Storage and Retrieval of Photonic Information

— from Electromagnetically Induced Transparency to Reduce of the Light Speed

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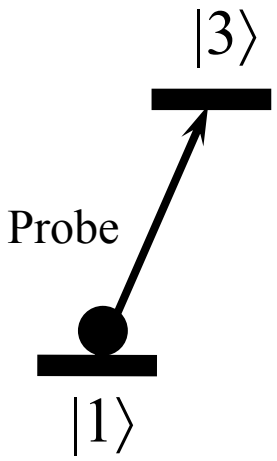
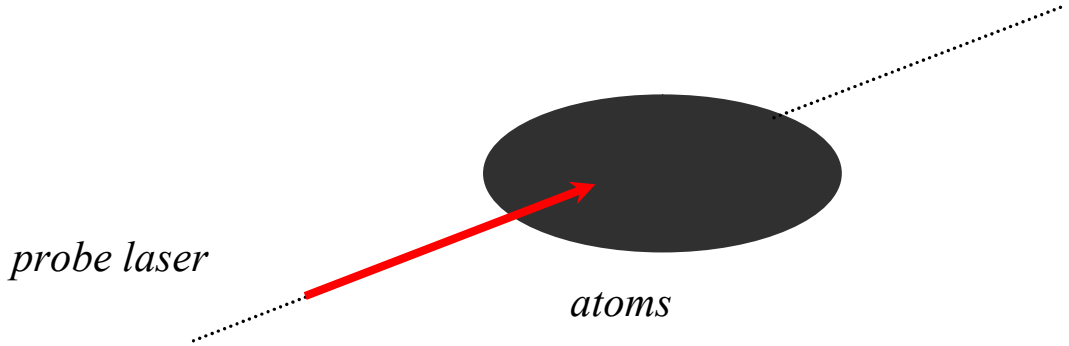
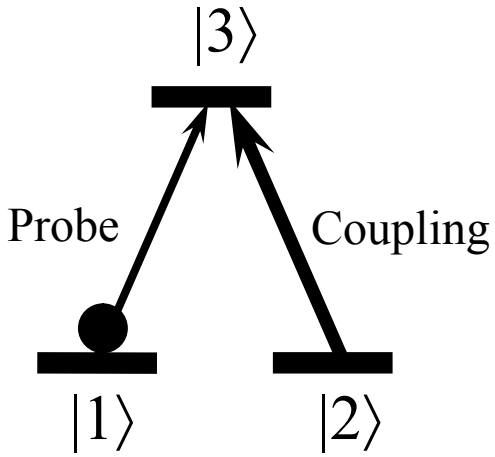
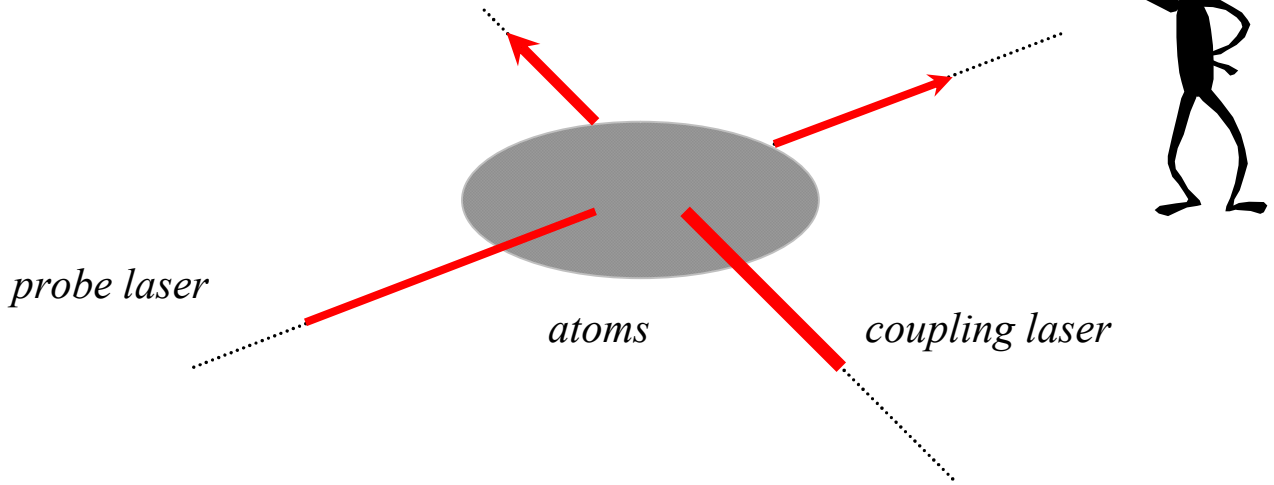
The Phenomenon of Electromagnetically Induced Transparency (EIT)

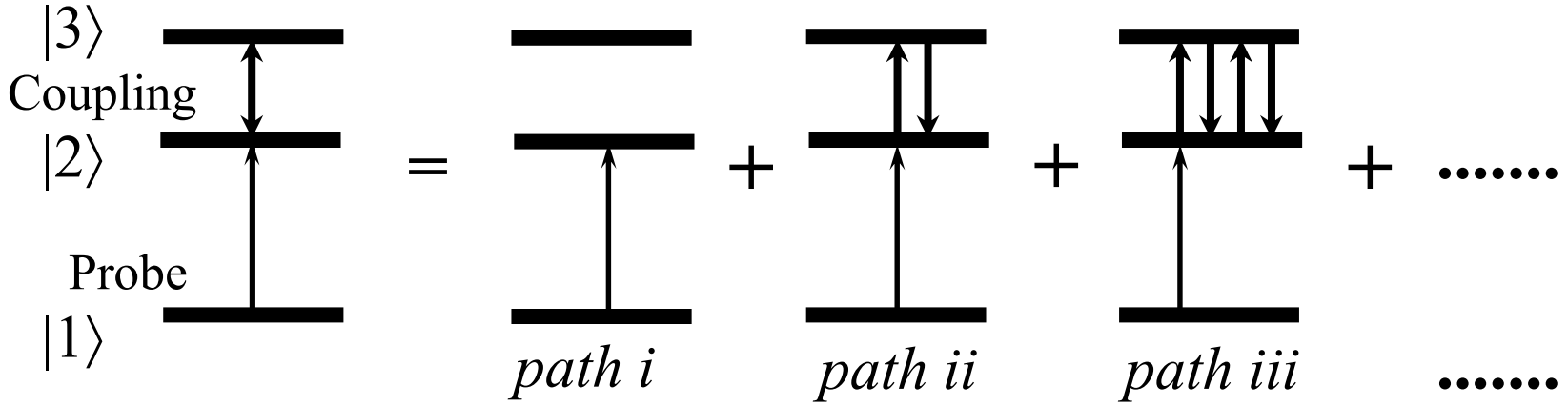








Quantum Interference



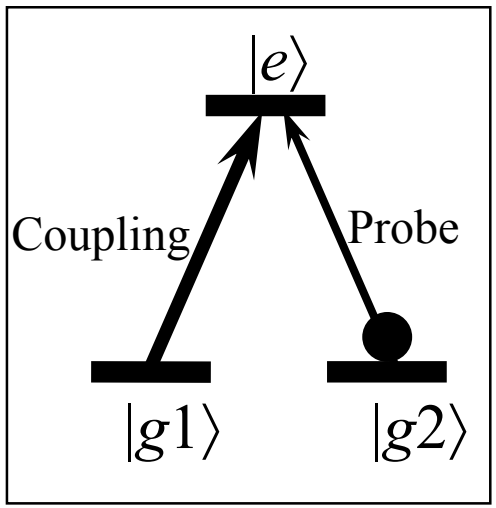
Transition amplitudes: A_i A_{ii} A_{iii} .....

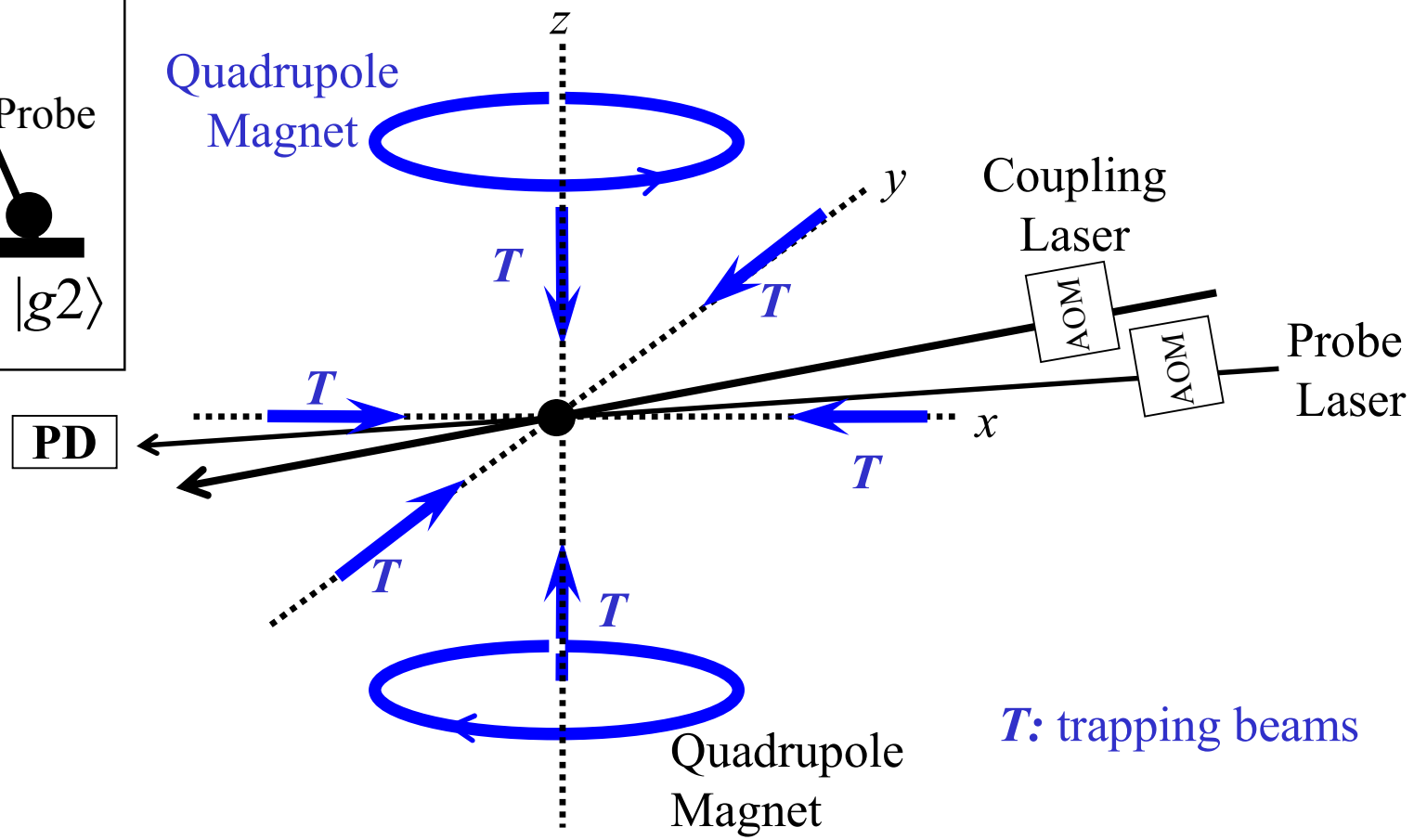
Transition probability of $|1\rangle \rightarrow |2\rangle = |A_i + A_{ii} + A_{iii} + \cdots\cdots|^2$

EIT is the destructive interference between A_i, A_{ii}, A_{iii}, ...

$\Rightarrow$ The probe absorption is suppressed.

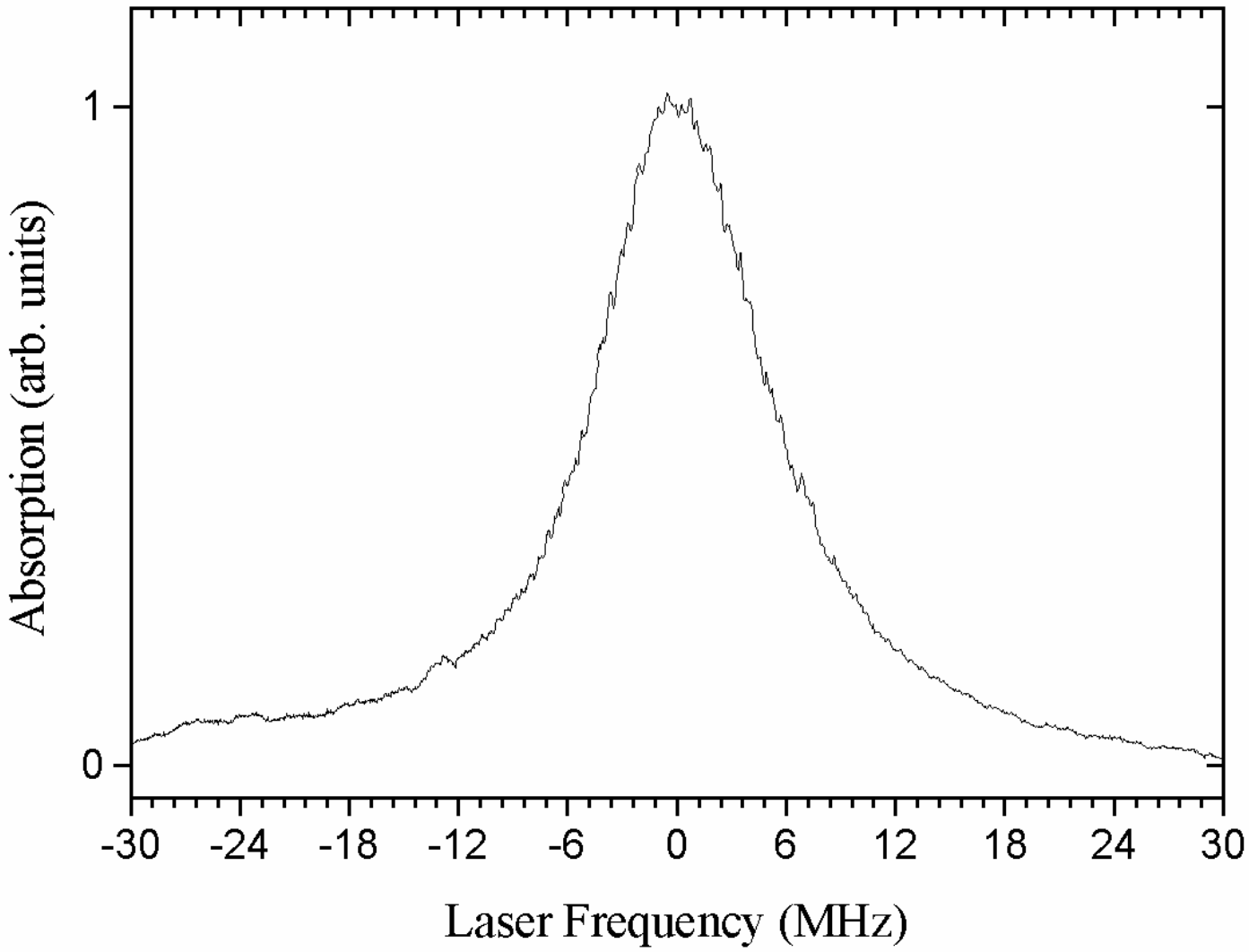
Experimental Setup



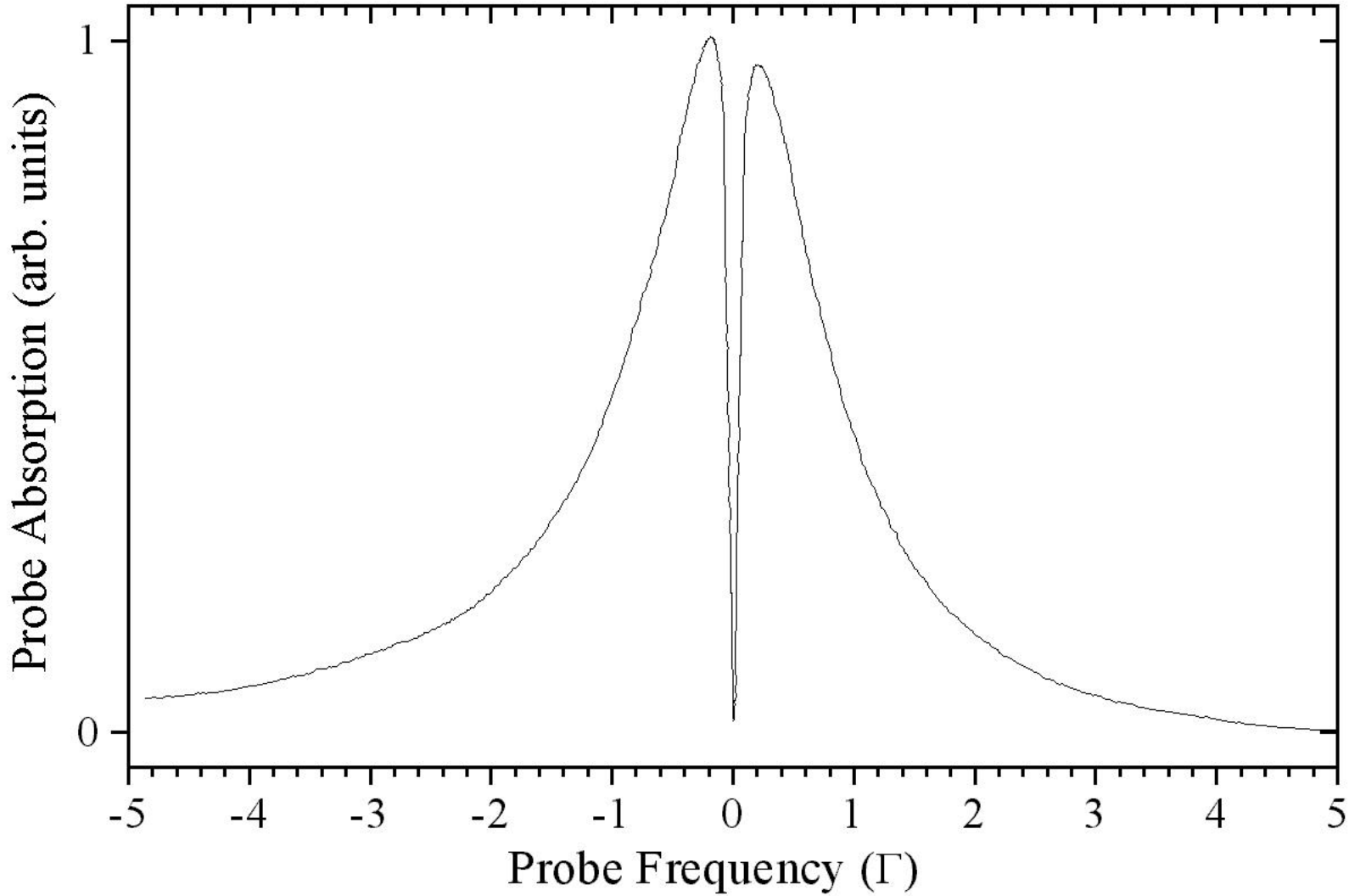


- Typically, we trap 10^9 ^{87}Rb atoms in the vapor-cell MOT.
- The probe and coupling fields propagate nearly in the same direction and they are switched by AOMs individually.

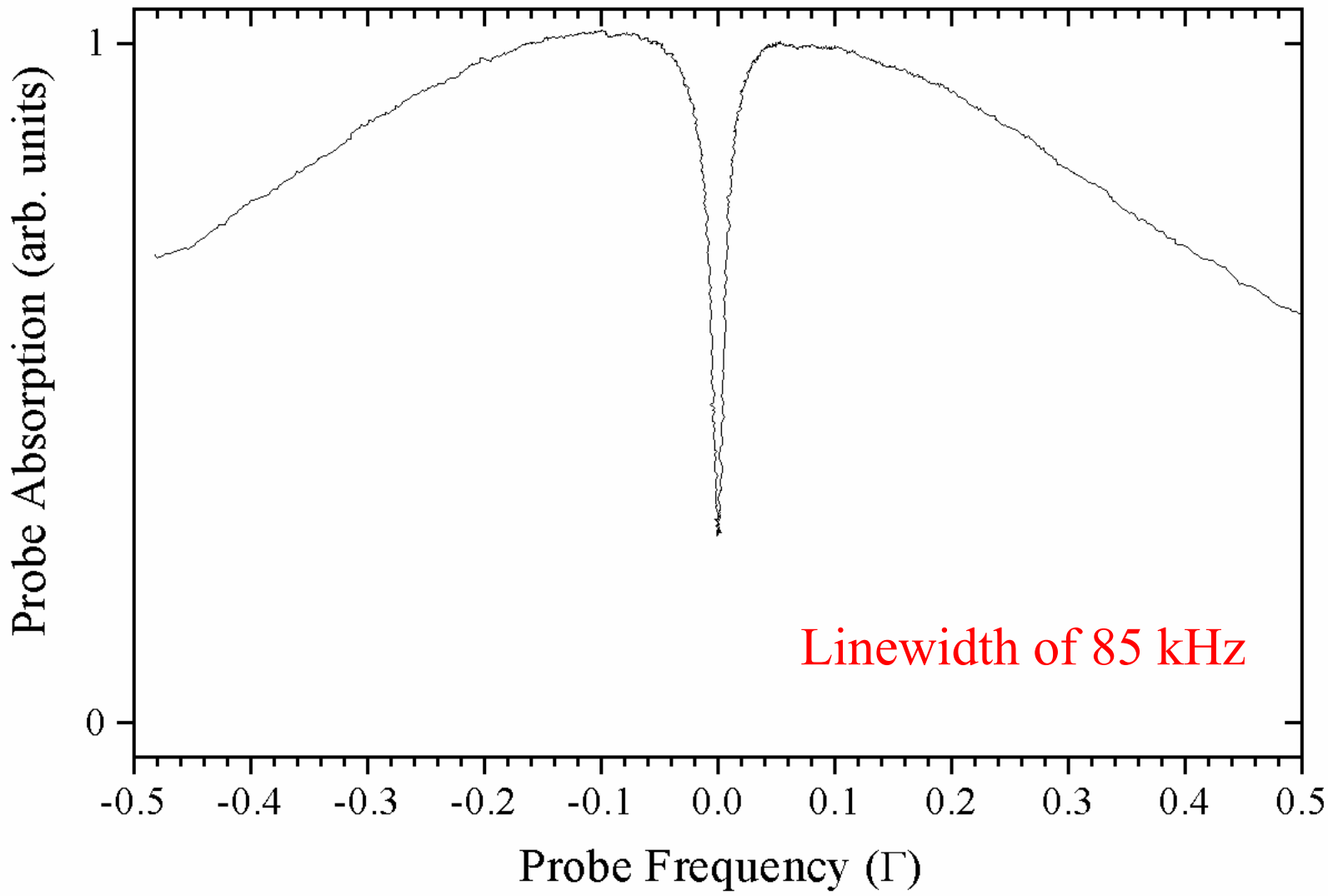
Experimental Spectrum without the Coupling Laser



Experimental Spectrum of 100% Transparency

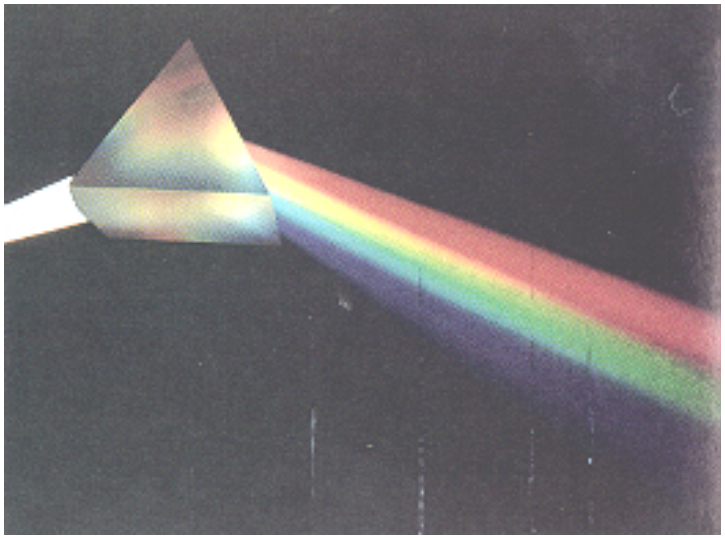


Narrow and High-Contrast EIT Window

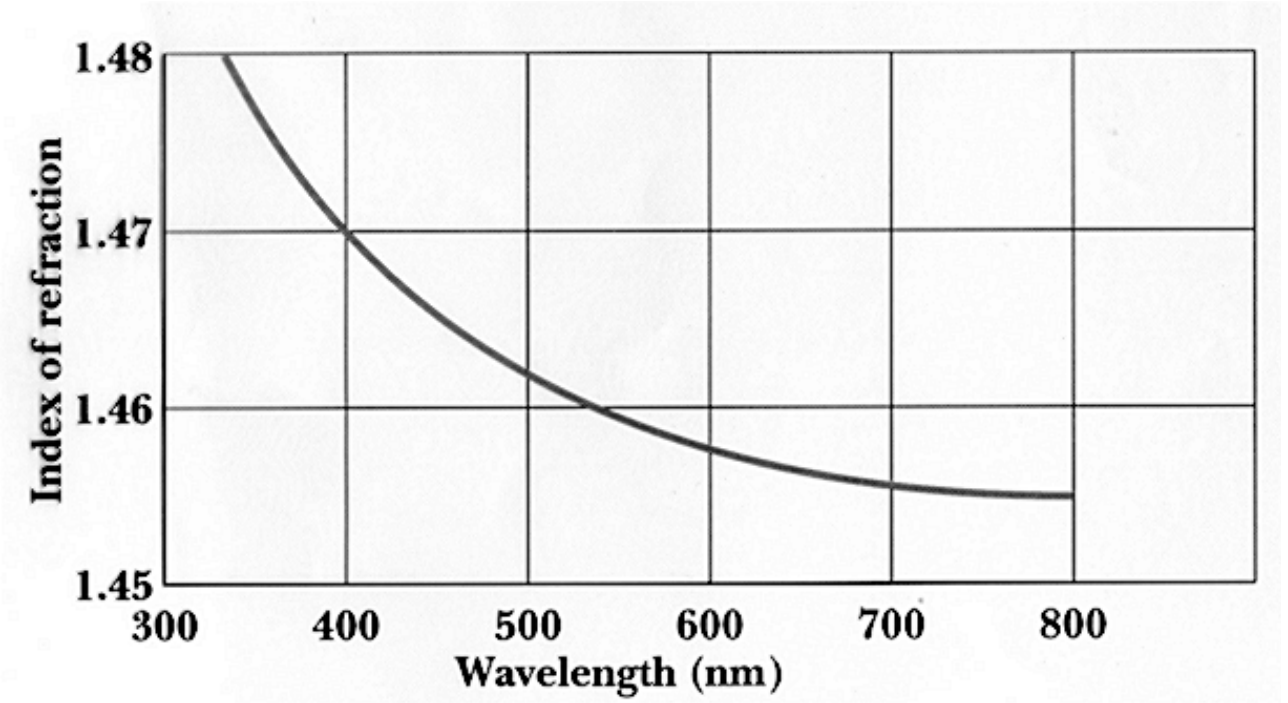


L. V. Hau, S. E. Harris, Z. Dutton, and C. H. Behroozi, “Light speed reduction to 17 metres per second in an ultracold atomic gas,” *Nature* 397, 594-598 (18 February 1999).

Chromatic Dispersion



$$k = n\frac{\omega}{c}, \quad v_g = \frac{d\omega}{dk} = \frac{1}{\frac{dk}{d\omega}} = \frac{1}{\frac{n}{c} + \frac{\omega}{c}\frac{dn}{d\omega}} = \frac{c}{n + \omega\frac{dn}{d\omega}}$$



The index refraction of fused quartz. $\omega \dfrac{dn}{d\omega} \approx 0.01$

The Optical Bloch Equation

$$\frac{d\hat{\rho}}{dt} = \frac{1}{i\hbar}\left[H_0 + H_c + H_p, \hat{\rho}\right] + \left\{\frac{d\hat{\rho}}{dt}\right\}$$

$\hat{\rho}_{31}(t) = \rho_{31}(t)\, e^{-i\omega_p t}$, where $\hat{\rho}$ is the slowly-varying part of ρ.

- Solve the optical Bloch equation to obtain the optical coherence of the probe transition. $(I_{\text{out}} = I_{\text{in}}\, \mathrm{e}^{-OD})$

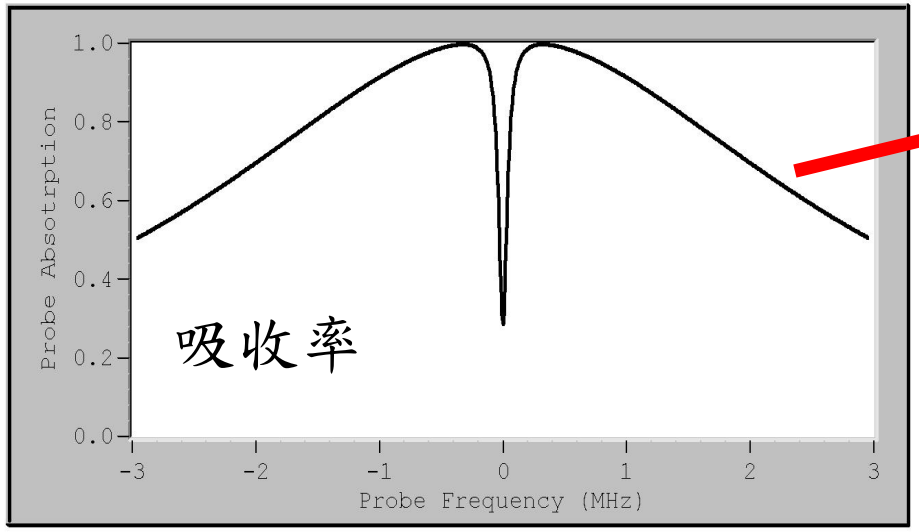
$$\Rightarrow \quad OD = N\,L\,(3\lambda^2/2\pi)\,Im[\rho_{31}]\,(\Gamma/\Omega_p),$$

$$n = 1 + N\,(3\lambda^3/8\pi^2)\,Re[\rho_{31}]\,(\Gamma/\Omega_p),$$ where N is atomic density.

- T_D calculated from the phase shift induced by the refractive index, n, of the medium.

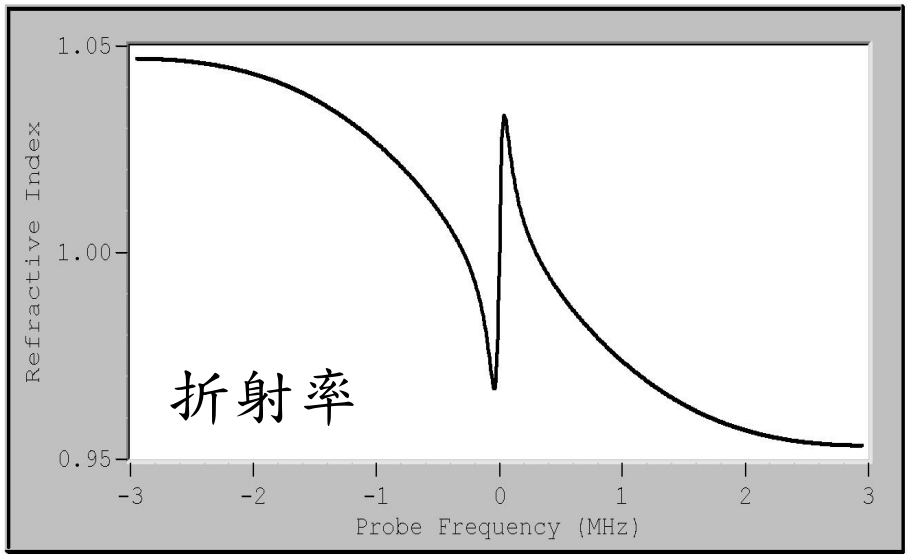
$$\Rightarrow \quad T_D = \frac{\partial}{\partial\omega_p}\left(\frac{2\pi}{\lambda}\, n\, L\right).$$

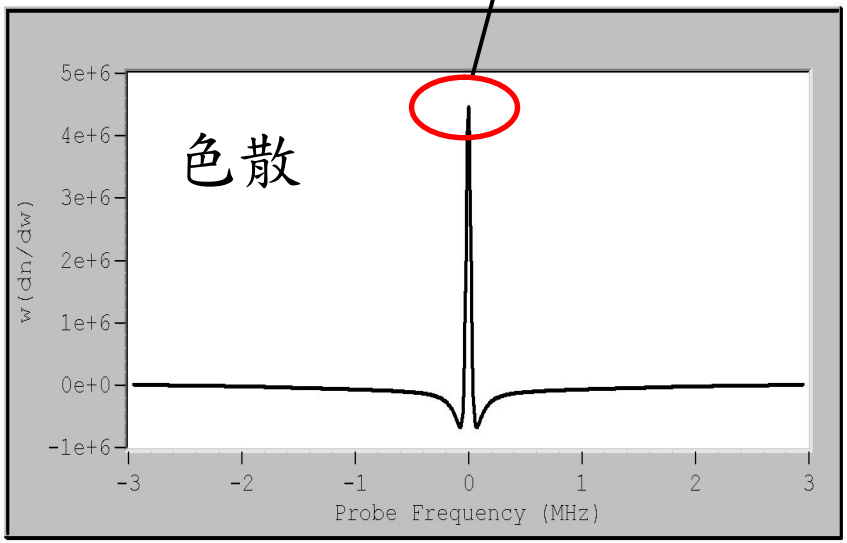
Group Velocity



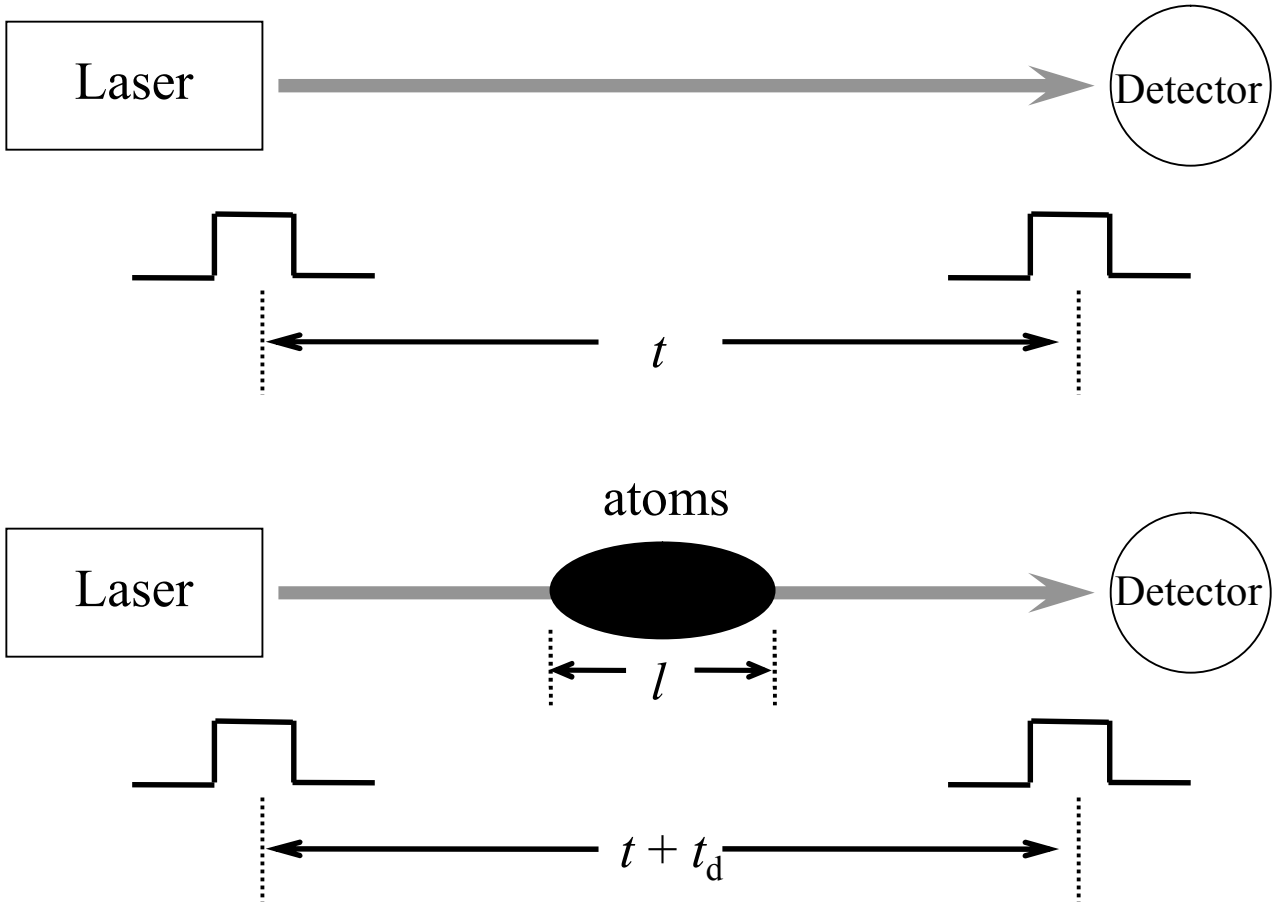
Determine $\gamma = 0.002\Gamma$

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



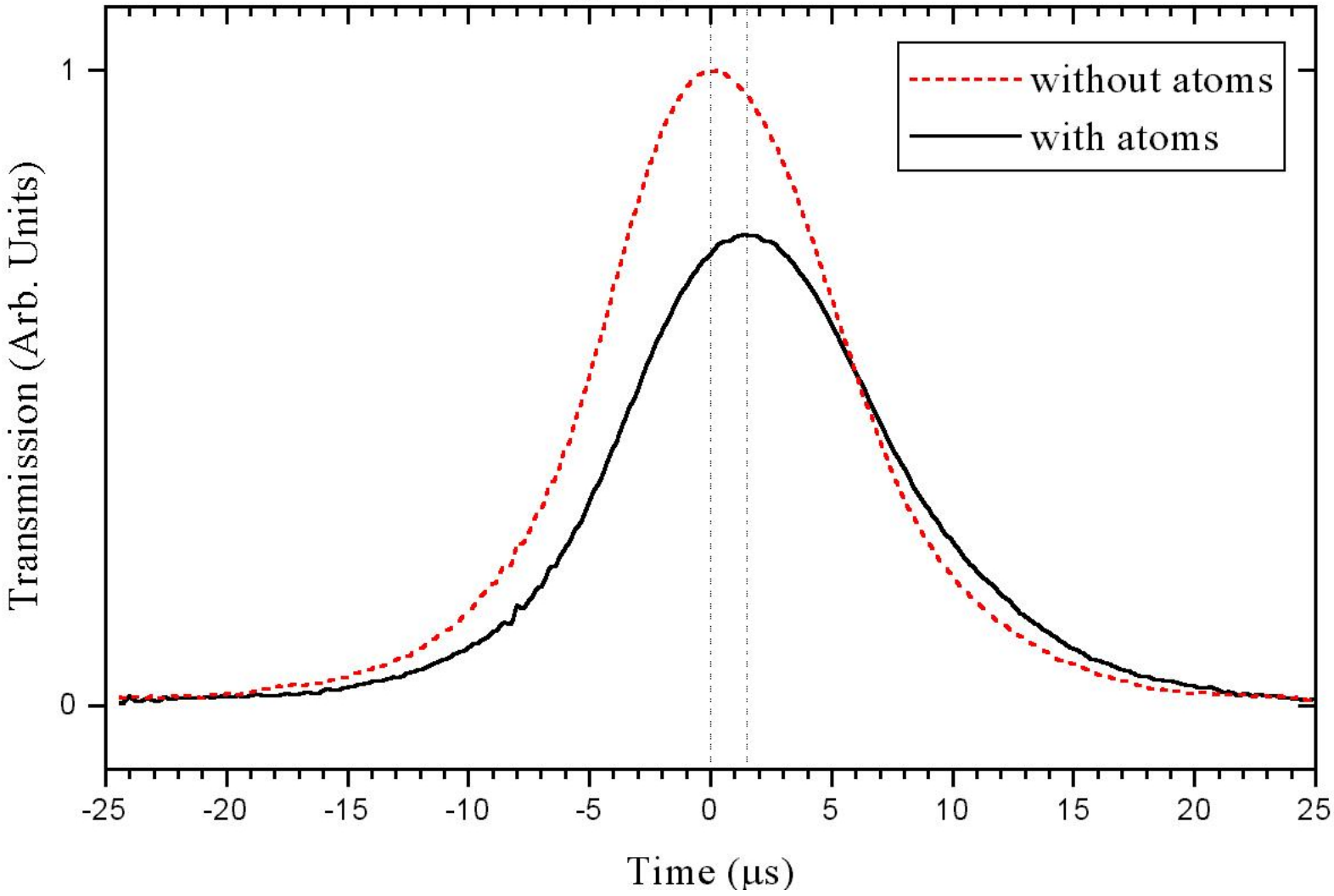


Measure Light Speed in a Medium



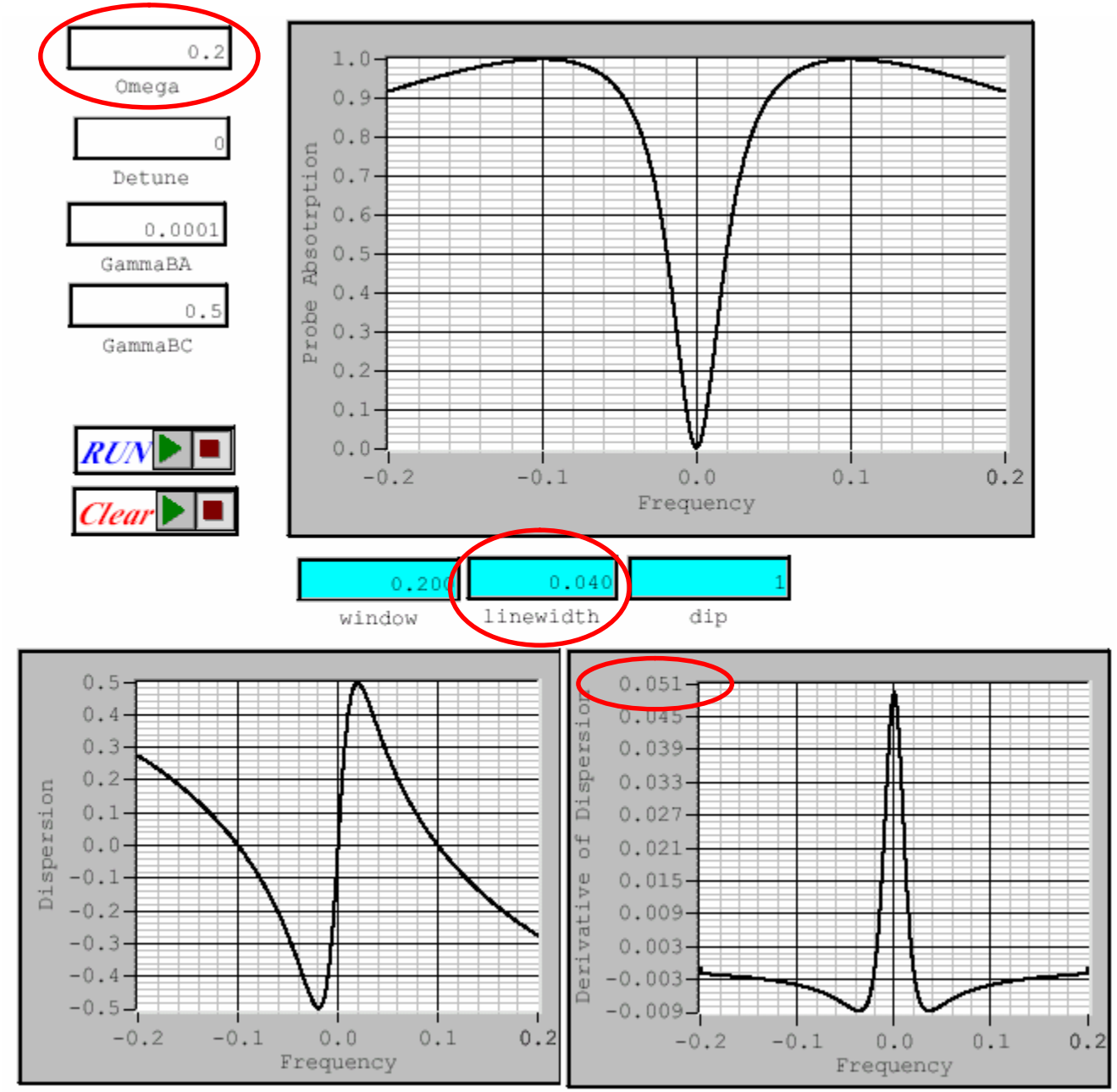
$$v \approx l / t_d$$

Reduction of the Light Speed due to EIT

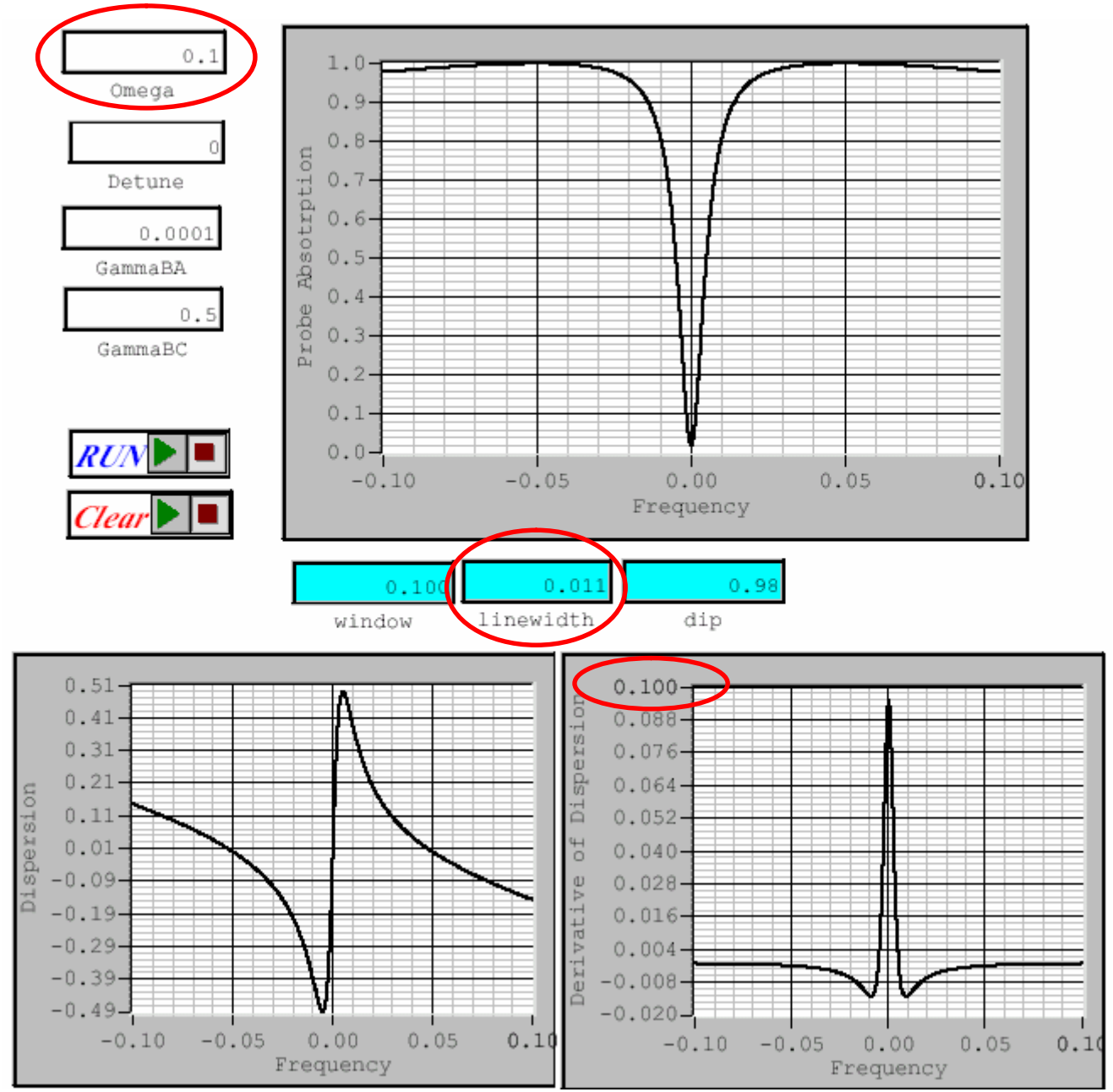


Length of the atom cloud ≈1 mm and delay time ≈ 1.5 μs ⇒ 600 m/s

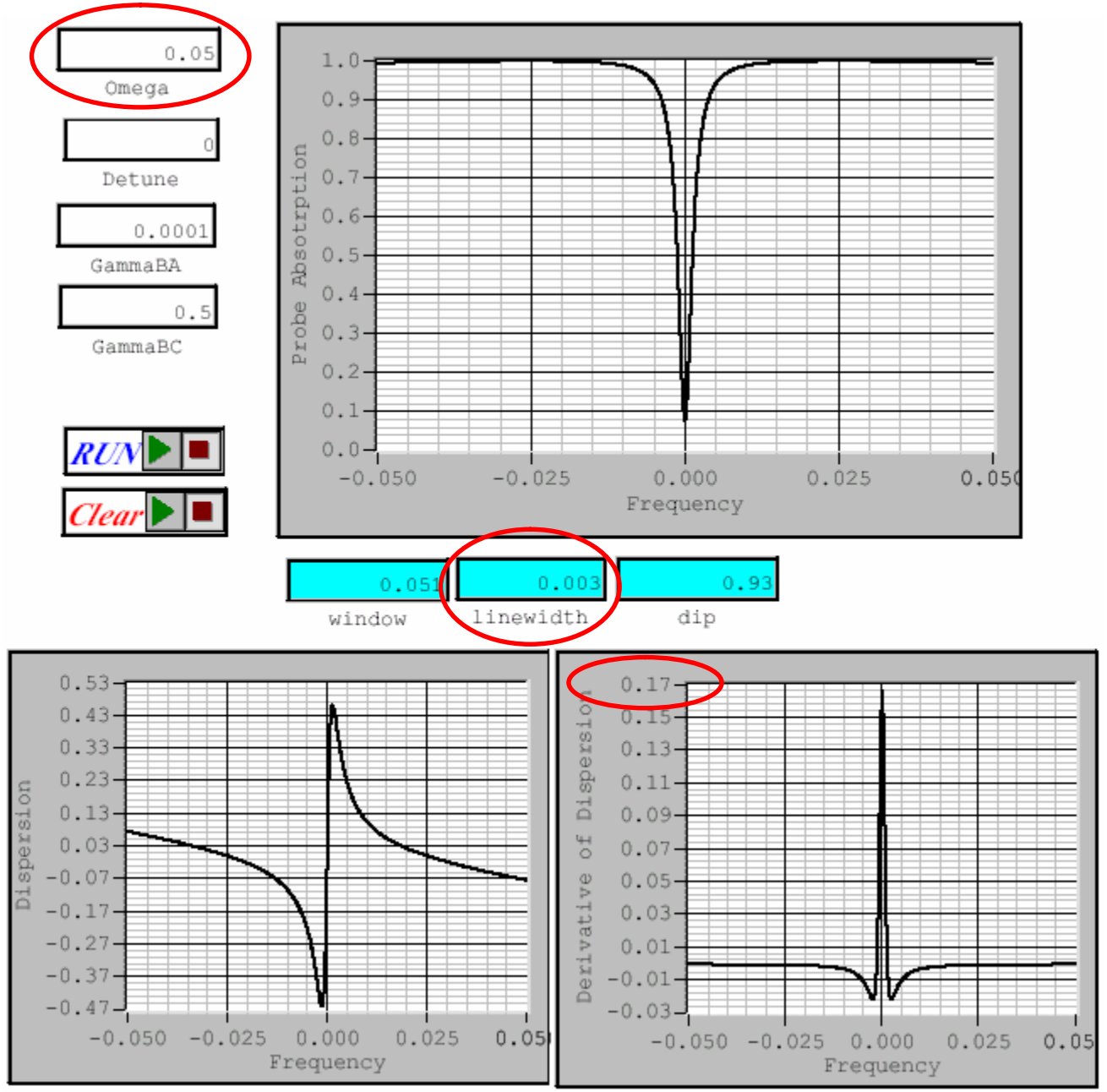
Storage of Light Pulses (1/3)



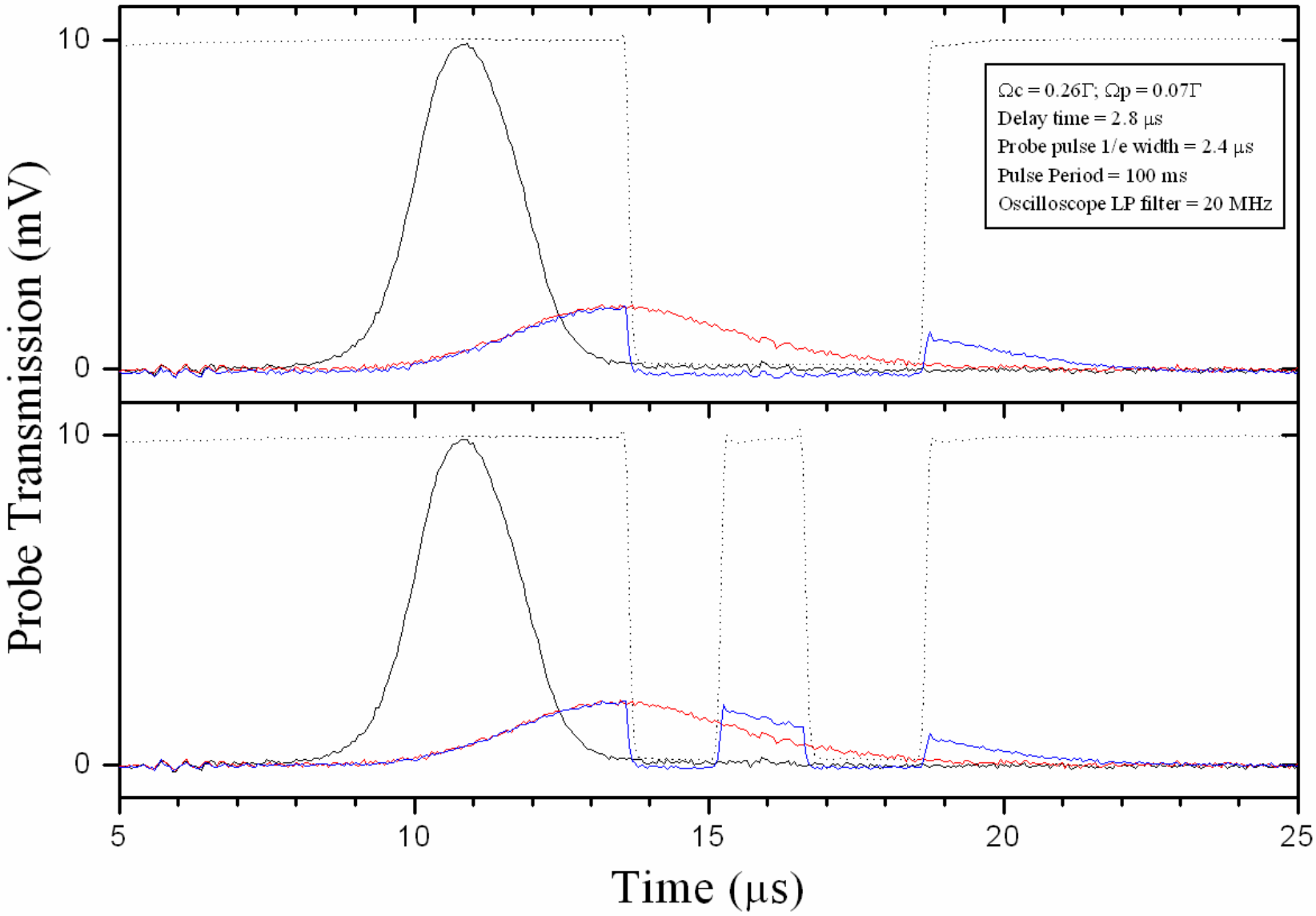
Storage of Light Pulses (2/3)



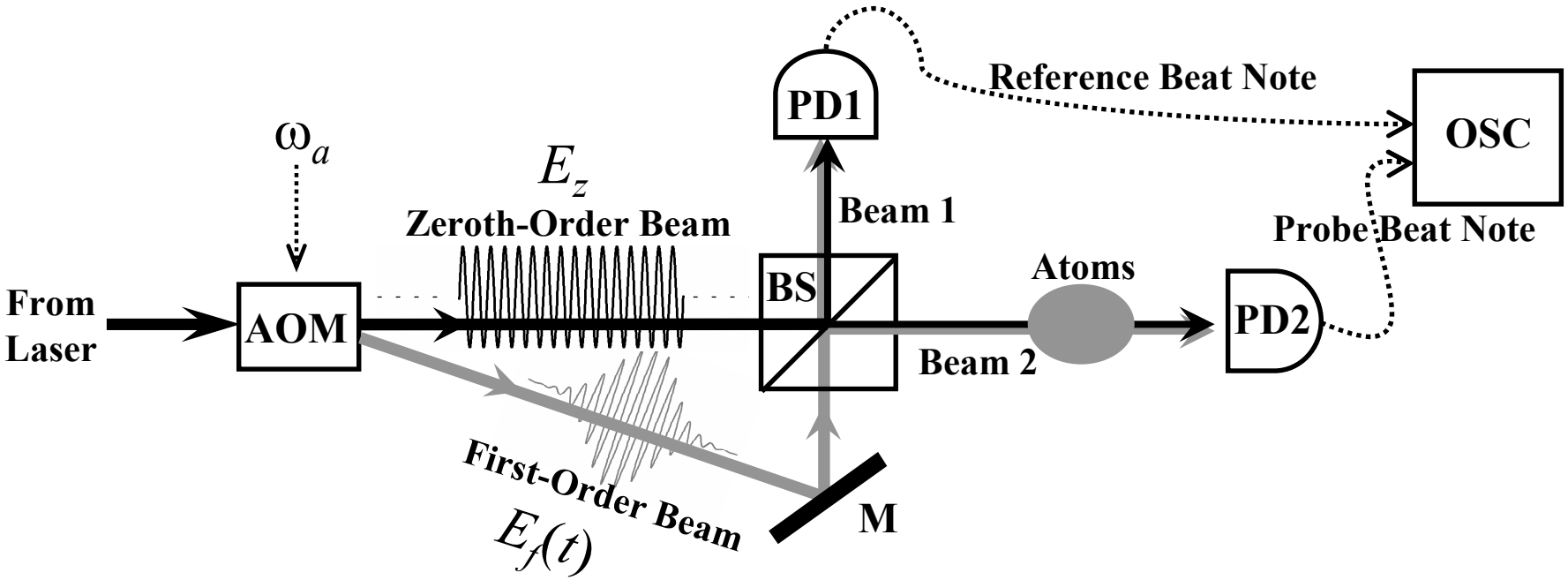
Storage of Light Pulses (3/3)



Storage and Retrieval of Light Pulses



The Beat-Note Interferometer

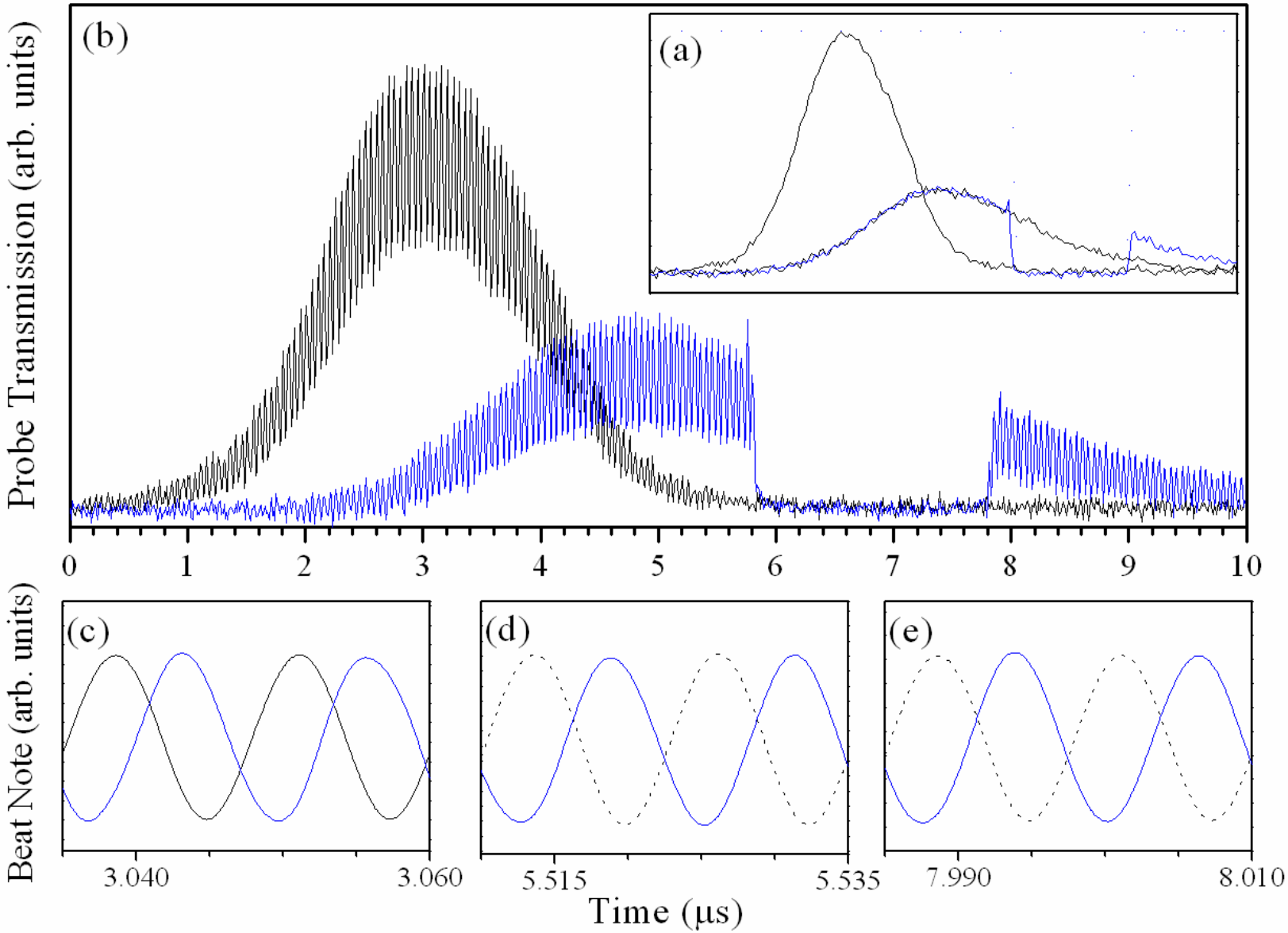


Reference Beat Note: $E_z^2 + E_f(t)^2 + 2E_z E_f(t) \cos(\omega_a t + \varphi_r)$

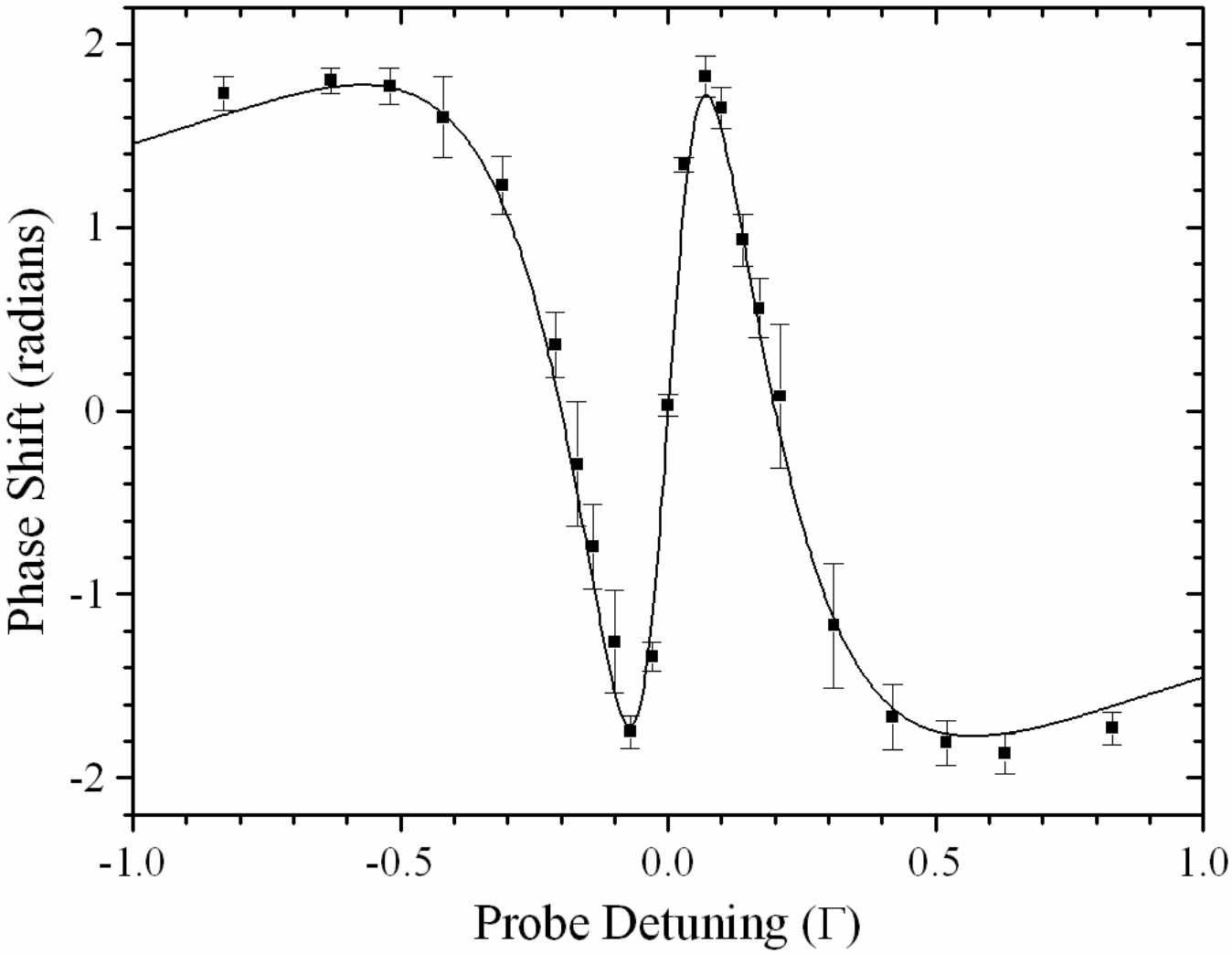
Probe Beat Note: $E_z^2 + E_f(t)^2 + 2E_z E_f(t) \cos(\omega_a t + \varphi_p + \Delta\varphi)$

- φ_r and φ_p are the phases that result from the optical paths, the AOM switching, or other factors.
- $\Delta\varphi$ is the phase shift induced by the atoms.
- Although φ_r and φ_p vary from one pulse to another, their difference is always fixed.

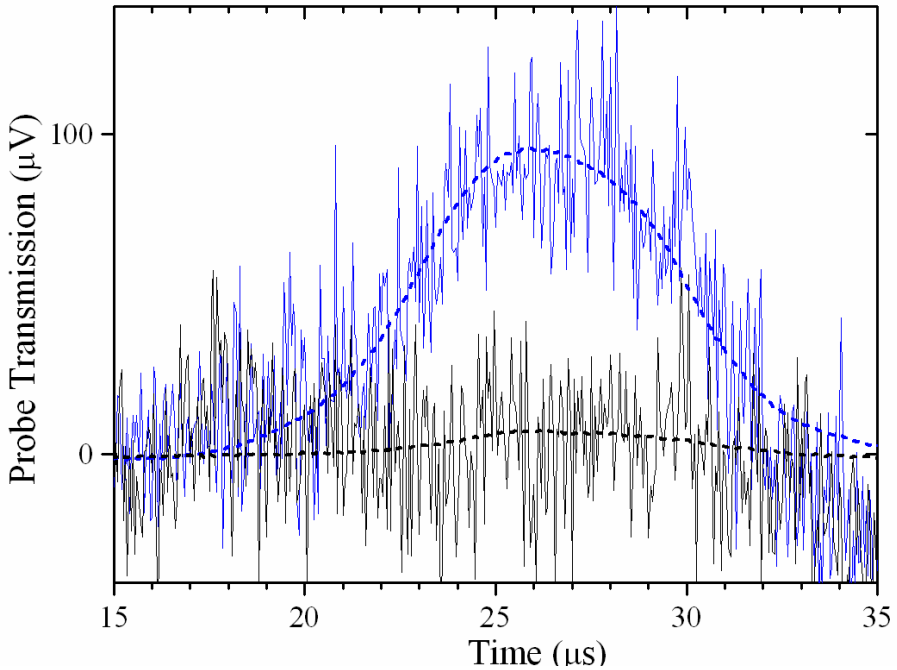
Phase Coherence of Stored Photonic Information

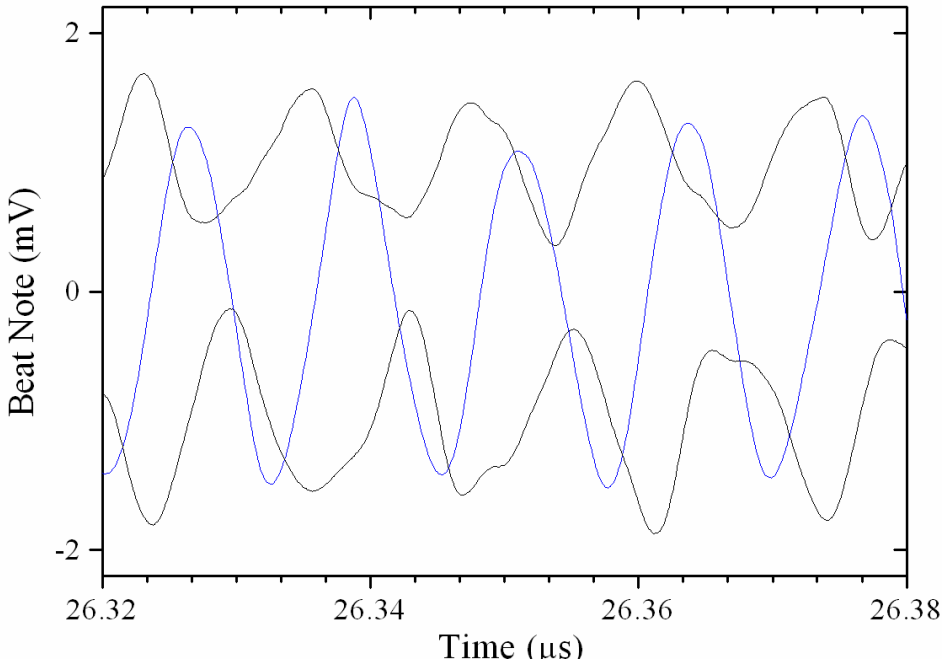


Experimental and Theoretical Data in the EIT Condition



Study of Few-Photon Light Pulses





- $\Delta_p = \pm 0.05\Gamma$.
- Blue and black lines are the probe transmissions in the absence and presence of the atoms; the peak powers are about 4 and 0.4 nW.
- The measured phase shifts of -1.5±0.5 and 1.8±0.4 radians are in agreement with the predicted values.