Optimal Light Storage in Atomic Vapor

01 November 2008

Nate Phillips[1]
nbphil@wm.edu

Irina Novikova[1]

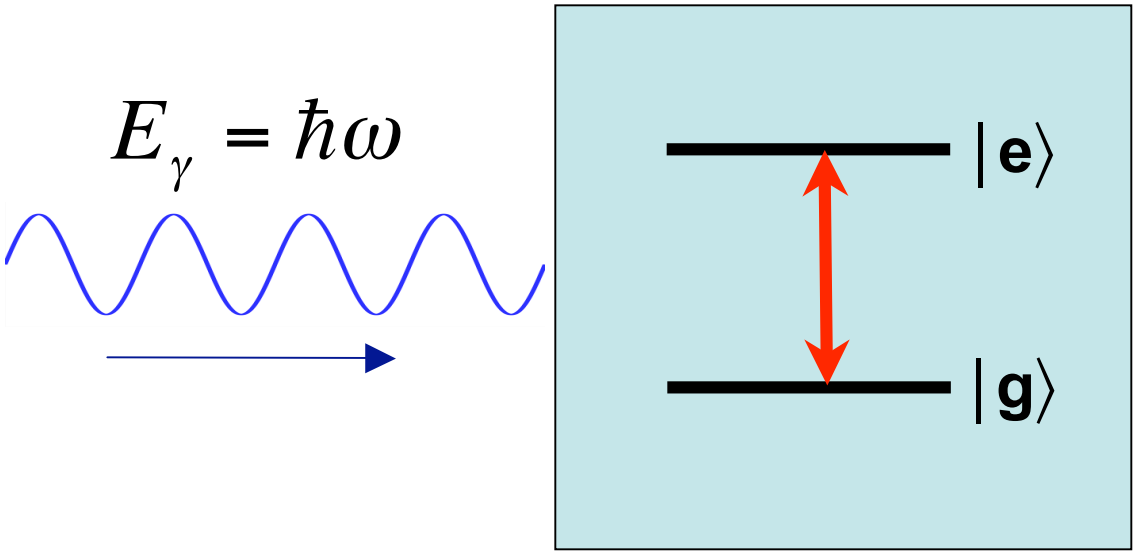
Alexey Gorshkov[2]

[1]College of William & Mary, Williamsburg, VA

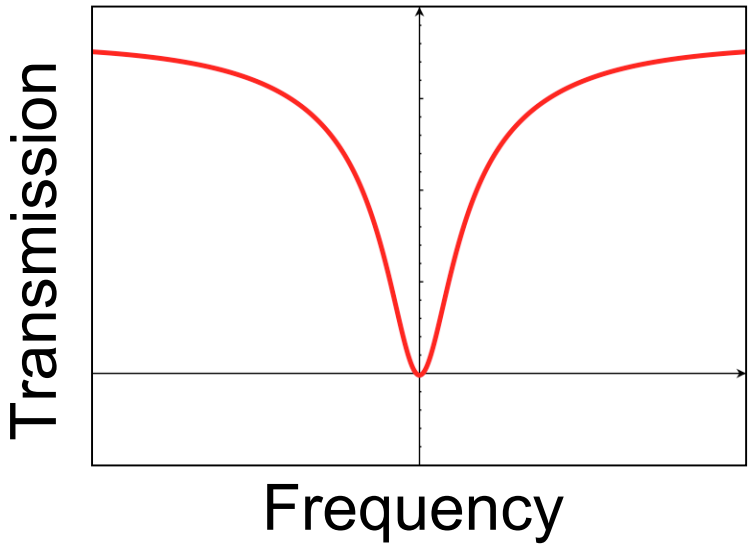
[2]Harvard University, Cambridge, MA

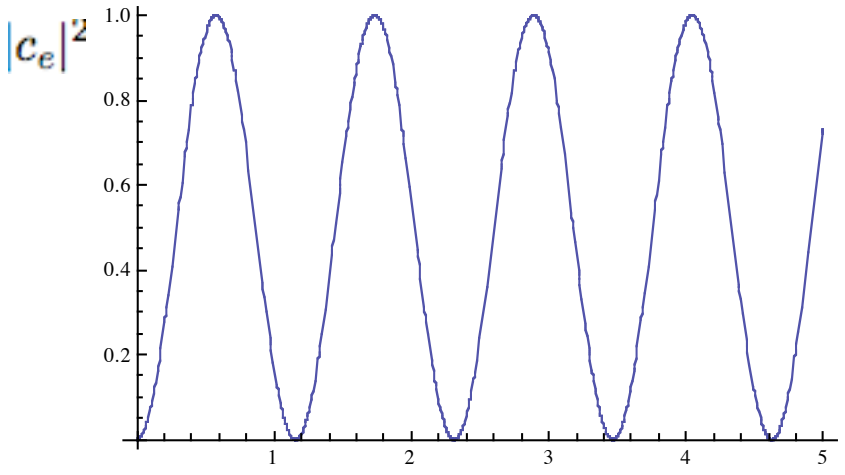
The Two-level System: Single Atom

$E_\gamma = \hbar\omega$

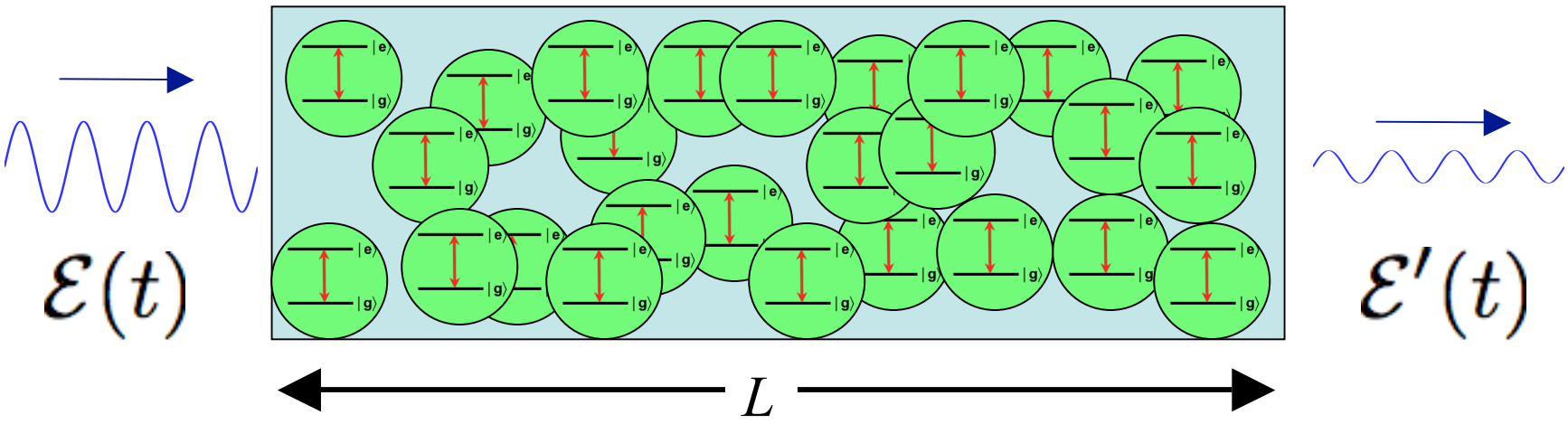


$$\Omega_R = \frac{\mathbf{d}_{eg}\cdot\mathcal{E}}{\hbar}$$





The Two-level System: An Ensemble

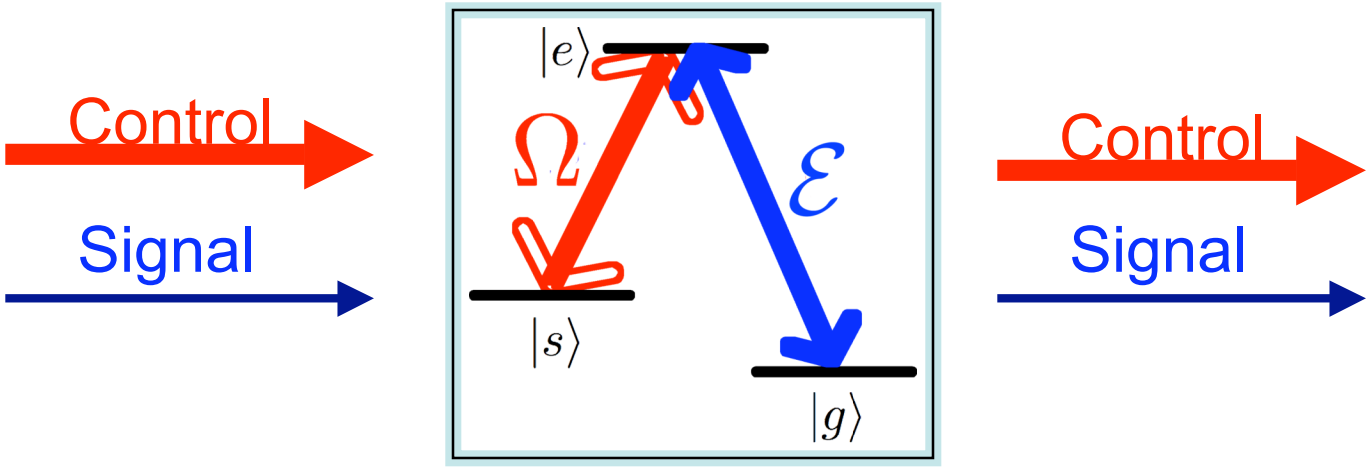


Solving Maxwell's & Schrödinger's respective equations:

$$|\mathcal{E}'(t)|^2 = |\mathcal{E}(t)|^2 \exp^{-\alpha L}$$

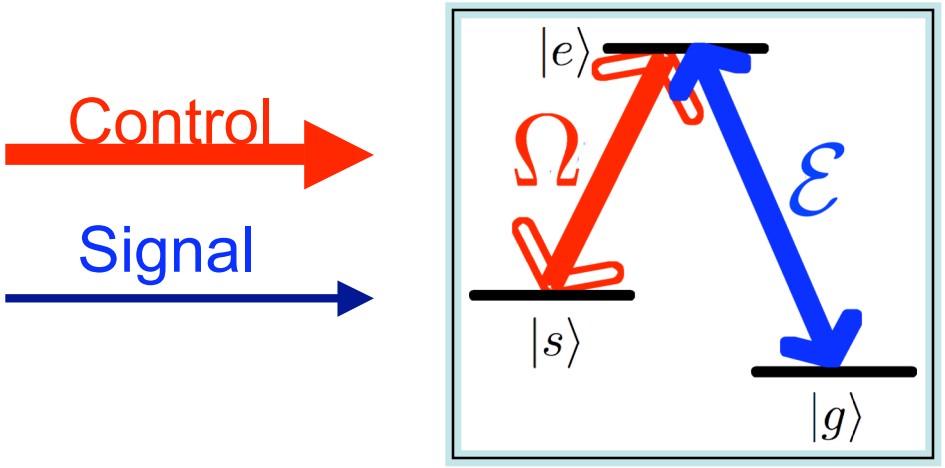
$$\mathrm{od} = \alpha L$$

Three-Level System: EIT



$$|\psi\rangle = \frac{\Omega|g\rangle - \mathcal{E}e^{-i\phi}|s\rangle}{\sqrt{\Omega^2 + \mathcal{E}^2}}$$

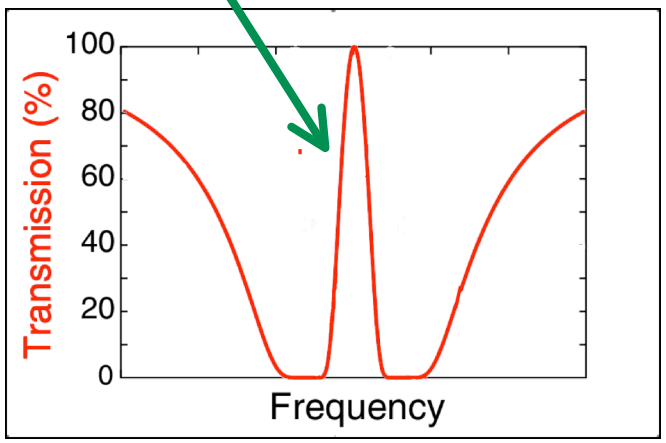
Three-Level System: EIT



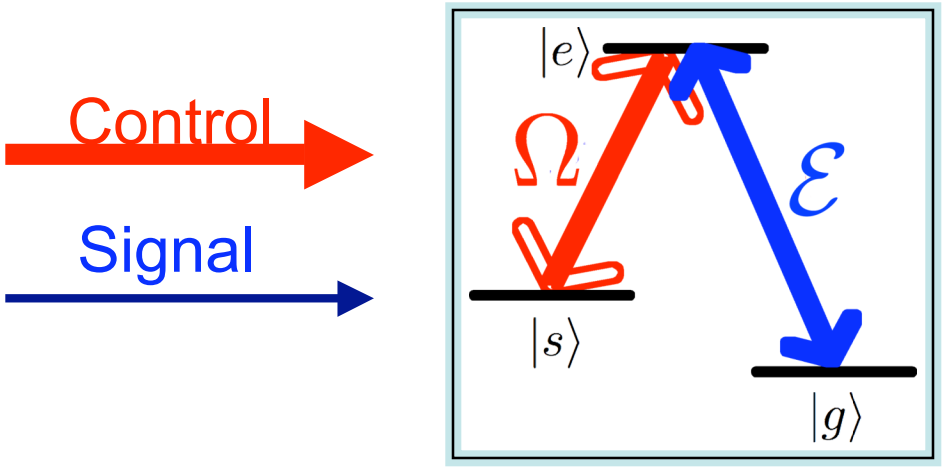
$$\gamma_{\mathrm{EIT}} = \frac{|\Omega|^2}{\sqrt{\gamma g^2 N k L}}$$

$$|\psi\rangle = \frac{\Omega|g\rangle - \mathcal{E}e^{-i\phi}|s\rangle}{\sqrt{\Omega^2 + \mathcal{E}^2}}$$

EIT transmission



Three-Level System: EIT

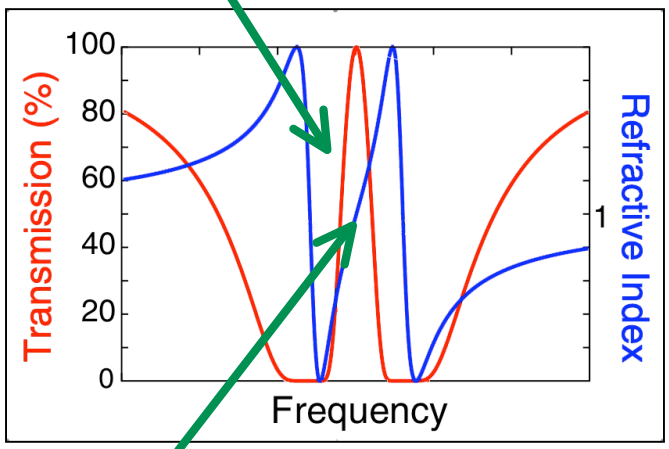


$$\gamma_{\mathrm{EIT}} = \frac{|\Omega|^2}{\sqrt{\gamma g^2 N k L}}$$

$$|\psi\rangle = \frac{\Omega|g\rangle - \mathcal{E}e^{-i\phi}|s\rangle}{\sqrt{\Omega^2 + \mathcal{E}^2}}$$

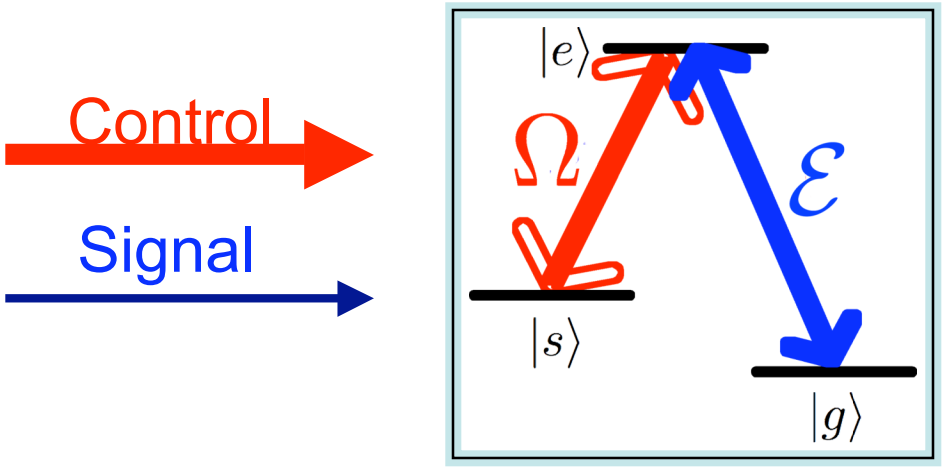
$$v_g = \frac{c}{1 + \omega \frac{dn}{d\omega}}$$

EIT transmission



Steep dispersion $\frac{dn}{d\omega} \gg 1$

Three-Level System: EIT

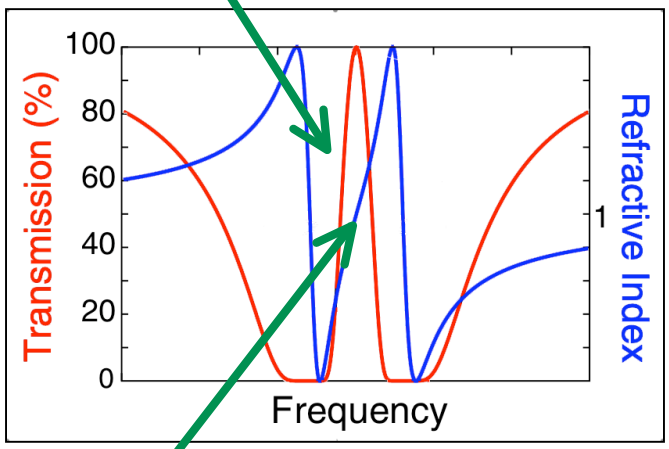


$$\gamma_{\mathrm{EIT}} = \frac{|\Omega|^2}{\sqrt{\gamma g^2 N k L}}$$

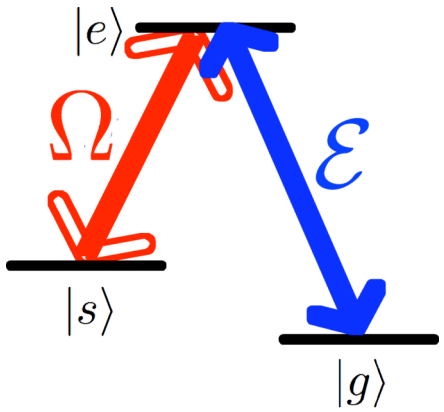
$$|\psi\rangle = \frac{\Omega|g\rangle - \mathcal{E}e^{-i\phi}|s\rangle}{\sqrt{\Omega^2 + \mathcal{E}^2}}$$

$$v_g = \frac{c}{1 + \sqrt{\gamma\alpha c}/|\Omega|^2}$$

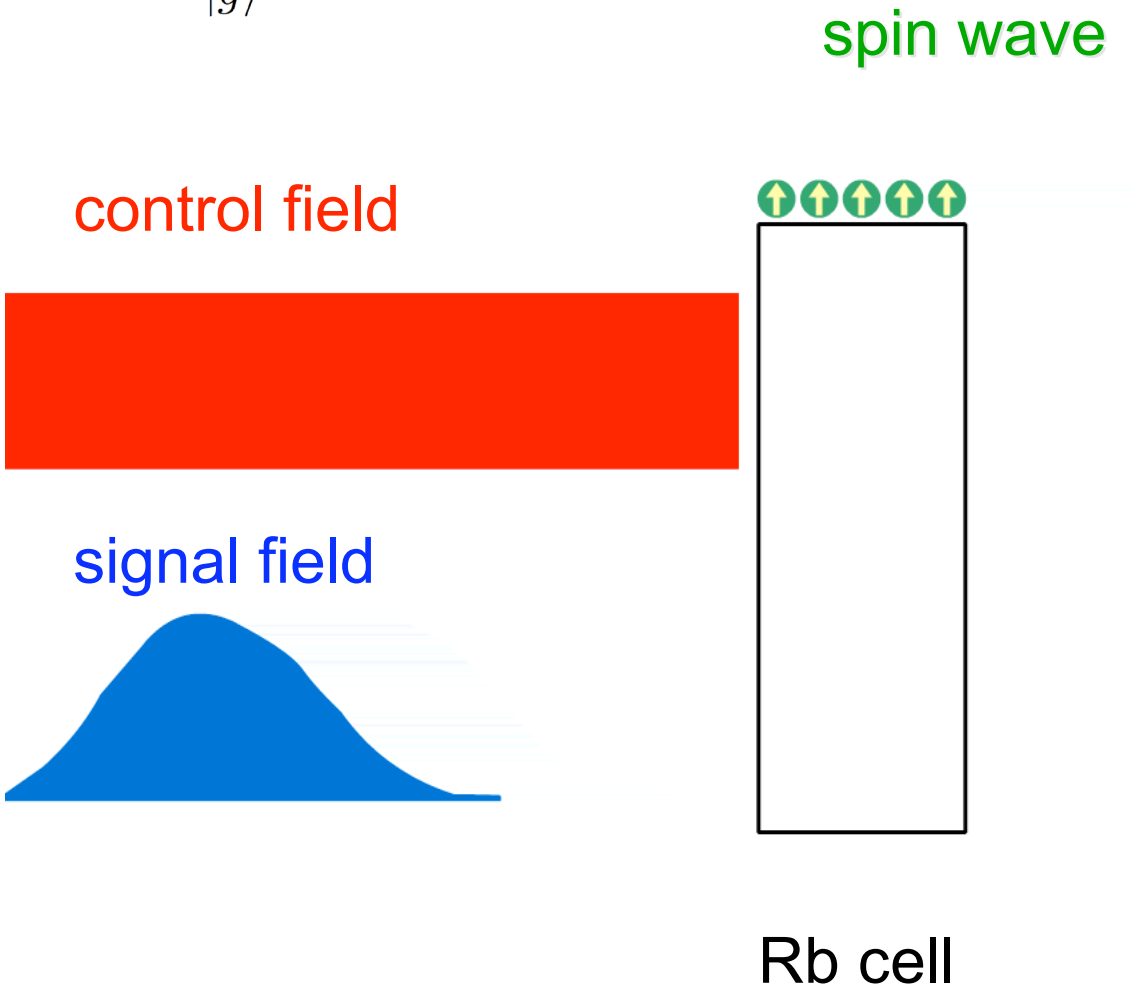
EIT transmission

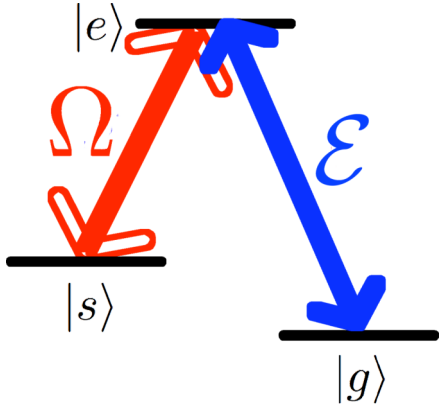


Steep dispersion $\frac{dn}{d\omega} \gg 1$



Stored Light



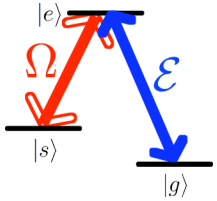


Stored Light

$$\eta = \frac{\int |\quad\quad|^2 dt}{\int |\quad\quad|^2 dt} = \frac{\int |\mathcal{E}_{\text{out}}|^2 dt}{\int |\mathcal{E}_{\text{in}}|^2}$$

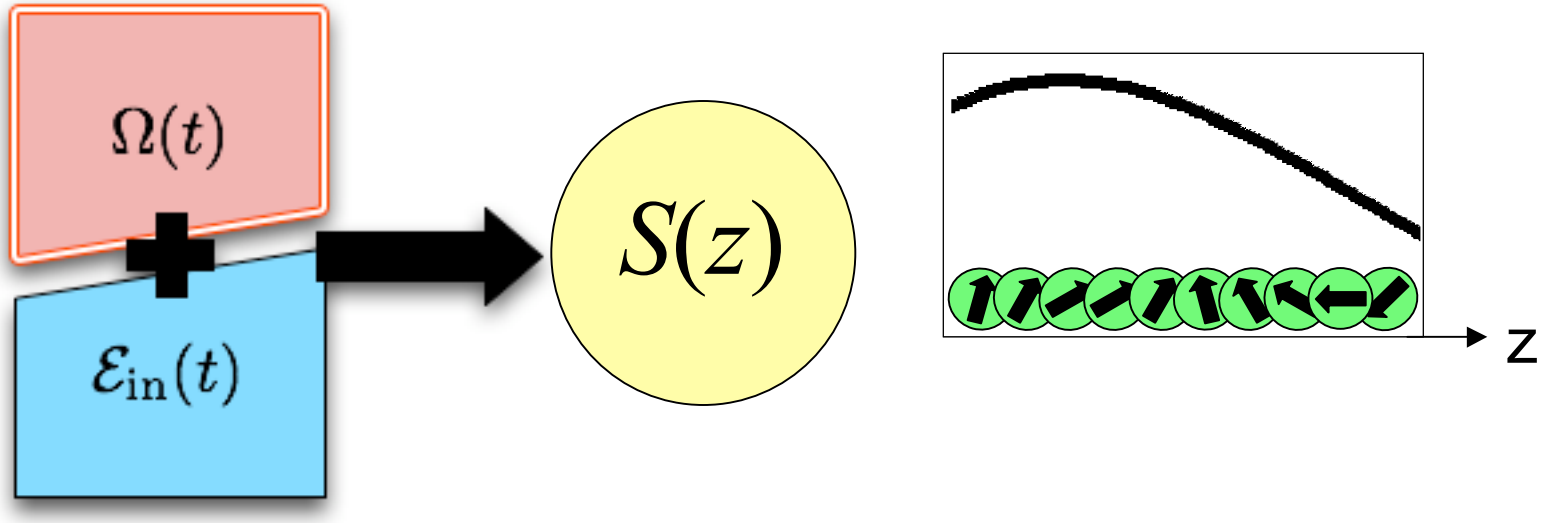
Goal:

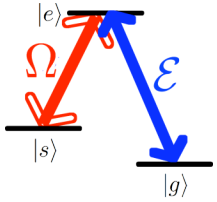
How to optimize memory efficiency in a way that all spectral components of the signal field fit inside the EIT transparency window?



$$|\psi\rangle = \frac{\Omega|g\rangle - \mathcal{E}e^{-i\phi}|s\rangle}{\sqrt{\Omega^2 + \mathcal{E}^2}}$$

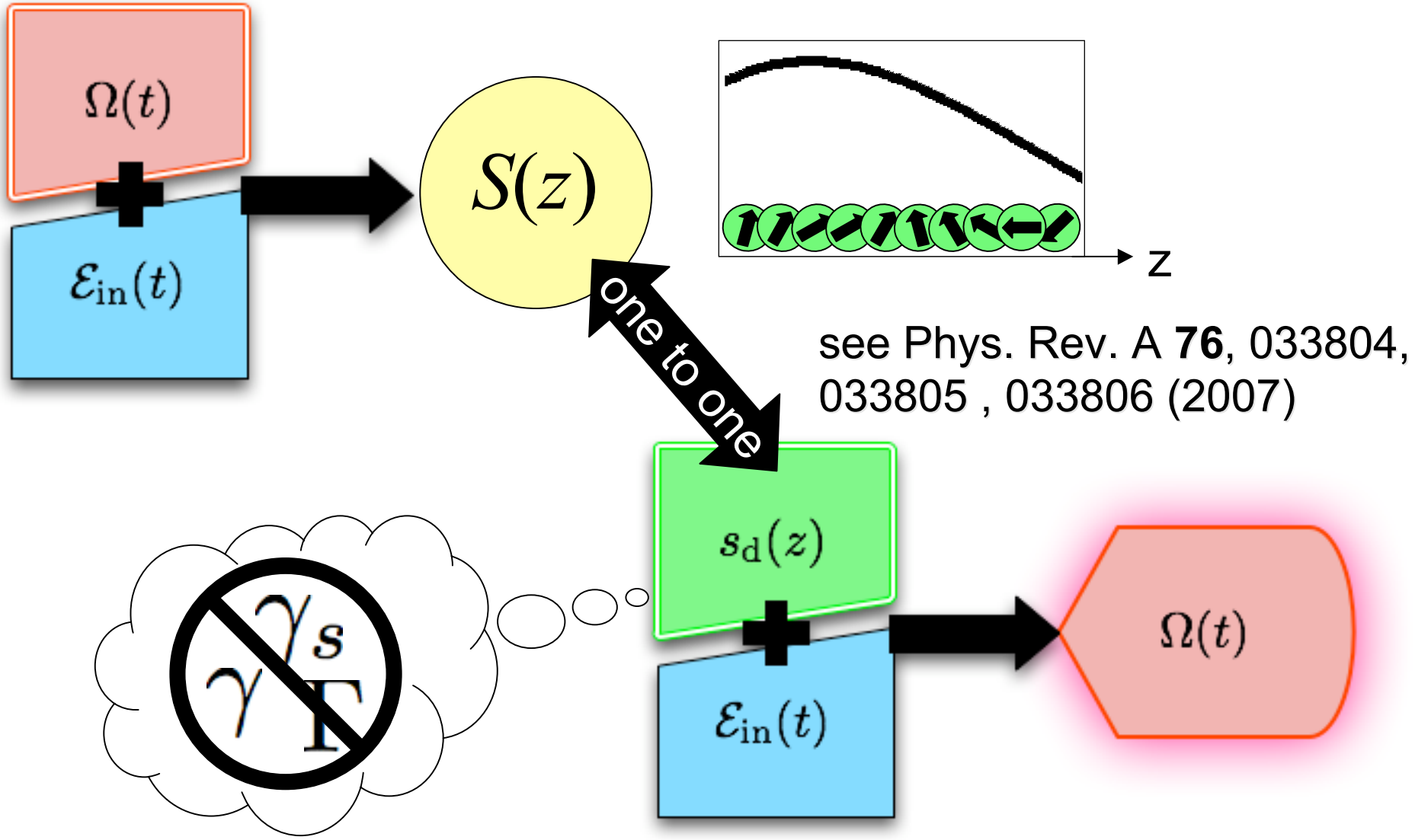
Creating the Optimal Spin Wave

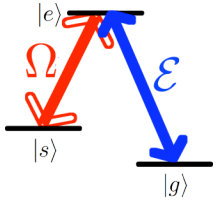




$$|\psi\rangle = \frac{\Omega|g\rangle - \mathcal{E}e^{-i\phi}|s\rangle}{\sqrt{\Omega^2 + \mathcal{E}^2}}$$

Creating the Optimal Spin Wave

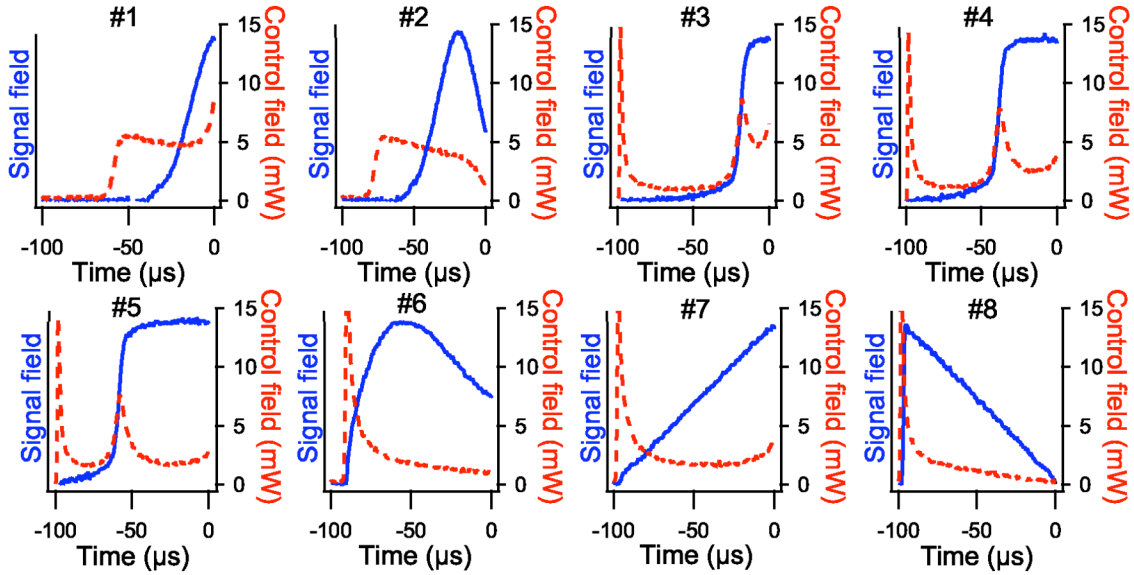


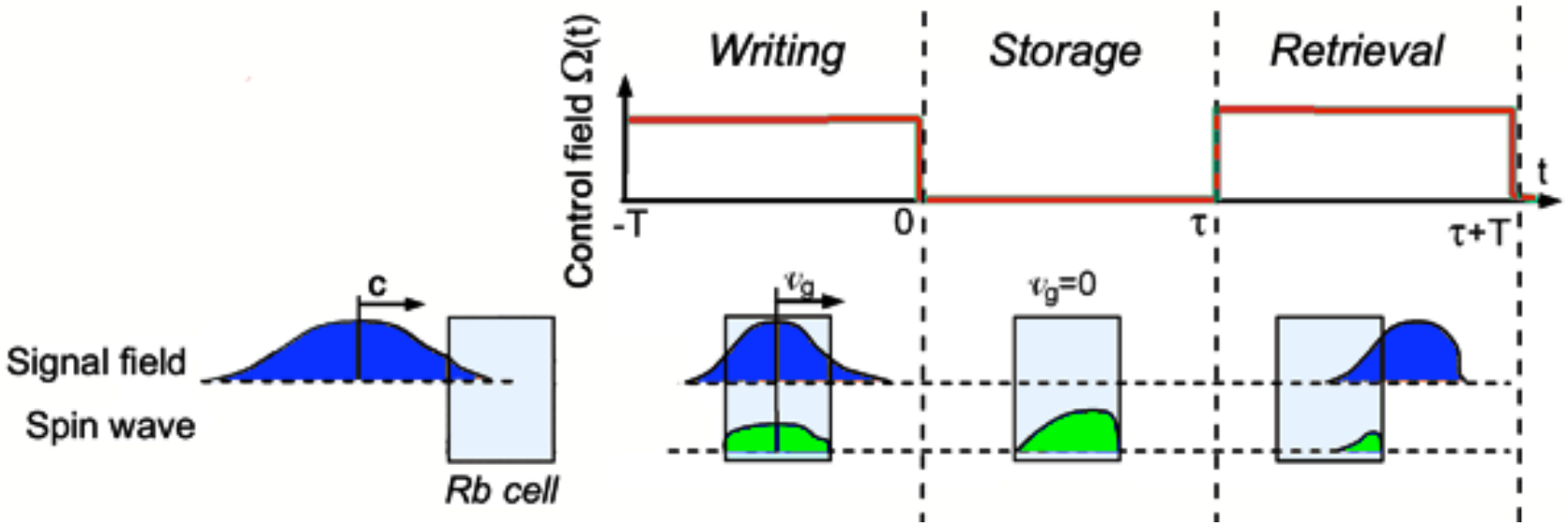


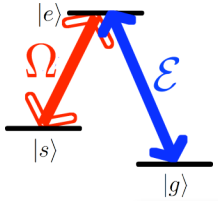
Calculating Control Fields

Phys. Rev. A **78**, 023801 (2008)

Cell: ^{87}Rb + 30 Torr Ne Buffer
Diode Laser tuned to *D*1 = 795 nm
$5\,S_{1/2}\,F=2 \rightarrow 5\,P_{1/2}\,F'=2\ \sigma^+$
$5\,S_{1/2}\,F=1 \rightarrow 5\,P_{1/2}\,F'=2\ \sigma^+$

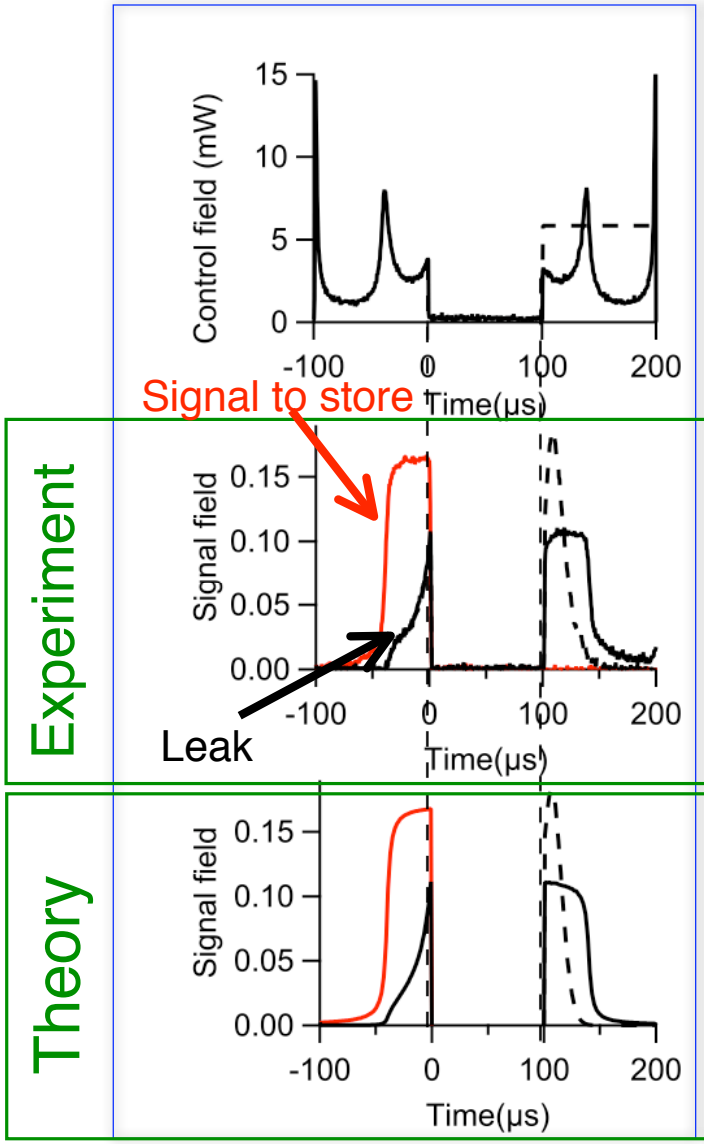


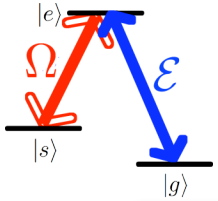




Calculated Control Fields

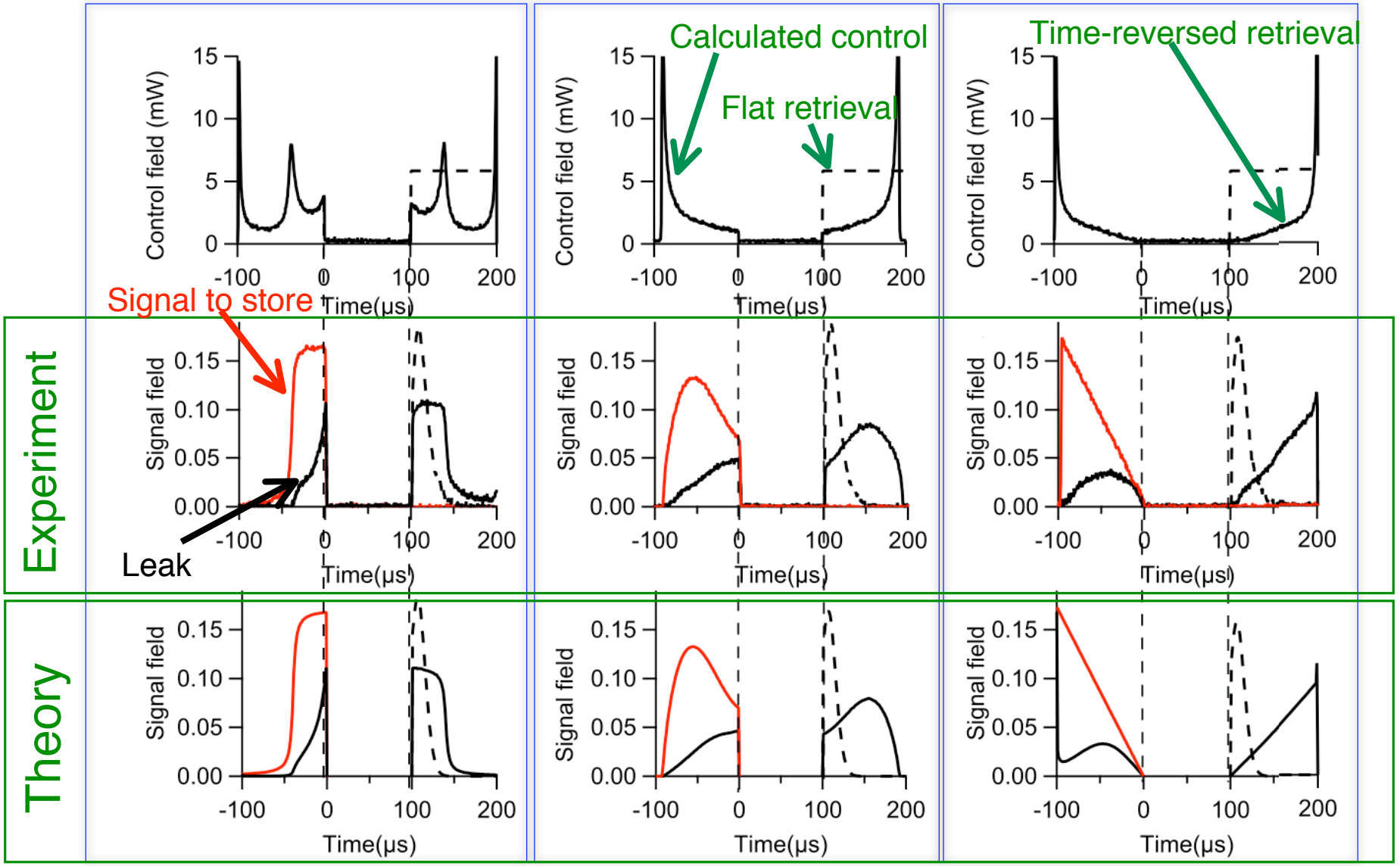
Phys. Rev. A **78**, 023801 (2008)



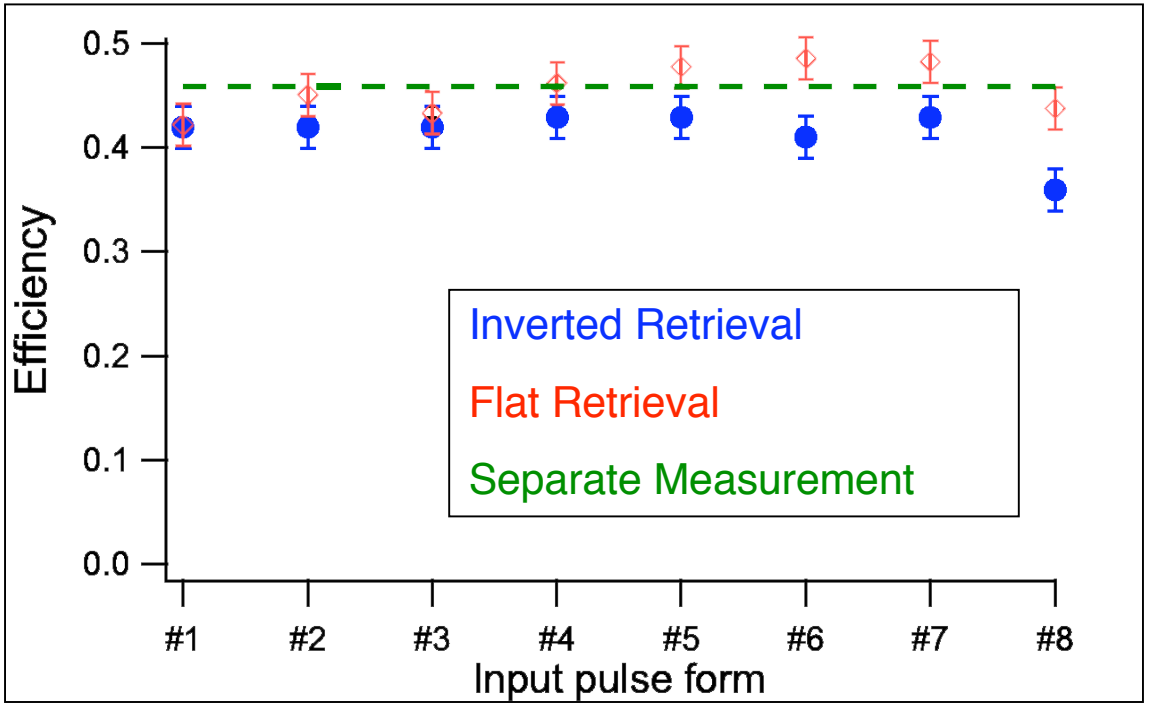


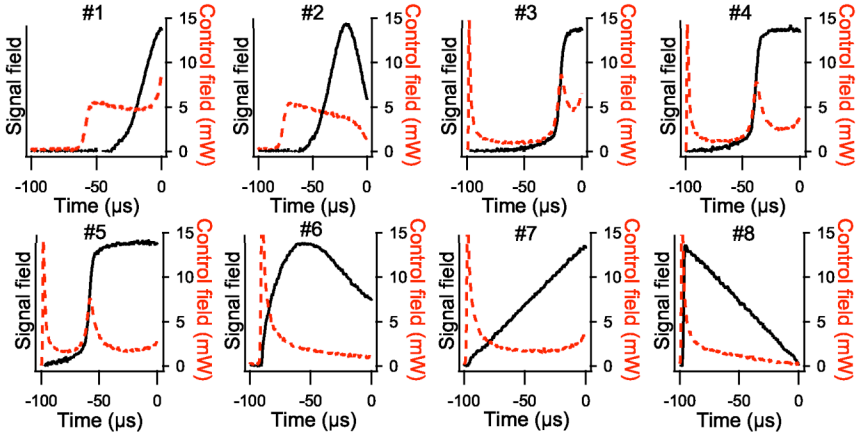
Calculated Control Fields

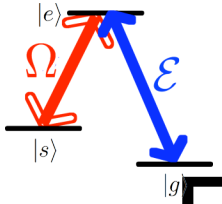
Phys. Rev. A **78**, 023801 (2008)



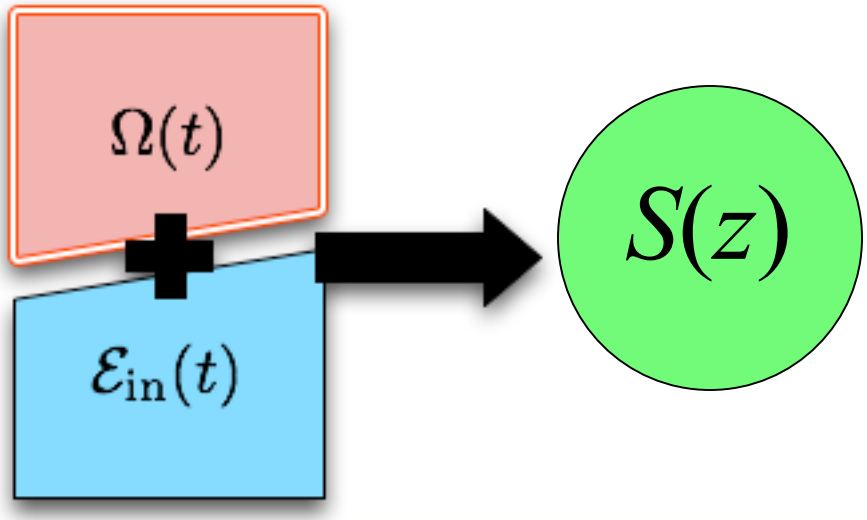
Storage Efficiencies

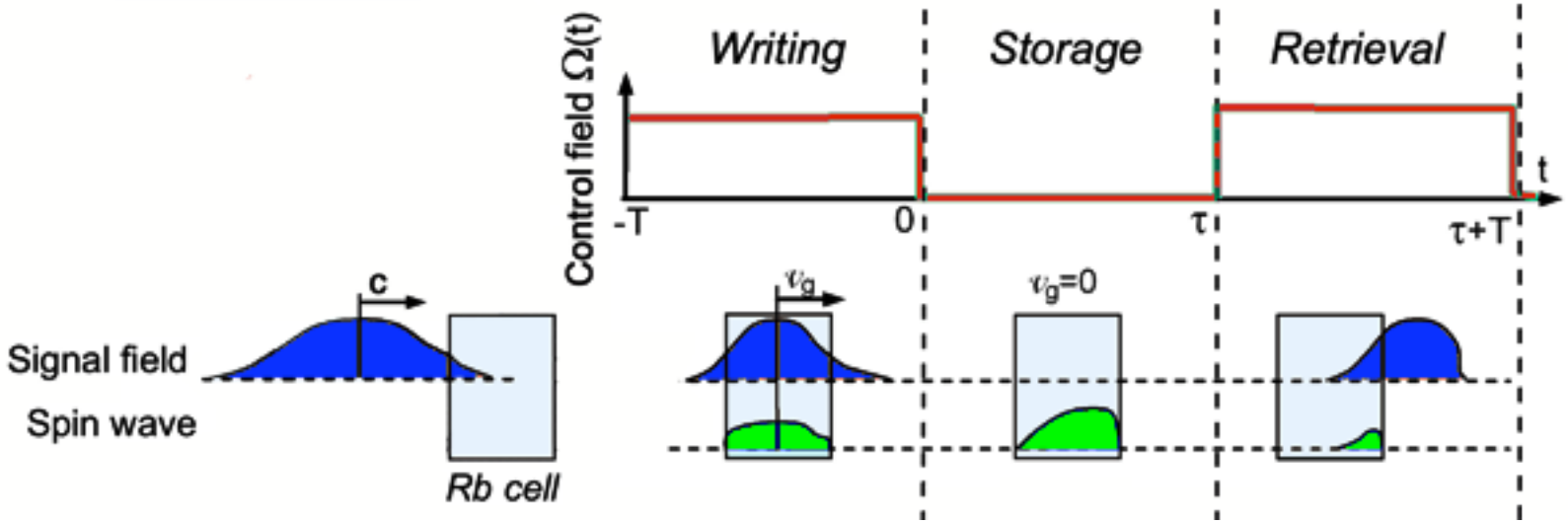


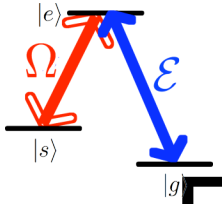




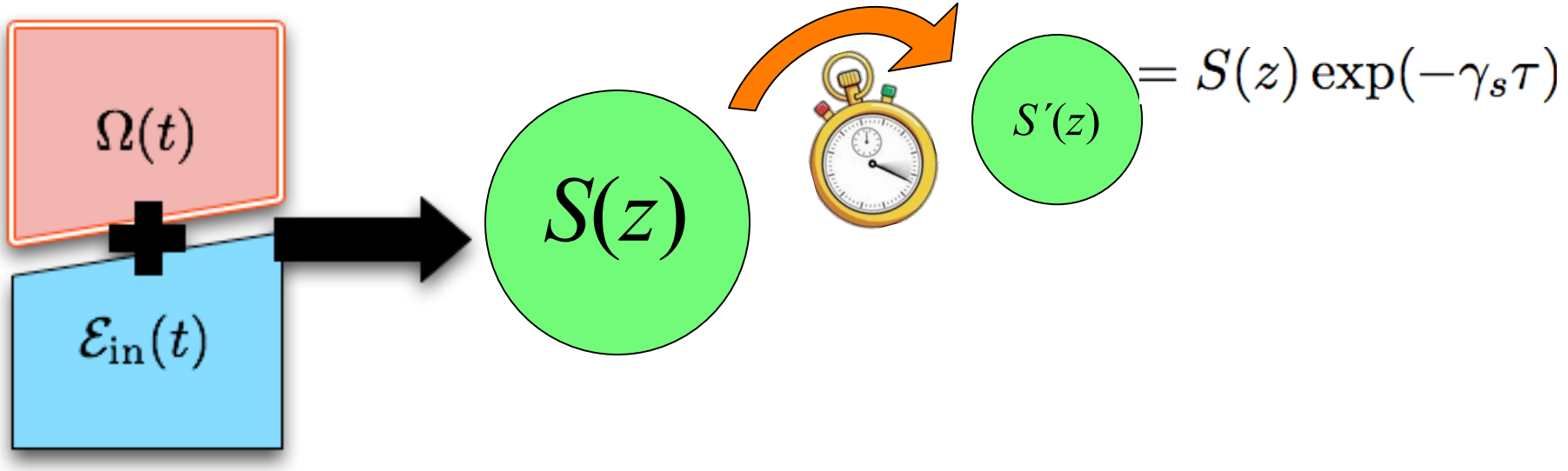
Full Control Over Stored Light

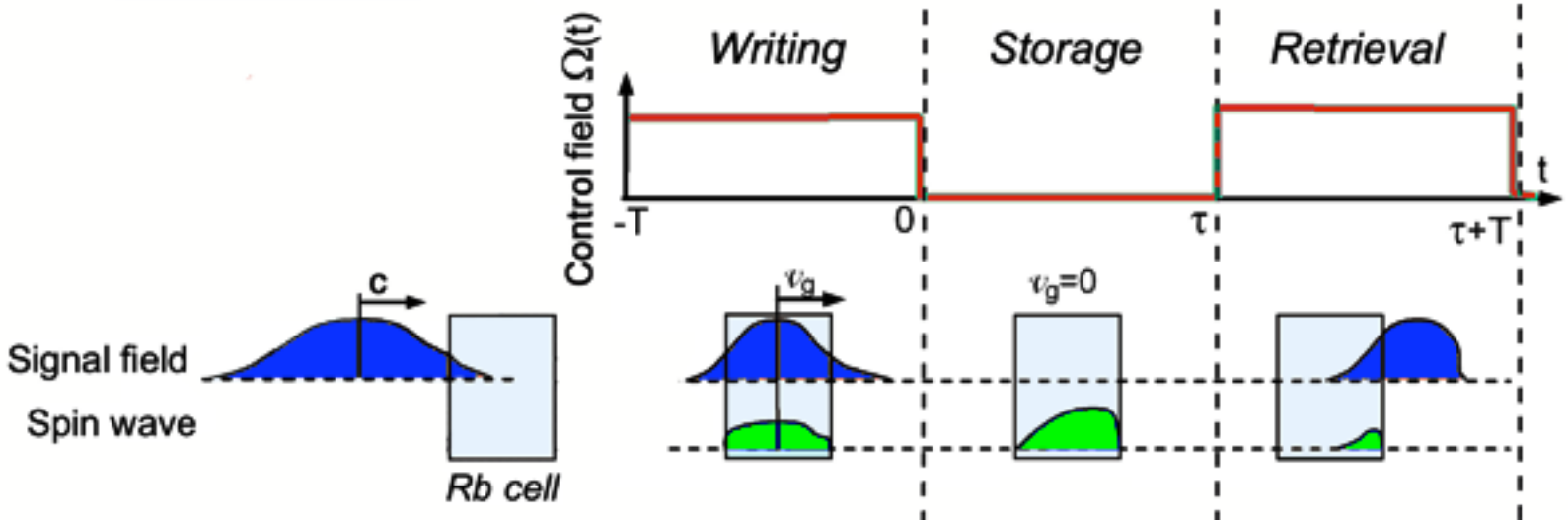


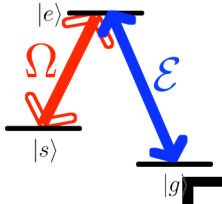




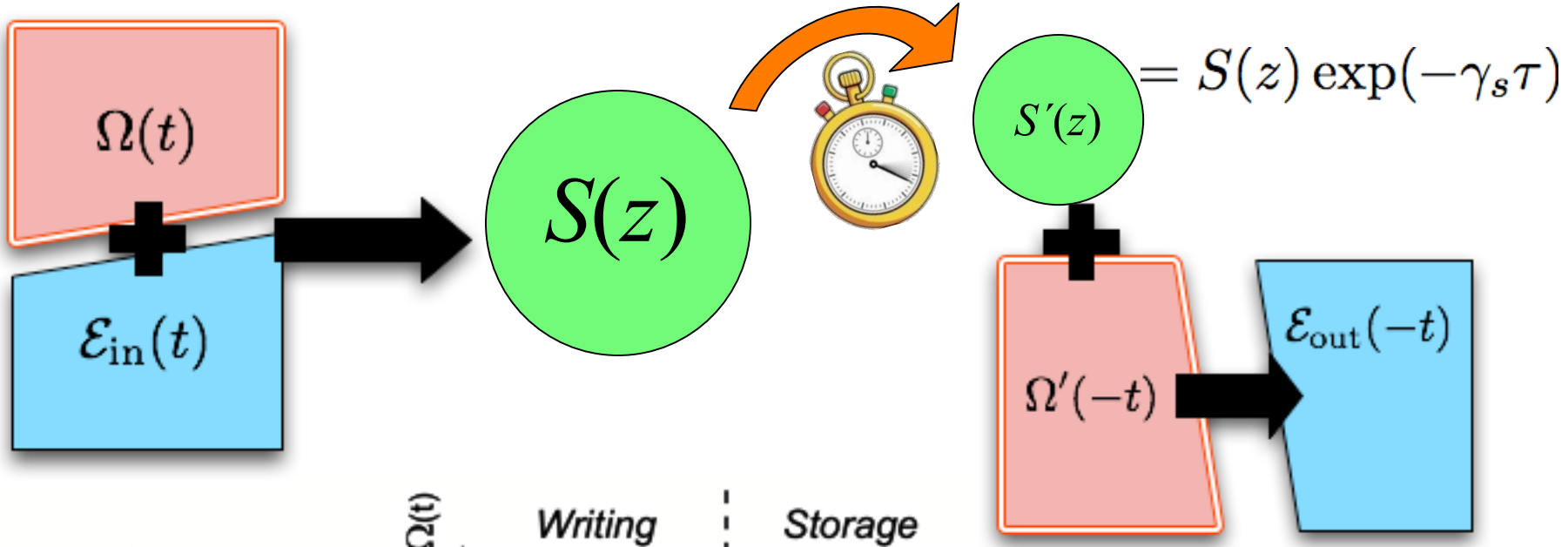
Full Control Over Stored Light

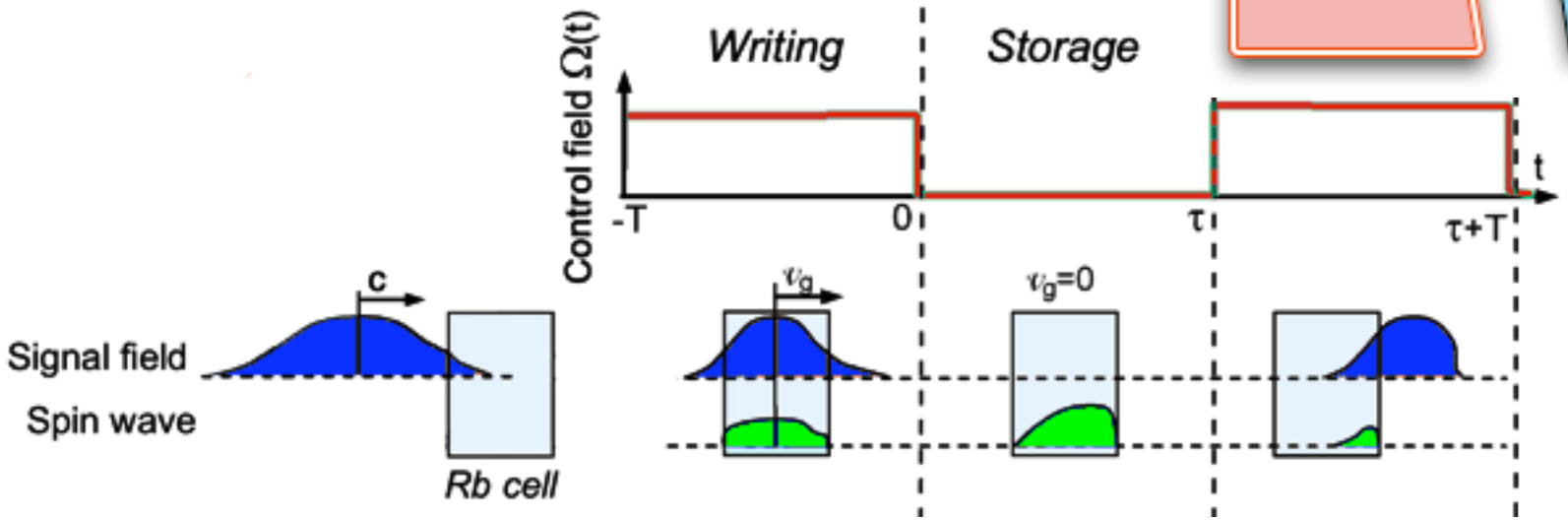




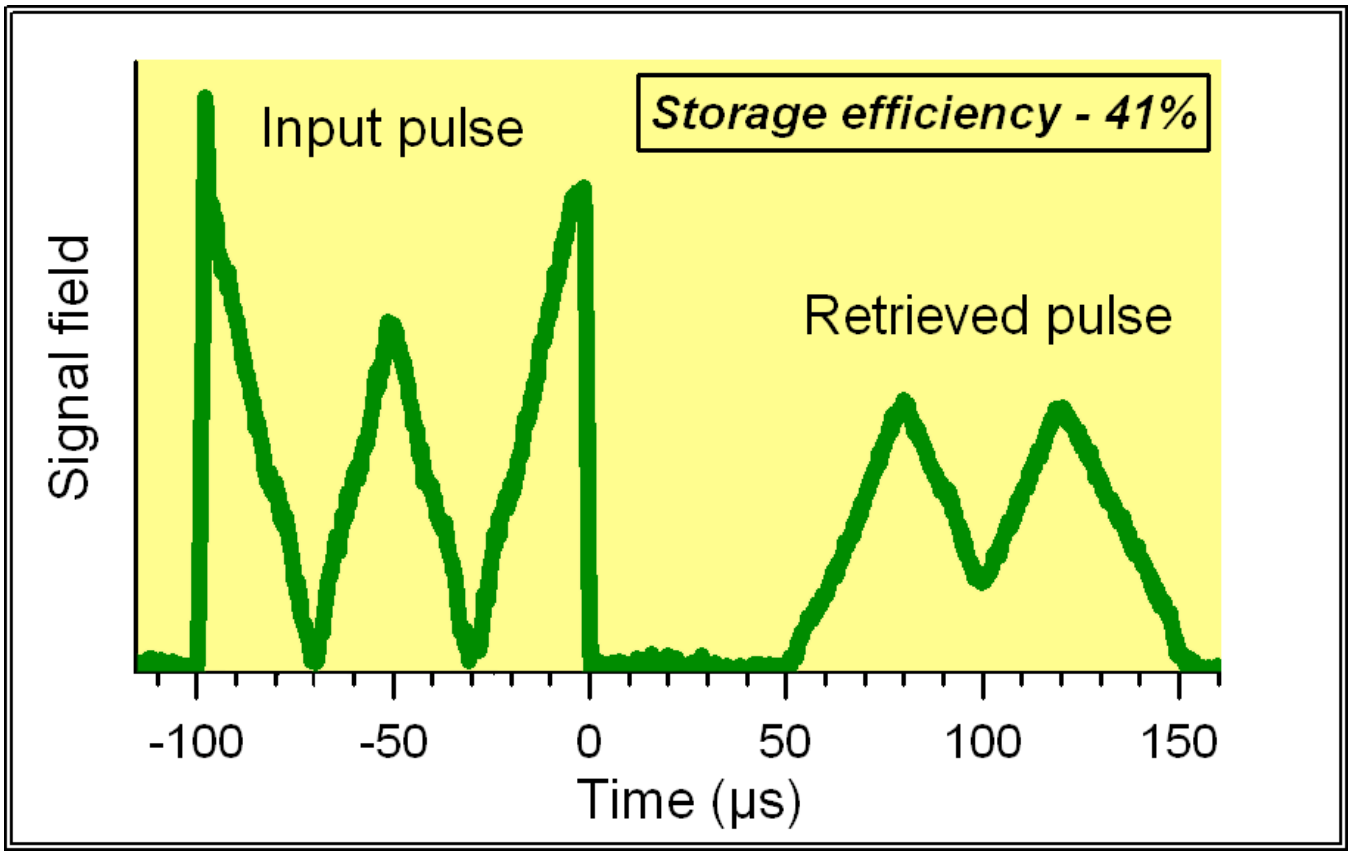


Full Control Over Stored Light

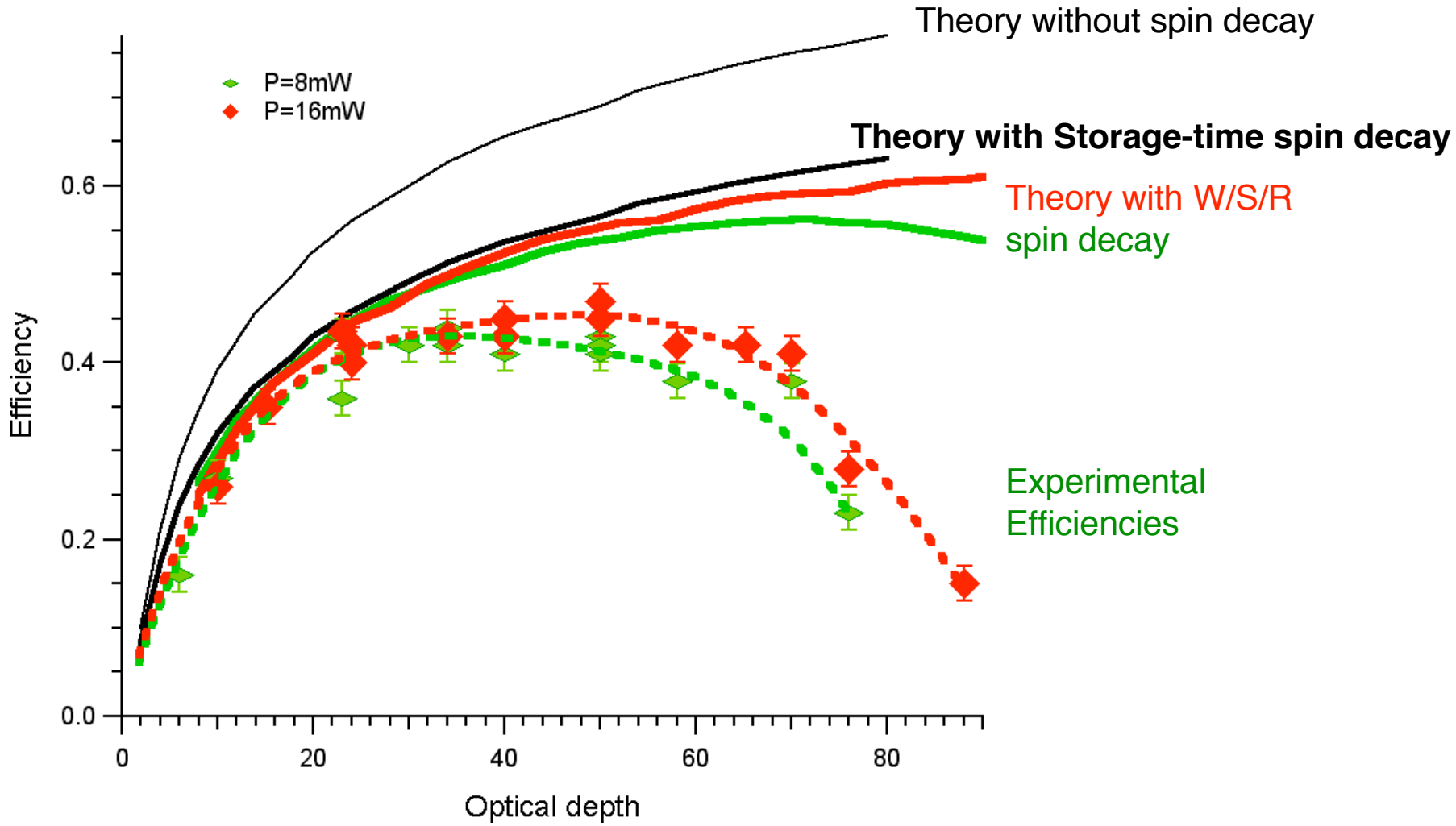




Full Control Over Stored Light

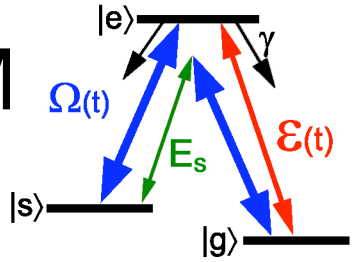


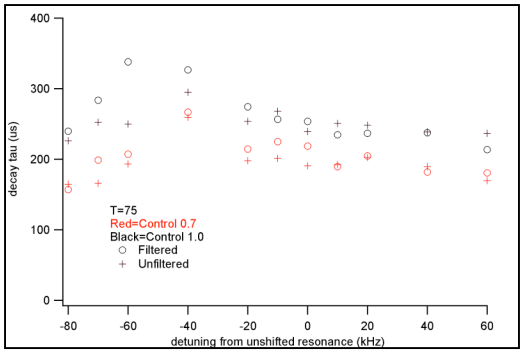
Optical Depth Dependence of Storage Efficiency



Current Experiments

- Investigate loss of efficiency at high o.d.
- Spin decay mechanism & rates
- FWM





nbphil@wm.edu

Some Great Reads!

Storage of Arbitrary Pulses; Optical Depth Dependence

•**NBP**, AG, and IN, Phys. Rev. A **78**, 023801 (2008)

Controlled Retrieval

•IN, **NBP**, AG, Phys. Rev. A **78**, 021802(R) (2008)

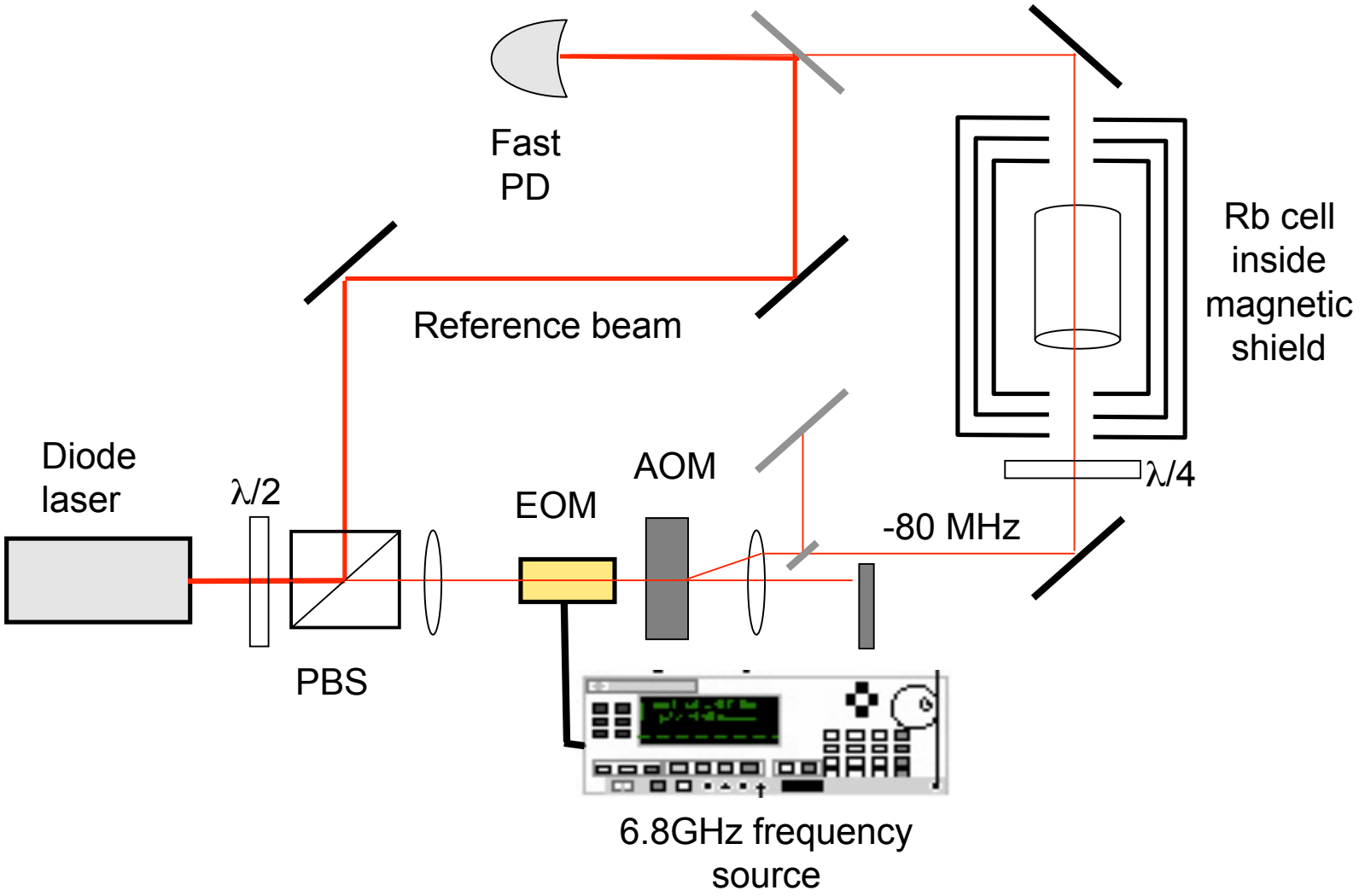
Calculation of Control Fields

•AG, *et al.*, Phys. Rev. A **76**, 033804, 033805 , 033805 (2007)

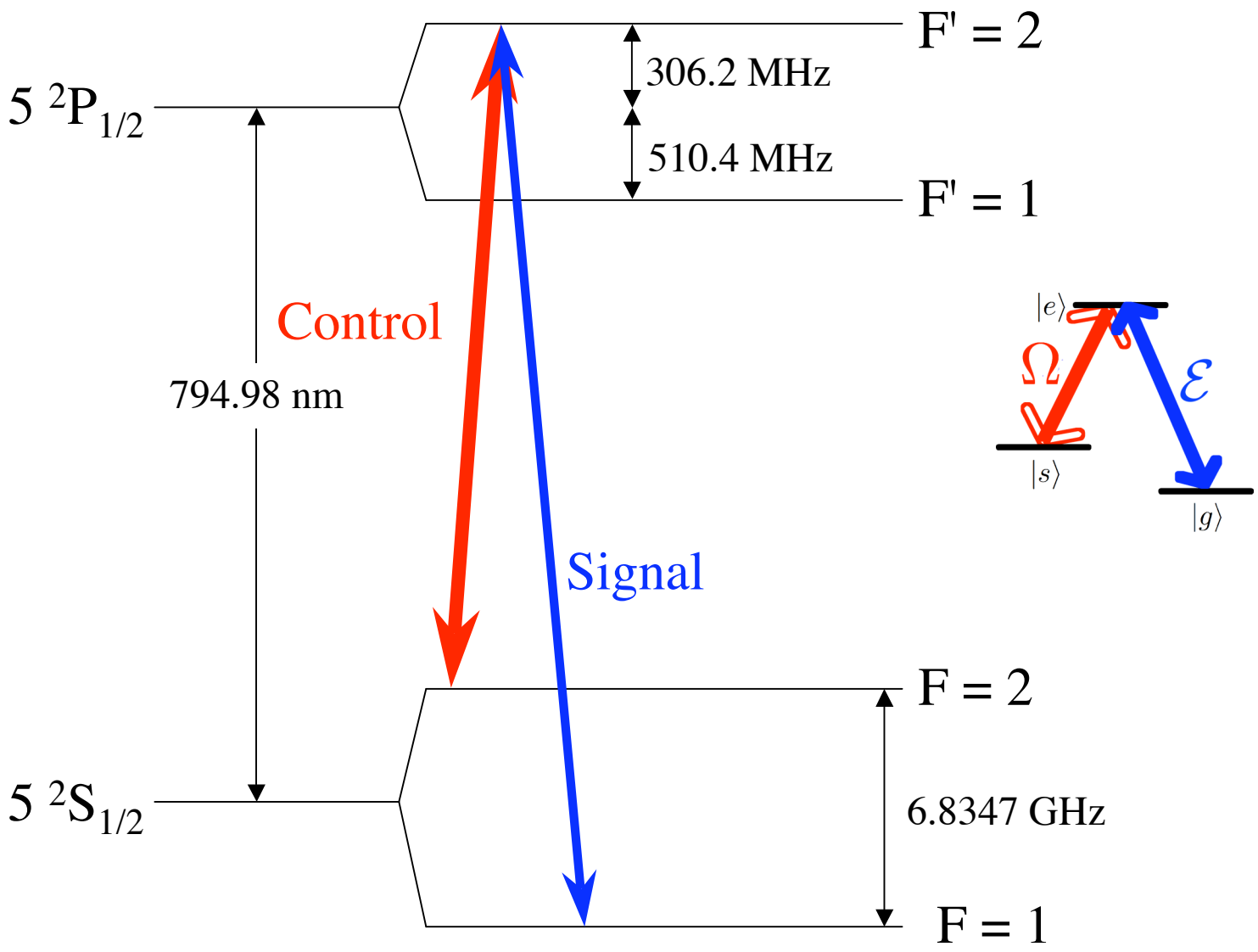
Overview of Universal Storage Approach

•AG, *et al.*, Phys. Rev. Lett. **98**, 123601, (2007)

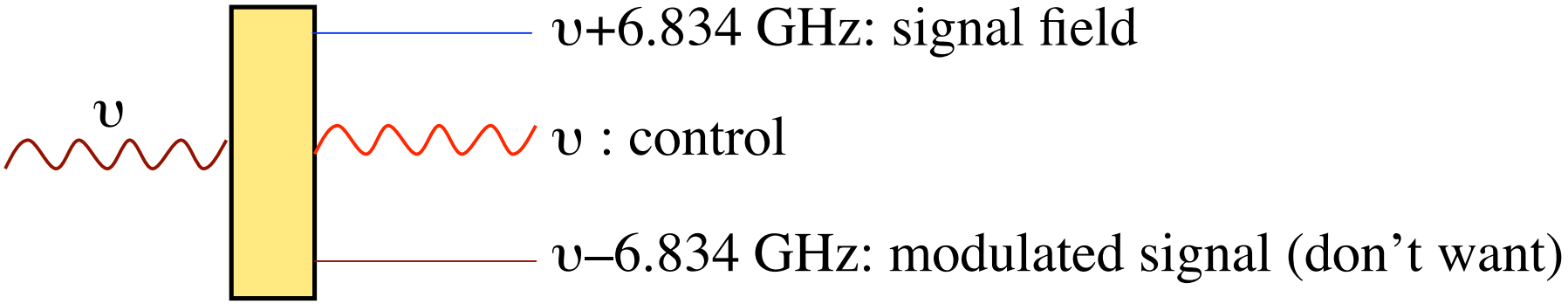
Experimental Arrangements



Our Atoms


F' = 2
306.2 MHz
510.4 MHz
F' = 1
5 $^2P_{1/2}$
Control
794.98 nm
Signal
F = 2
6.8347 GHz
5 $^2S_{1/2}$
F = 1
$|e\rangle$
Ω
$\mathcal{E}$
$|s\rangle$
$|g\rangle$

Producing Fields: EOM



EOM phase-modulates our cw beam at 6.834 GHz and creates 2 new "sidebands".