Slow Light in 3 and 4-Level System

AMO Seminar Oral (2010.12.20)

報 告 人：徐 薇 棉

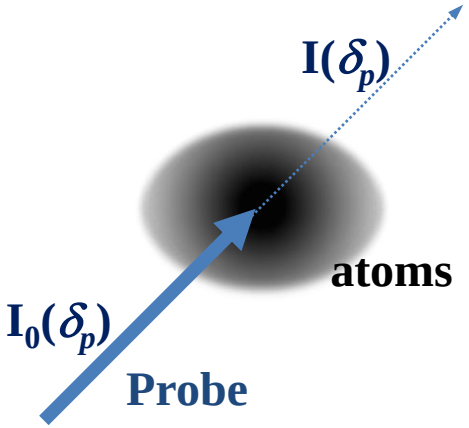
指導老師：余 怡 德

Outline

- **Electromagnetically Induced Transparency**
  - **3-Level System : Spectrum, Slow light**
- **Motivation for 4-Level System**
  - **4-Level System : Spectrum, Slow light**
  - **3 & 4-Level System Slow light**
- **Summery**

Electromagnetically Induced Transparency

- **2 Level System**



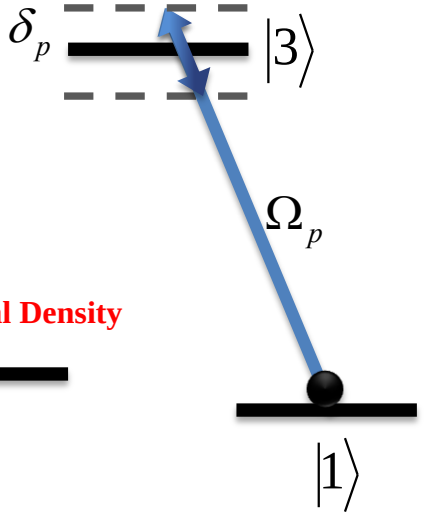
$$E = E_0 \exp[ikz]$$

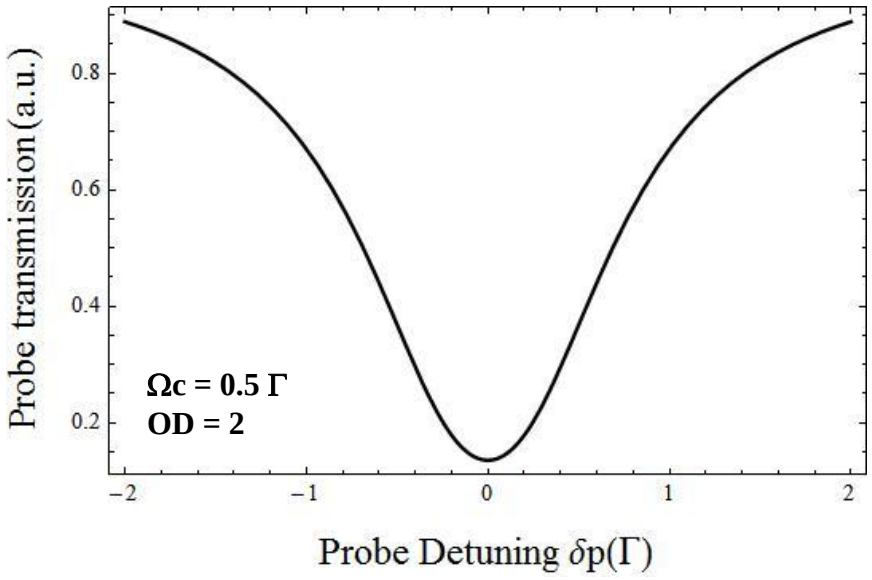
$$k = \mathrm{Re}[k] + i\,\mathrm{Im}[k]$$

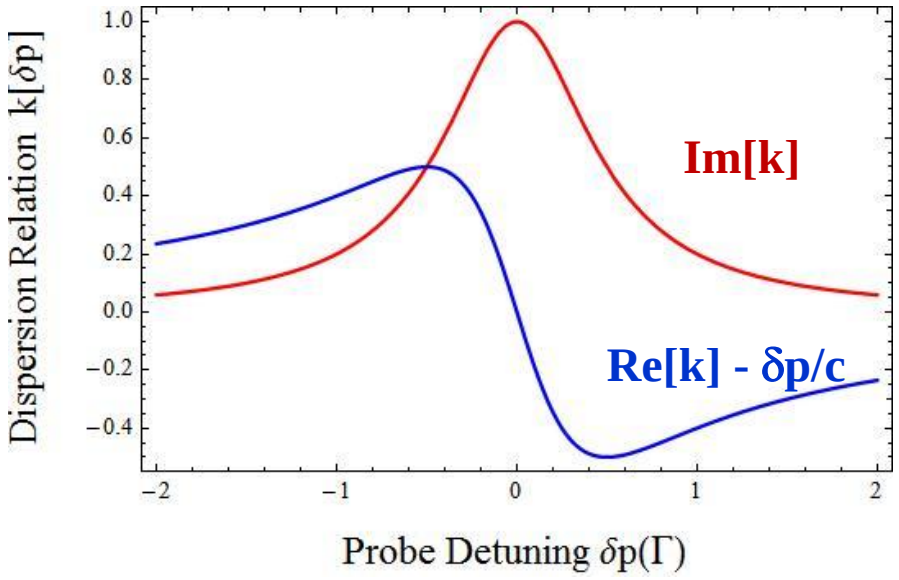
$$I = |E|^2 = I_0 \exp(-2\,\mathrm{Im}[k]\,z)$$

$$I(\delta_p = 0) = I_0 \exp(-OD)$$

Optical Density

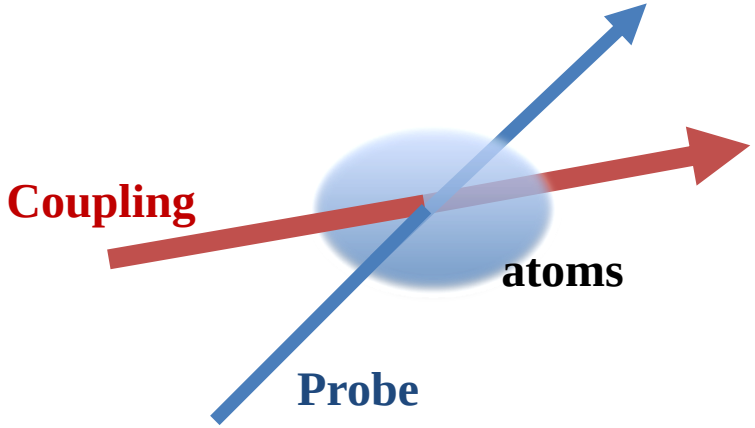


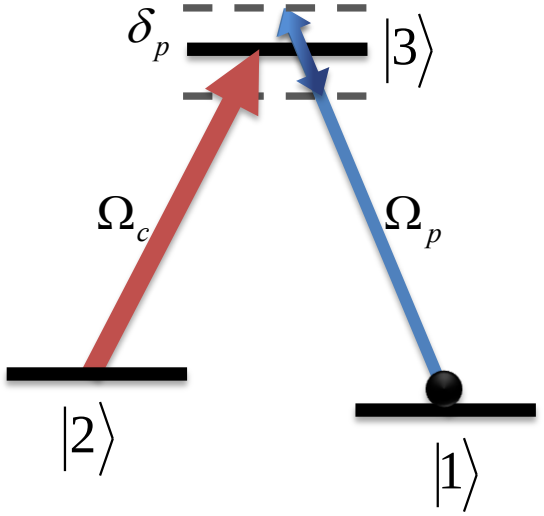


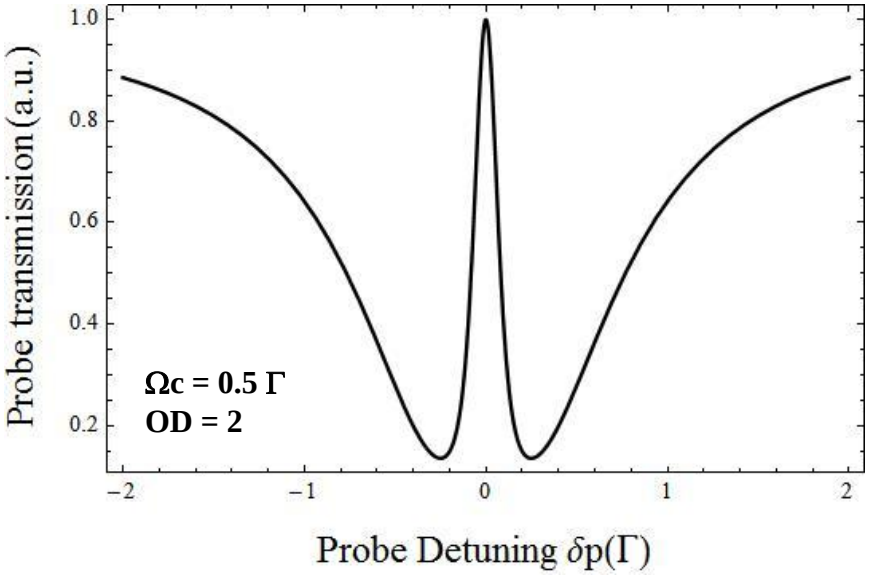


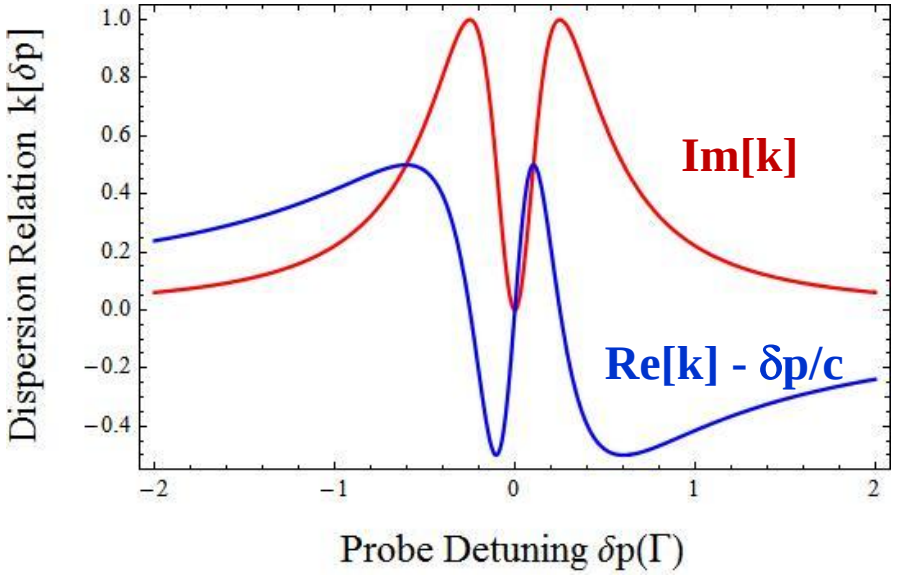
Electromagnetically Induced Transparency

- **3 Level System**



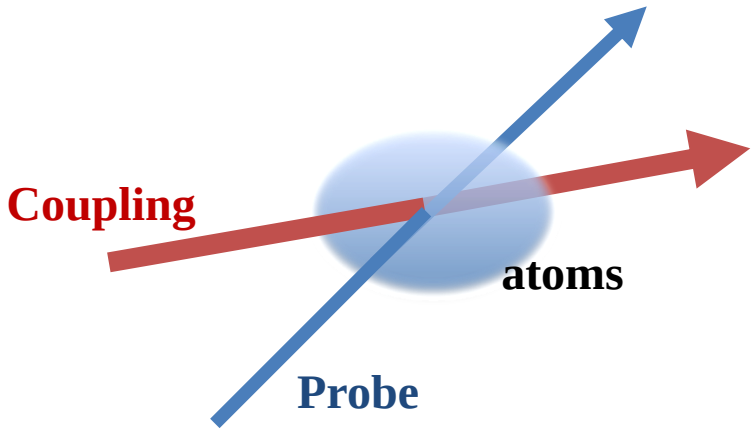


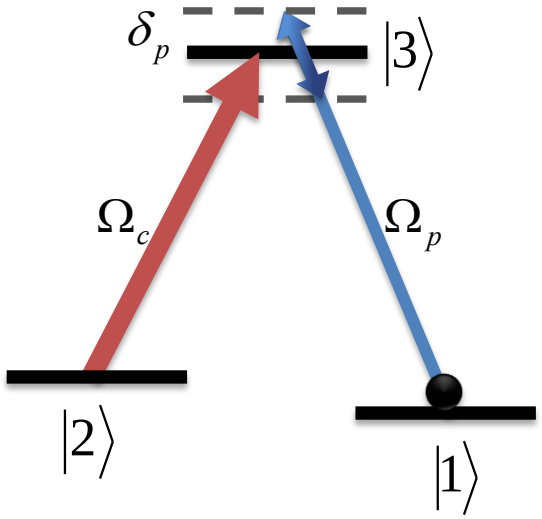




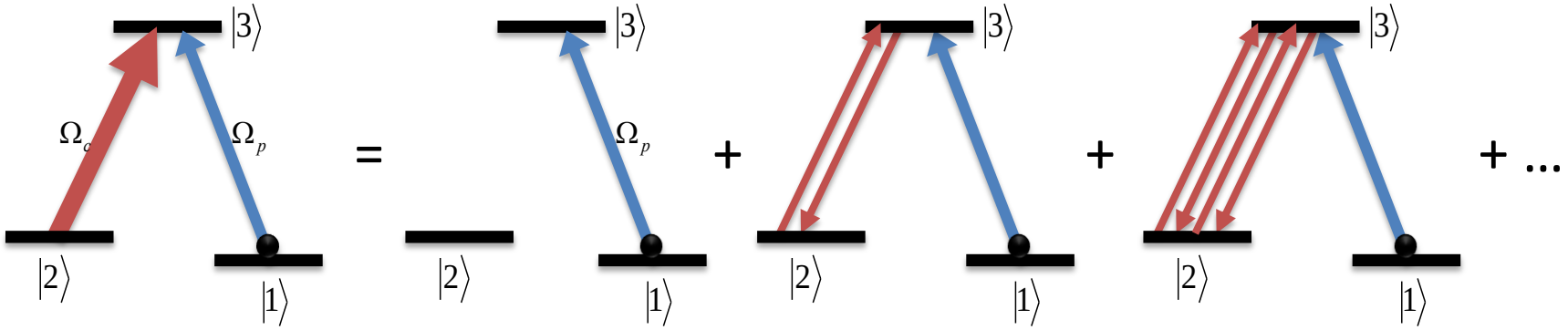
Electromagnetically Induced Transparency

- **3 Level System**





- **Quantum Interference**



Transition Probability $= |\ A_i + A_{ii} + A_{iii} + \ldots\ |^2$

|1>→|3>

→Destructive interference →The probe beam is not absorbed.

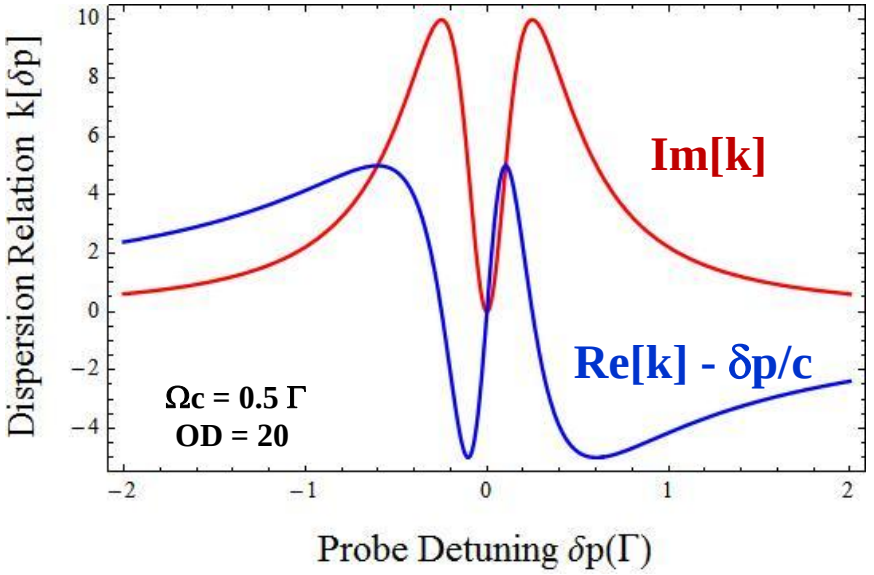
Electromagnetically Induced Transparency

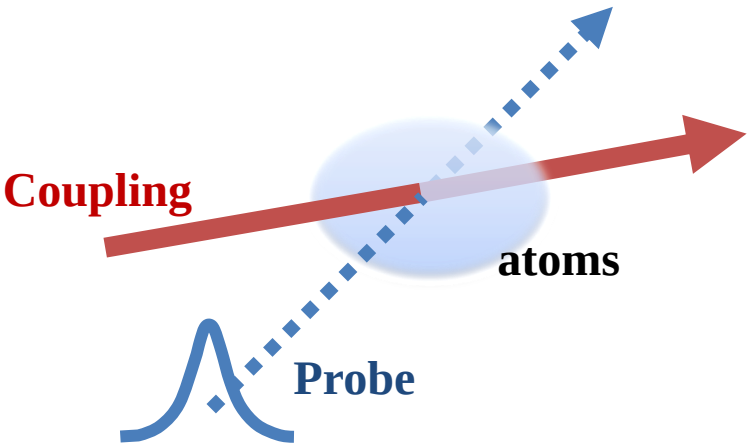
- **Dispersion relation**

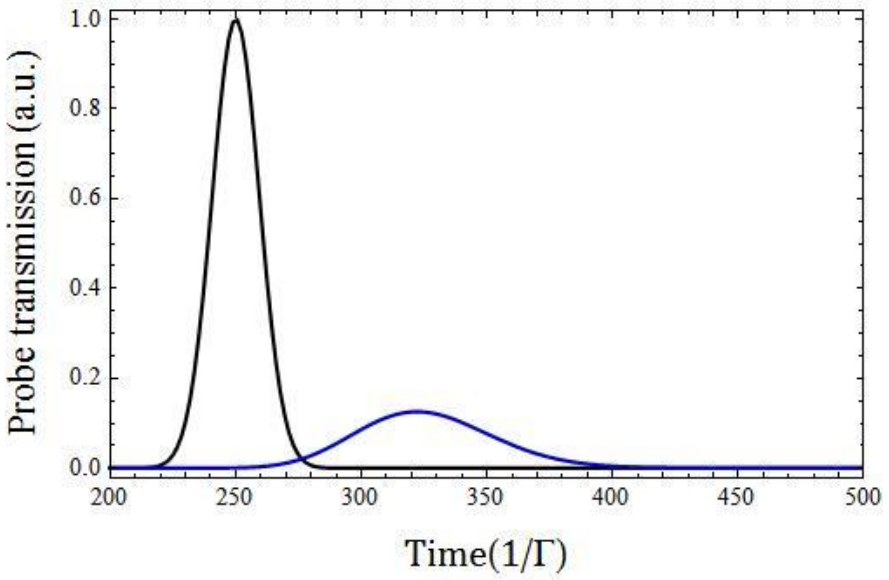
$$k = n(\omega)\frac{\omega}{c}$$

$$v_g = \frac{d\omega}{dk} = \frac{1}{dk/d\omega} = \frac{c}{n + \omega\frac{dn}{d\omega}}$$

~10^6

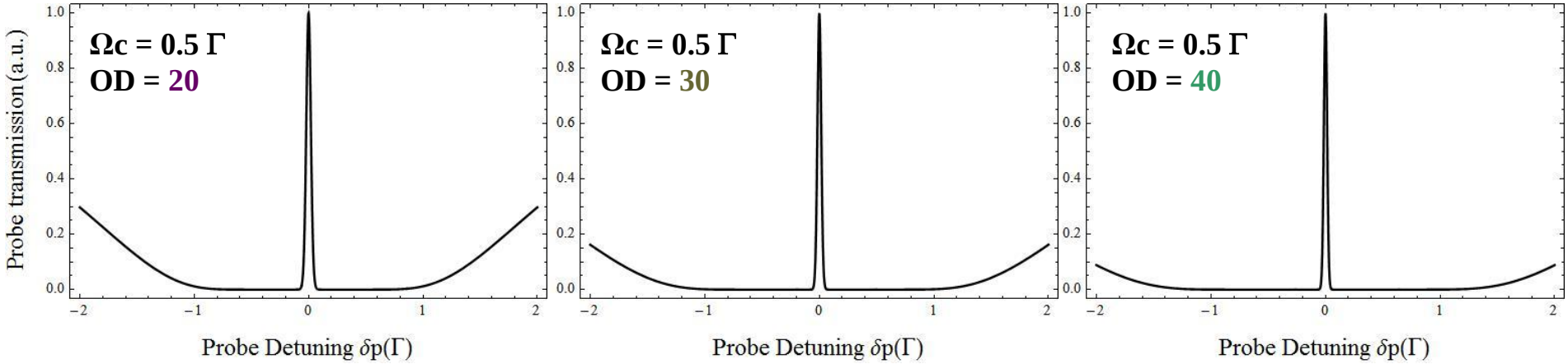


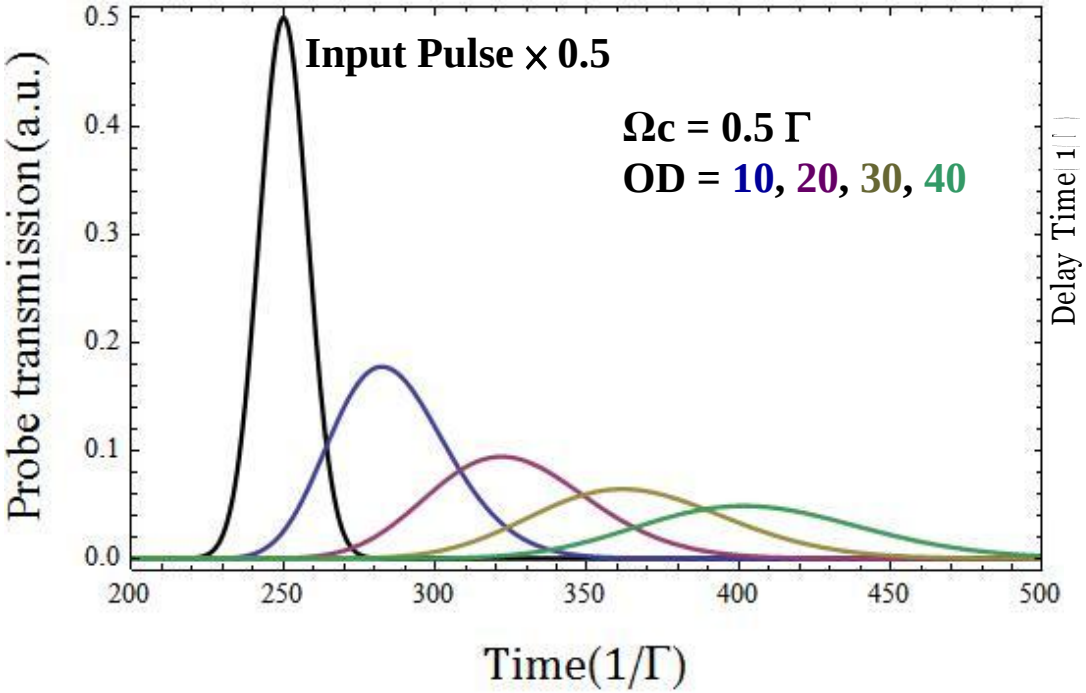


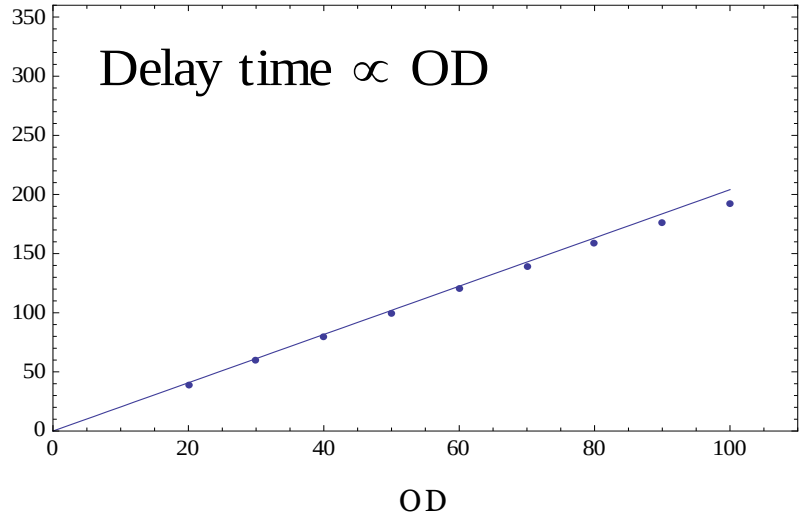


Slow Light

- **Change Optical Density (OD)**

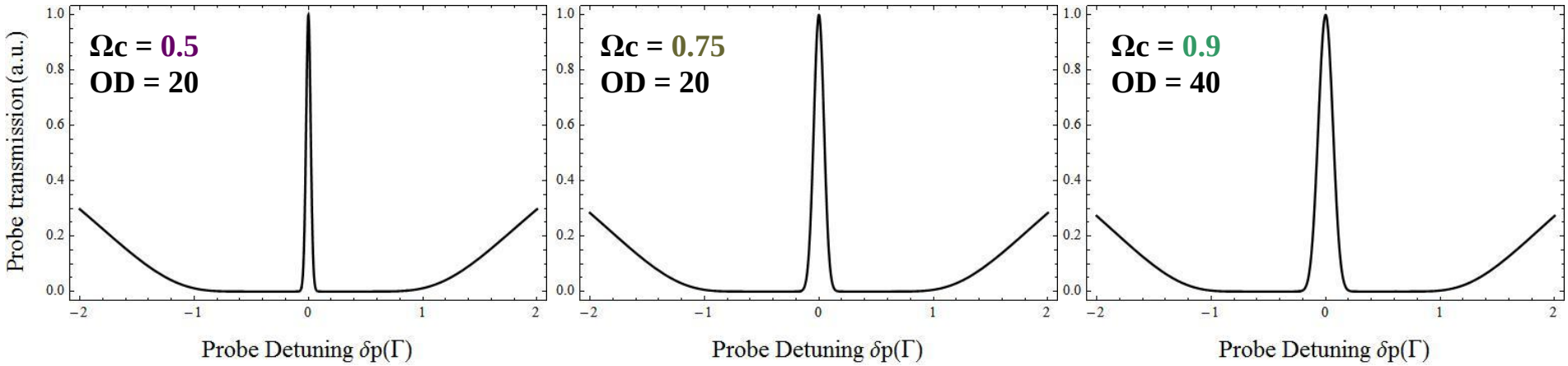


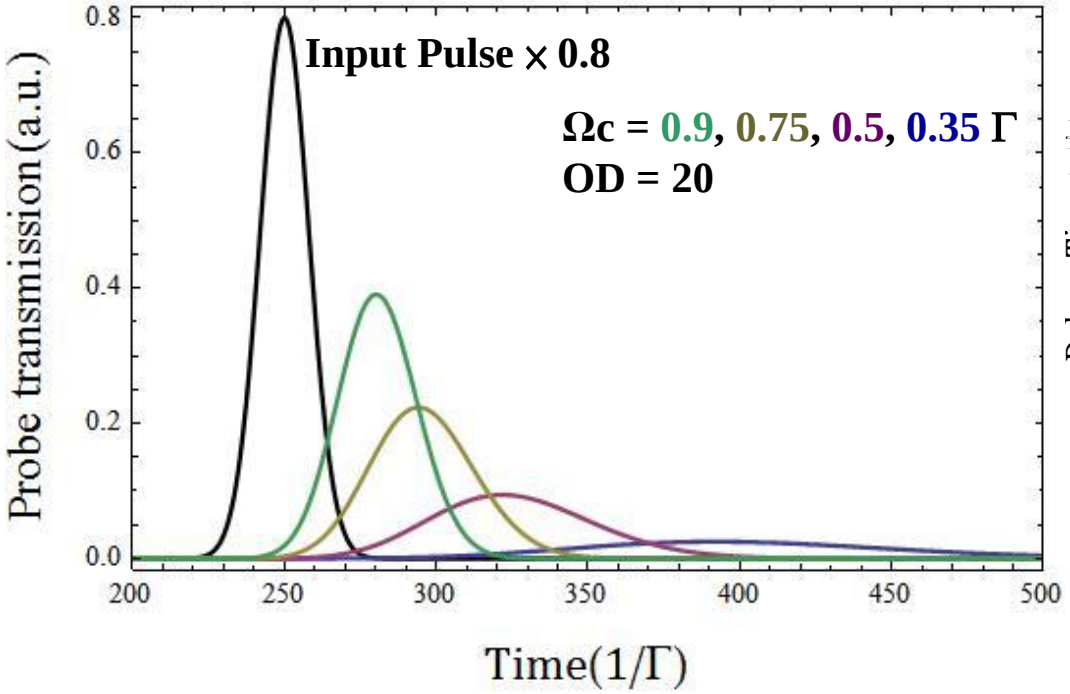


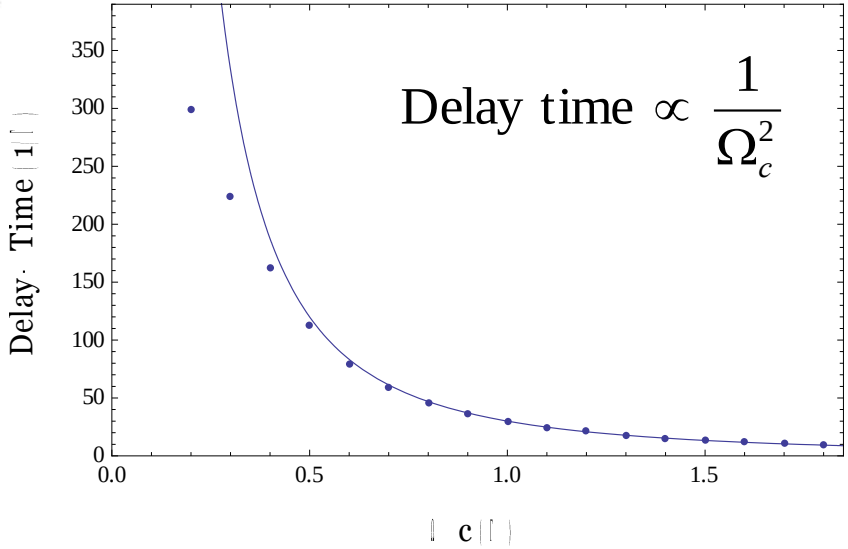


Slow Light

- **Change Coupling Intensity Ωc**

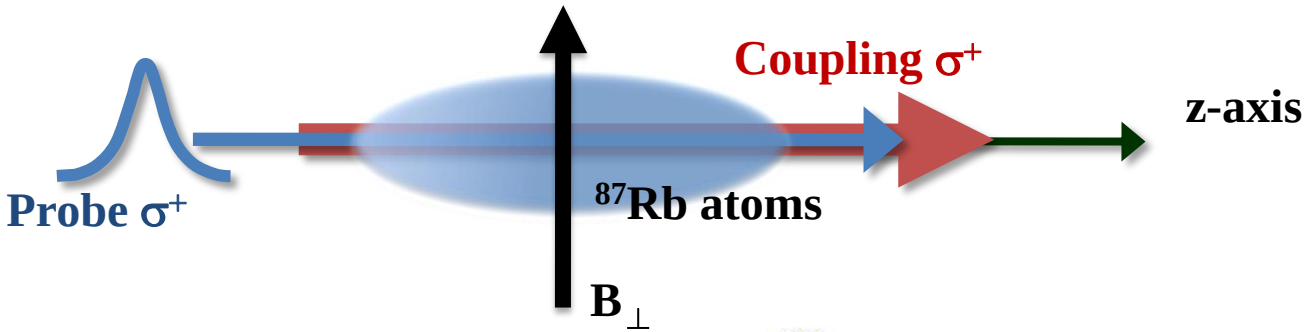


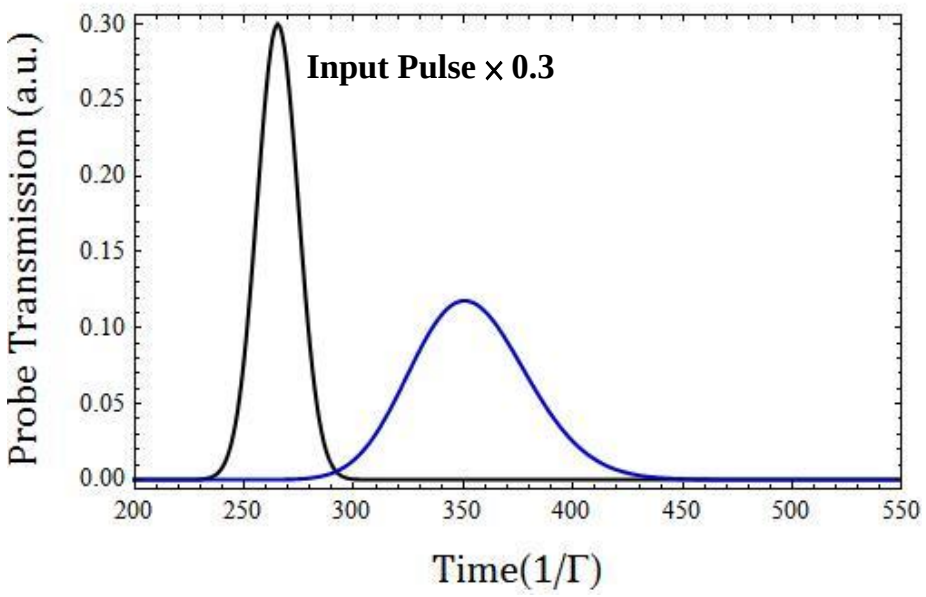


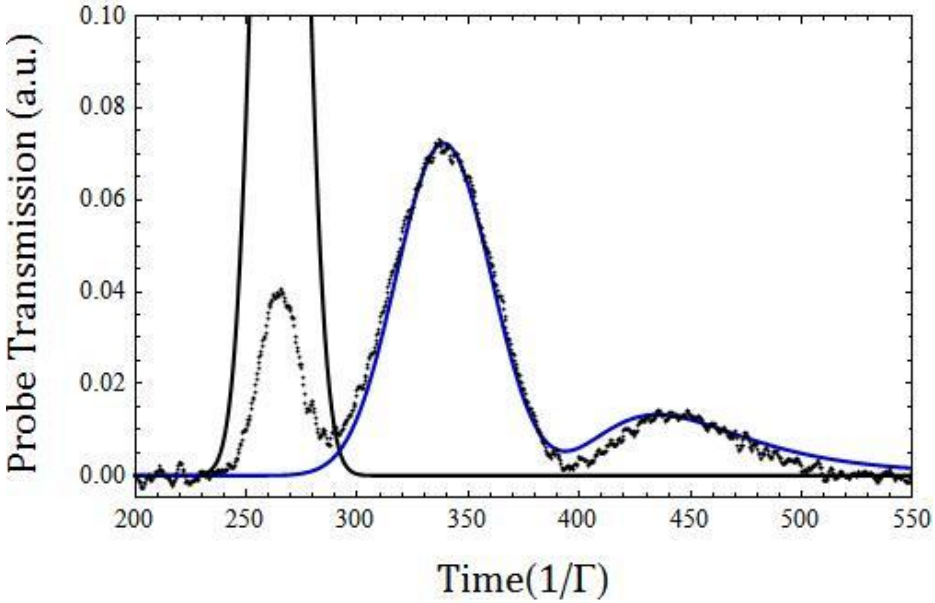


Motivation of Slow Light in 4-Level System

- **Apply a transverse magnetic filed**



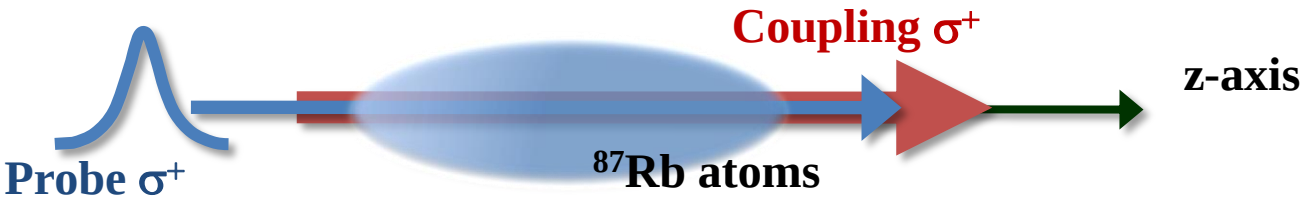




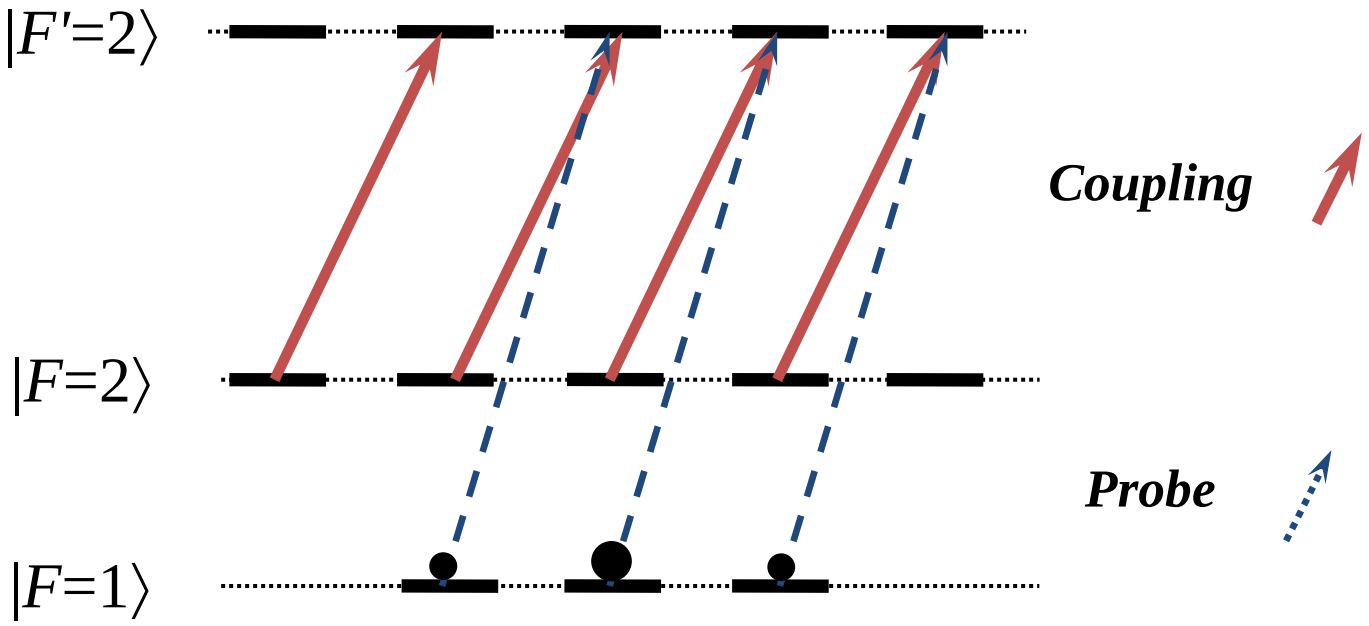
- **The slow light splits into two pulses with different group velocities.**

Motivation of Slow Light in 4-Level System

- **Select the z-axis (quantization axis)**

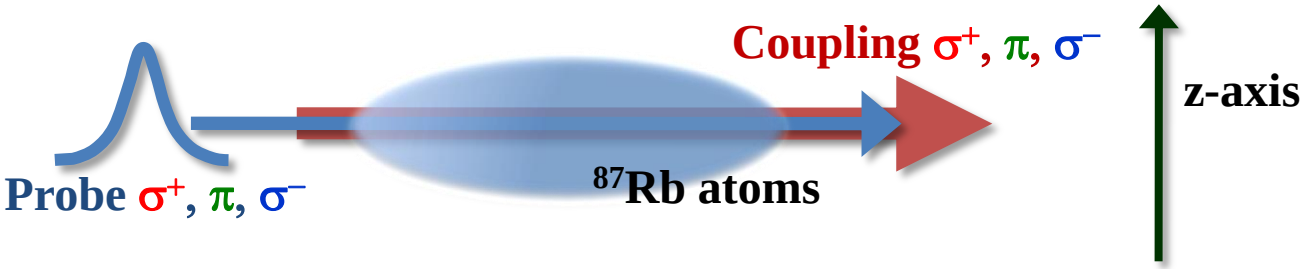


m =	–2	–1	0	+1	+2

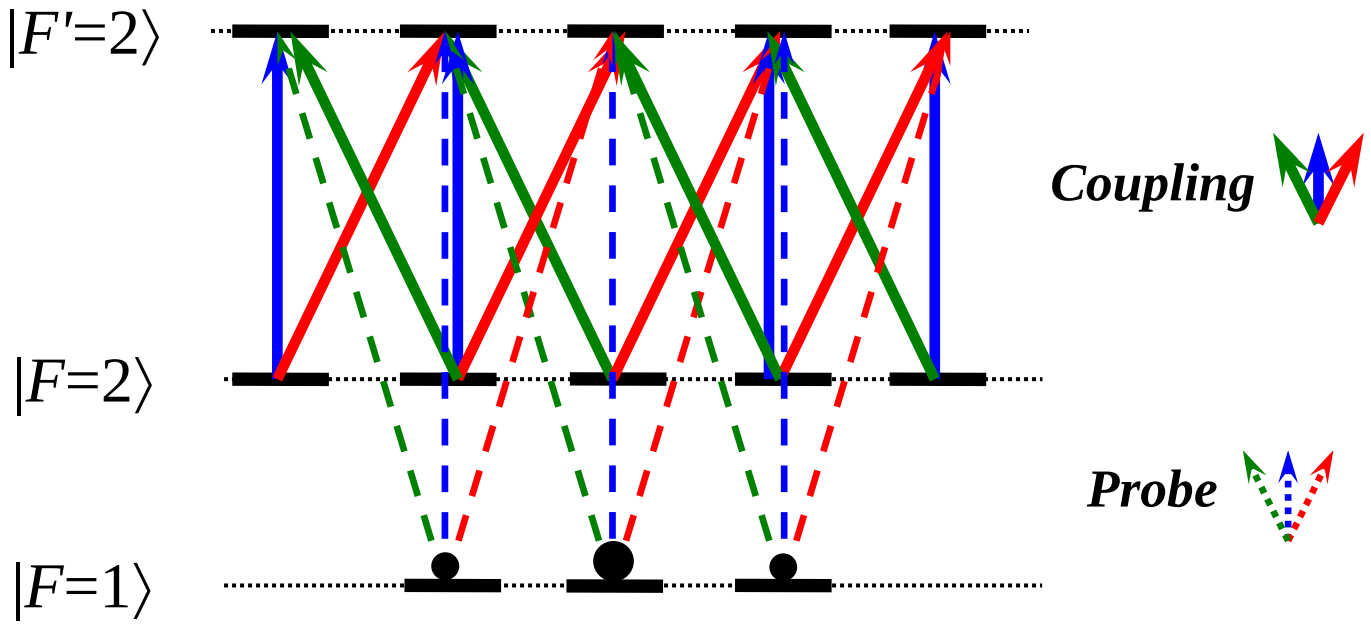


Motivation of Slow Light in 4-Level System

- **Select the z-axis (quantization axis)**

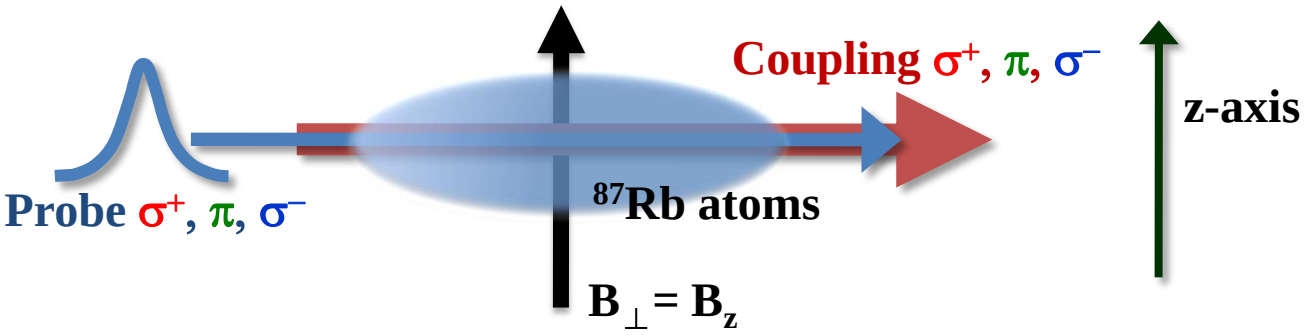


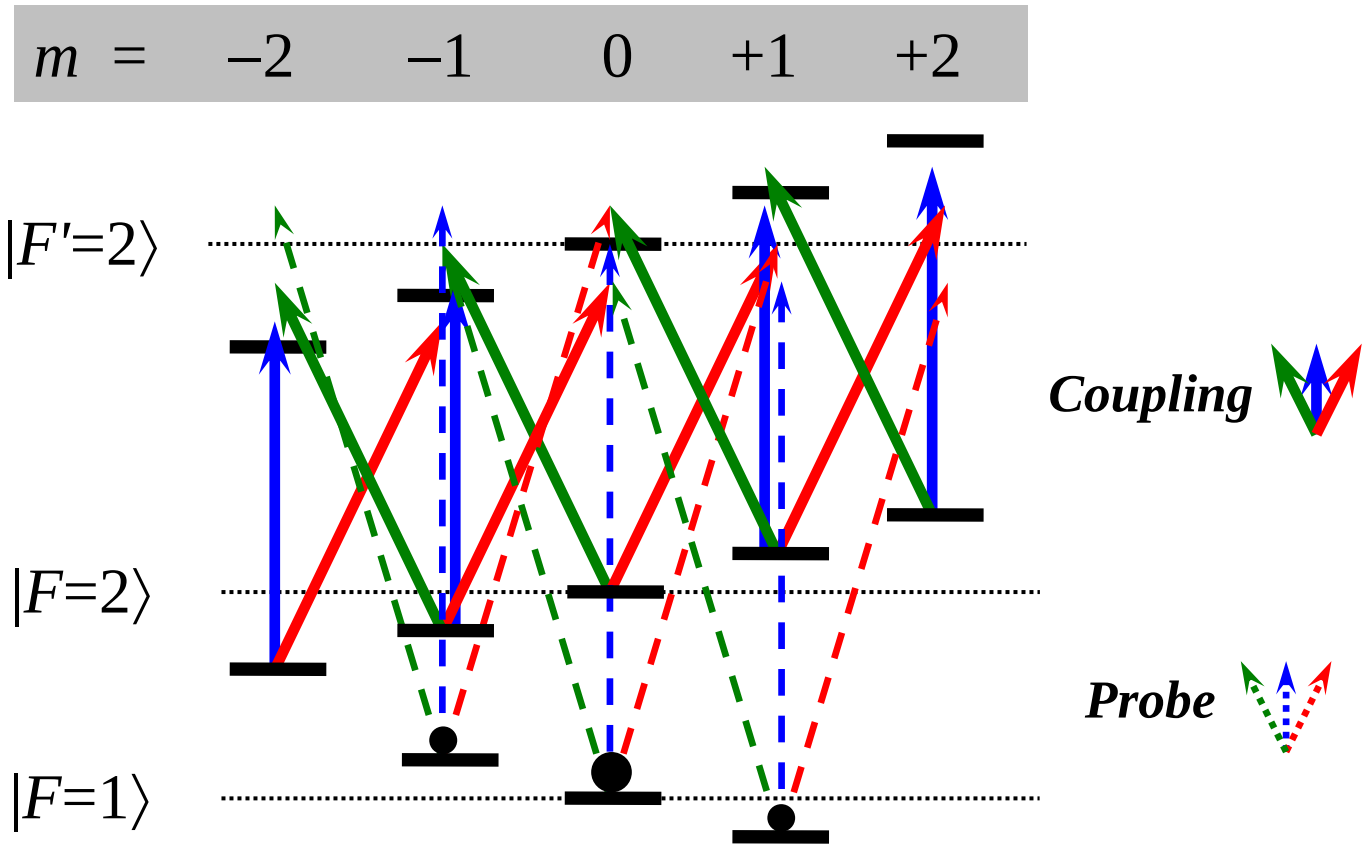
m =	–2	–1	0	+1	+2



Motivation of Slow Light in 4-Level System

- **13-Level system with Zeeman shift**



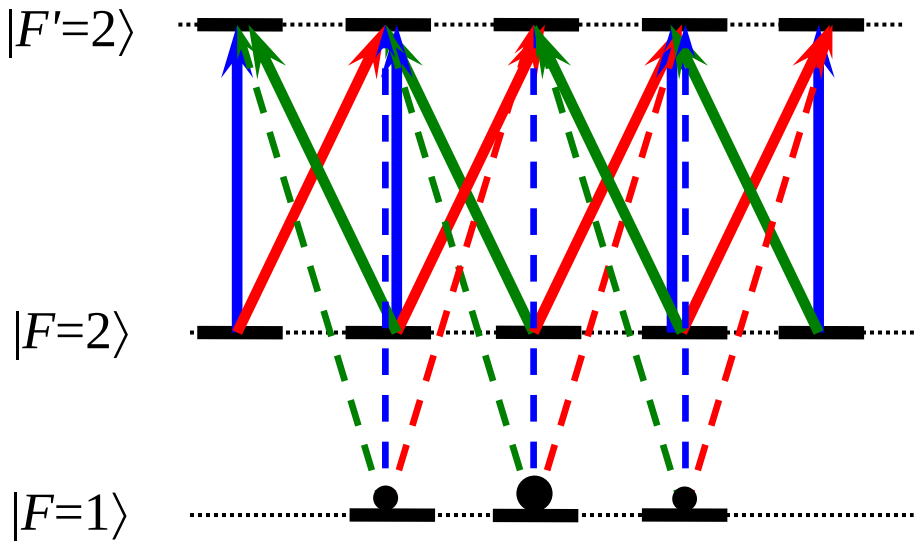


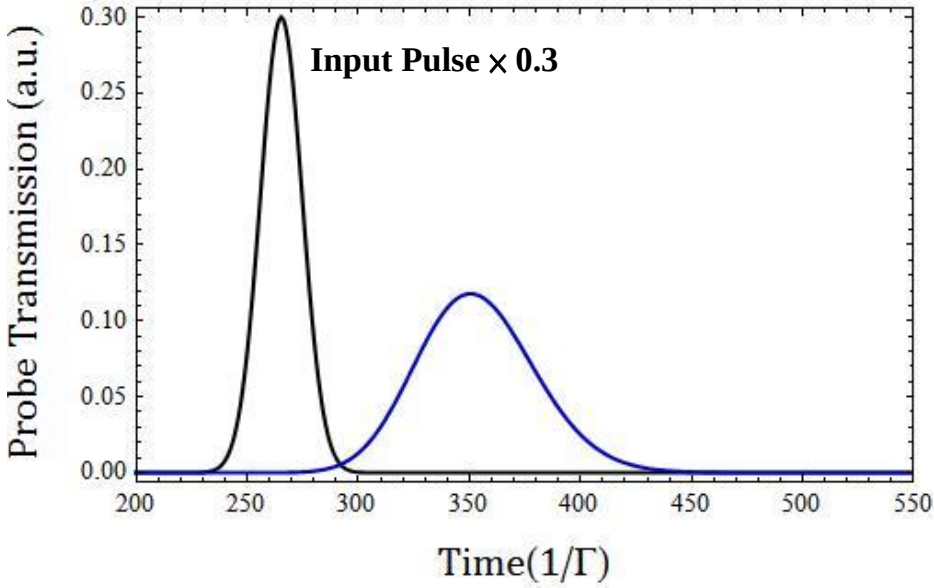
Motivation of Slow Light in 4-Level System

- **13-Level system with Zeeman shift**

m =	–2	–1	0	+1	+2

$B_z = 0$



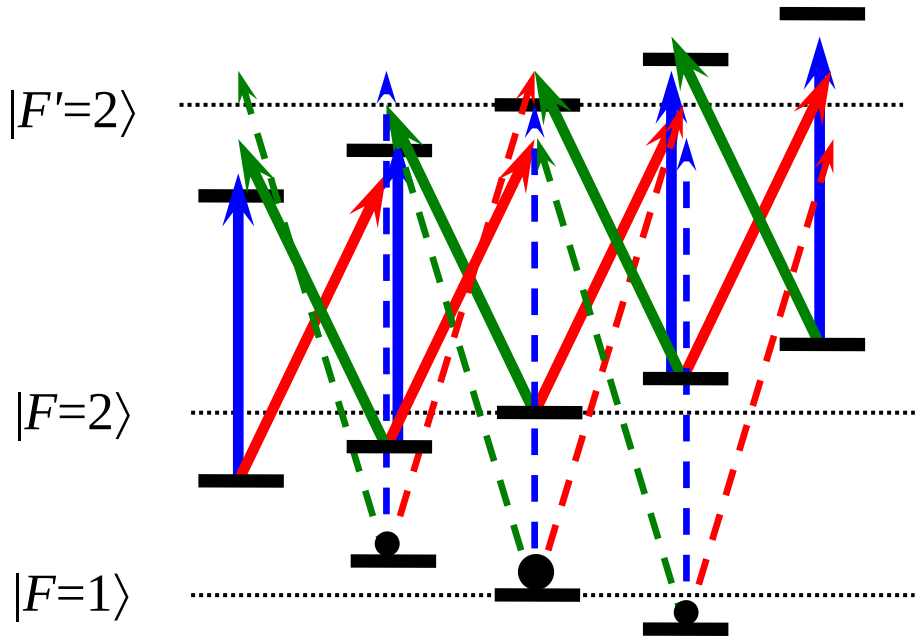


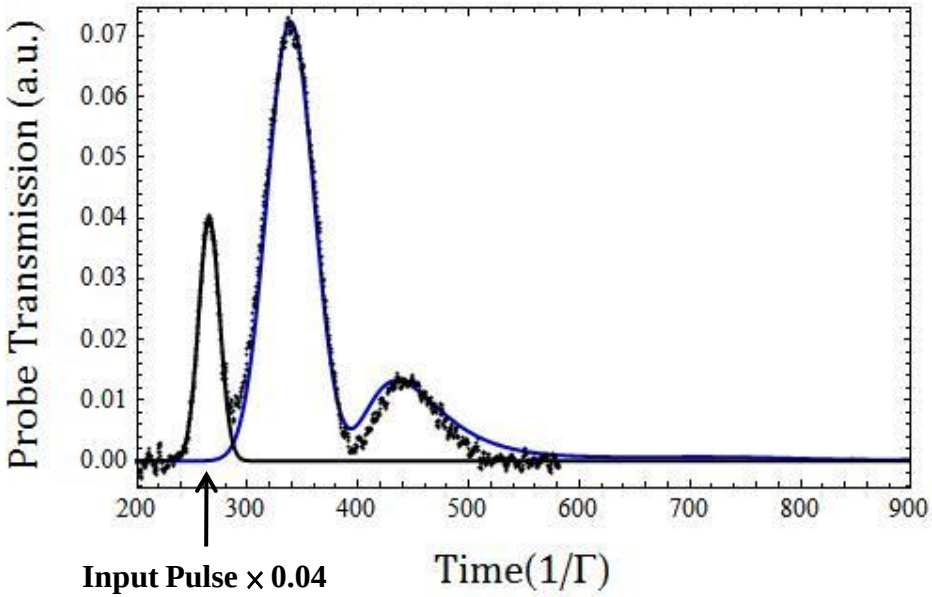
Motivation of Slow Light in 4-Level System

- **13-Level system with Zeeman shift**

m =	–2	–1	0	+1	+2

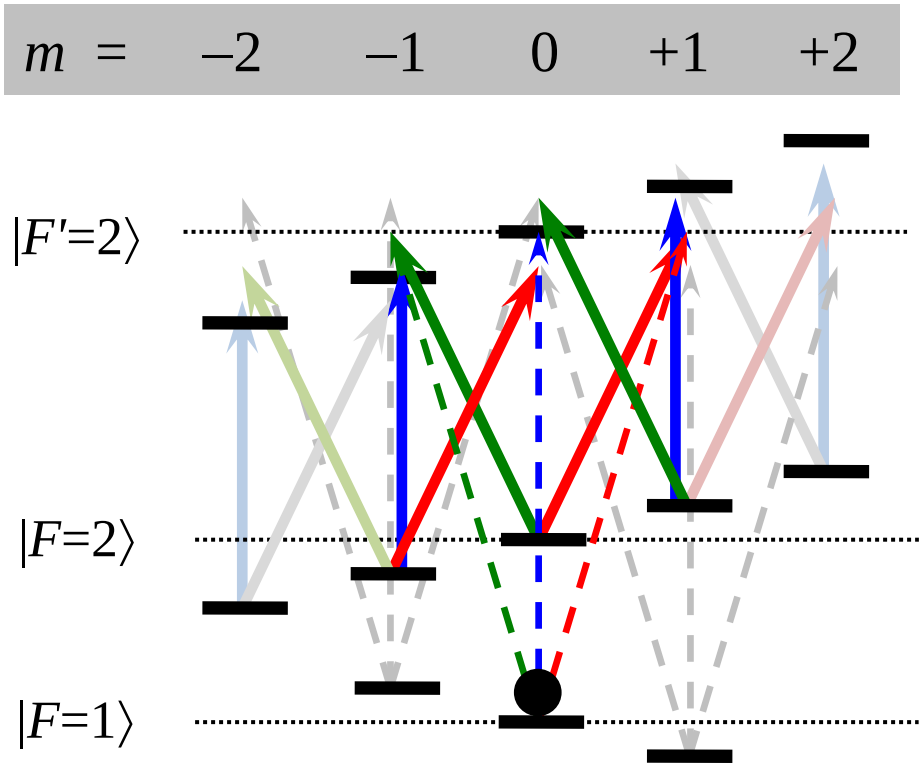
B_z = 107 mG



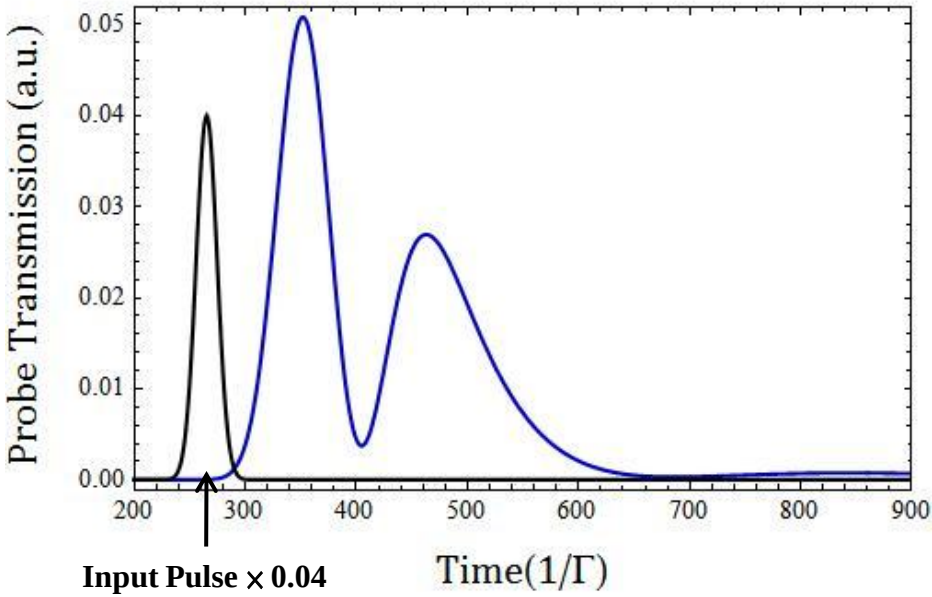


Motivation of Slow Light in 4-Level System

- **13-Level system with Zeeman shift**

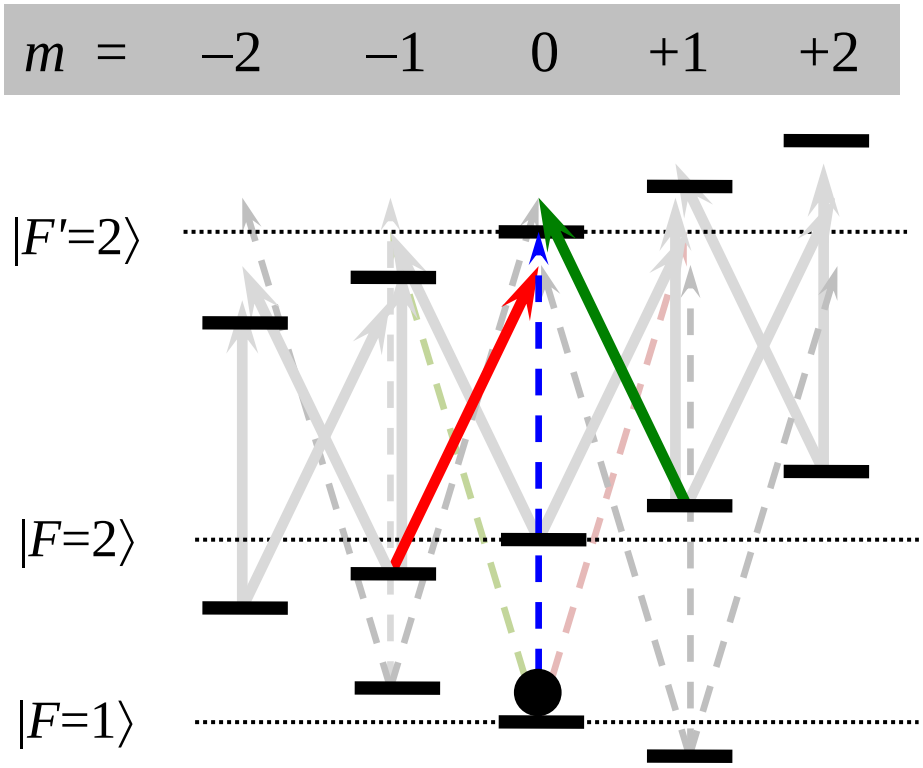


B_z = 107 mG

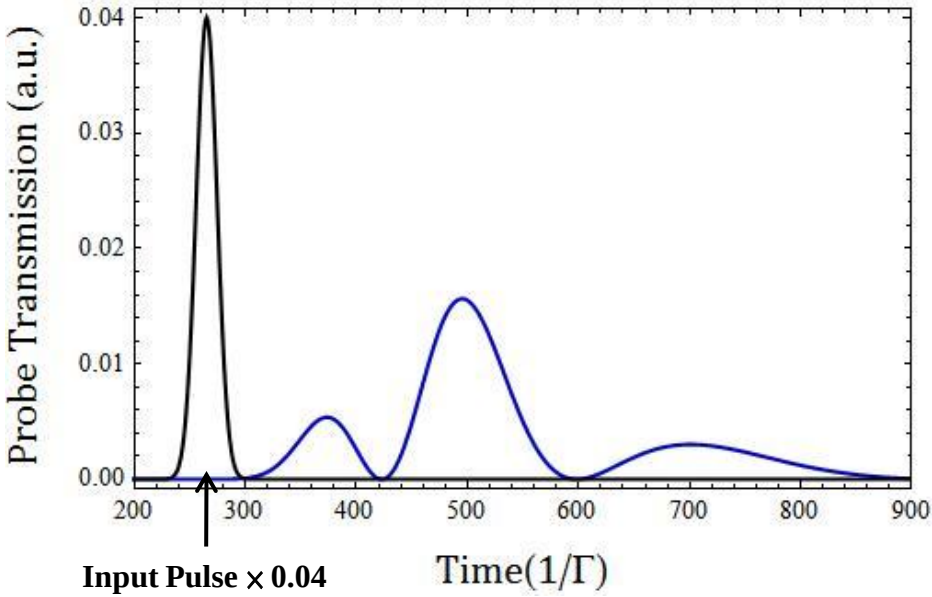


Motivation of Slow Light in 4-Level System

- **13-Level system with Zeeman shift**



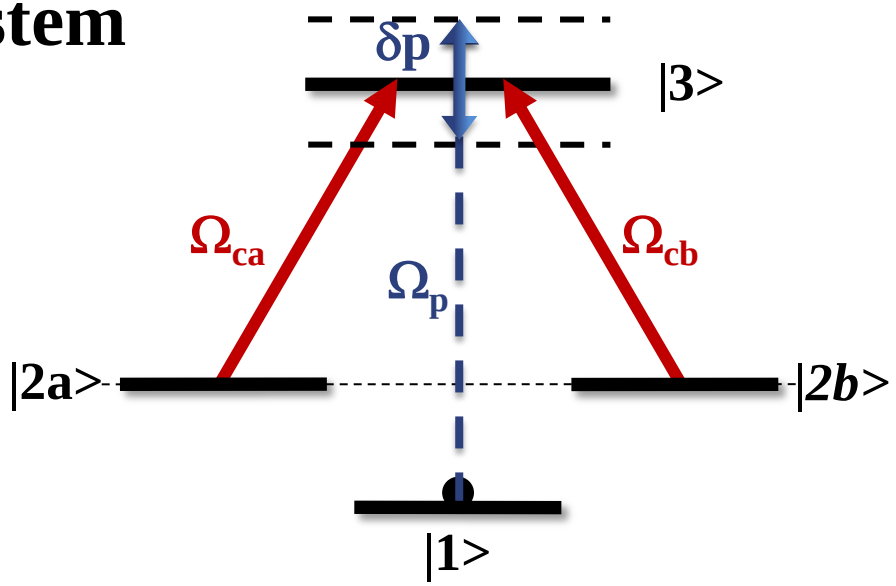
B_z = 107 mG

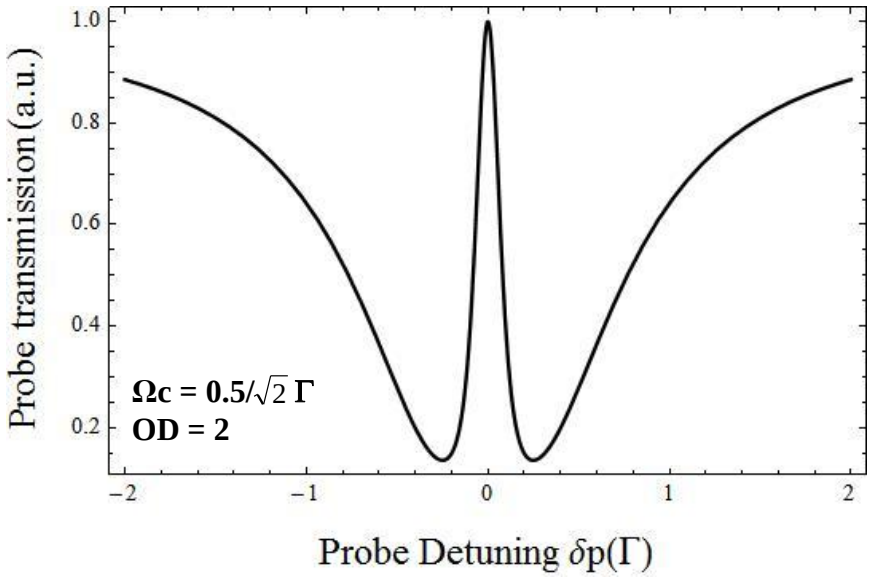


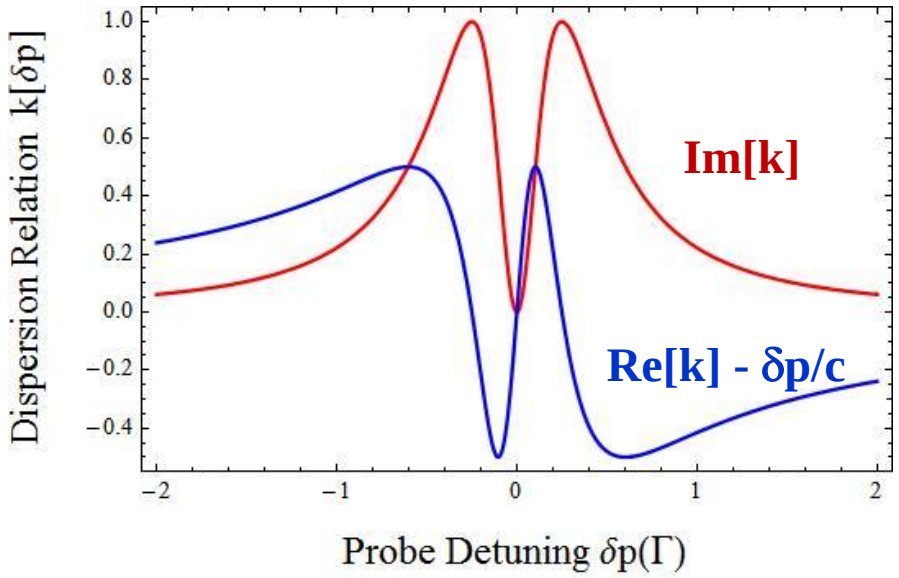
- **In a simple 4-level system, the slow light also exhibits multi-pulse output.**

4-Level System

- **4-Level system**

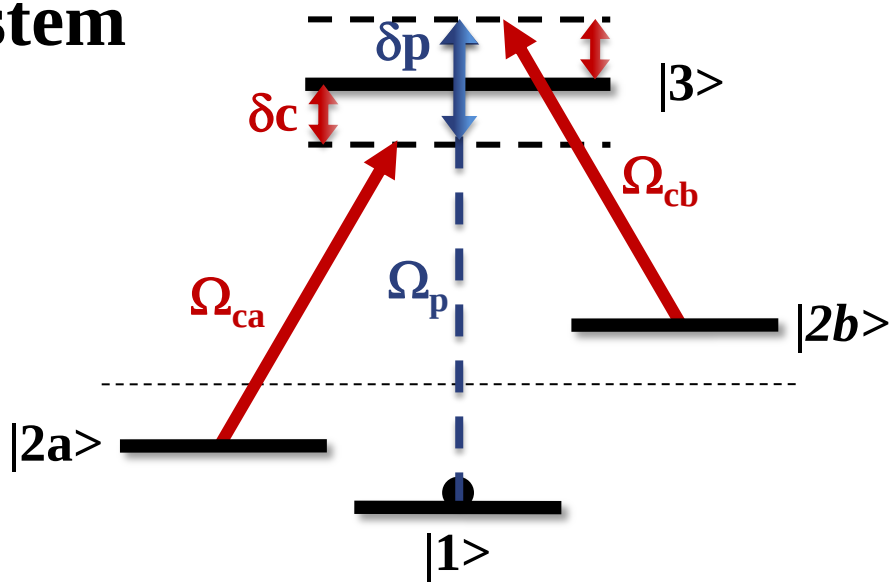


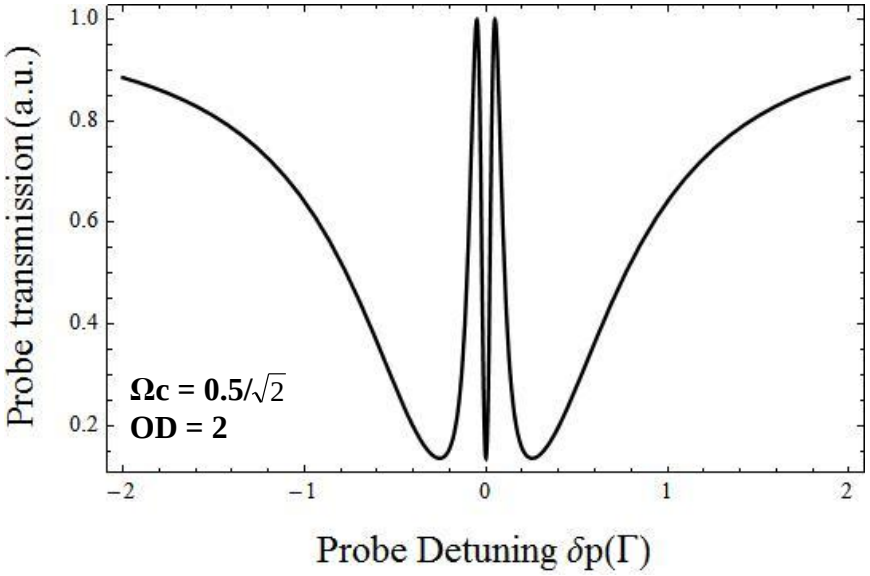


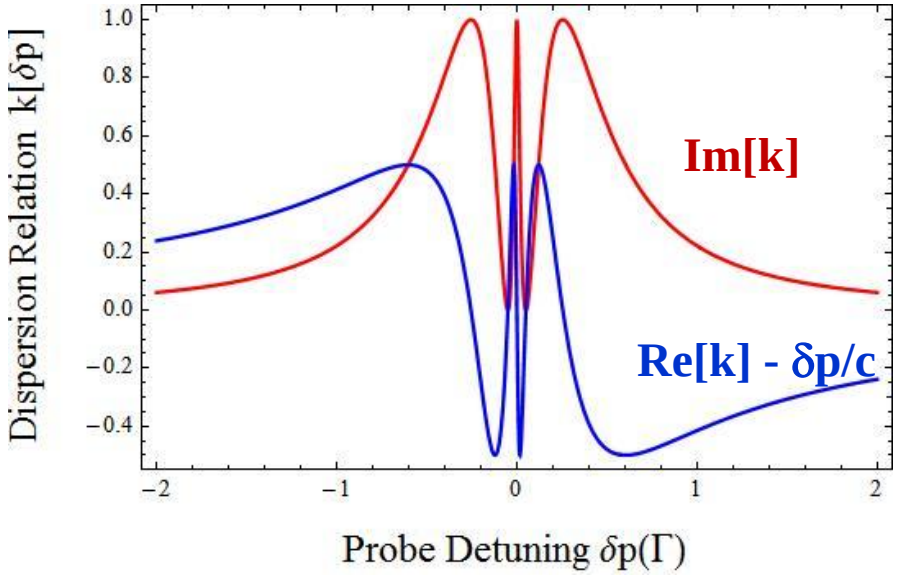


4-Level System

- **4-Level system**

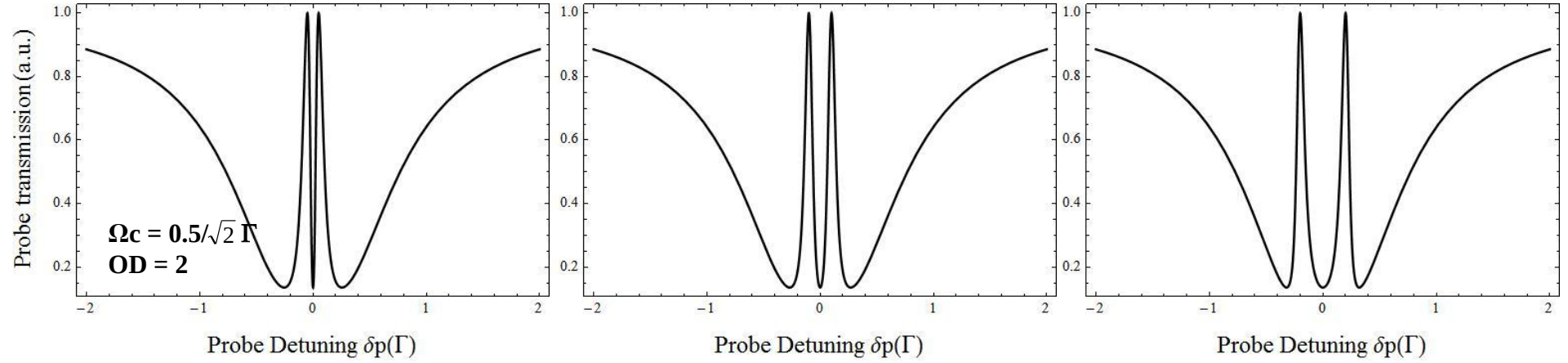


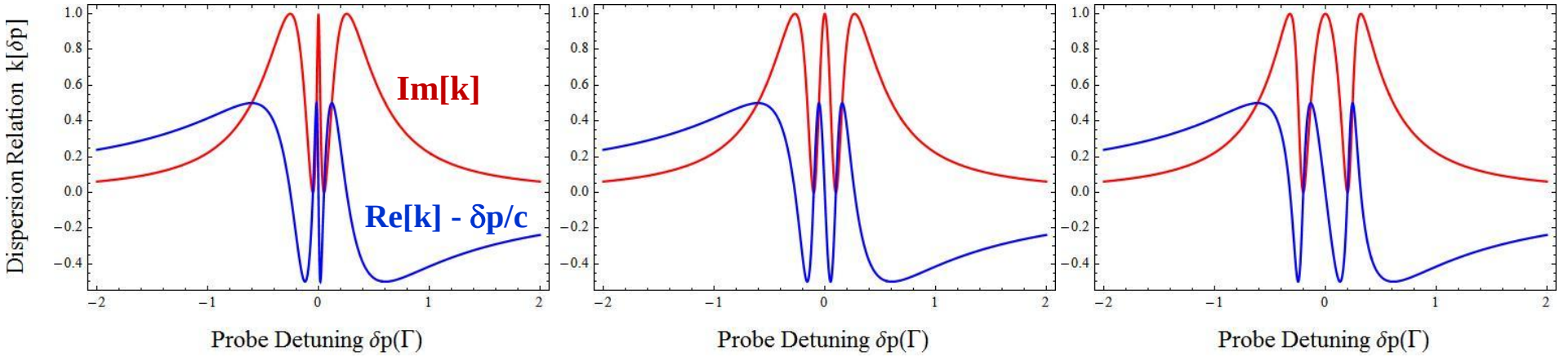




4-Level System

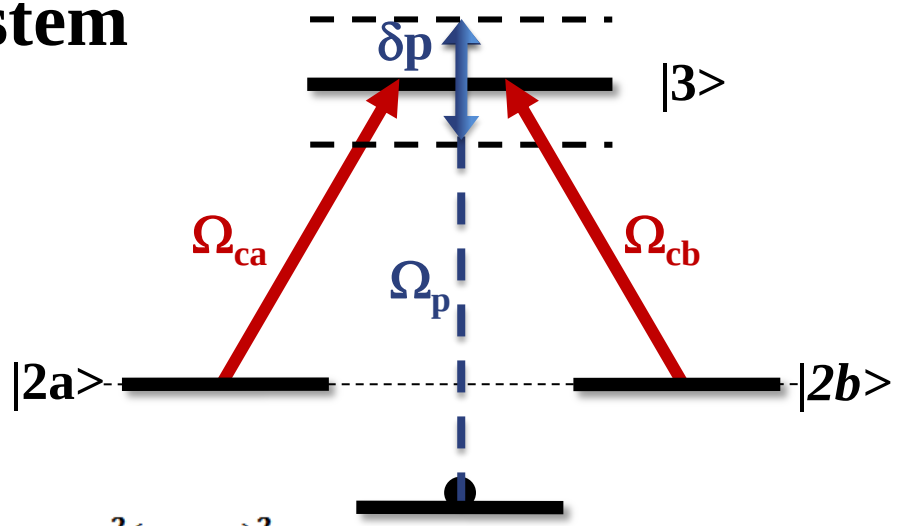
- **4-Level system: Change δc = 0.05, 0.1, 0.2 Γ**



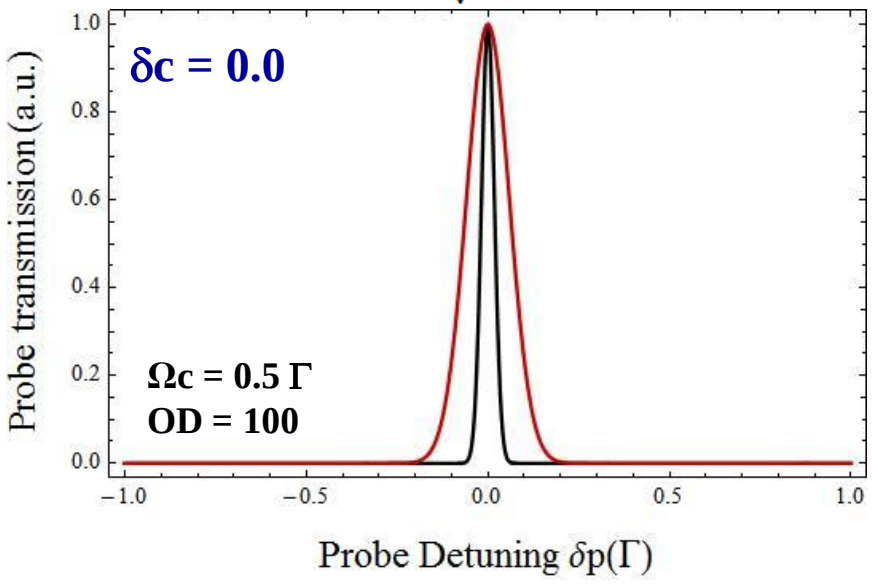


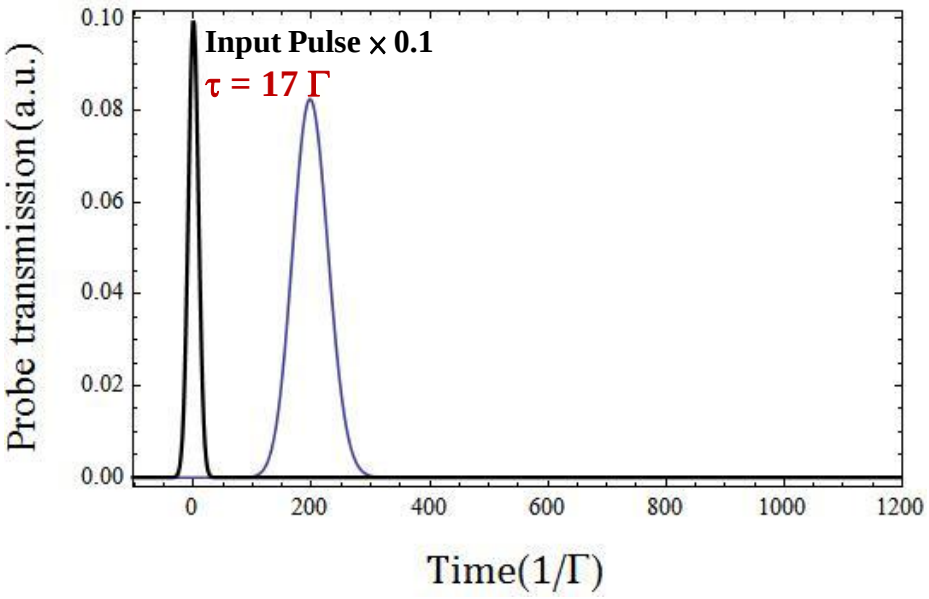
Slow Light in 4-Level System

- **4-Level system**



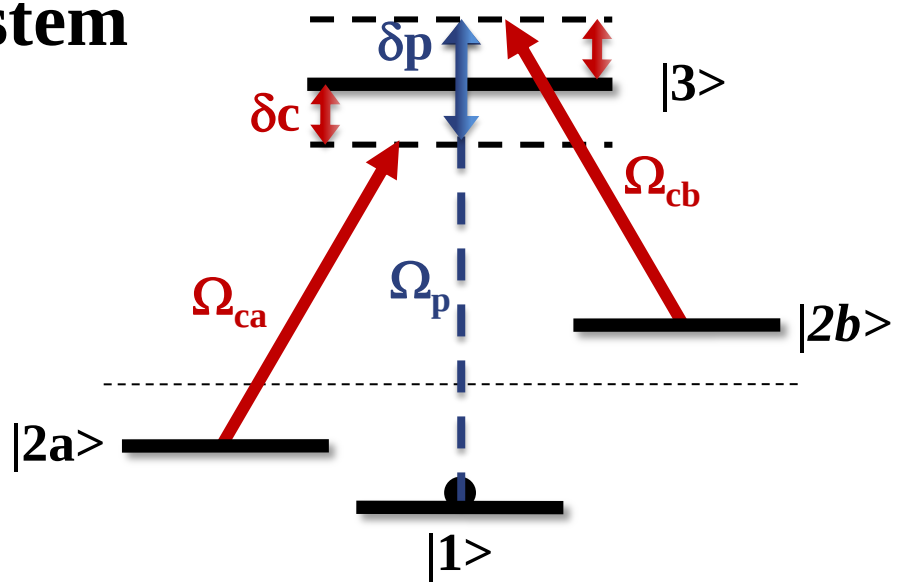
$$E(\omega) = \frac{E_0 \tau}{\sqrt{2}} e^{-\frac{\tau^2(\omega-\omega_0)^2}{4}} \quad \textit{Fourier Transform} \quad E(t) = E_0 e^{-\left(\frac{t}{\tau}\right)^2 + i\omega_0 t}$$

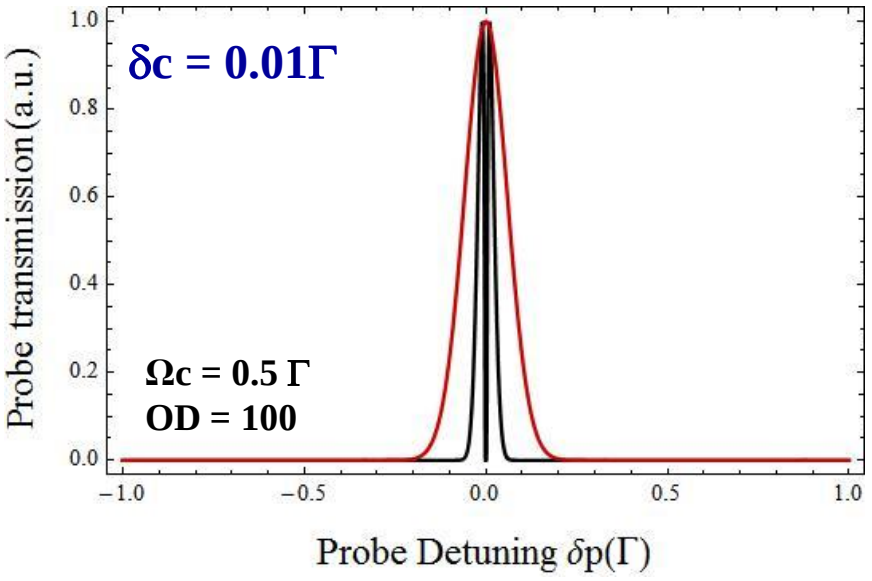


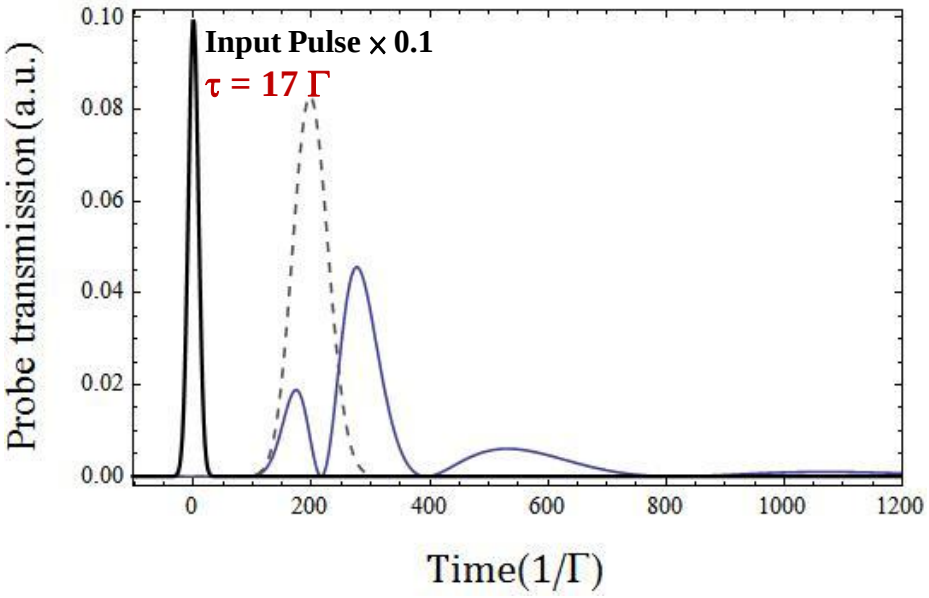


Slow Light in 4-Level System

- **4-Level system**

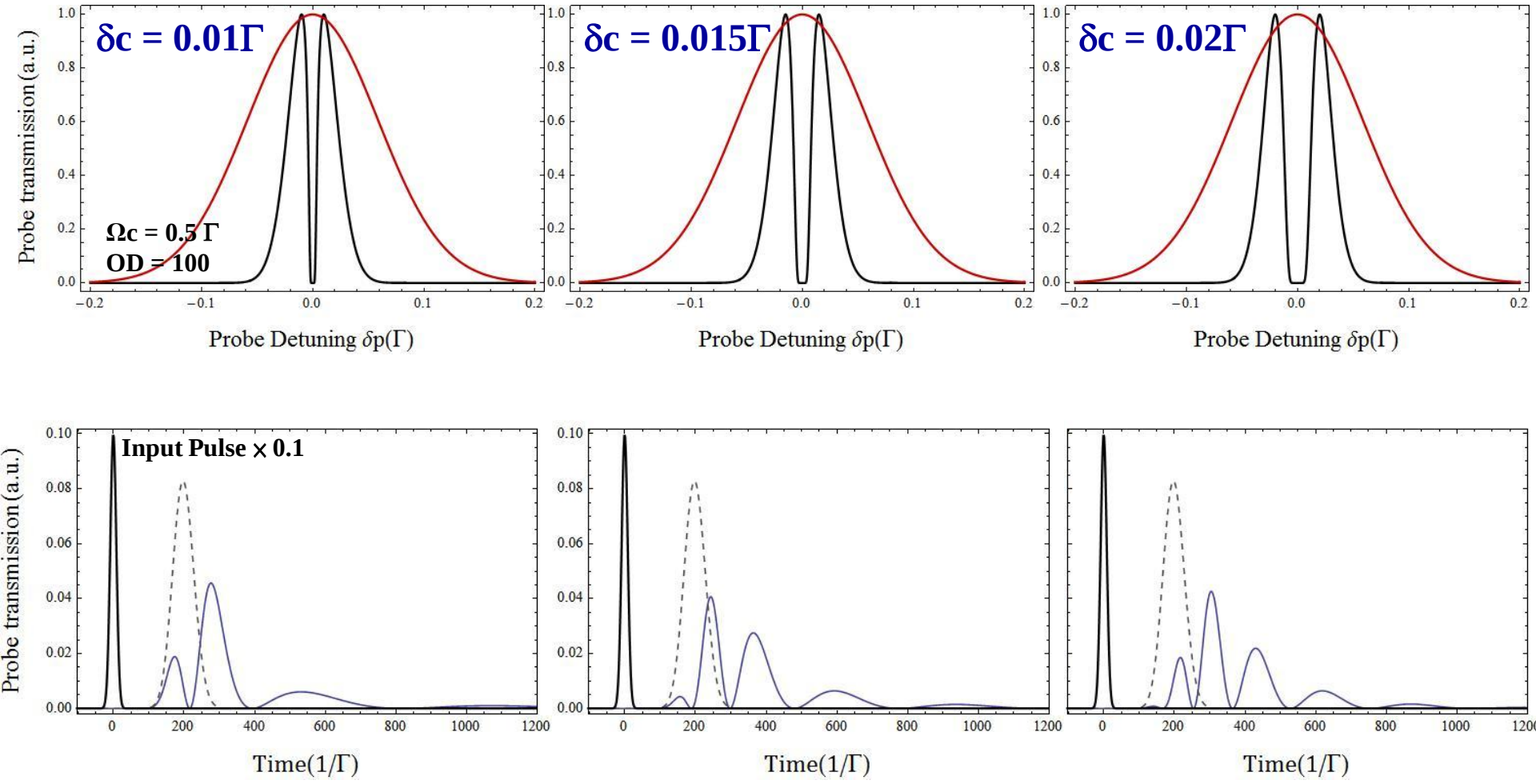






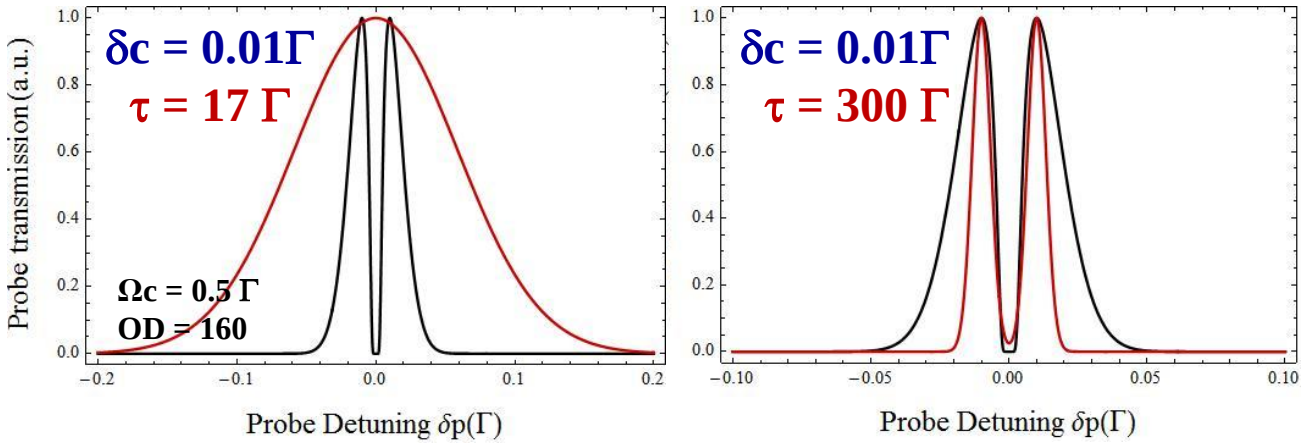
Slow Light in 4-Level System

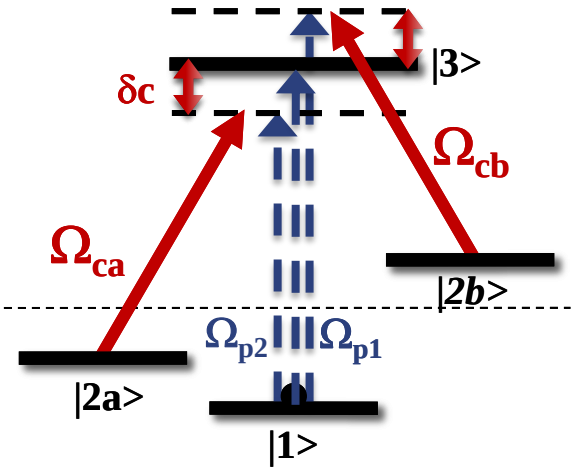
- **4-Level system: Change δc = 0.01, 0.015, 0.02 Γ**

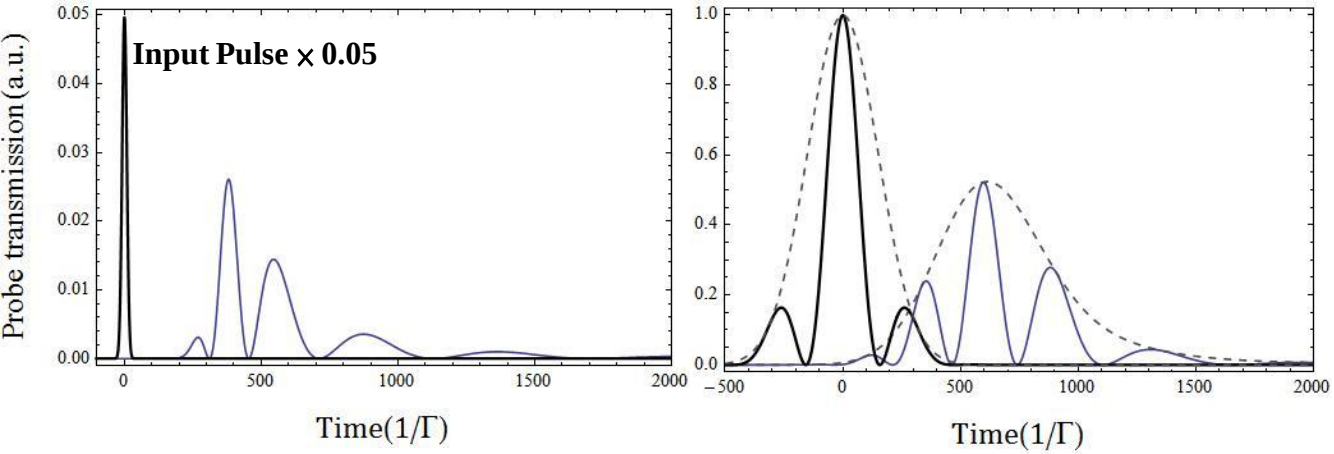


Slow Light in 4-Level System

- **4-Level system**



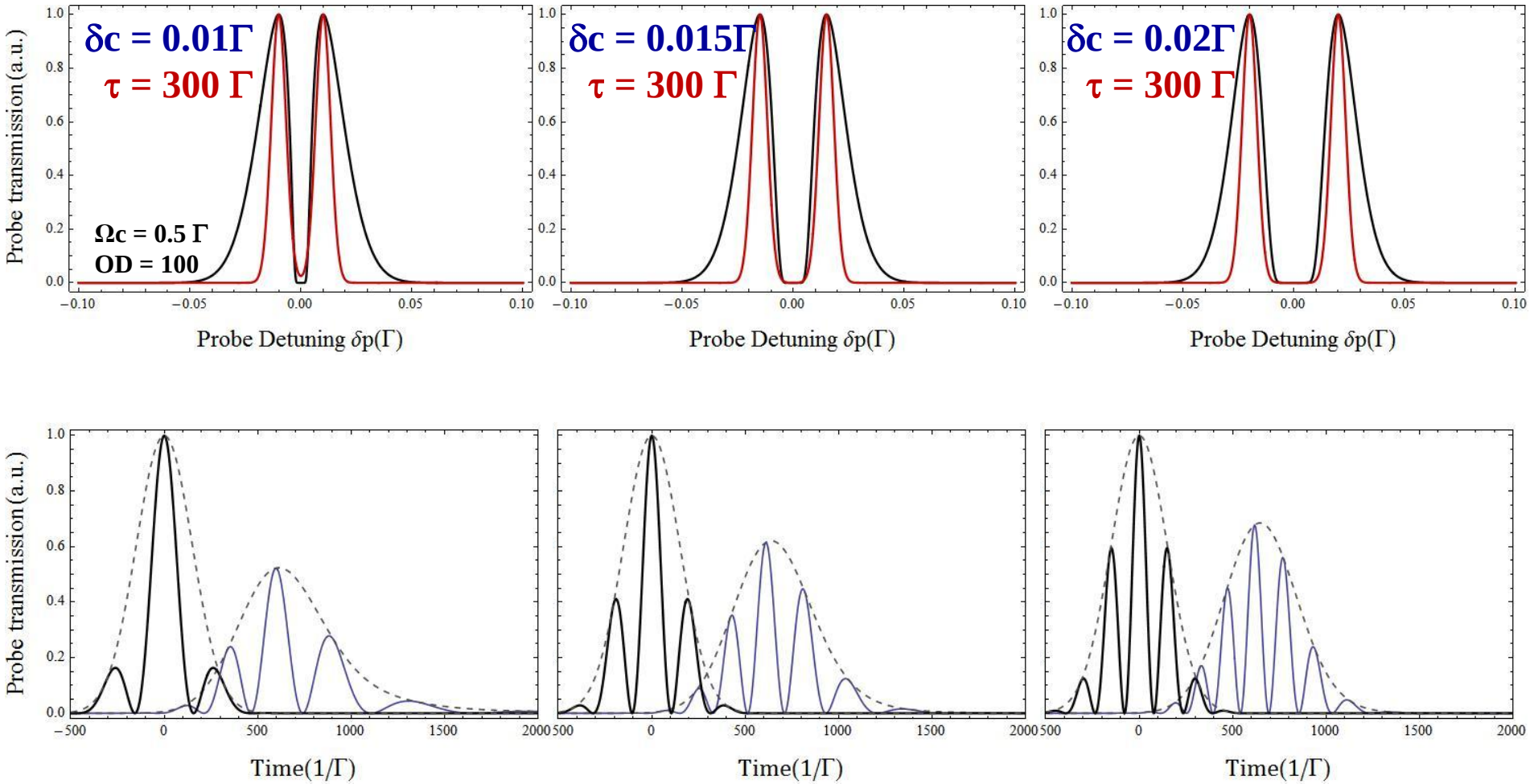




$$E(\omega) = \frac{E_0 \tau}{\sqrt{2}} e^{-\frac{\tau^2(\omega-\omega_0)^2}{4}} \quad \textit{Fourier Transform} \quad E(t) = E_0 e^{-\left(\frac{t}{\tau}\right)^2 + i\omega_0 t}$$

Slow Light in 4-Level System

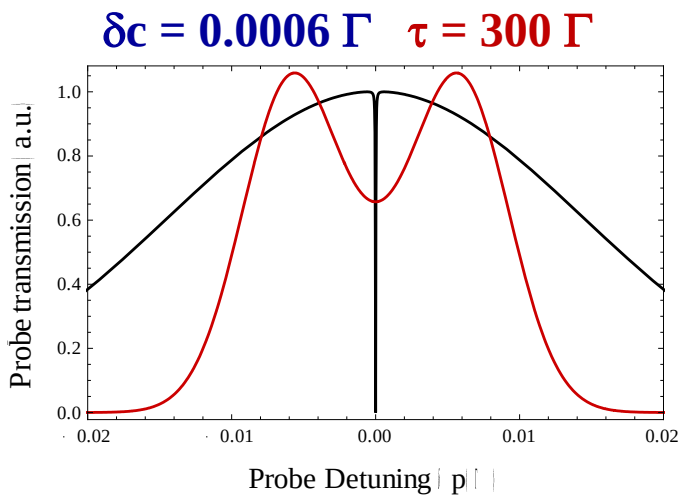
- **4-Level system: Change δc = 0.01, 0.015, 0.02 Γ**

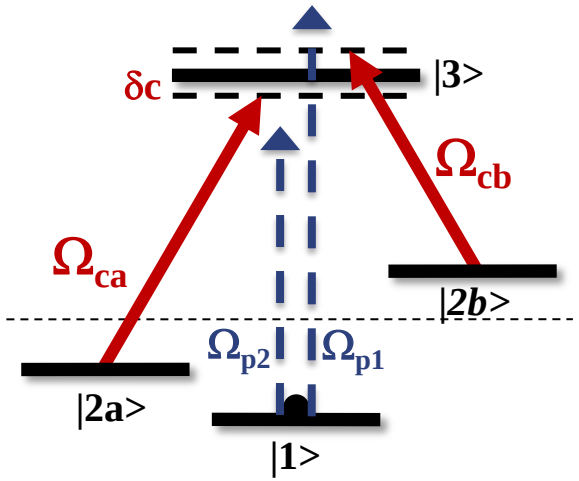


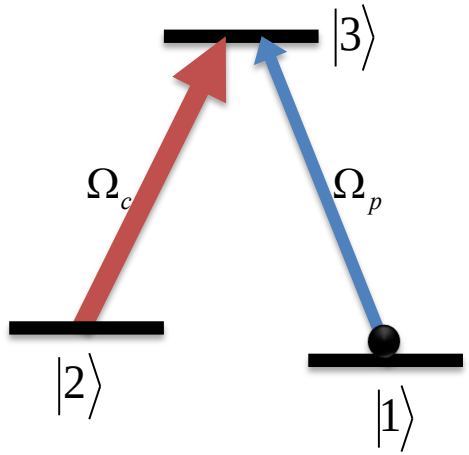
- **Multi-pulse output is due to the interference of light that lies on the two EIT windows.**
- **Separation of EIT window ↑, the number of output pulses ↑.**

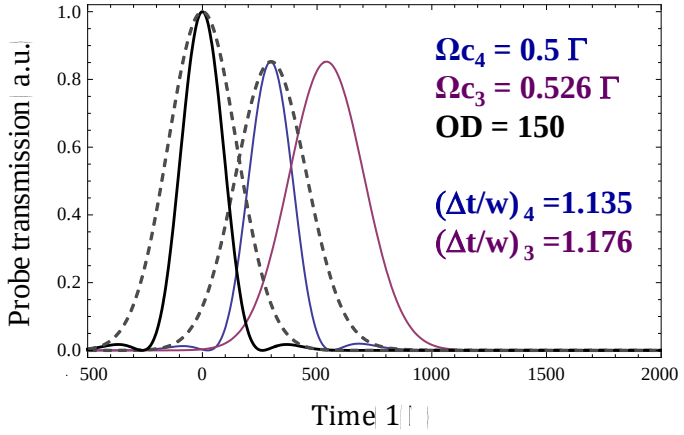
Slow Light in 3 & 4-Level System

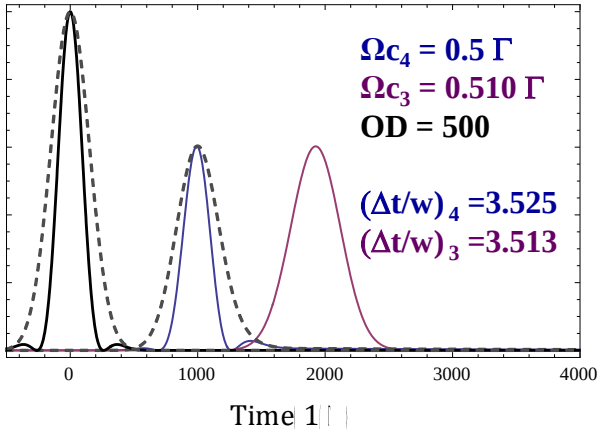
- **4-Level system: δc = 0.0006 Γ**

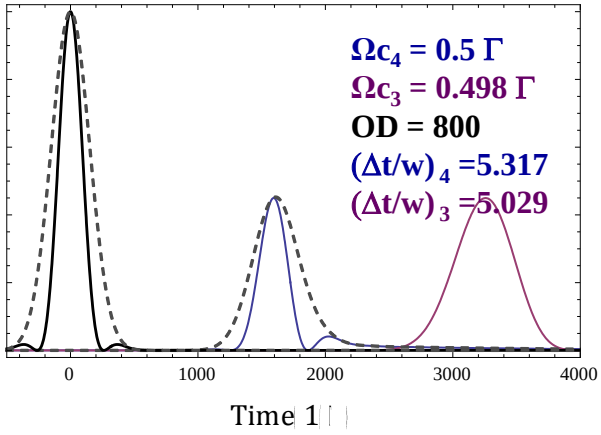








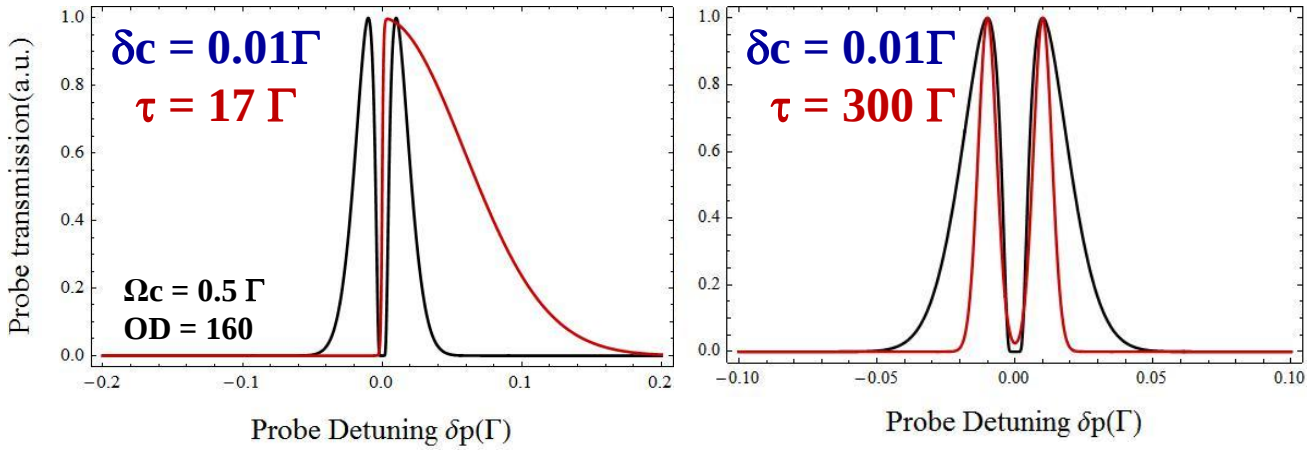


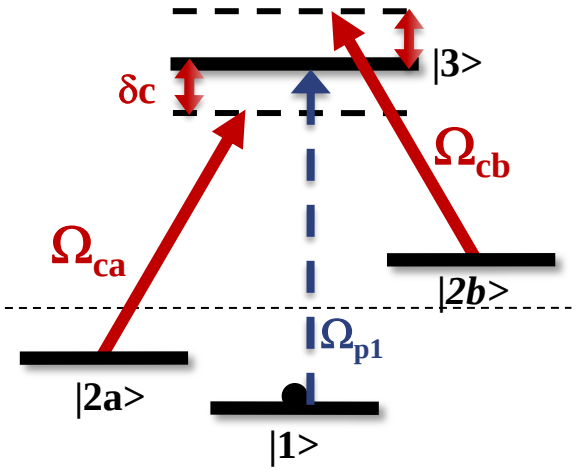


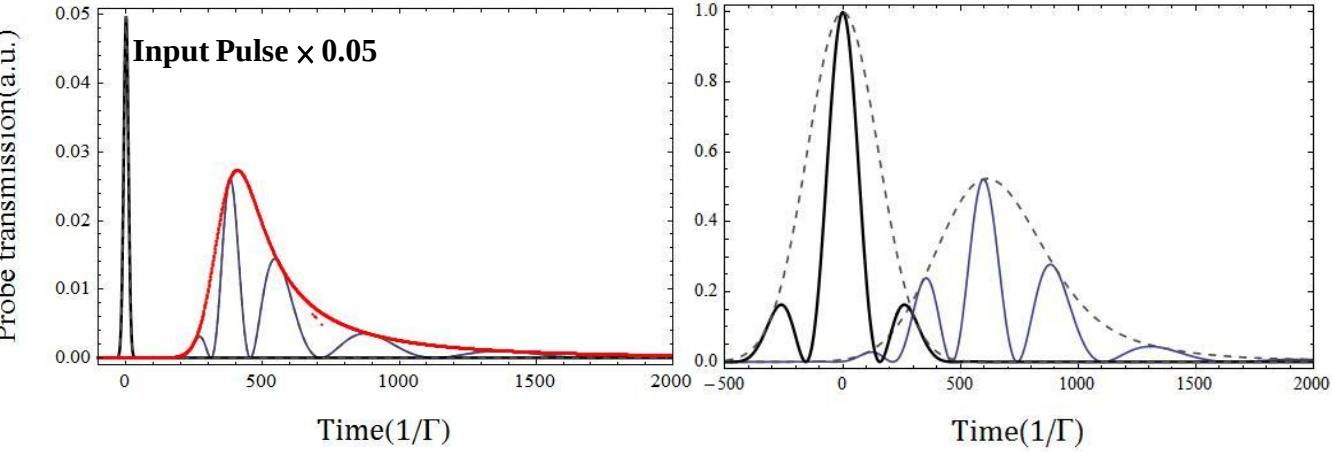
- **(Δt / w) : Ratio of delay time Δt to output pulse width w.**

Slow Light in 4-Level System

- **4-Level system**

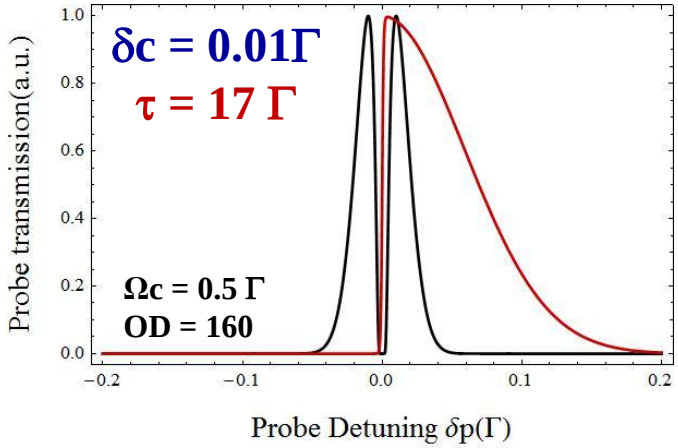


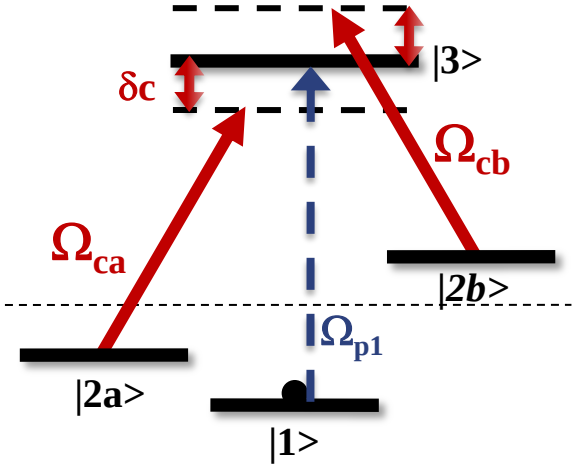


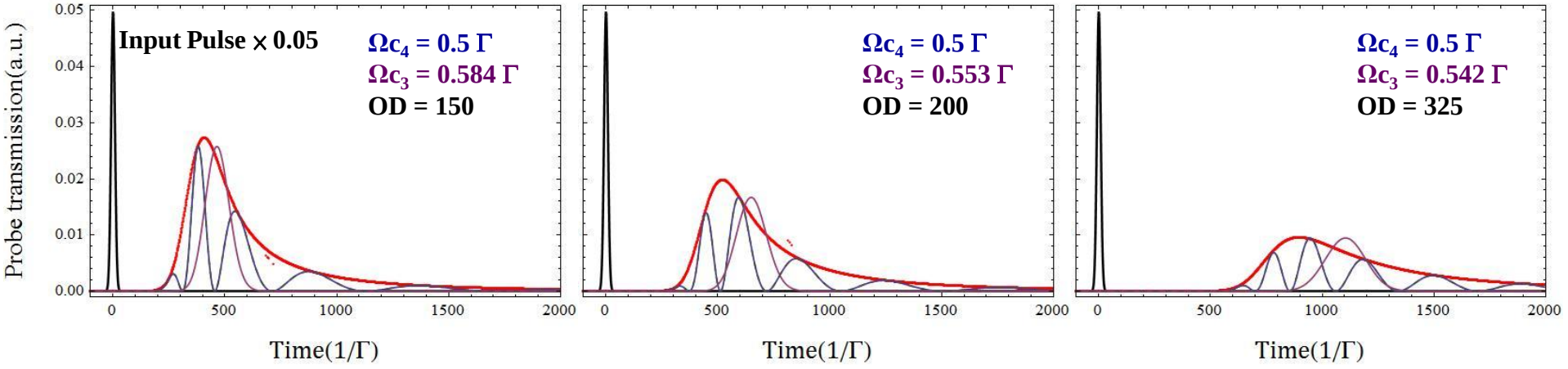


Slow Light in 4-Level System

- **4-Level system**







Summery

- **Slow Light in 3-Level system**
  - **In a EIT system, the probe beam can be transparent due to quantum interference at certain frequency.**
  - **The reduction of group velocity is due to a large variation in linear dispersion within the EIT window.**
  - **Delay time is proportional to $OD/\Omega c^2$**

- **Slow Light in 4-Level system**
  - **We can tune the location of two EIT windows by changing the coupling detuning.**
  - **Multi-pulse output comes from the interference of light that lies on the two EIT windows.**
  - **It help us to identify the underlying mechanism of 2 pulses slow light with different group velocities in the 13-level system with $B_{\perp}$.**

Thank you for your attention !