

QED of Surface Plasmons

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Outline

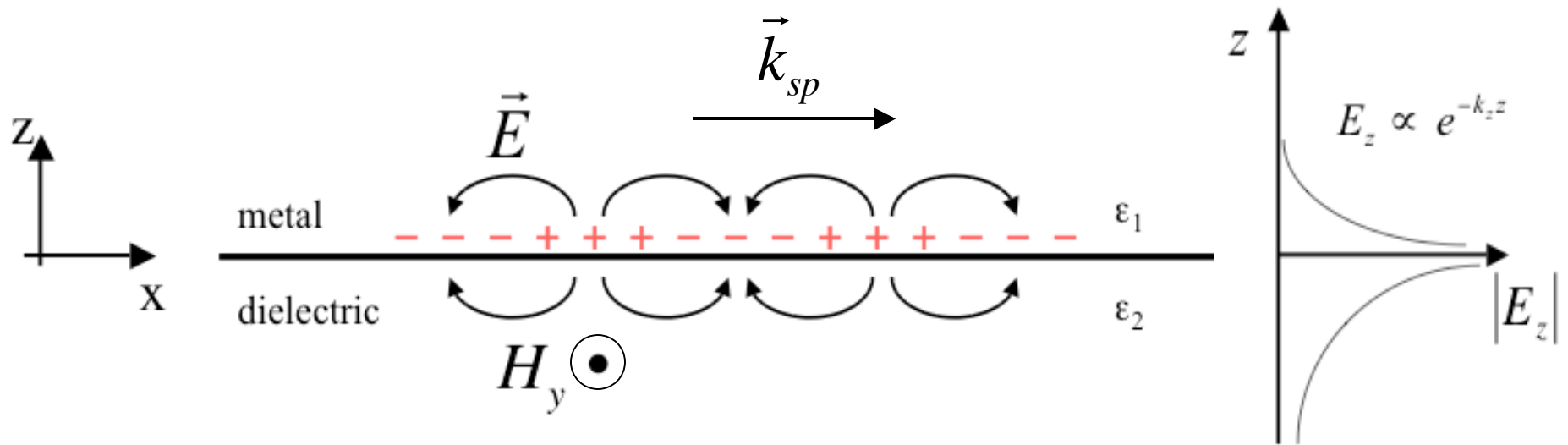
- Surface Plasmons (SP)
 - **Why and how?**
- Dipole radiation near a metal film
 - **The role of surface plasmons**
- Incident pulse onto a metal film
 - **Field quantization**
 - **Correlations of mixed state and bell state SP's**
- Summary



Why Surface Plasmons?

- Surface plasmons have many attractive properties
 - **Strong localized fields that promise to enhance non-linear optical effects**
 - **Sub-wavelength properties**
 - **Enhance coupling between light and matter**
- SP's rely on metals, a lossy and dispersive media
 - **Important to understand radiation characteristics near these surfaces**

What are surface plasmons?

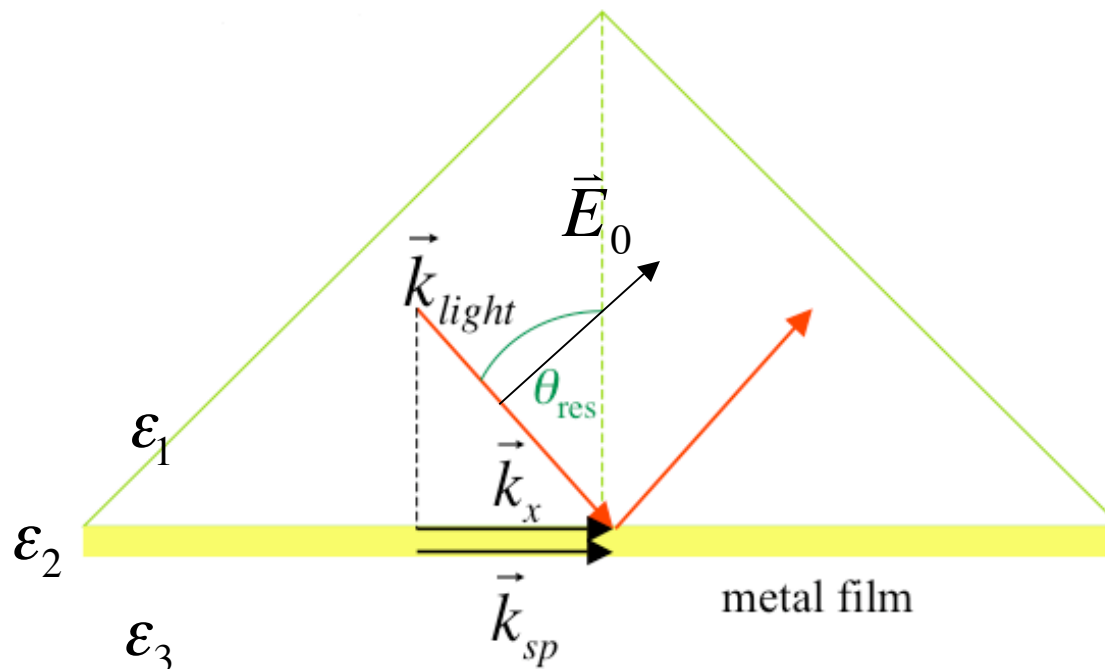


- Surface plasmons are charge density waves propagating along the interface of a metal and dielectric
- Evanescent fields of surface plasmons extend into the metal film and dielectric from the surface

Creation of Surface Plasmons

- Radiative coupling to a surface plasmon mode

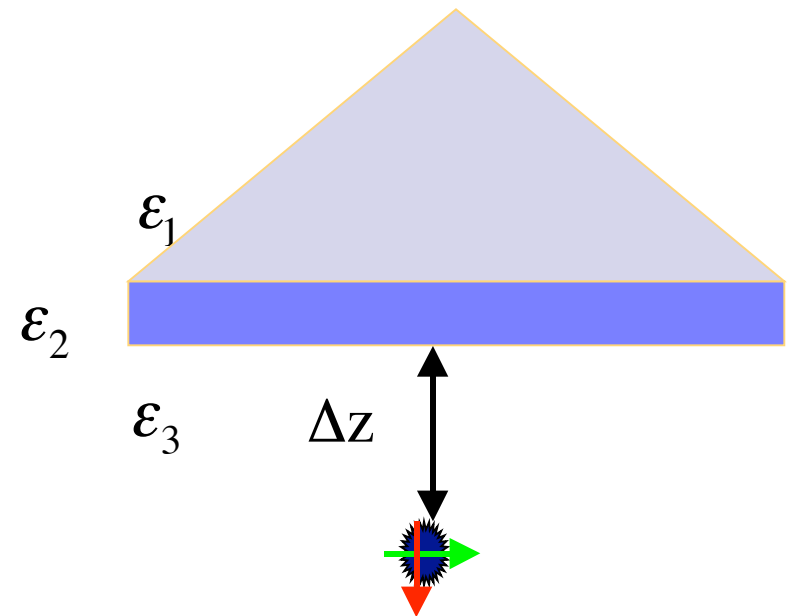
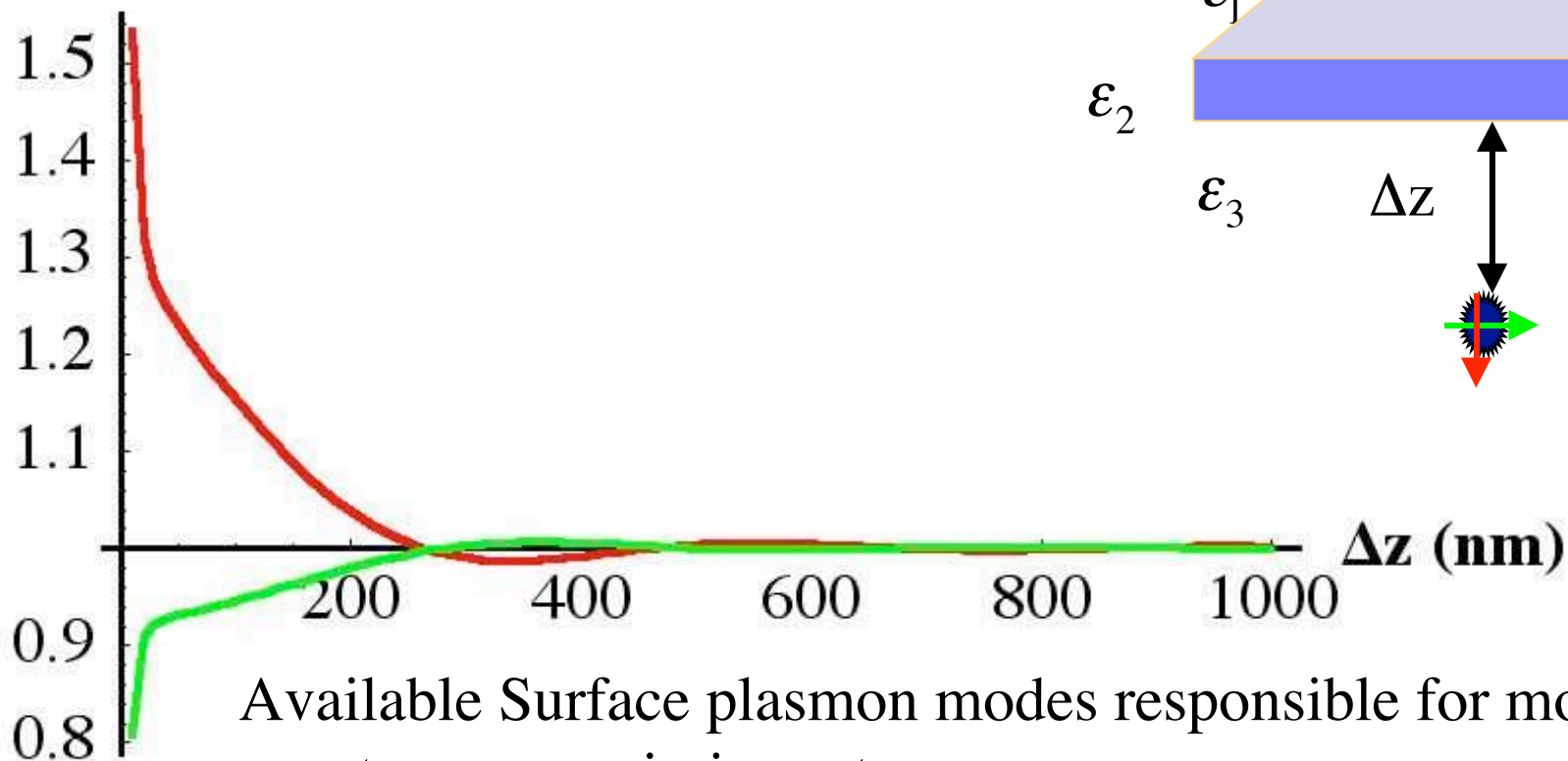
- Requires wave vector matching $k_x = k_{sp}$



- Surface plasmon evanescent field intensity 10-100 times that of \vec{E}_0

Dipole Emission near a metal film

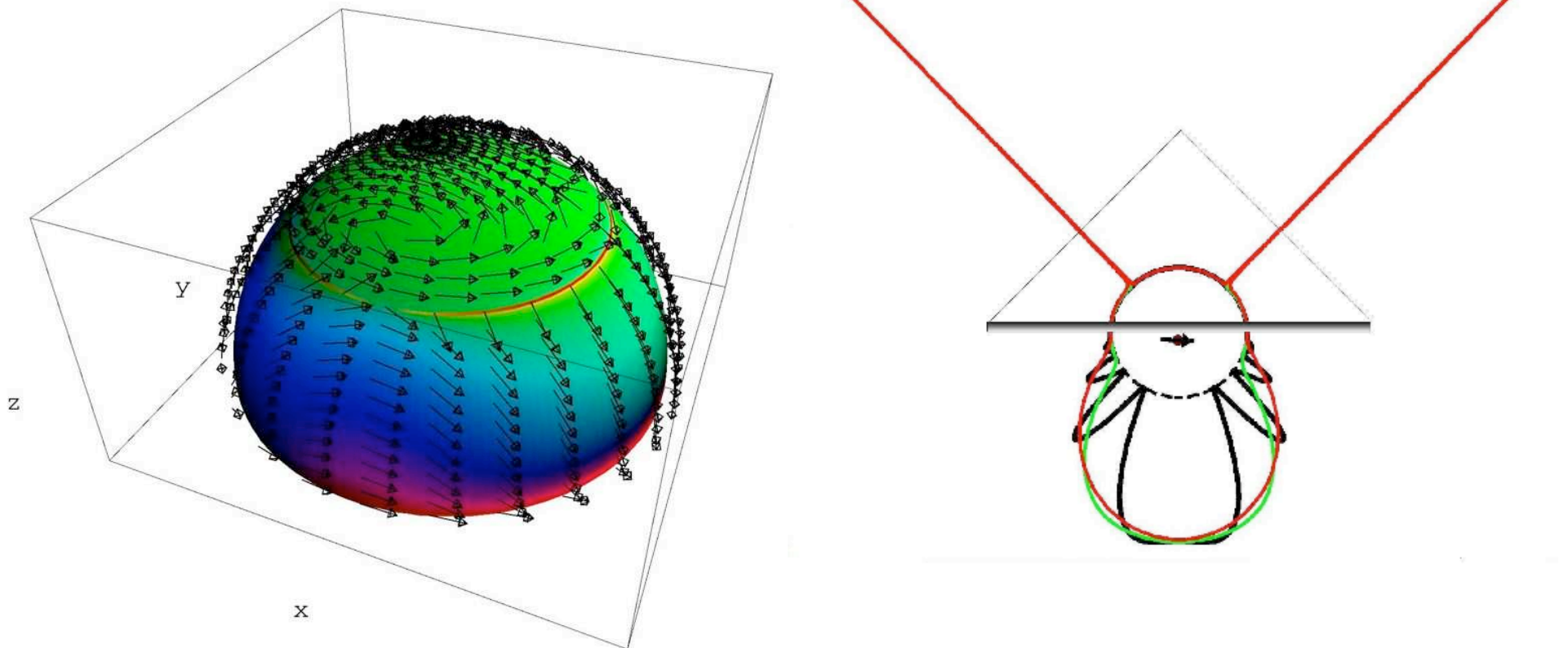
$$\frac{\Gamma}{\Gamma_0} = 1 + \frac{3\lambda d_i^2}{8d^2} \text{Im}[R_{ii}]$$



Available Surface plasmon modes responsible for modified spontaneous emission rate.

Modified Dipole Radiation

- Dipole radiation modified by metal film
- Surface plasmon modes transmitted into far field



Quantization of the EM Field

- Metal film is a dispersive and absorbing dielectric
- Noise current sources account for losses*

$$\nabla \times \nabla \times \hat{\mathbf{E}}(\mathbf{r}, \omega) - \frac{\omega^2}{c^2} \epsilon(\mathbf{r}, \omega) \hat{\mathbf{E}}(\mathbf{r}, \omega) = i\omega\mu_0 \hat{\mathbf{j}}_N(\mathbf{r}, \omega)$$

$$\hat{\mathbf{j}}_N(\mathbf{r}, \omega) = \frac{\omega}{\mu_0 c^2} \sqrt{\frac{\hbar}{\pi \epsilon_0} \epsilon_I(\mathbf{r}, \omega)} \hat{\mathbf{f}}(\mathbf{r}, \omega)$$

- Green's functions allow the calculation of the electric field operators

$$\hat{\mathbf{E}}(\mathbf{r}, \omega) = i\omega\mu_0 \int d^3\mathbf{r}' \vec{\mathbf{G}}(\mathbf{r}, \mathbf{r}', \omega) \hat{\mathbf{j}}_N(\mathbf{r}', \omega)$$

*L. Knoll, S. Scheel, D-G Welsch, arxiv:quant-ph/0006121

Entangled photon pulses

- We consider photon pulses incident on a metal film
- $\hat{a}_{\theta_{\pm}, \pm}$ creates a photon pulse incident at $\pm\theta_{SP}$ and of right/left circular polarization

- Mixed state

$$\rho = \frac{1}{2} \hat{a}_{\theta_{+}, +}^{\dagger} \hat{a}_{\theta_{-}, -}^{\dagger} |0\rangle \langle 0| \hat{a}_{\theta_{+}, +} \hat{a}_{\theta_{-}, -} + \frac{1}{2} \hat{a}_{\theta_{+}, -}^{\dagger} \hat{a}_{\theta_{-}, +}^{\dagger} |0\rangle \langle 0| \hat{a}_{\theta_{+}, -} \hat{a}_{\theta_{-}, +}$$

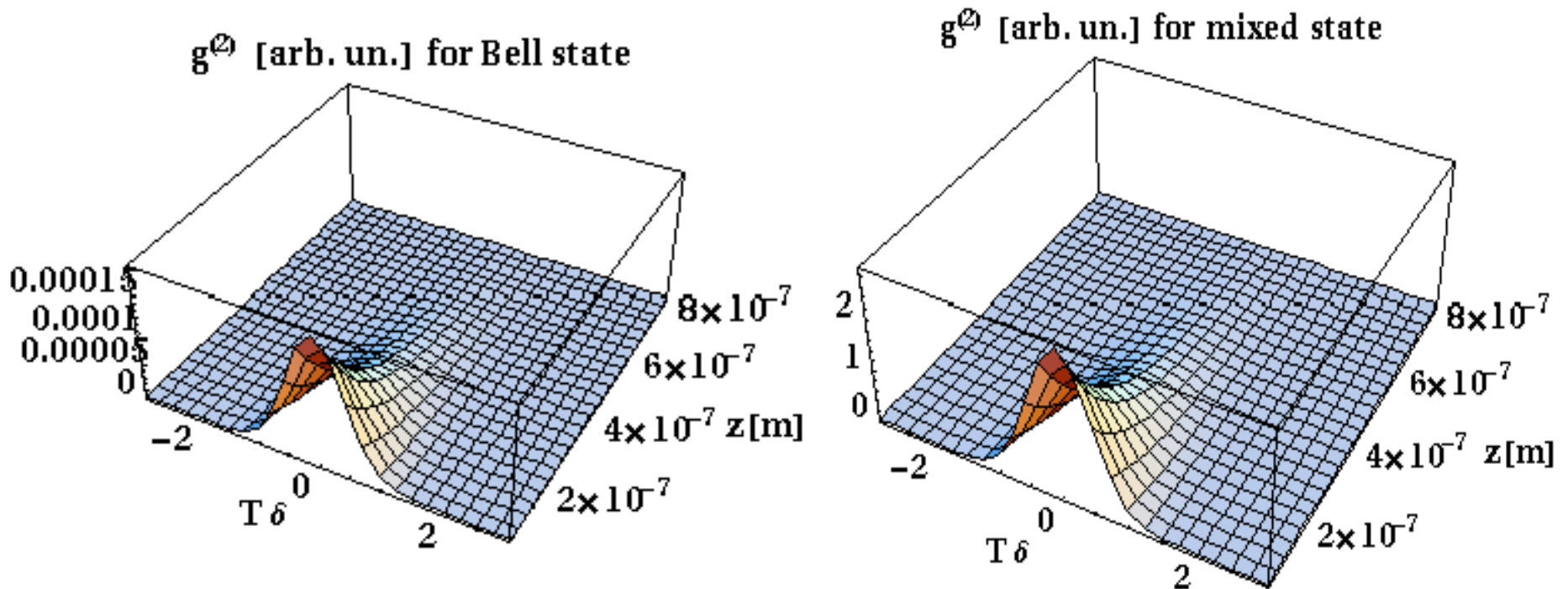
- Bell state

$$|\psi\rangle = \frac{1}{\sqrt{2}} (\hat{a}_{\theta_{+}, +}^{\dagger} \hat{a}_{\theta_{-}, -}^{\dagger} - \hat{a}_{\theta_{+}, -}^{\dagger} \hat{a}_{\theta_{-}, +}^{\dagger}) |0\rangle$$

Field correlations

- $g^{(2)}$ measurements of the SP evanescent field

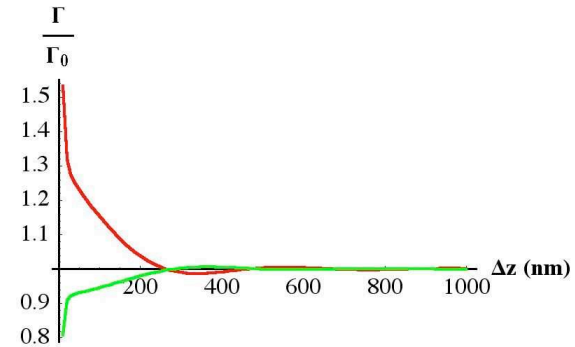
$$g^{(2)}(\delta\omega) = \langle \psi | \hat{E}_i^\dagger(\mathbf{x}, \omega_0 + \delta\omega) \hat{E}_j^\dagger(\mathbf{x}, \omega_0) \hat{E}_j(\mathbf{x}, \omega_0) \hat{E}_i(\mathbf{x}, \omega_0 + \delta\omega) | \psi \rangle$$



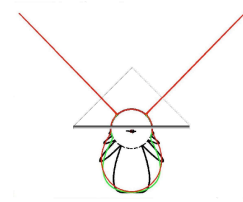
- Incomplete destructive interference of SP fields

Summary

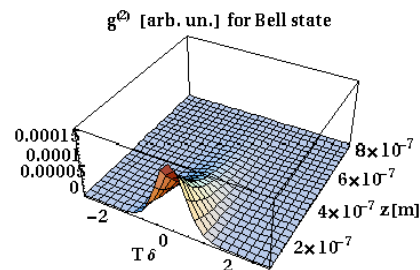
- Analyzed spontaneous emission coefficients of a dipole near a thin metal film



- Surface plasmons provide a means to couple the near-field into the far-field



- Derived the correlations for photon pulse induced surface plasmons



Acknowledgments



NSERC
CRSNG



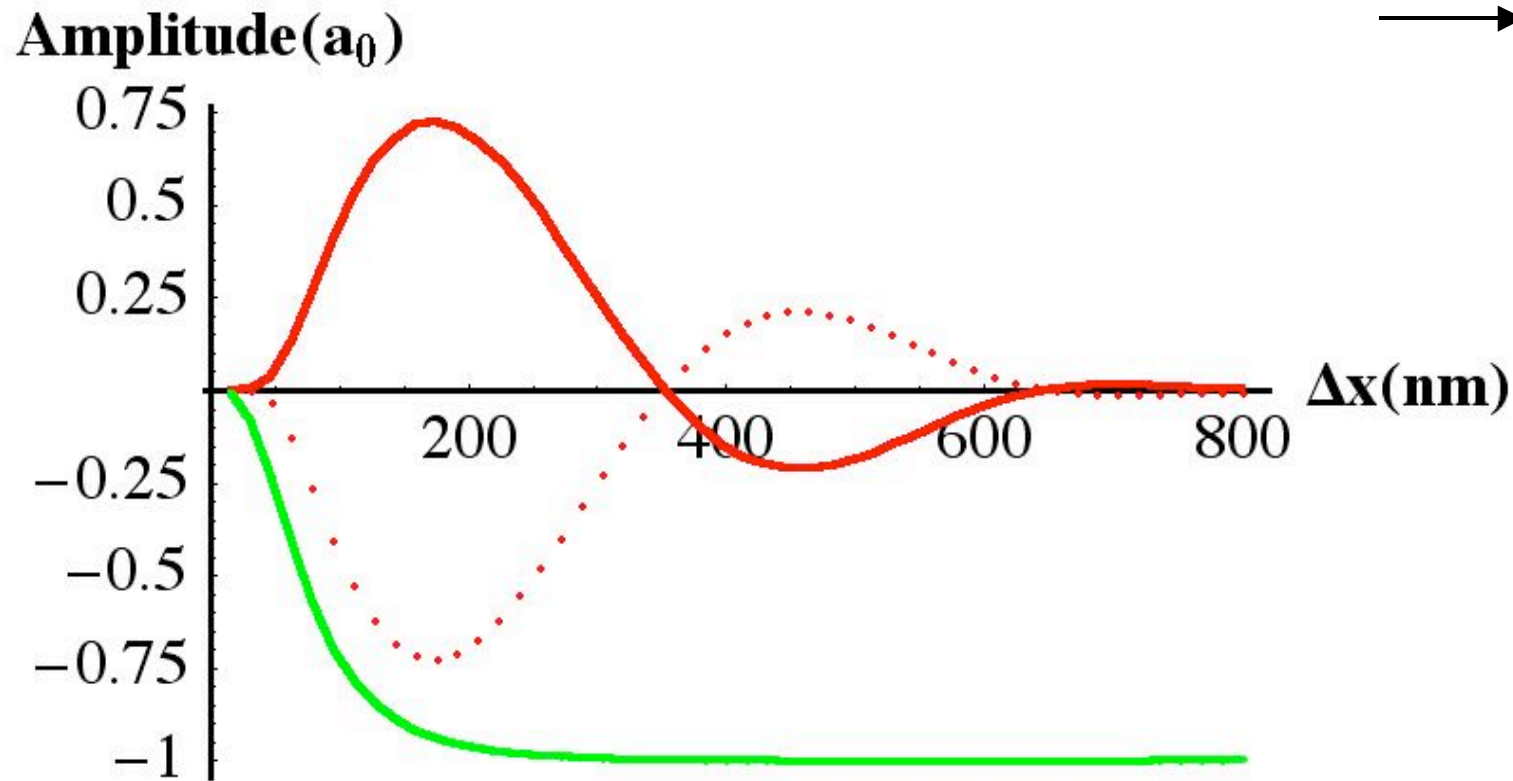
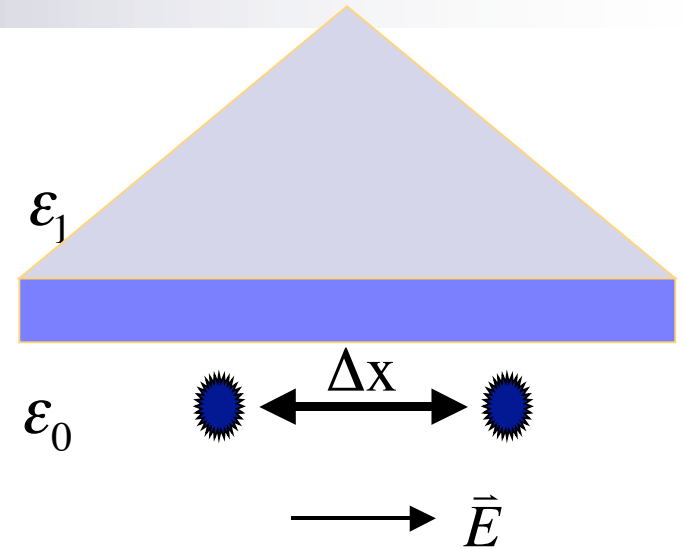
CORE



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Coupled Dipoles

- Metal interface allows additional coupling between dipoles
- Couple dipoles into surface plasmon modes more readily



Green's Functions

- Derive Green's functions from continuity of the EM field at the dielectric interfaces

$$G_{ij}(\mathbf{r}, \mathbf{r}', \omega) = \int d^2\mathbf{k}_p e^{i\mathbf{k}_p \cdot (\mathbf{r} - \mathbf{r}')} G_{ij}(\mathbf{k}_p, \omega; z, z')$$

- Green's function describes how EM radiation propagates through the medium.

- Information about SPs contained within Green's functions.

