Quantum information storage in atomic media

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Overview

Introduction

- What is Electromagnetically induced transparency?
- Setting up the EIT experiments
- Experimental EIT
- Measuring the EIT width
- Ground state decoherence
- Storage of light
- Single photon source

Conclusions

Introduction

- Light is a good carrier of quantum information.
- Every computer needs memory.
- Photons don't like to stay put.
- Atoms are very good to store information.
- Atoms interact strongly with light.

Our task is to develop an interface that would allow transfer of quantum information between optical and atomic media.

Introductory terms

Group velocity

$$v_g(\omega) = \frac{c}{n(\omega) + \omega \frac{\mathrm{d}n}{\mathrm{d}\omega}}$$

This term can allow us to reduce the group velocity

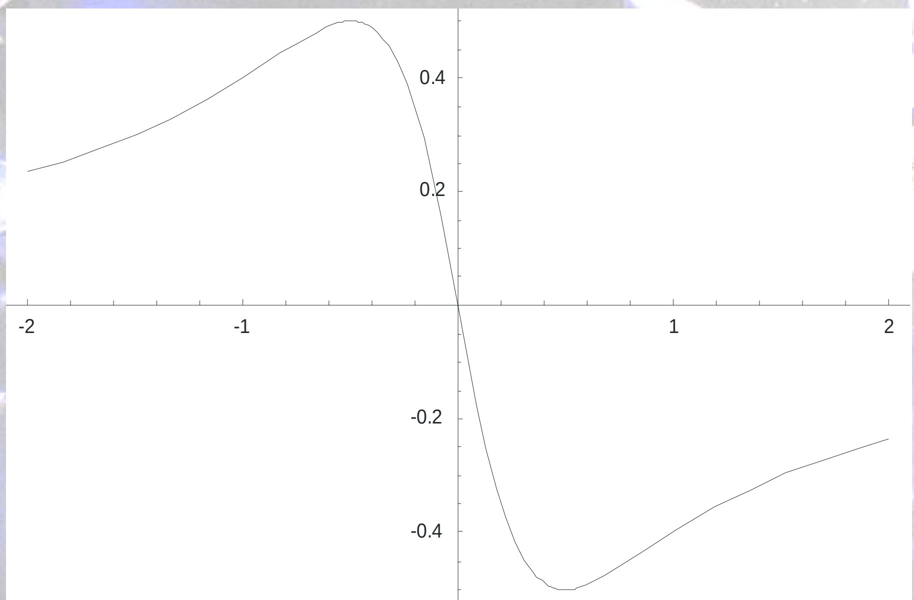
Dispersion relations

$$n = n_r + i \cdot \frac{\alpha}{2\frac{\omega}{c}}$$

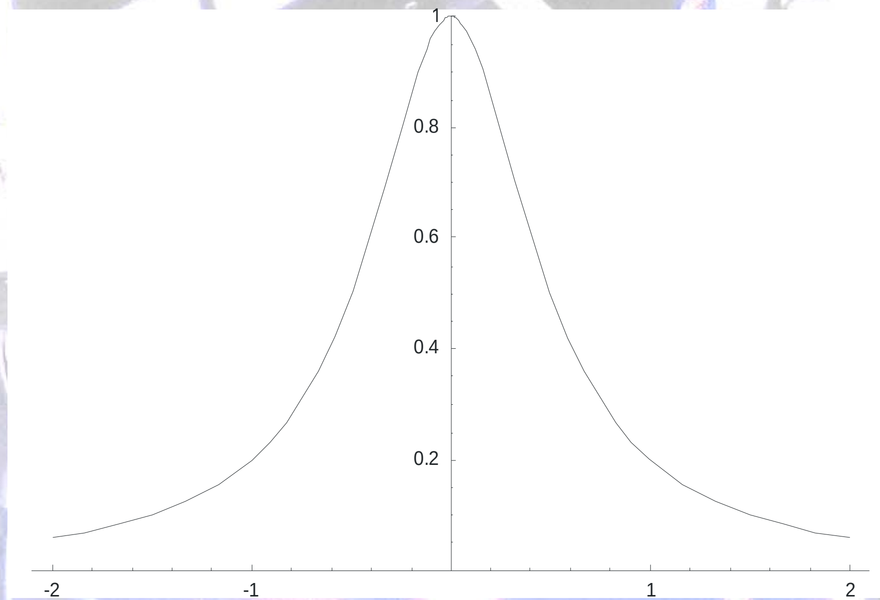
Dispersion	$n_r = \mathrm{Re}(n)$
Absorption	$\alpha = \frac{2\omega}{c}\mathrm{Im}(n)$

Behavior close to an atomic resonance

Dispersion



Absorption

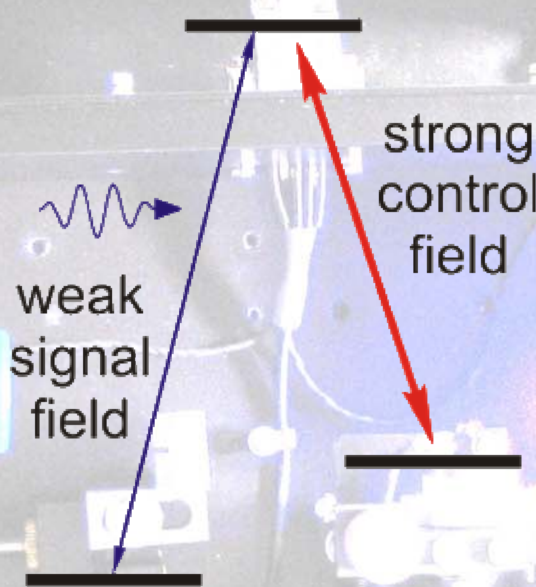


The problem: In normal media a change in the group velocity is always associated to big absorption

Introducing EIT

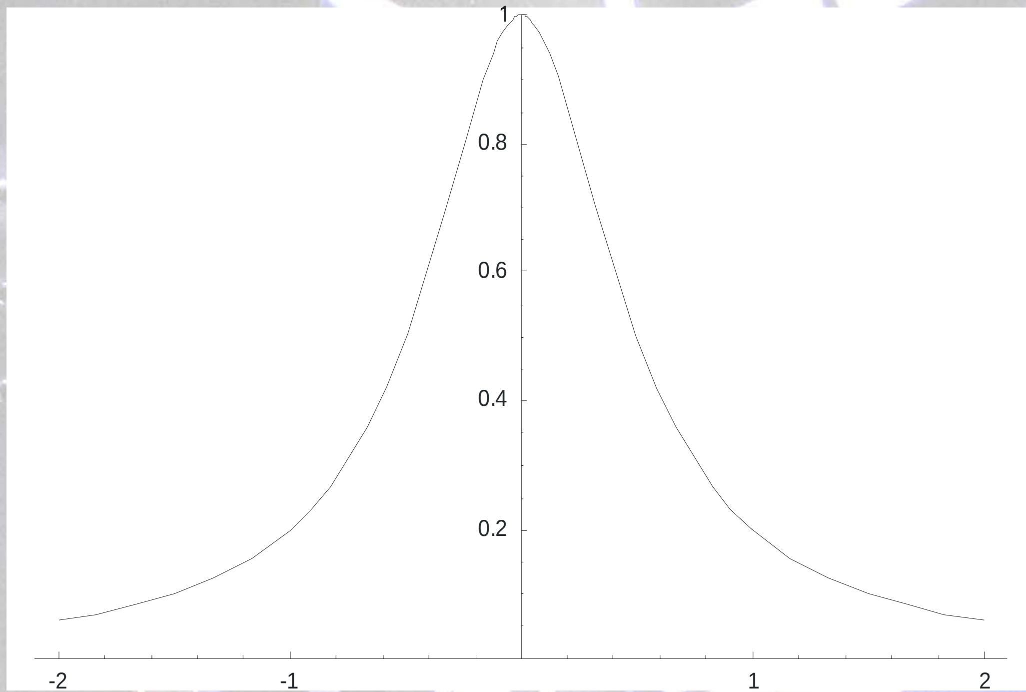
The solution: electromagnetically-induced transparency (EIT).

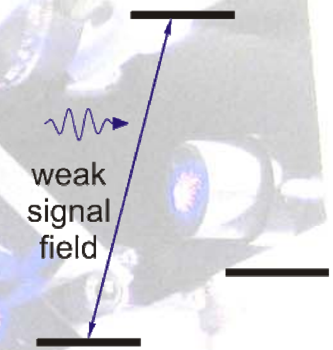
Lambda system



Harris S. Phys. Today 50 (7) 36-42 (1997)

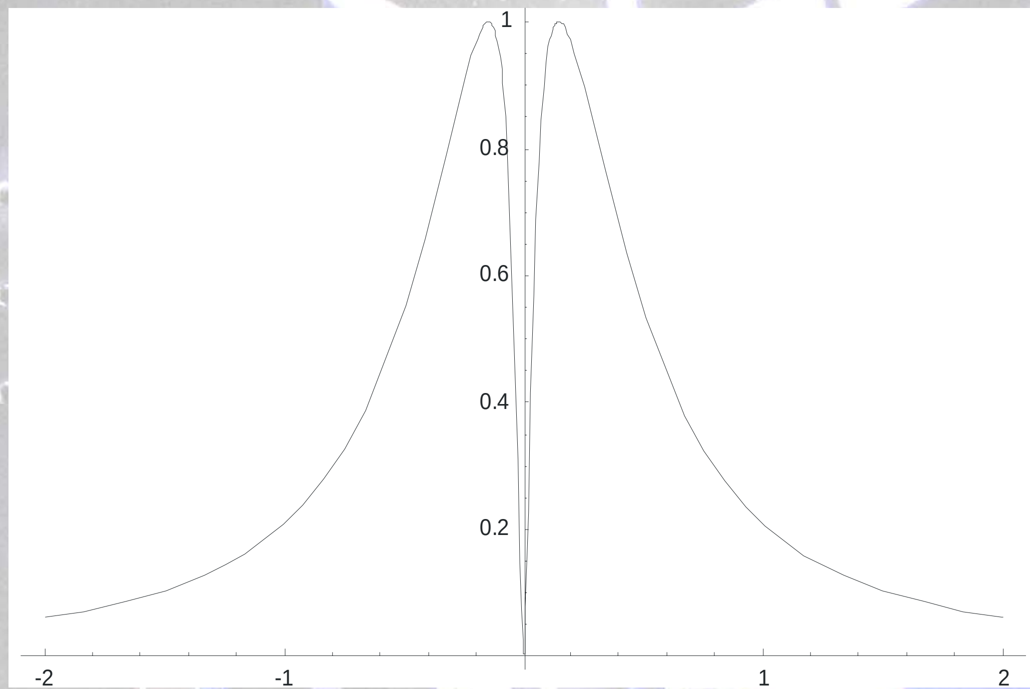
Absorption of the signal field

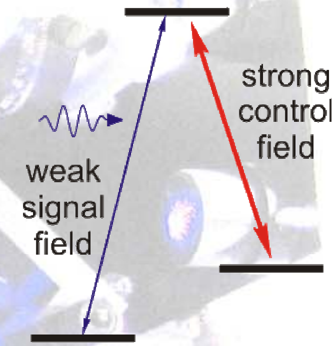




w/o control field

Absorption of the signal field

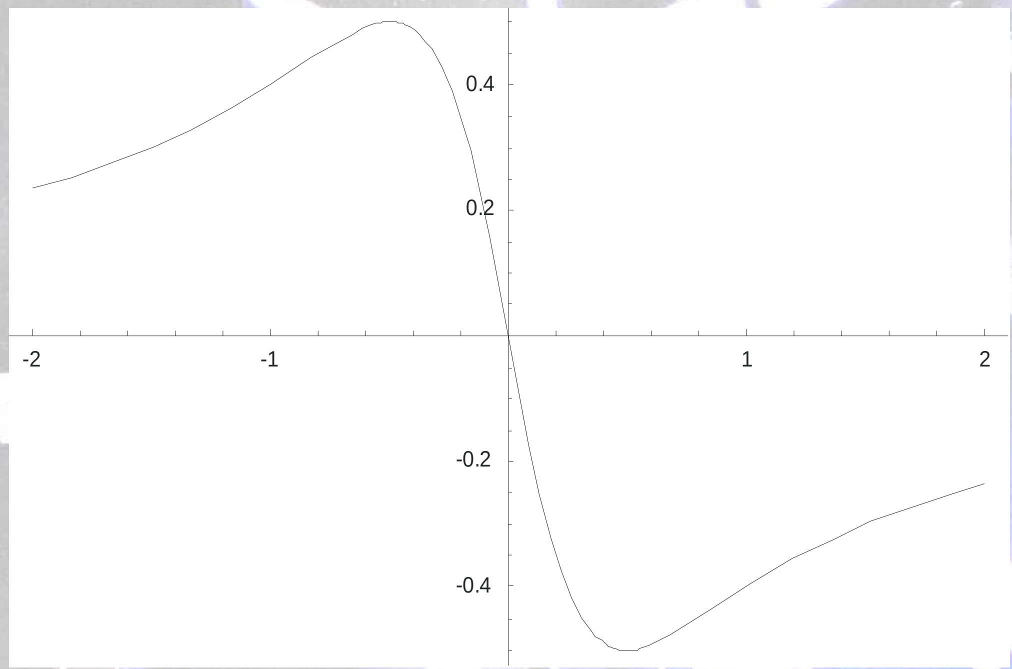


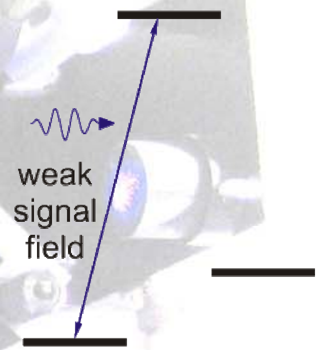


with control field

- **Light propagates through an otherwise opaque medium.**

Dispersion of the signal field





w/o control field

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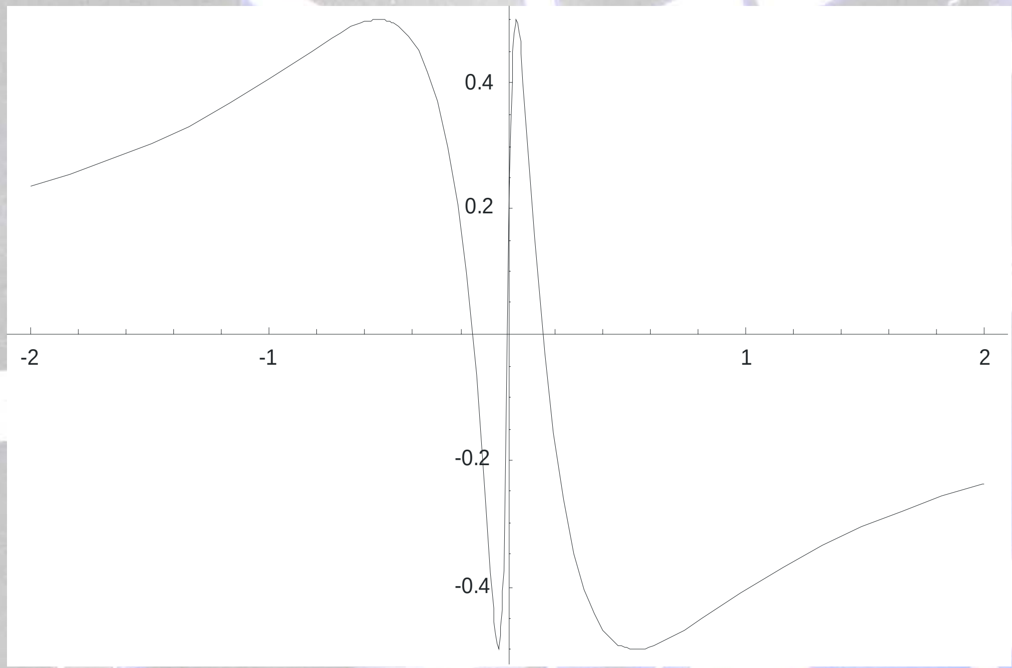
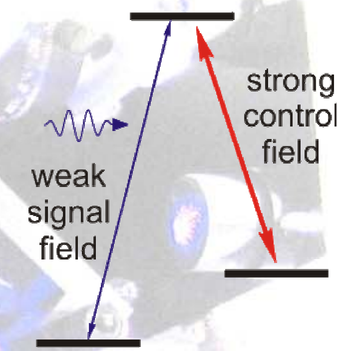
Dispersion of the signal field

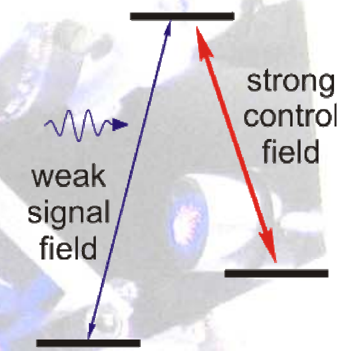


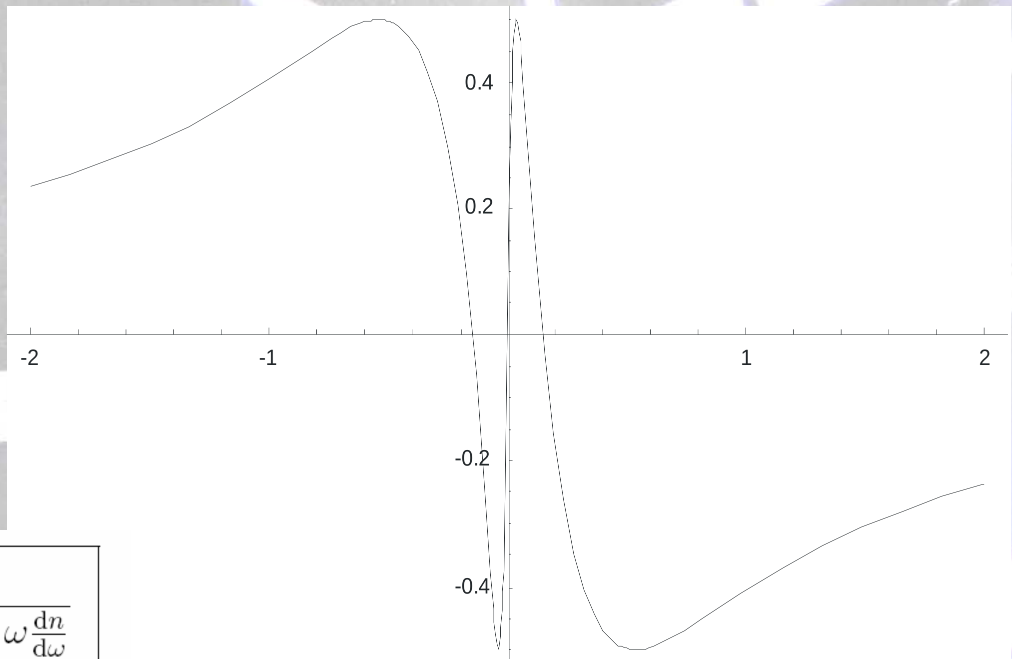


with control field

- We can enormously reduce the group velocity
- The slope is proportional to the strength of the control field

Dispersion of the signal field





with control field

Remember:

$$v_g(\omega) = \frac{c}{n(\omega) + \omega \frac{\mathrm{d}n}{\mathrm{d}\omega}}$$

- **We can enormously reduce the group velocity**
- **The slope is proportional to the strength of the control field**

How can we use EIT to store information?

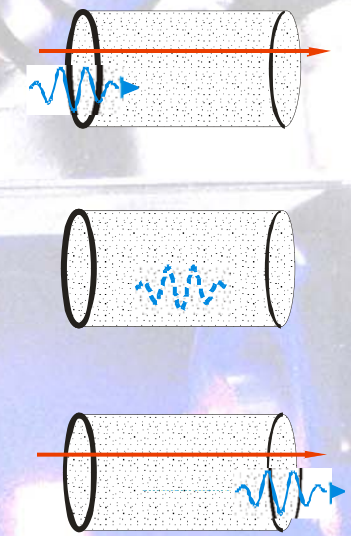
- Reducing the velocity to zero will store the light pulse. (Turning control field off)

- The process can be reversed, thus implementing a quantum memory cell for light.

- This method is good for storing quantum and classical information alike.

- The regenerated pulse should possess exactly the same quantum properties.

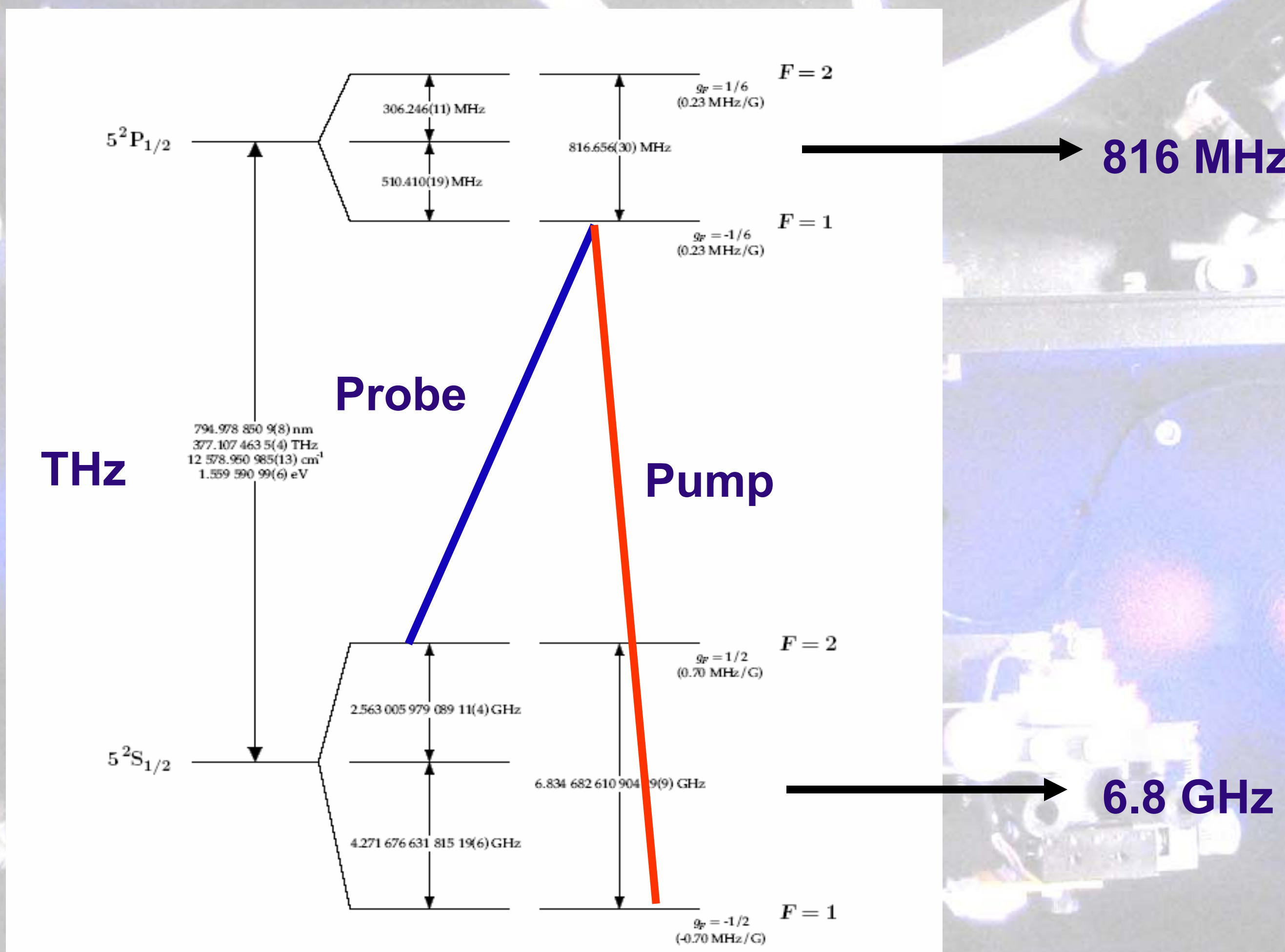
- Information is stored in the atoms



D. Phillips, A. Fleischhauer: Phys. Rev. Lett. 86, 783 (2001)

EIT in an atomic medium

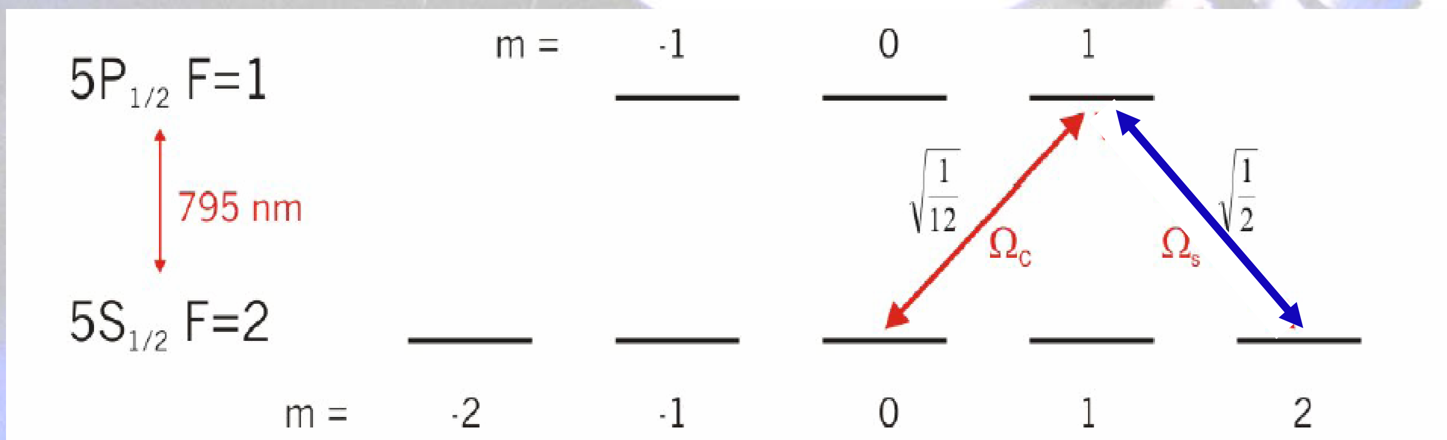
- Atomic Rubidium vapor (D1 line at 795nm)



EIT in an atomic medium

An alternative scheme:

Zeeman substates of the hyperfine ground states

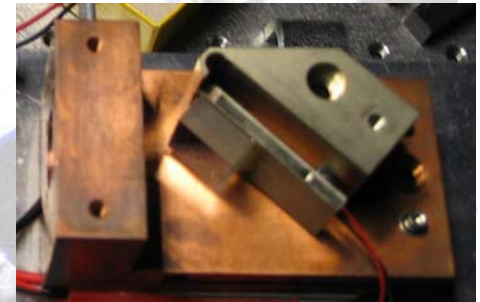


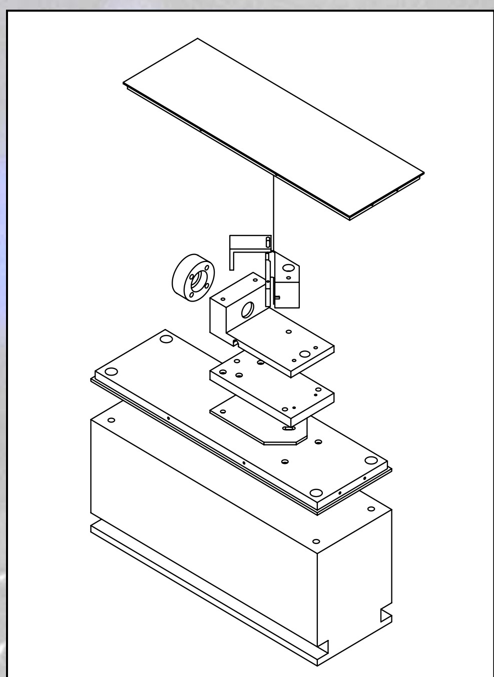
We can use different polarizations of the same laser to observe EIT

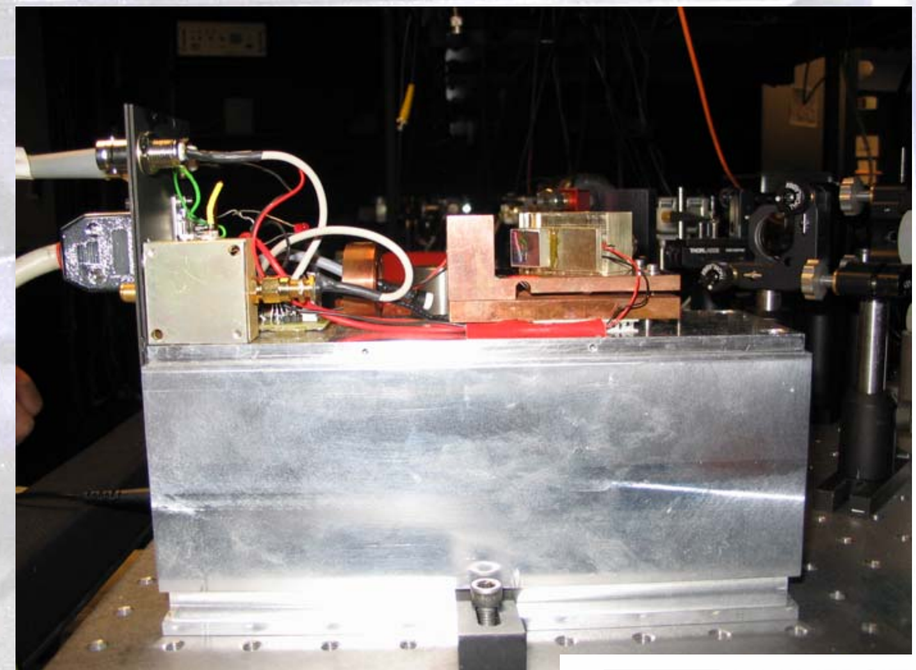
Now we go to the real experiments….

Laser diode system

- Tunable to the rubidium transitions
- Narrow linewidth.
- Keep a constant temperature in the diode
- The electronic control drives the piezo scan over the band of achievable wavelengths.







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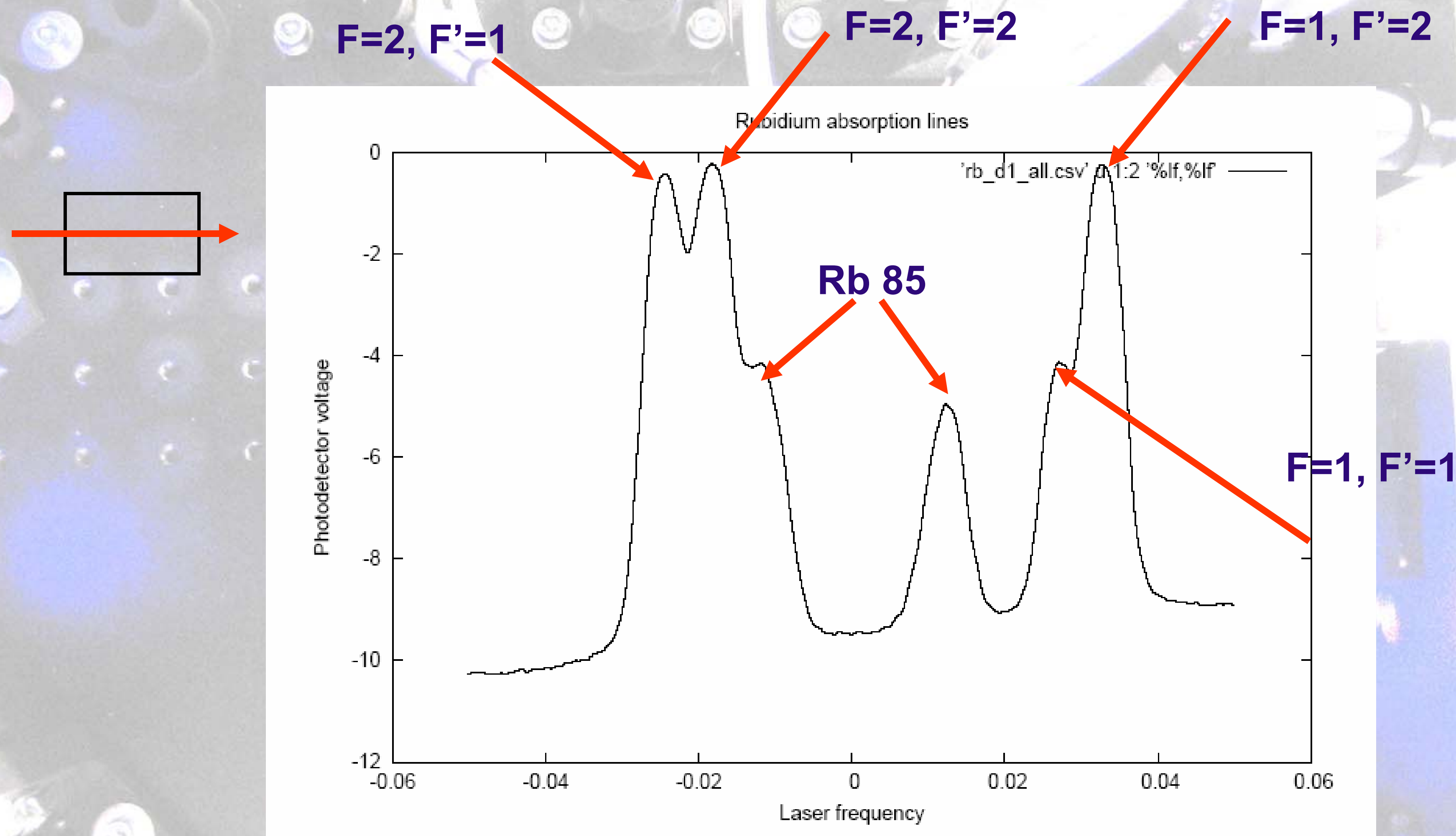
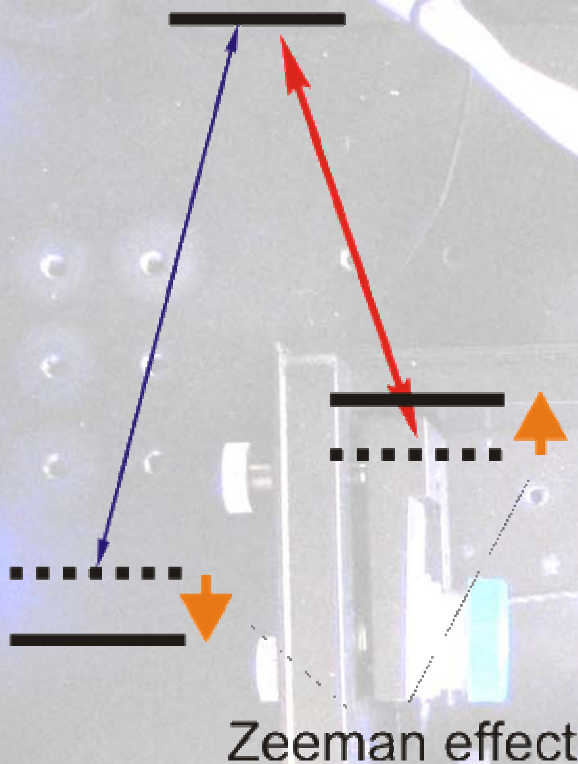
Rubidium spectroscopy



The effect of magnetic field on EIT



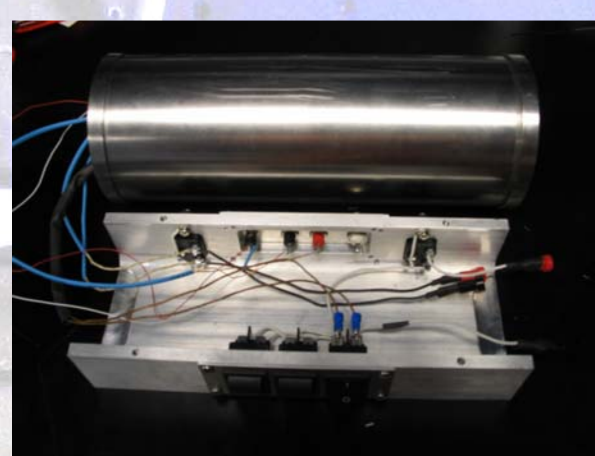
Magnetic field

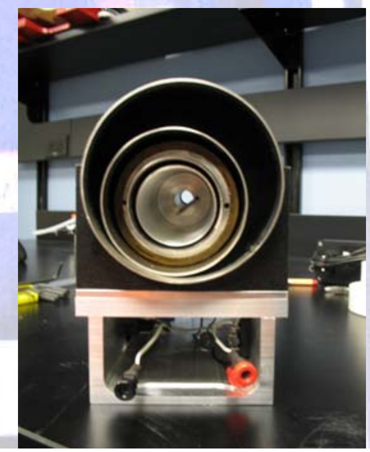
- **Zeeman effect**
- **Levels get shifted**
- **Two-photon resonance destroyed**
- **EIT lost**

Magnetic field destroys EIT

Interaction zone

- We have to shield our Rubidium cells.
- Cylinders of Mu-metal are nested together.
- Degaussing procedure is necessary.
- The level of shielding reaches below the micro gauss level.





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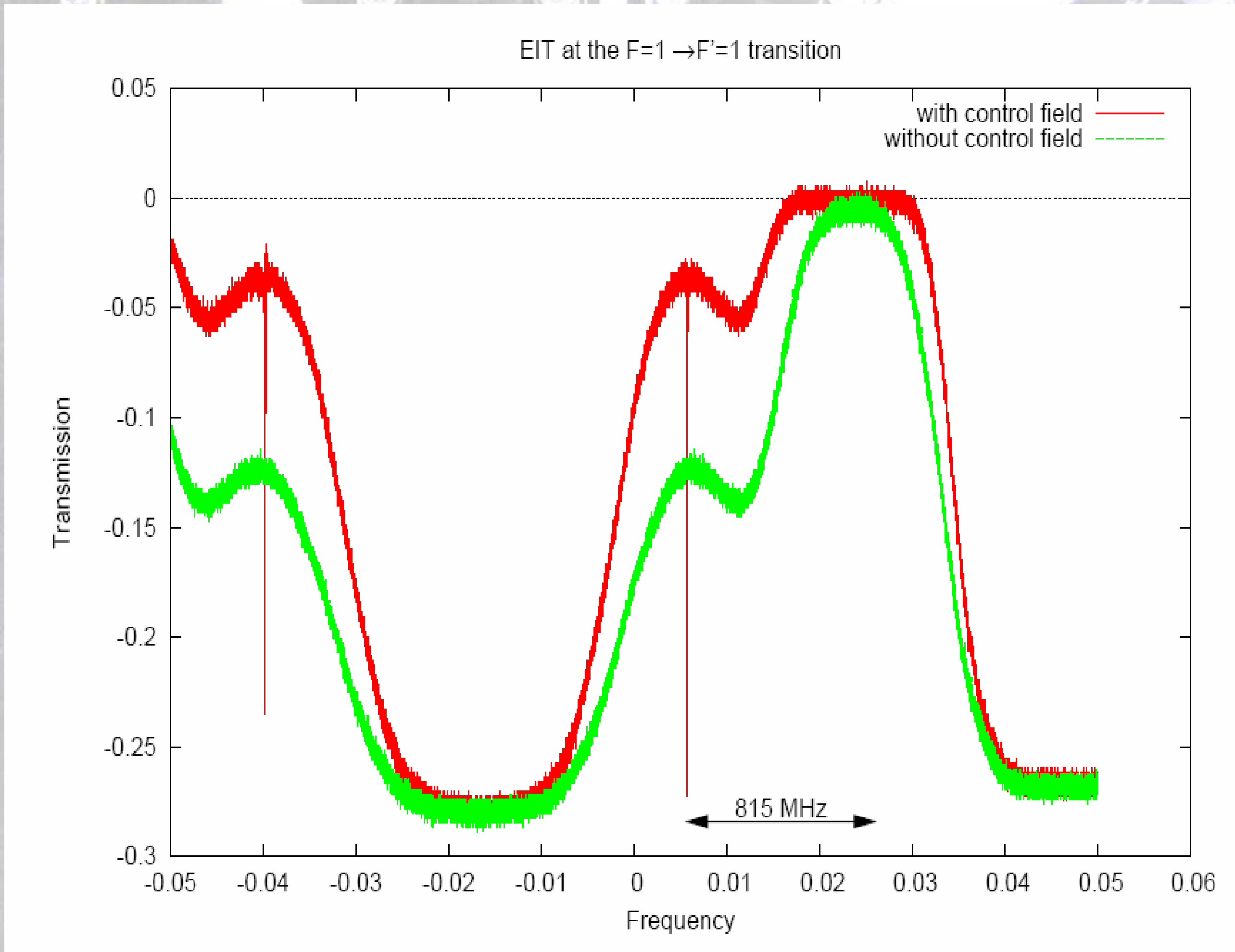
EIT in the hyperfine levels of Rubidium



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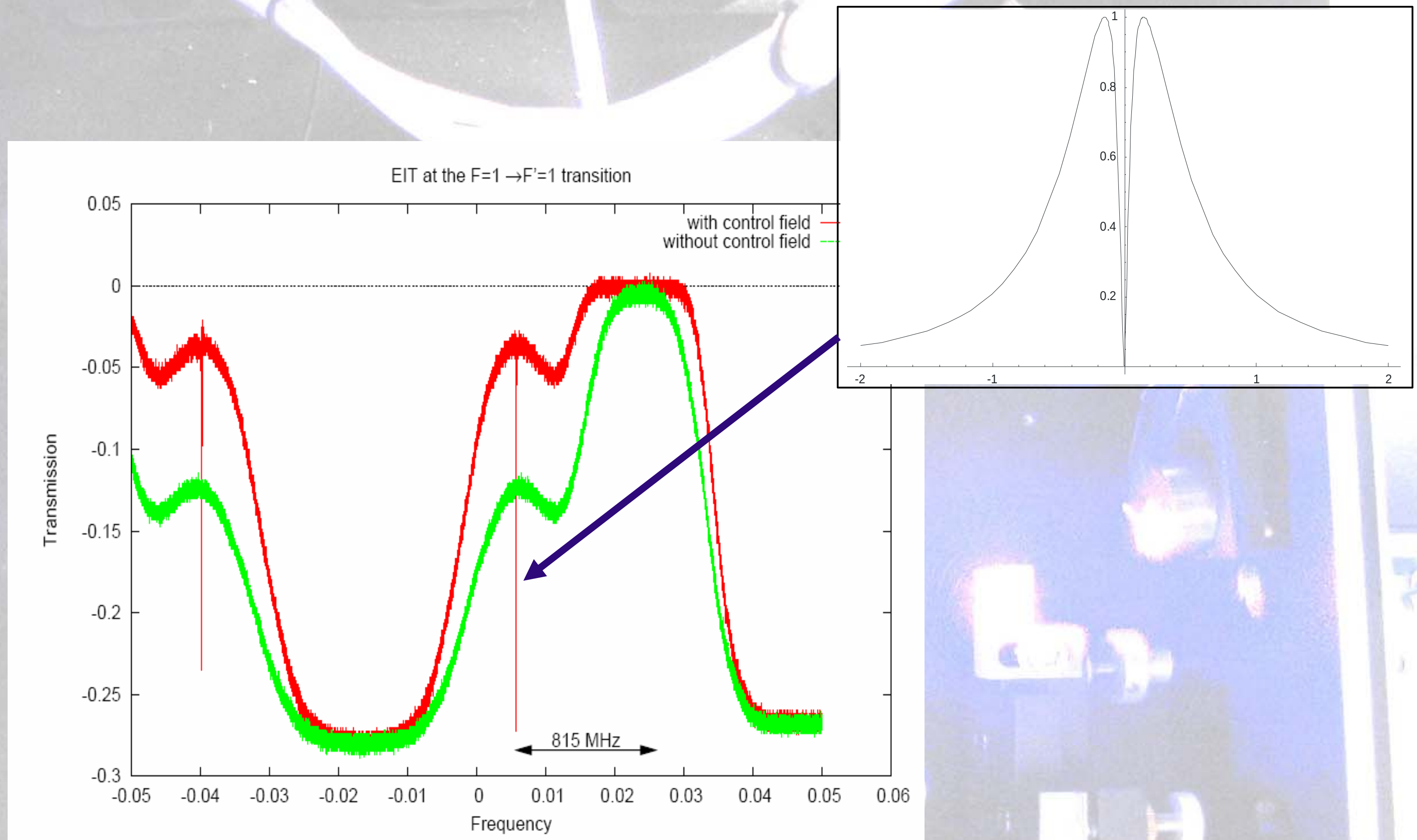

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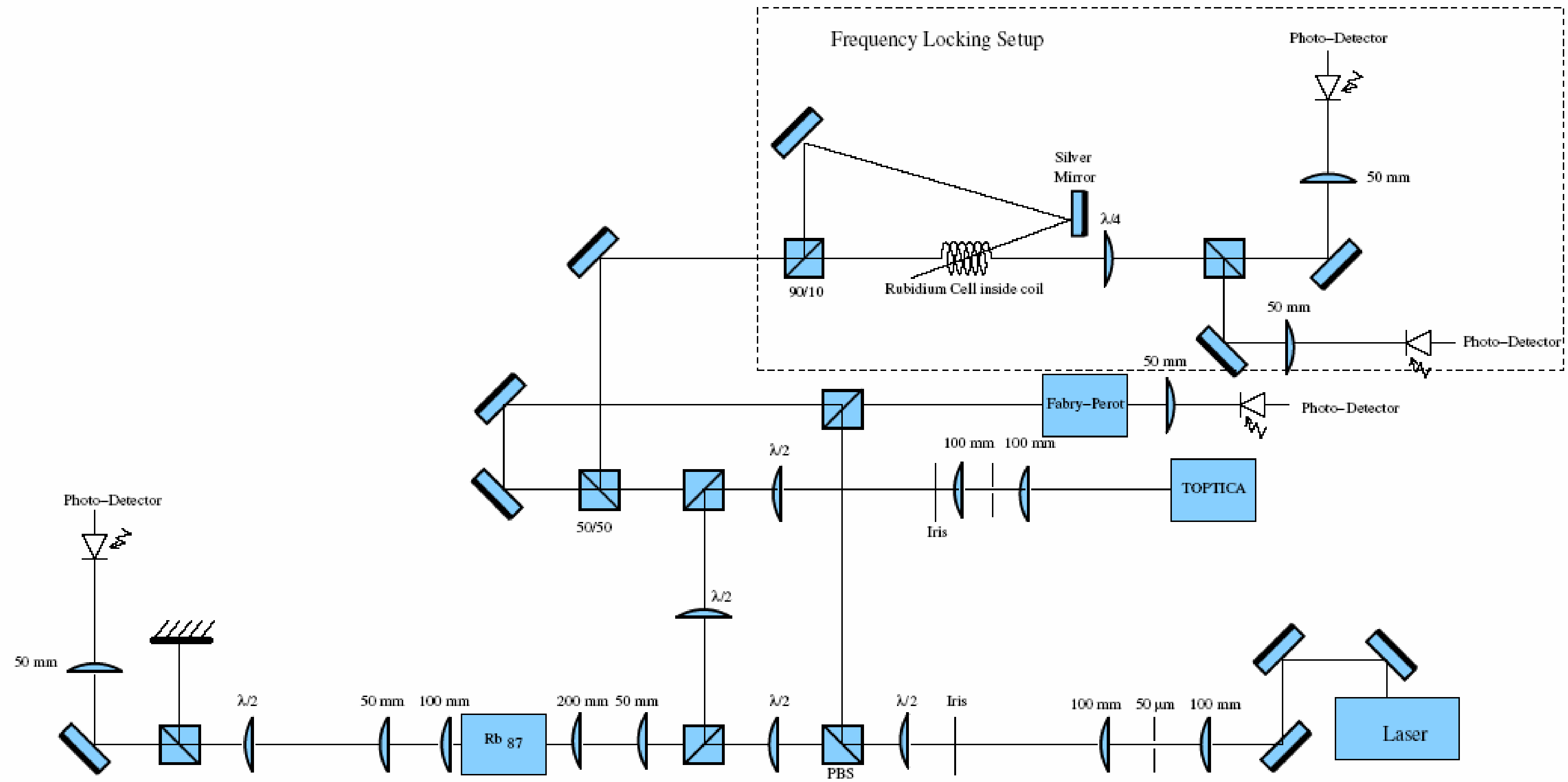
EIT in the hyperfine levels of Rubidium



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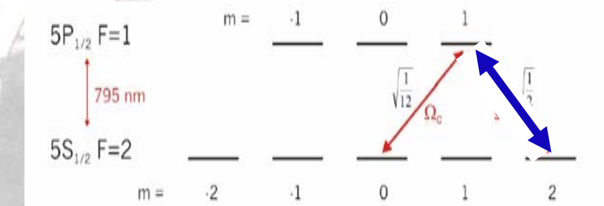
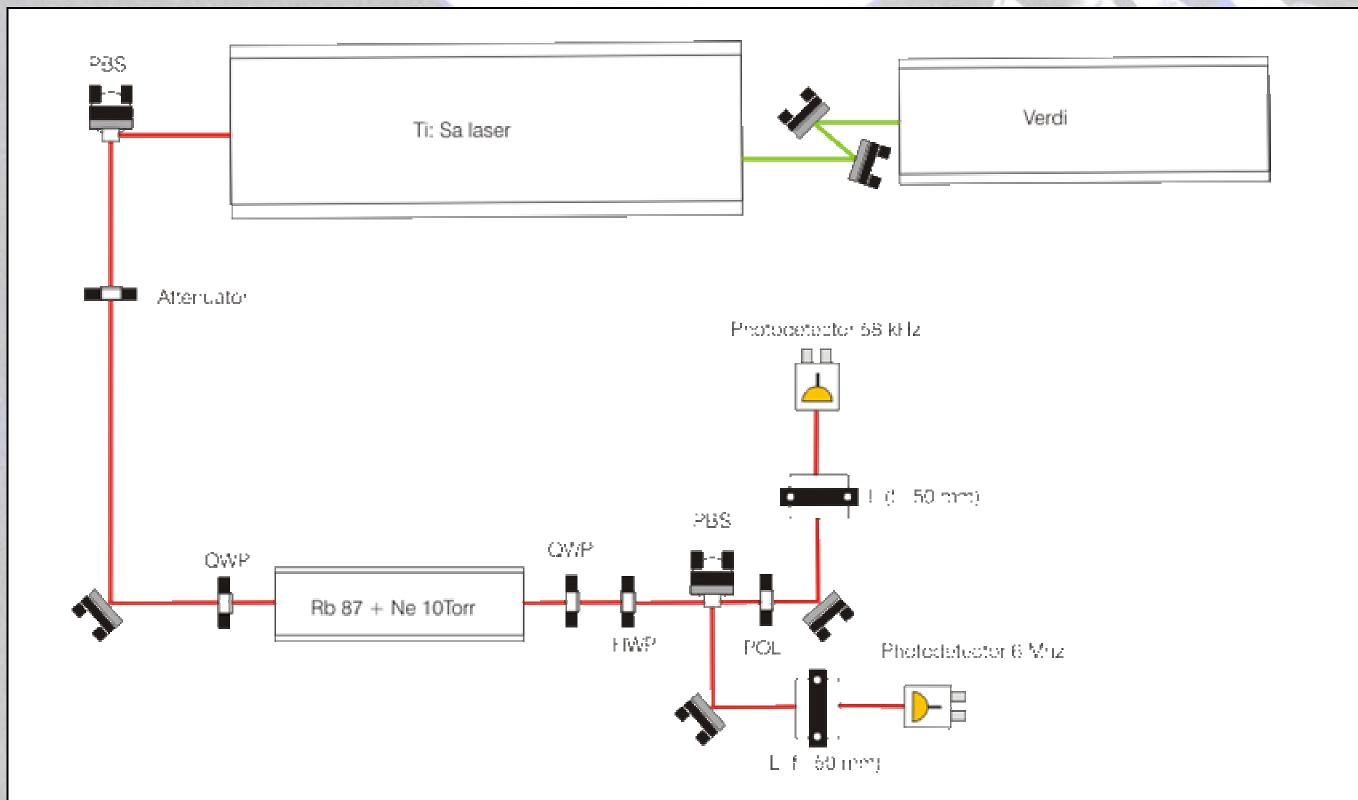
EIT in Zeeman sublevels

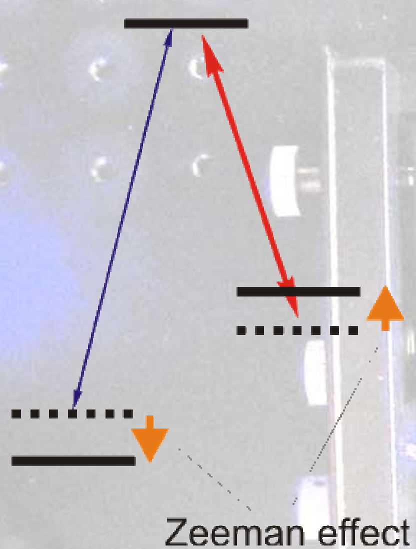


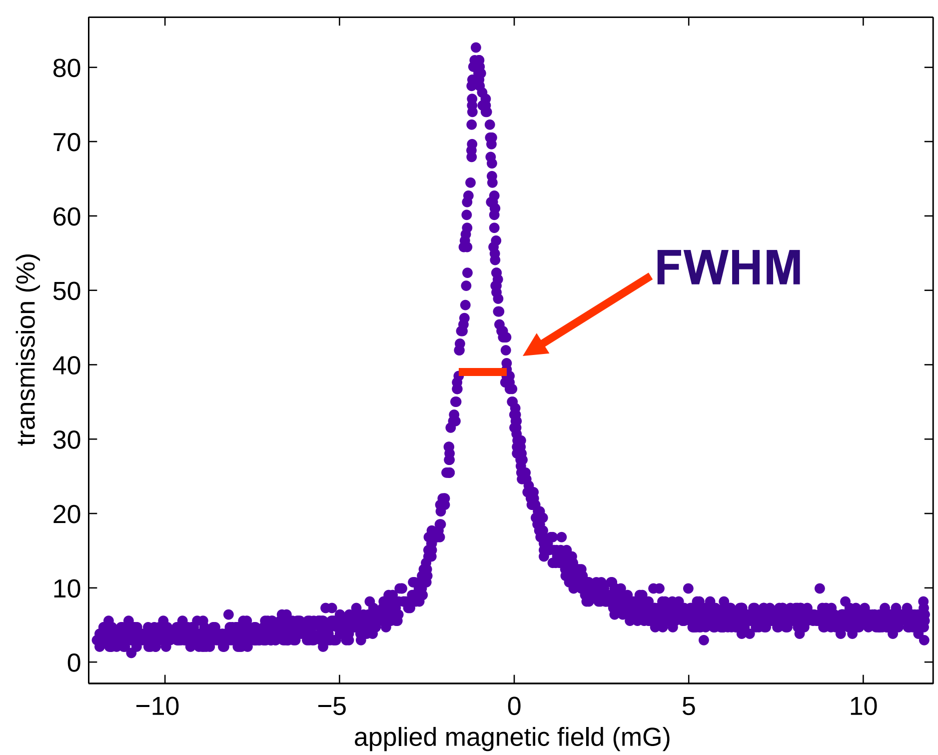


Measuring the EIT width (Method I)

We want to measure the width of the EIT transparency window because it contains information on the maximum storage time.

We detuned the two-photon resonance using magnetic field.





2 mG FWHM → 2.5 kHz EIT width

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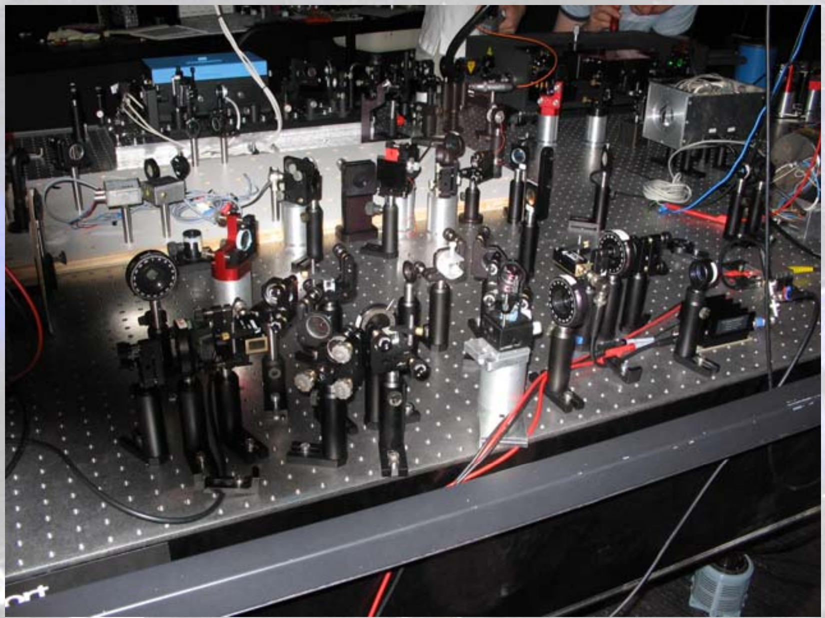
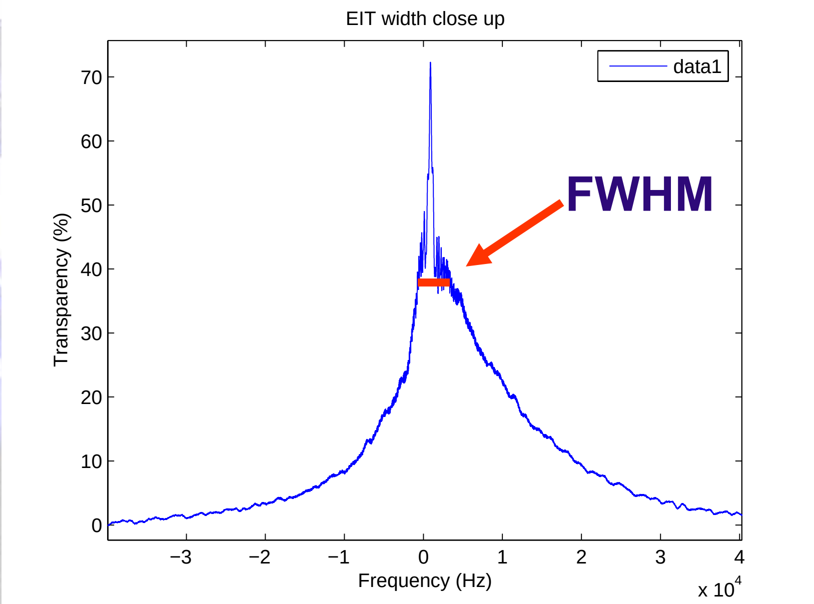
Measuring the EIT width (Method II)

We tuned control laser vs. signal laser using an Acousto-optical modulator.

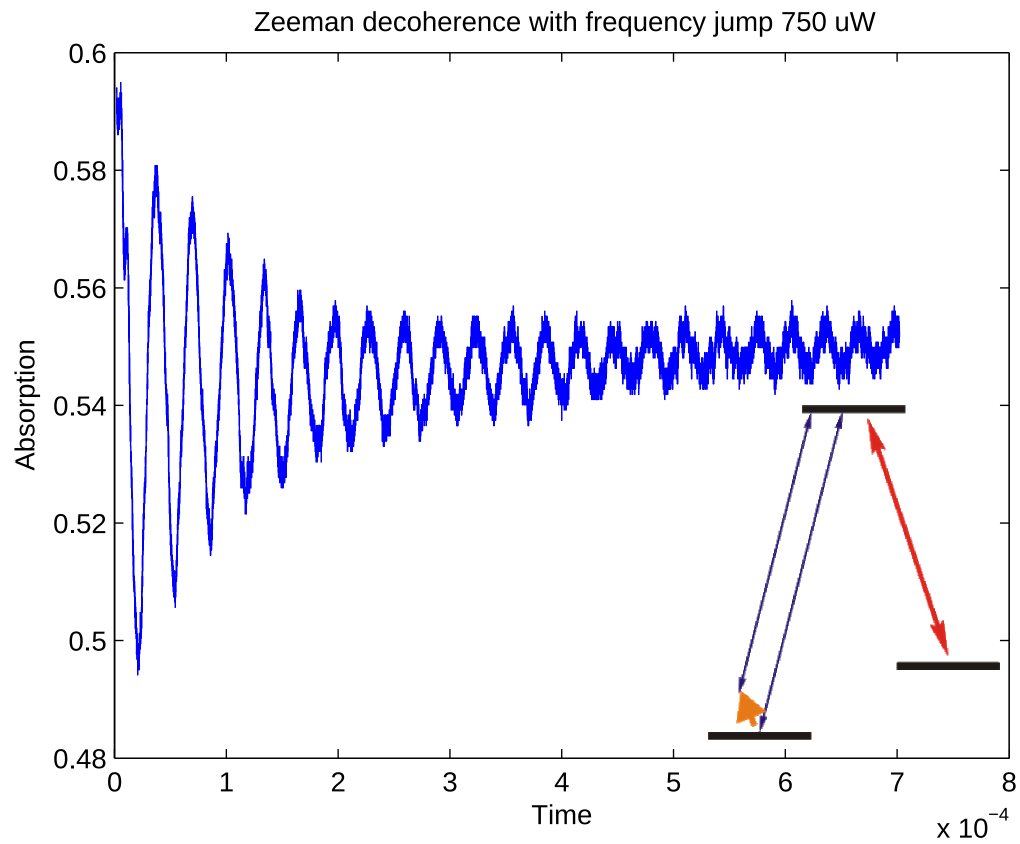
Our EIT width is about 10kHz FWHM, that means our laser should be stable at that level





Measuring the EIT width (Method III)

- Observe EIT → Ground state coherence is created
- Shift laser from two-photon resonance
- Ground state coherence will oscillate with respect to the lasers.
- Oscillations will damp when ground states decohere
- Decoherence time can be measured



S.Park, H. Cho: Phys. Rev. A 69 023806 (2004)

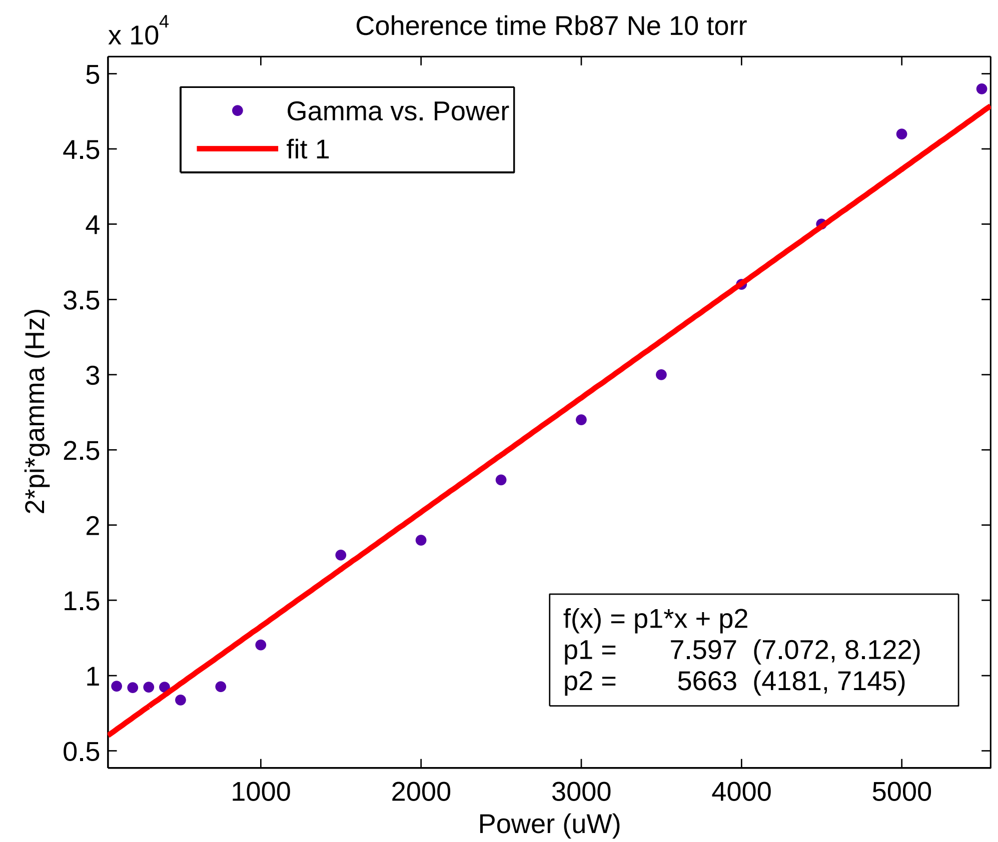
Ground state coherence lifetime: power dependence

Ground state decoherence time ⏲ Inverse of the EIT width

Large fields → power broadening

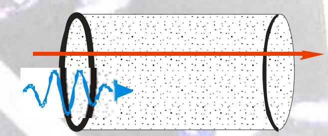
Small fields → ground state decoherence measurement

- The decoherence time is the ultimate limit to store light.

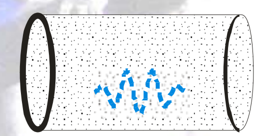


Storing light by EIT

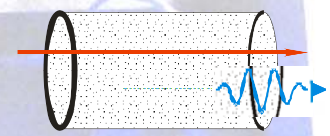
1 Couple a pulse of light into an EIT medium



2 Turn control field off adiabatically
→ quantum state of the signal pulse
stored as a collective atomic excitation



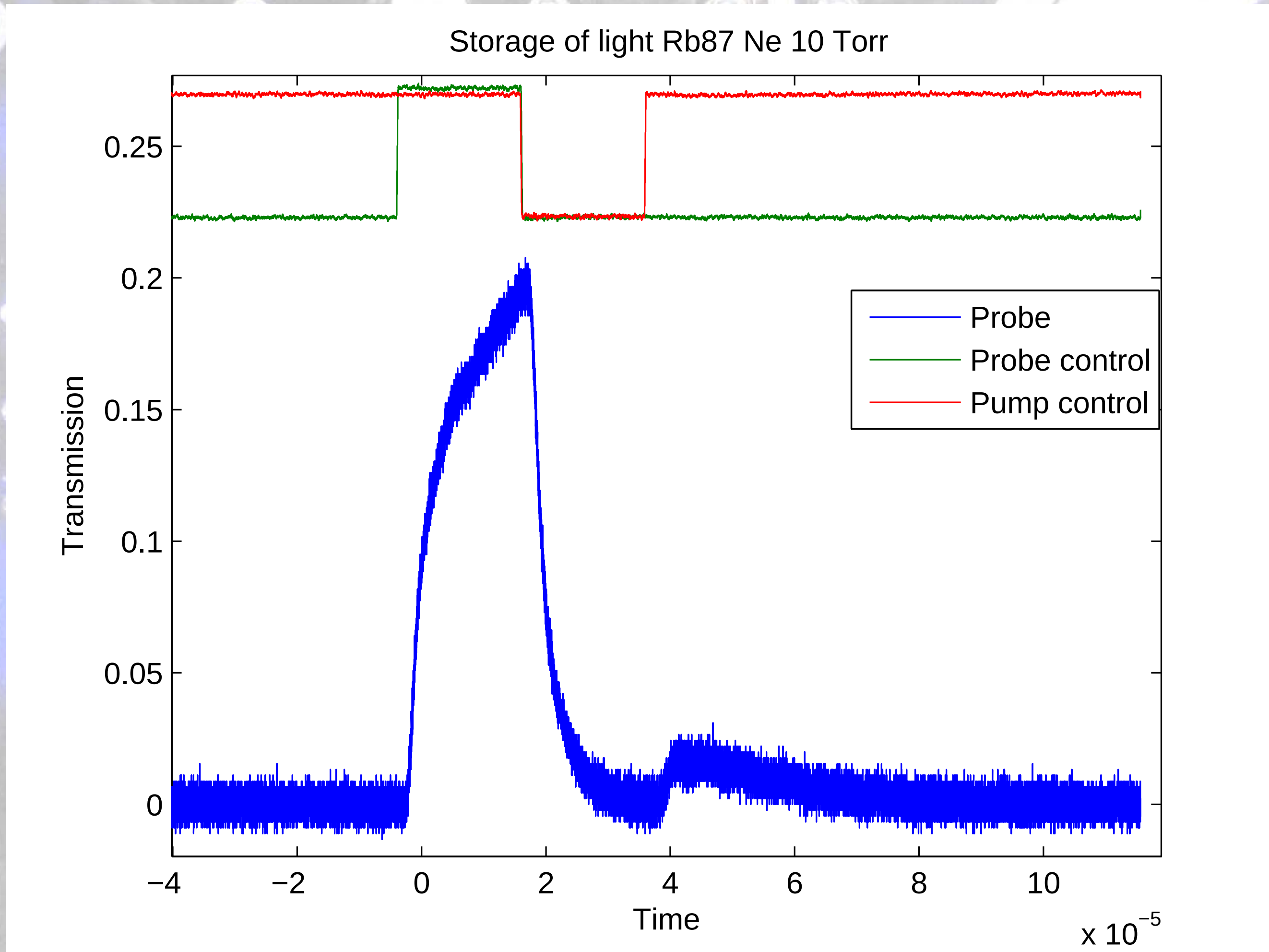
3 Turn control field back on
→ optical pulse released in the original quantum state



Storing light by EIT (Technical challenges)

- We need pulses in the probe field. Switch via Acousto-optical modulators
- The group velocity is proportional to the power of the pump field.
- We need to smoothly switch off the pump field to reach the zero of the group velocity.

Storage of light (Preliminary results)



Voila!!

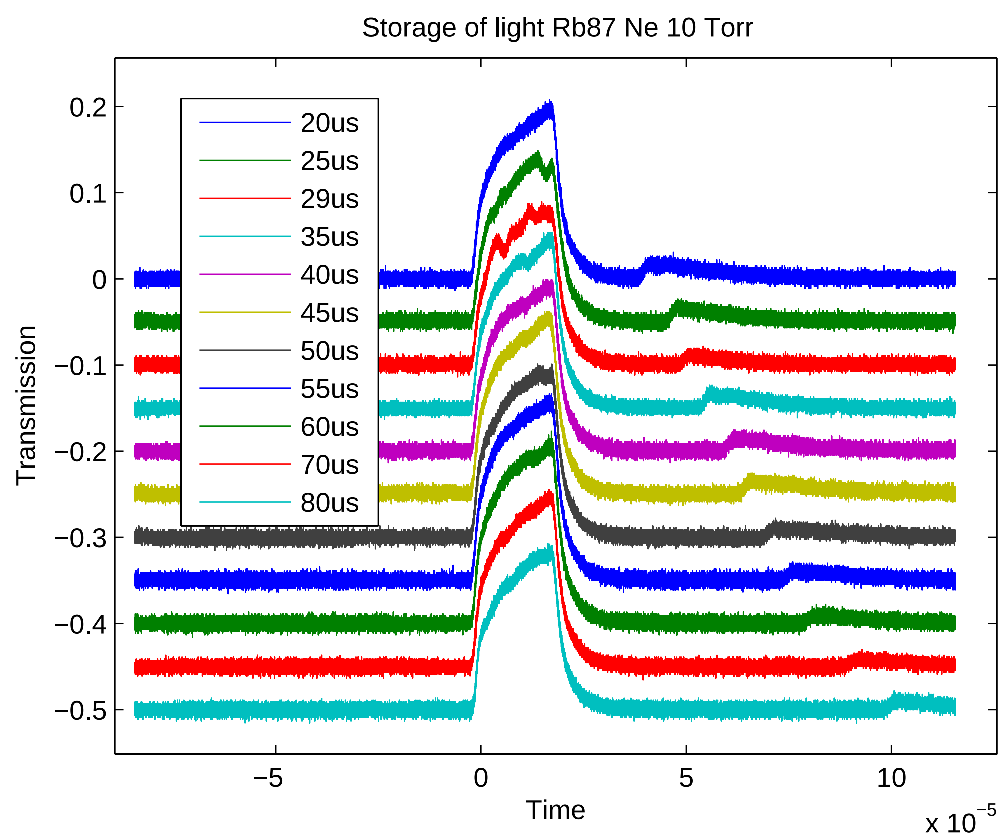
Stored light

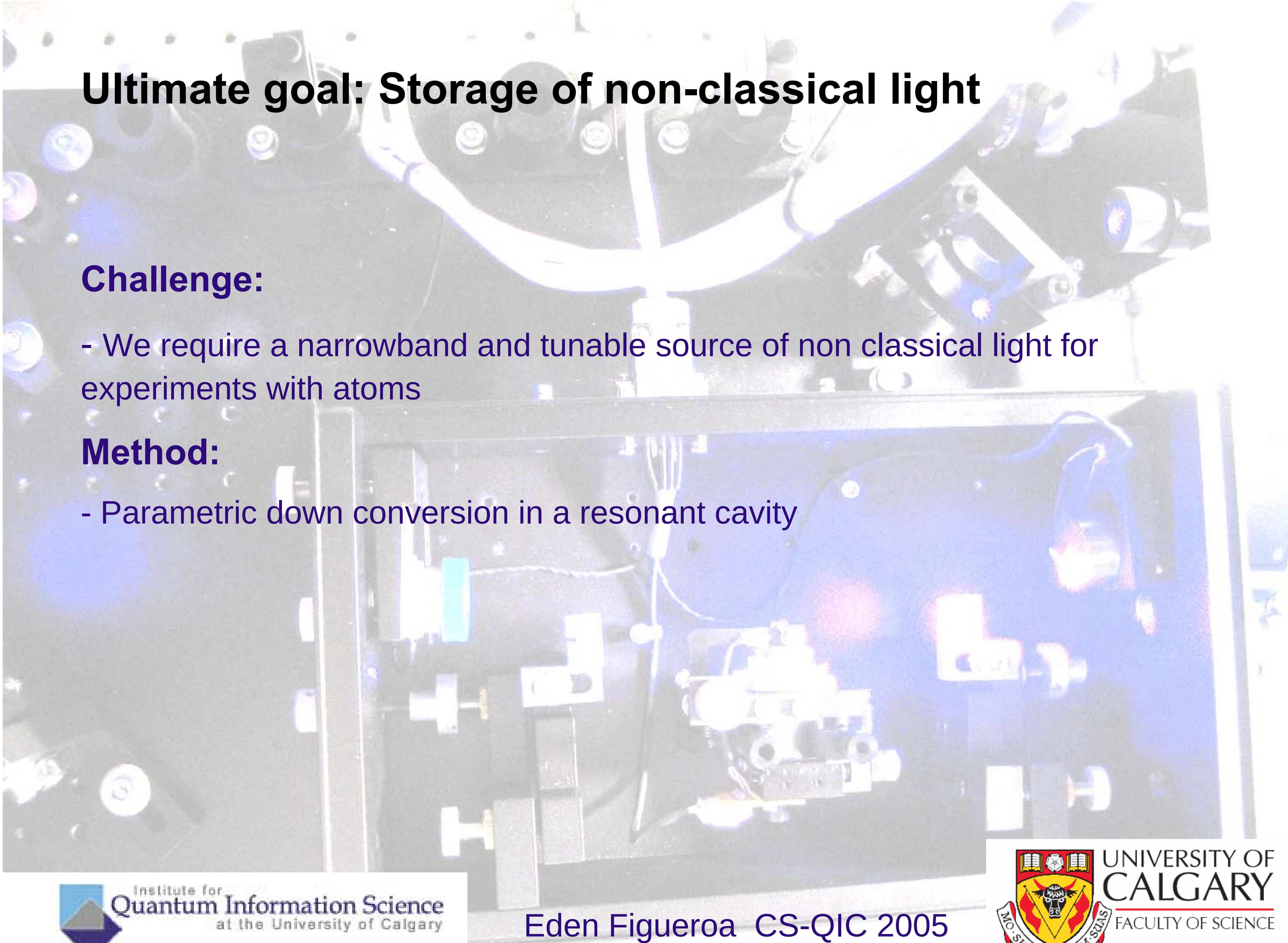
Storage of light (Preliminary results)

Storage of light up to 80 μs

Storage can be improved by using Gaussian pulses

80 μs = 240 km in free space





Ultimate goal: Storage of non-classical light

Challenge:

- We require a narrowband and tunable source of non classical light for experiments with atoms

Method:

- Parametric down conversion in a resonant cavity

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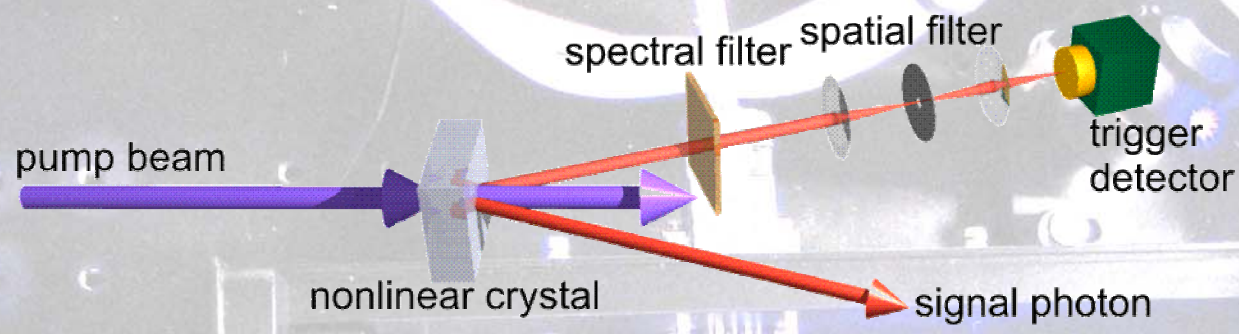
Parametric down-conversion



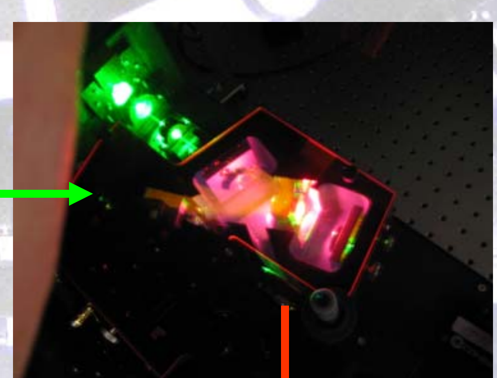
– “Red” photons are always born in pairs

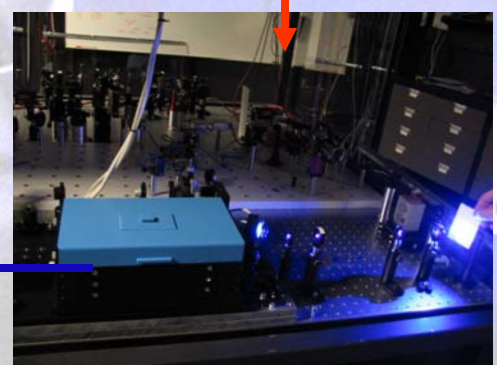
– Photon detection in one emission channel
$\rightarrow$ there must be a photon in the other channel as well (Heralded photons)

Single photon source

Pump laser 10W (560nm)

Ti:Sapphire laser 1.8 W (795nm)

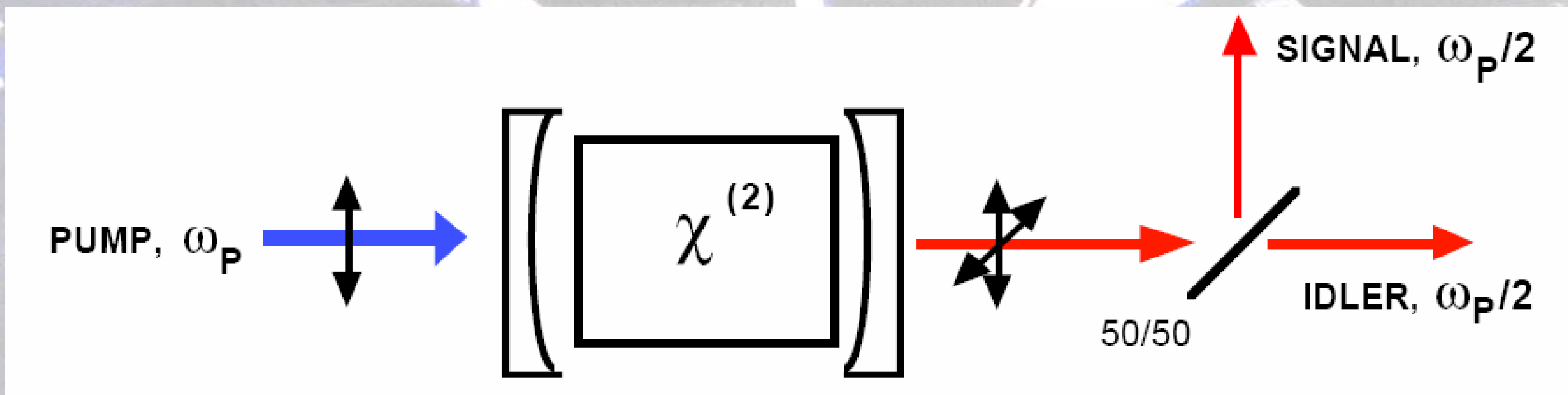




Frequency doubler 700 mW (397.5nm)

OPO

Optical parametric oscillator



- This cavity must be stabilized so that the signal photon wavelength is exactly the same as that of the desired atomic transition.

- One photon in a pair will be detected while the other one will be stored in an EIT medium.

- We will verify whether the EIT storage preserves the single-photon state.

Summary

- Building and characterization of a tunable laser system
- Production of EIT configurations in Rb 87 atoms
- Design of a magnetic shielding together with temperature stabilization for our cells.
- Measurements of EIT width by different methods
- Measurements of decoherence times of ground states
- Preliminary results on storage of light
- Overview of the single photon source

Future work

- Implementation of an OPO pumped with light coming from a frequency-doubling cavity to be used as a source of non-classical states of light.

- Design and characterization of a filtering system for narrow band single-photons.

- Storage and retrieval of single photons in Rubidium vapor.

Thanks to:

Lab visit at 5 PM!!!

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Juergen Appel, PhD Student

Sergei Babichev, PhD student

And the Institutions supporting our research:

DAAD Deutscher Akademischer Austausch Dienst German Academic Exchange Service

NSERC CRSNG

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Alberta Ingenuity

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