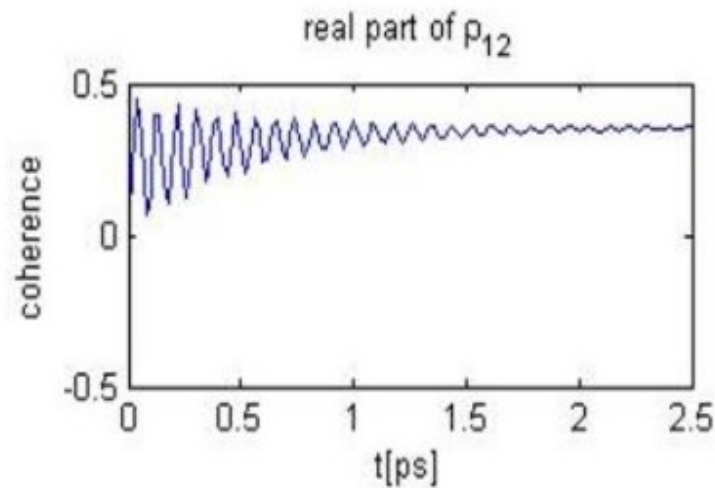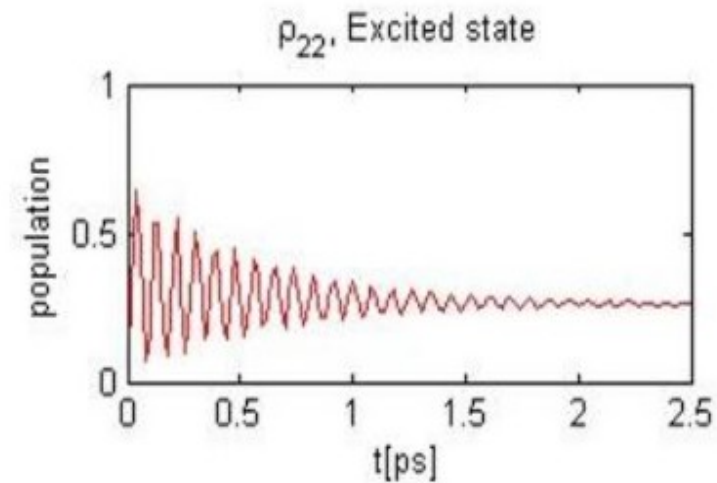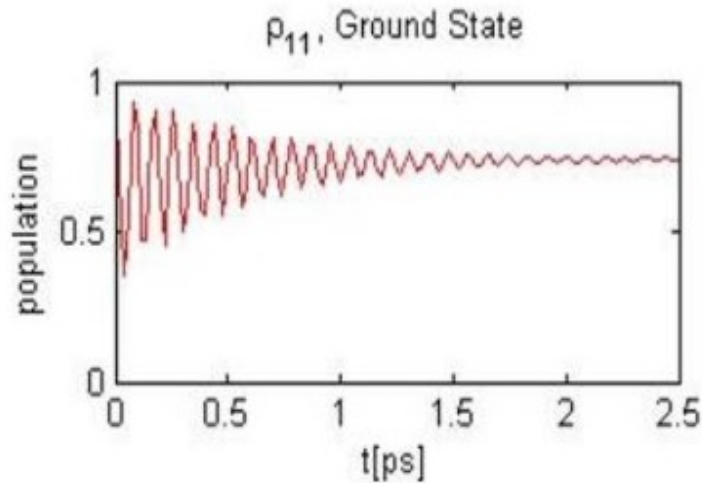
d= 5nm $\hat{z}$
E_L = 1.8e8 V/m
$t_s \cong 0.3$ ps

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Effect of Enhancement on Preparation

- The presence of a gold nanoparticle reduces the field intensity required to reach a desired steady state

- The presence of a gold nanoparticle reduces the time required to reach a desired steady state
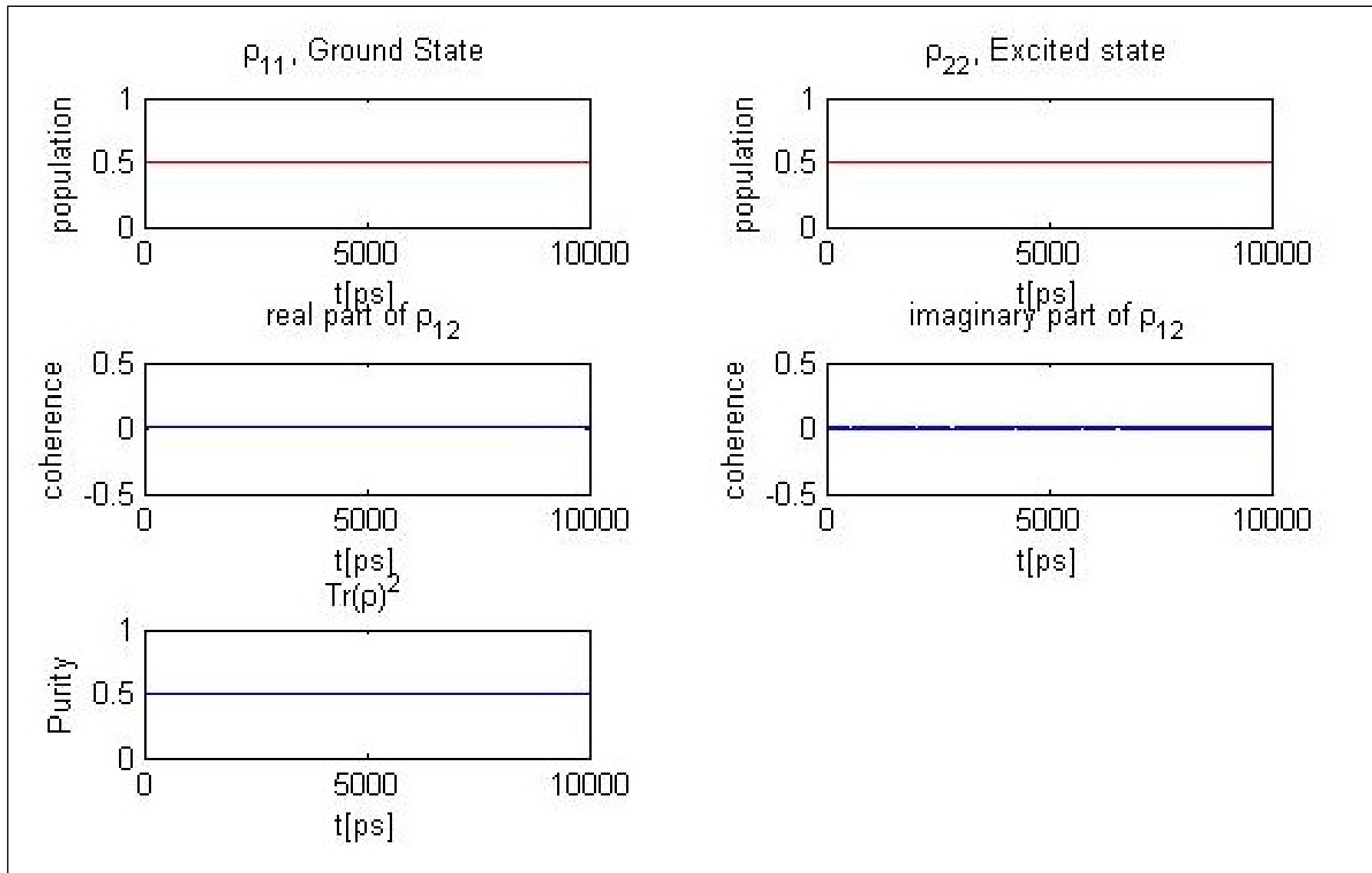
Qubit purification

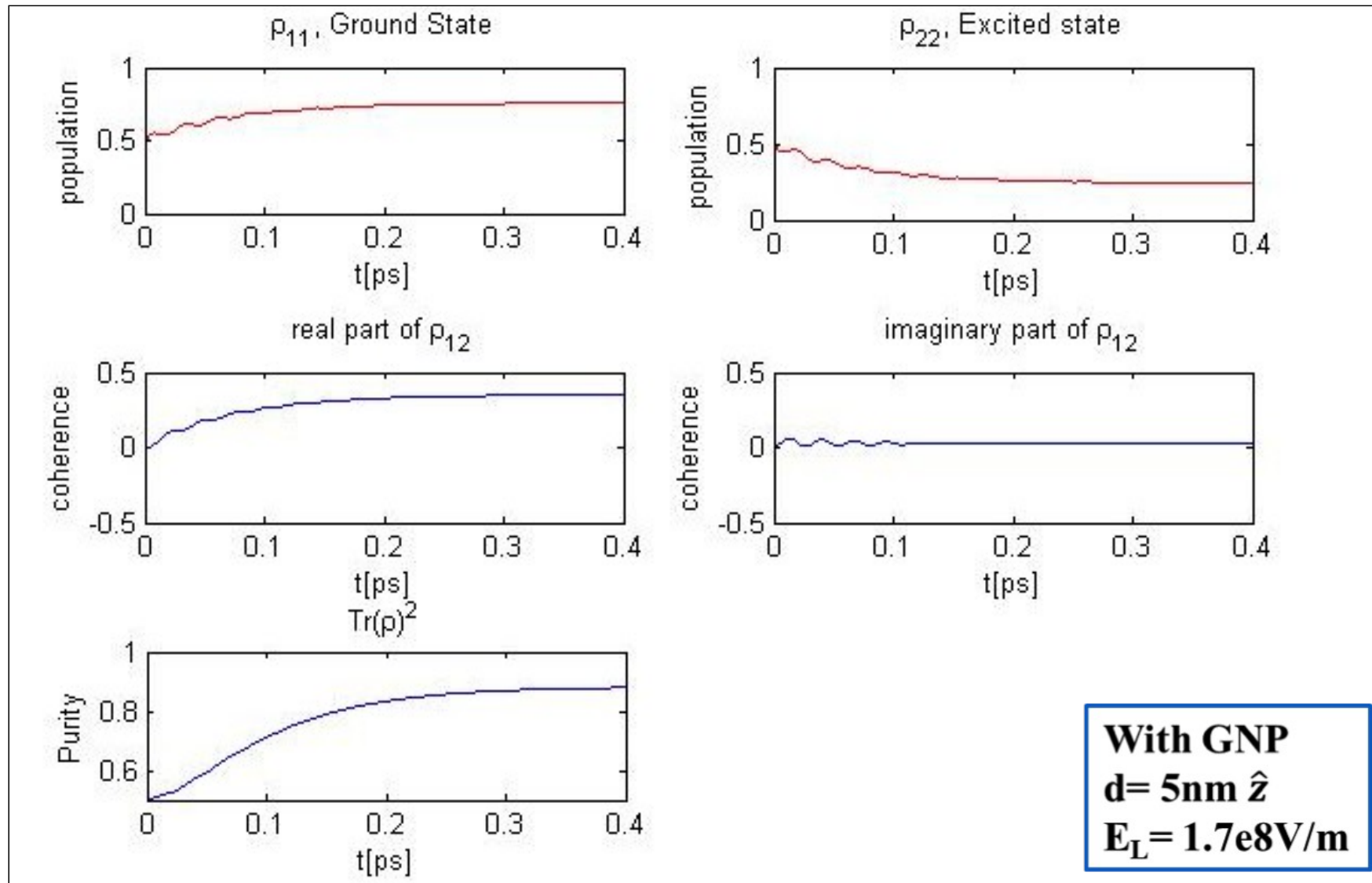- Effect of surface-enhancement on qubit purification

$$Purity = Tr(\rho^2)$$

- Qubit purification is not possible with only Hamiltonian controls

# State Purification from Mixed State: Hamiltonian Control

State Purification from Mixed State: Surface Enhanced Control

Effect of Enhancement on Purification

• Surface enhancement can greatly reduced the time and incident field intensity required to reach a desired quantum state

•Surface enhancement allows for the purification of mixed quantum states on a faster timescale (without spontaneous decay to the ground state)

Future Directions: Three-Level System
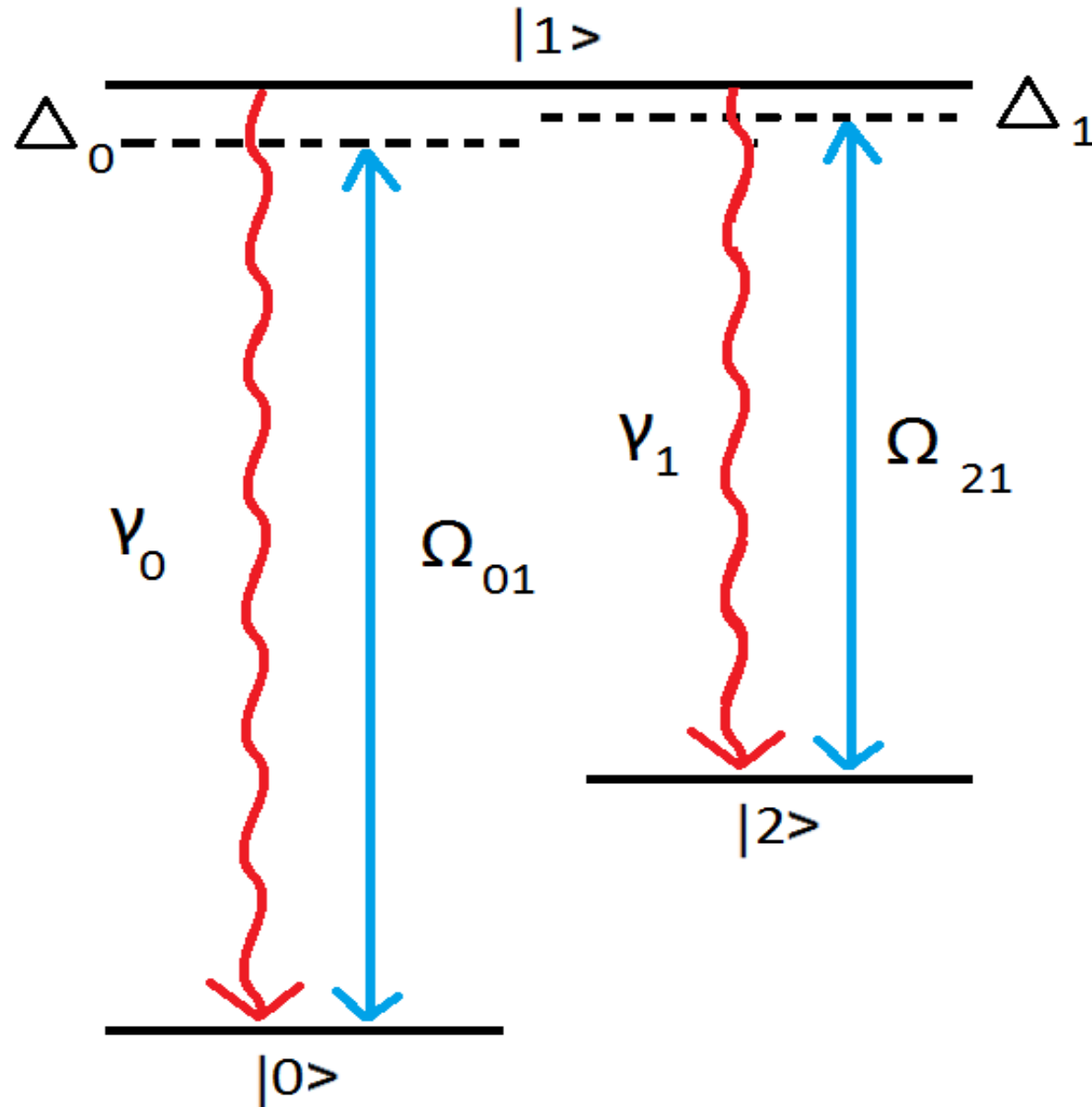
Intensity-Intensity Correlation Spectra

• Intensity-intensity correlation spectra in driven three-level fluorescent system

• How are these spectra affected by surface enhancement?

• Can we use these spectra to detect changes in the quantum system's environment?

Preliminary Results:
Intensity-Intensity Correlation Spectra
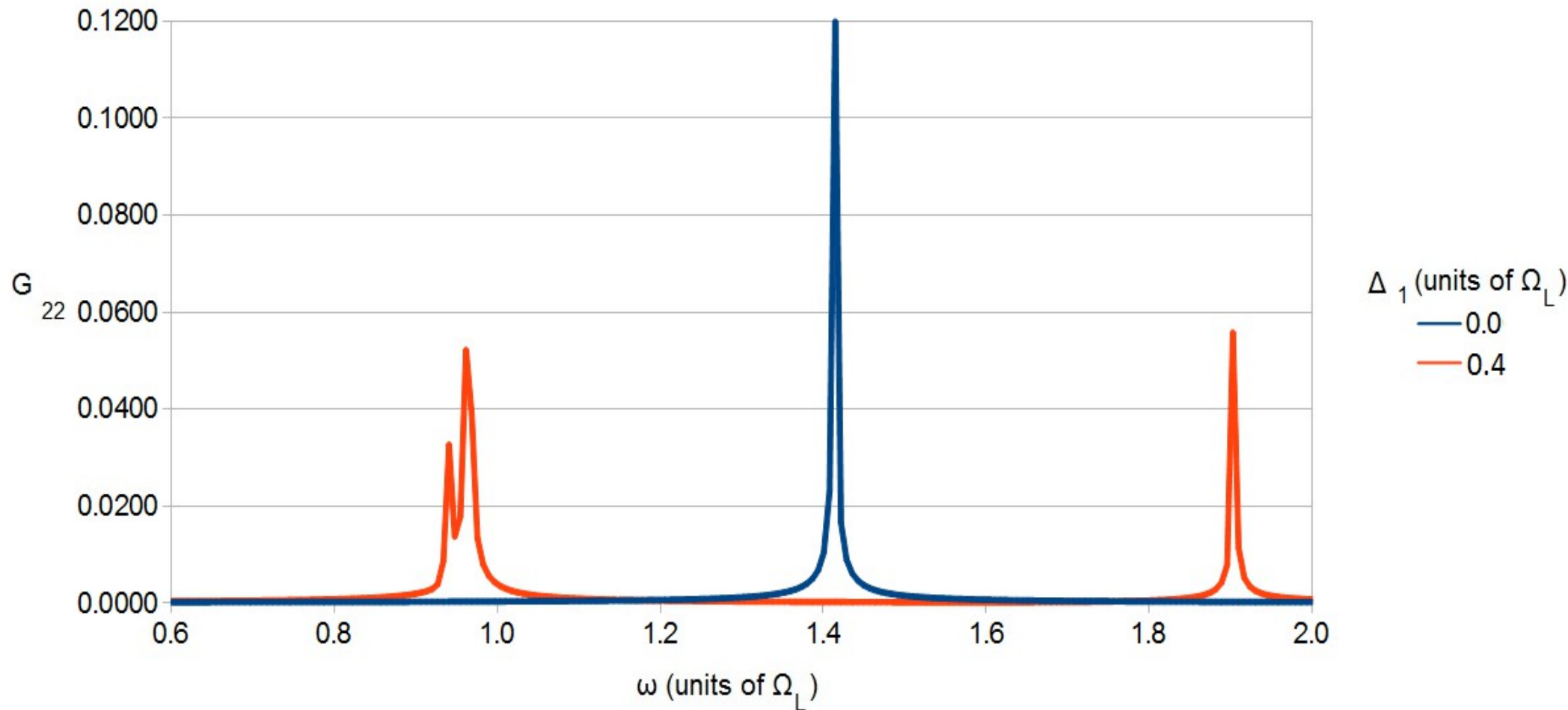
Acknowledgements

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Graduate Opportunities available
Contact rangan@uwindsor.ca