Quantum State Storage in a slow light cavity

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LUND UNIVERSITY

Outline:

1. Cavity storage idea
2. Engineering absorption for tuning cavity transmission
3. Slow light cavity
4. Storage experiment
5. Obtaining 100% absorption?

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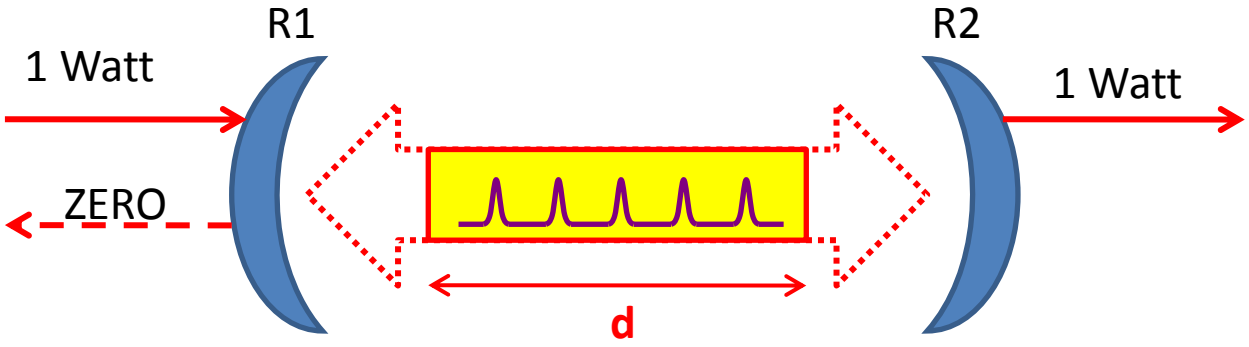
AFC in the impedence matched cavity:



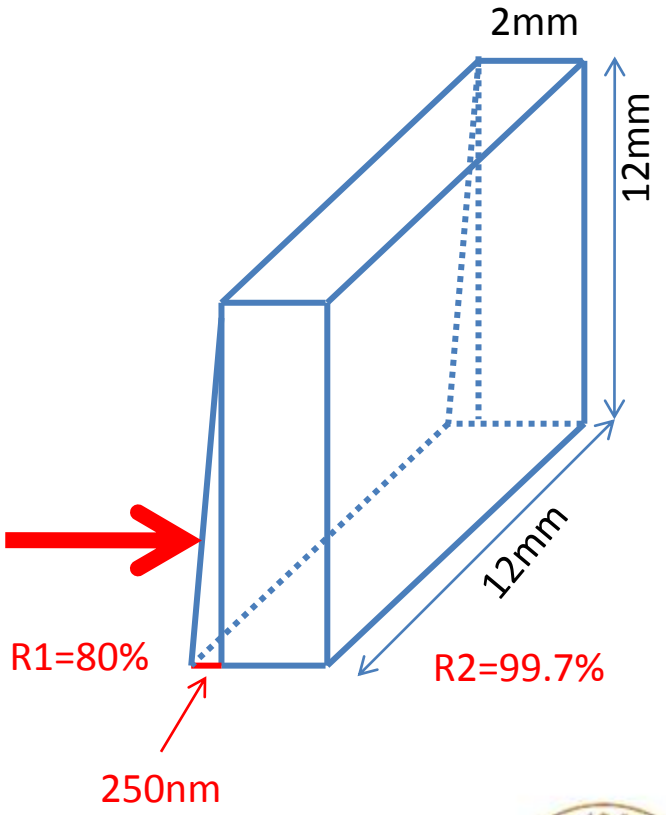
$$if \quad R_1 = R_2 \Rightarrow reflected \quad power = 0$$

$$add \;\; absorption \;\; media \quad \& R_2 \approx 1 \Rightarrow R_1 = e^{-2d\alpha_0} \Rightarrow \alpha_0 = \frac{1}{-2d} \ln R_1$$

Mikael Afzelius and Christoph Simon, Phys Rev A **82,** 022310 (2010)

Cavity Design

- 0.05% Pr:YSO
- Light propagation along the b axis
- Wedges: to control the overlap between cavity resonance frequency & ion absorption linewidth
- ≈ 9GHz inhomogeneous line-width



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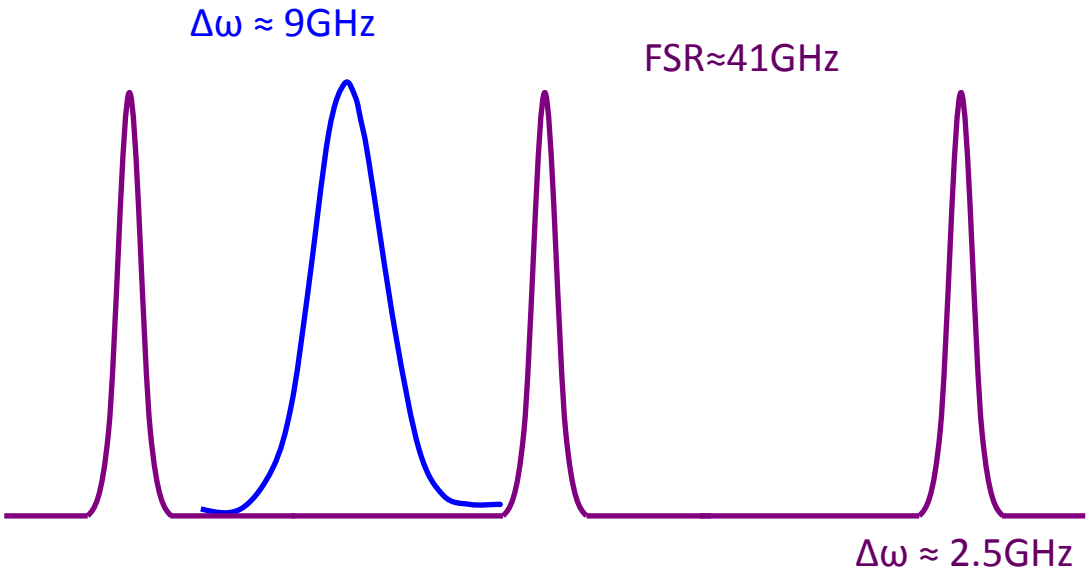
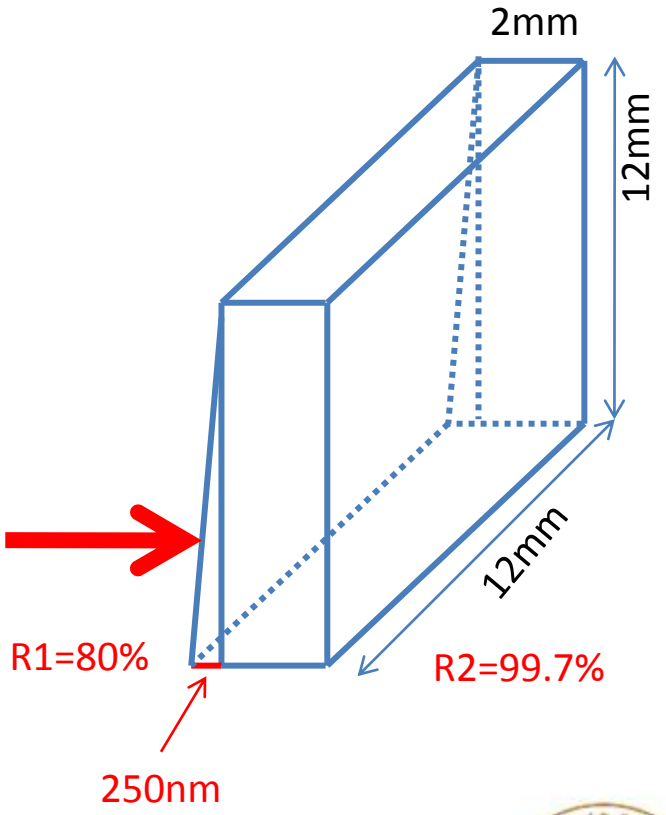
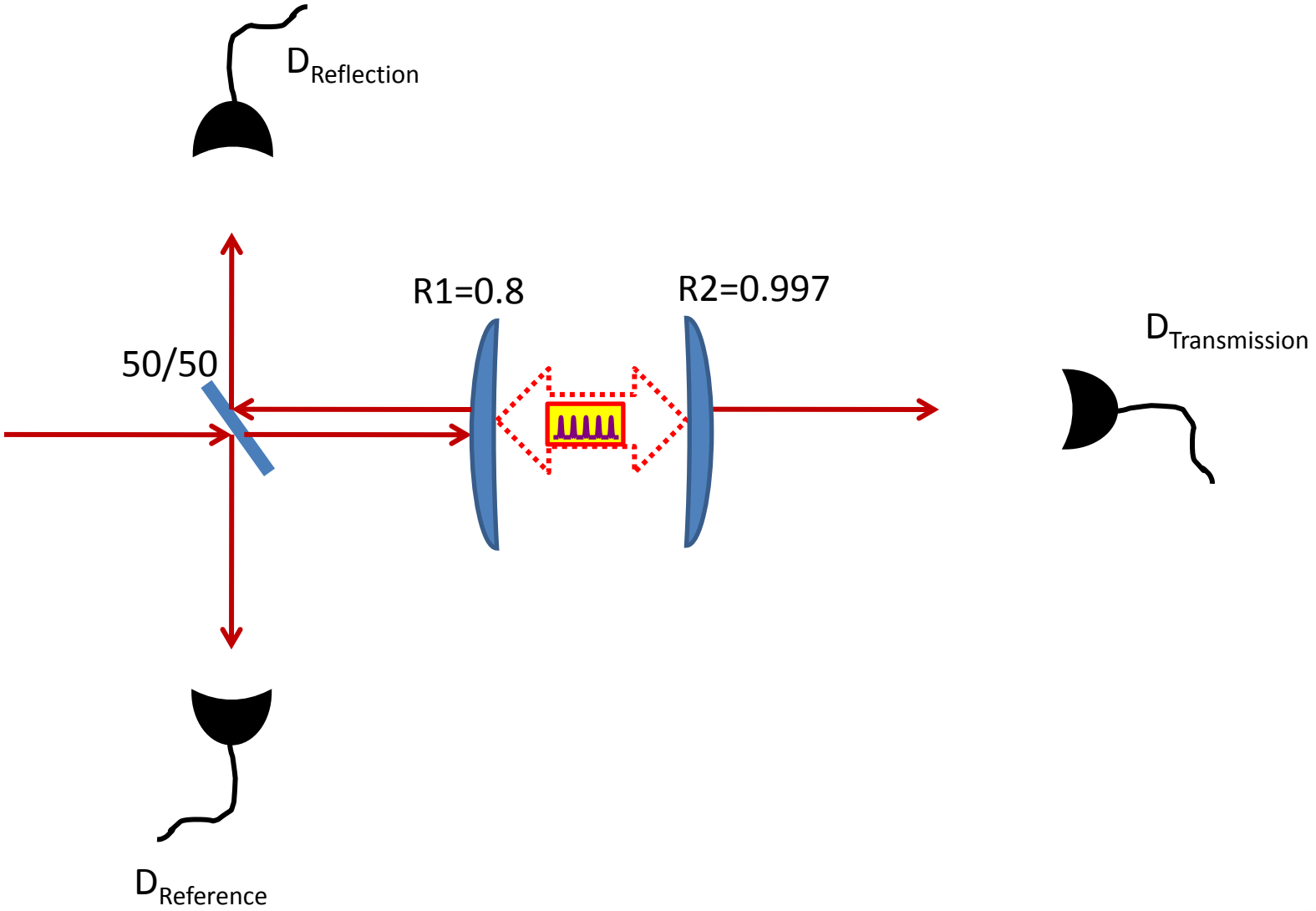




Experimental setup



Mode spacing

$$\Delta\omega_{\text{mode}} = \omega_{q+1} - \omega_q = q.\frac{2\pi}{2L}.\frac{c}{n_g(\omega)}$$

$$v_g(\omega) = \left(\frac{d\omega}{dk}\right) = \frac{c}{n_g(\omega)}$$

$$n_g(\omega) = n_r(\omega) + \omega\frac{dn_r(\omega)}{d\omega}$$

$$\textit{Cold cavity}: \quad n_r(\omega) >> \omega\frac{dn_r(\omega)}{d\omega}$$

$$\textit{Slow light}: \quad n_r(\omega) << \omega\frac{dn_r(\omega)}{d\omega}$$

$$\textit{Fast light}: \quad n_r(\omega) \approx -\omega\frac{dn_r(\omega)}{d\omega}$$

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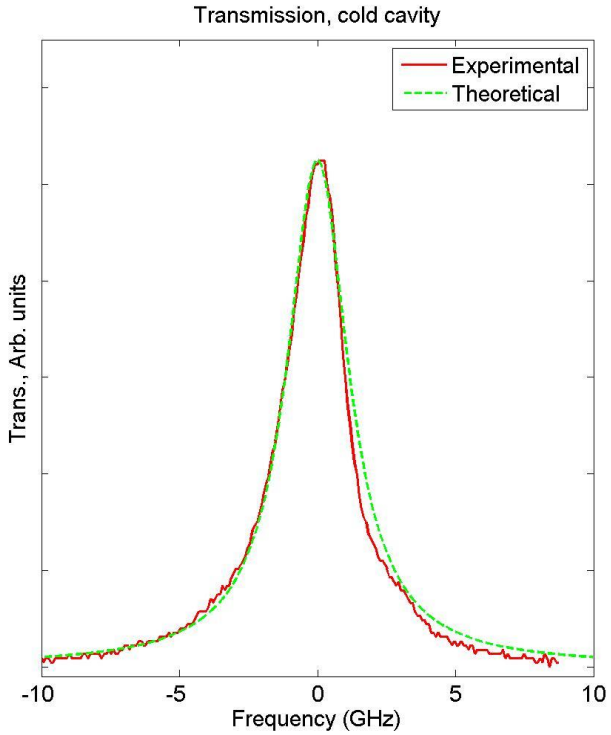
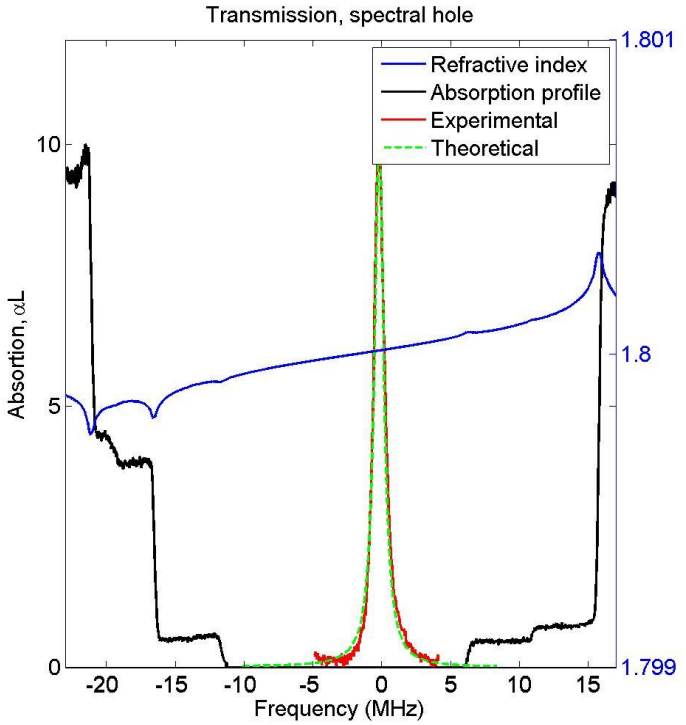
cavity transmission

Cold cavity ≈ 2.5GHz



Cavity trans. through pit ≈ 2MHz



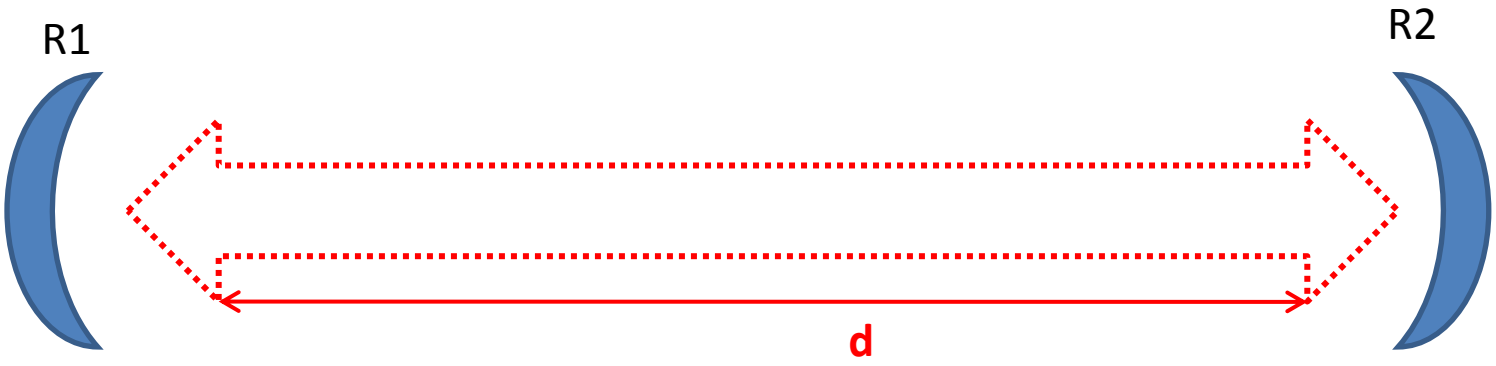
$$\mathrm{Im}(\chi(\omega)) \propto \alpha(\omega)$$

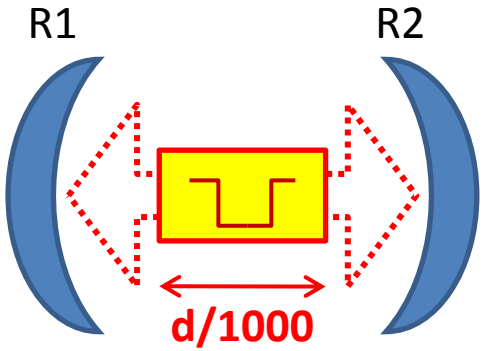
Kramers-Kronig relation

$$\mathrm{Re}(\chi(\omega)) \propto n_R(\omega)$$

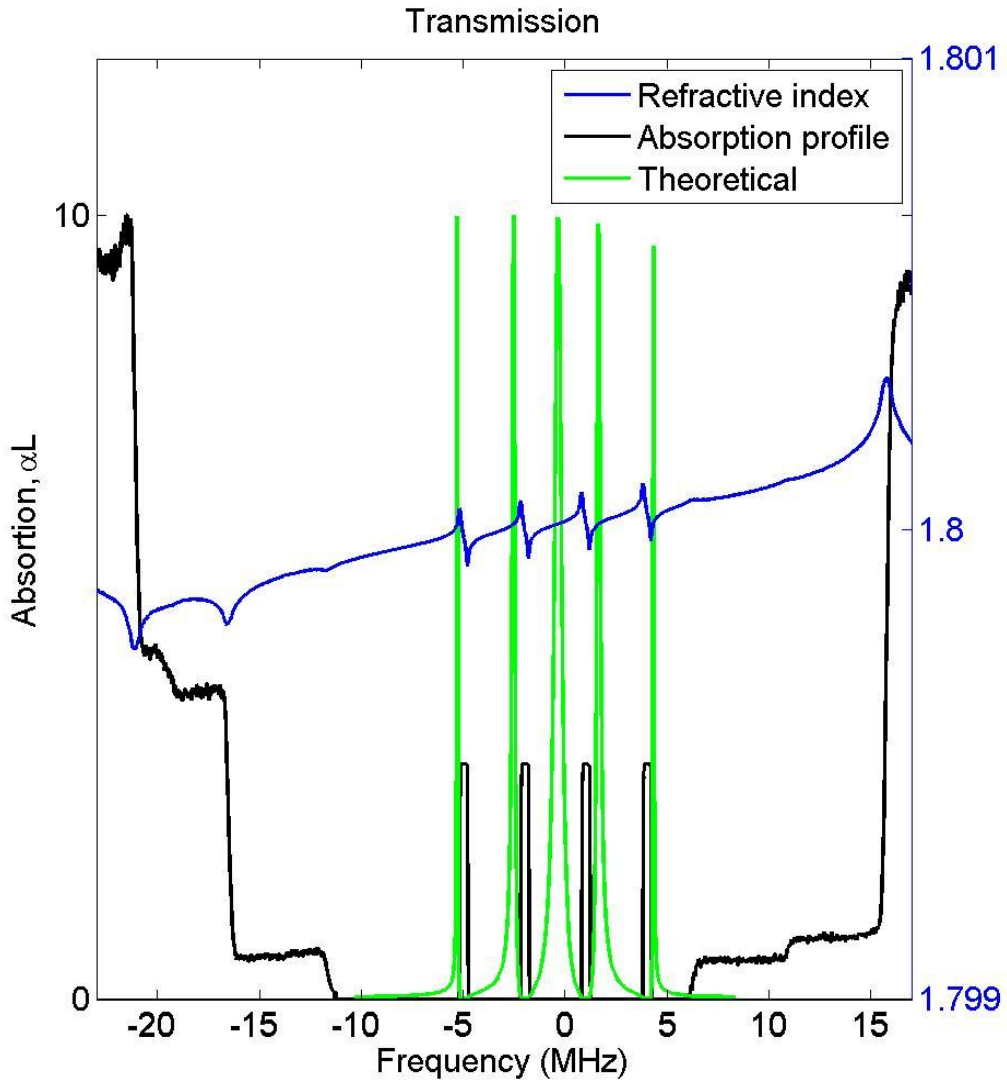
Note: Regarding finesse, for 29GHz scan we had just one cavity transmission

To have the same linewidth in the Cavity with and without medium:

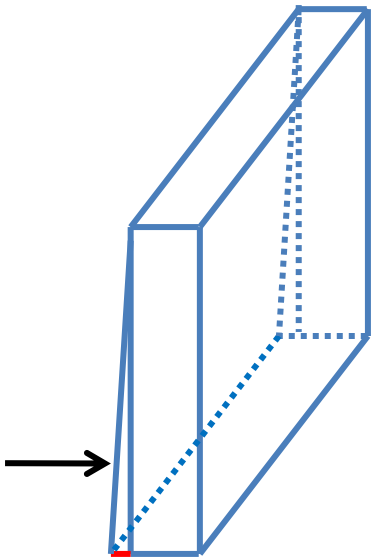


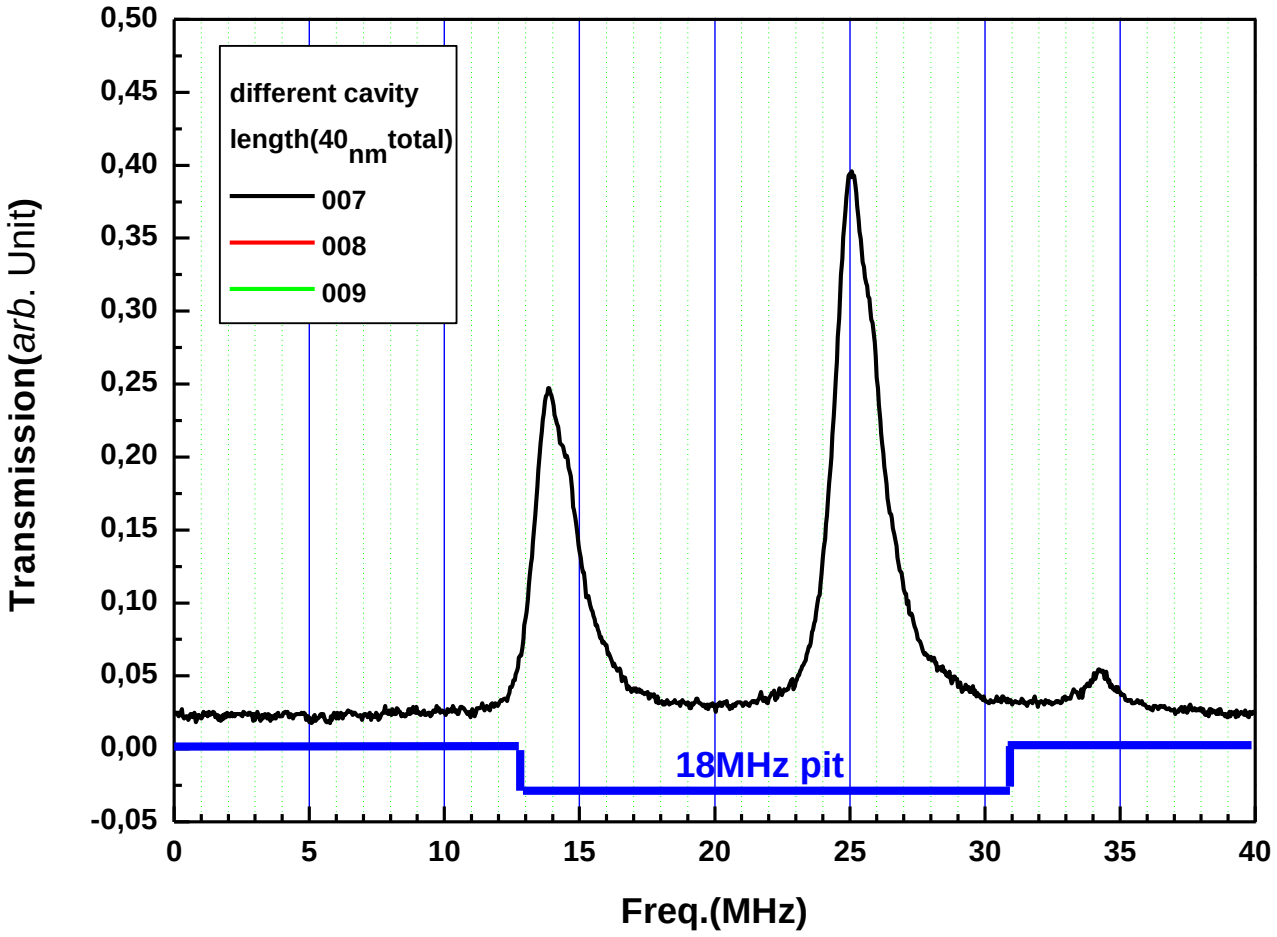


Possibility to engineer the cavity transmission



Tuning the cavity transmission frequency





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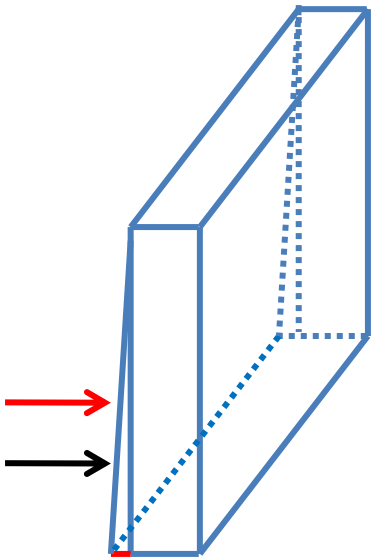

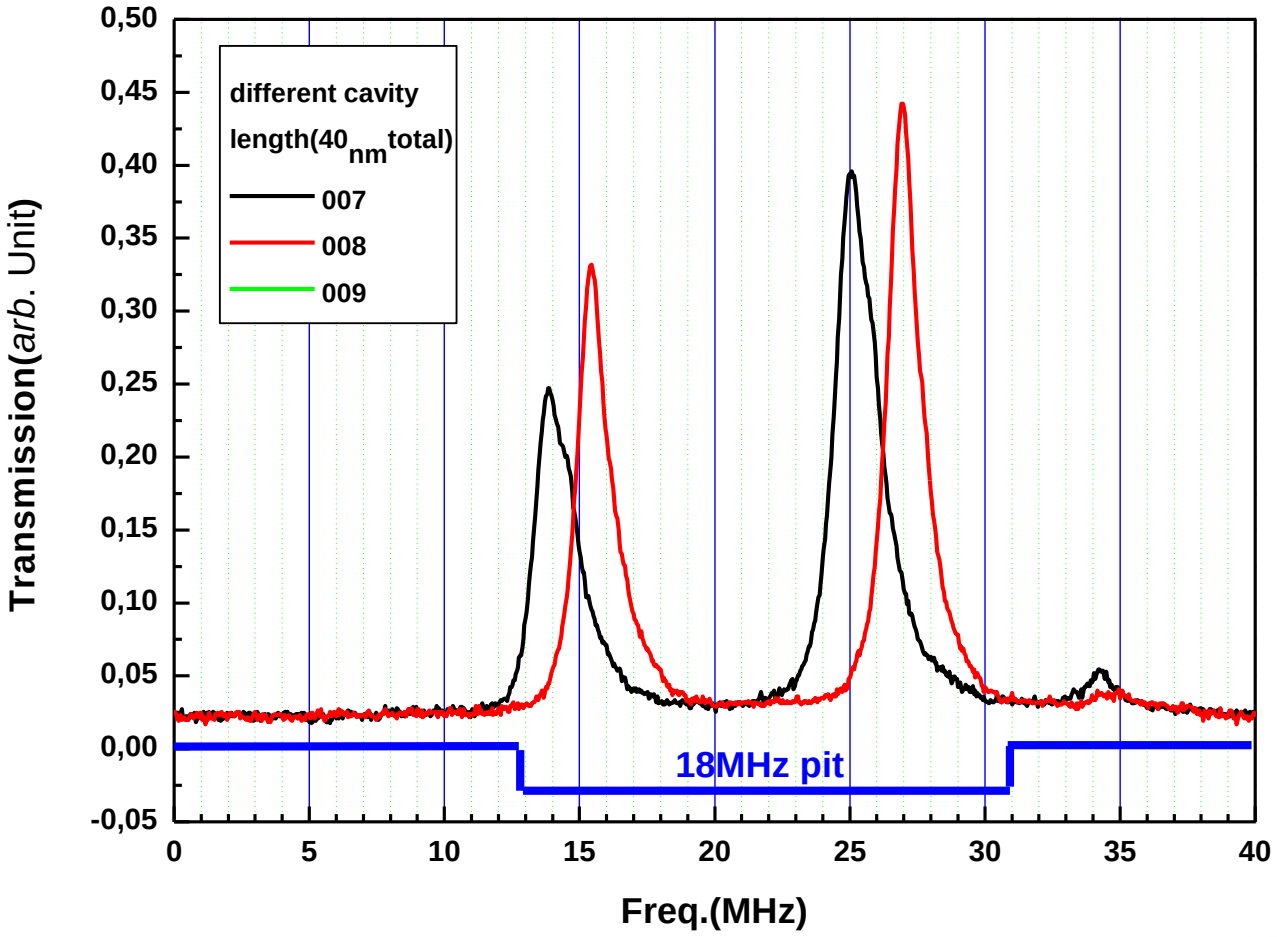

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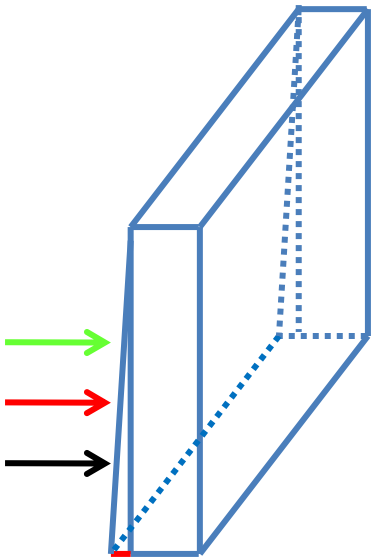

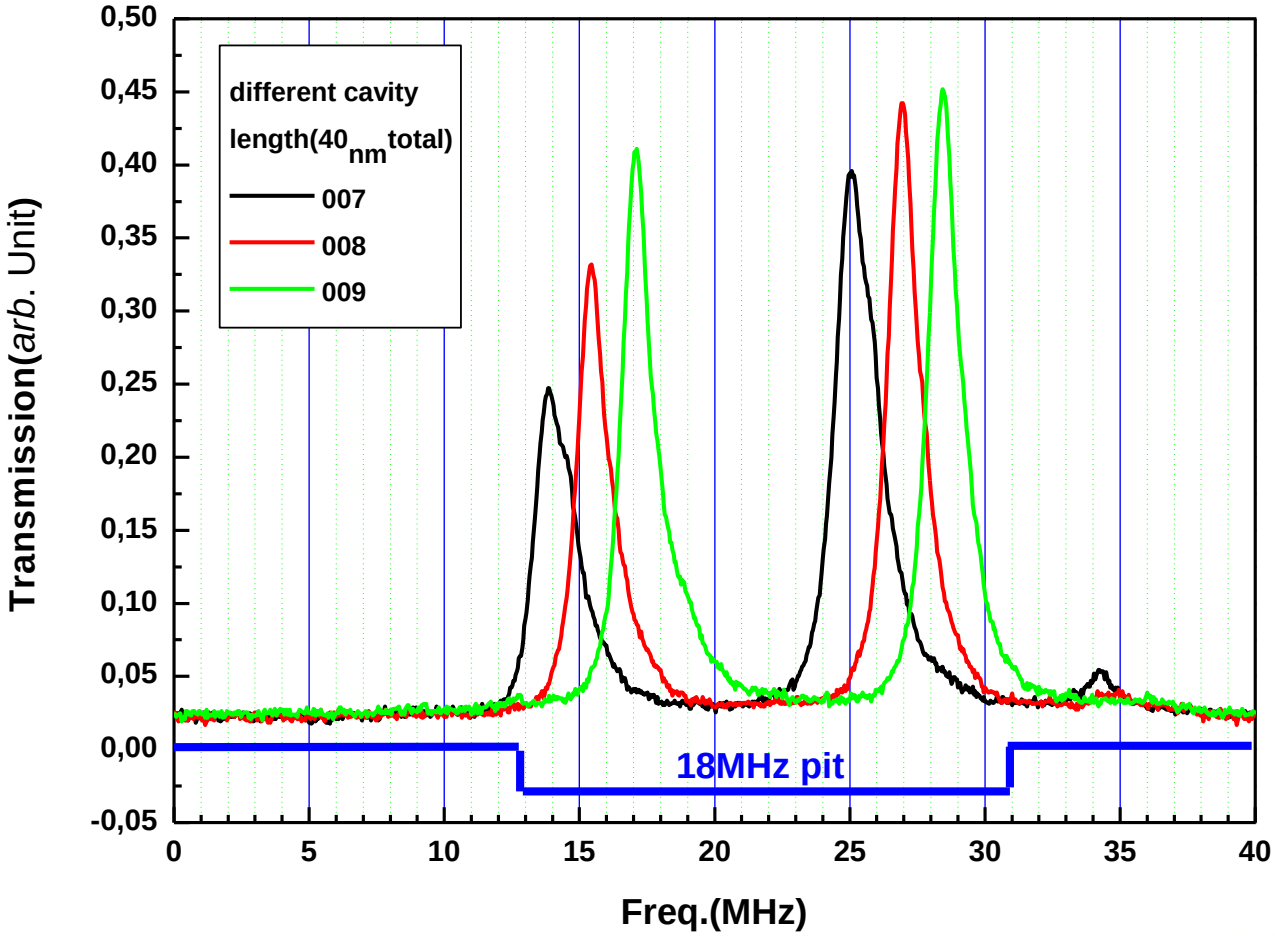

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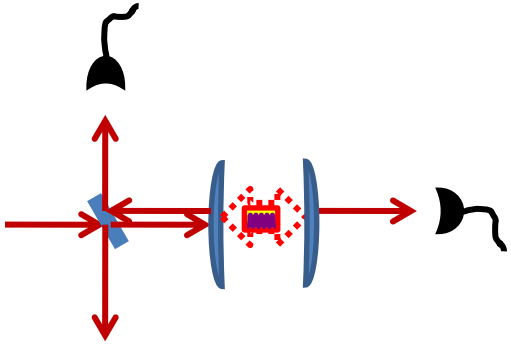
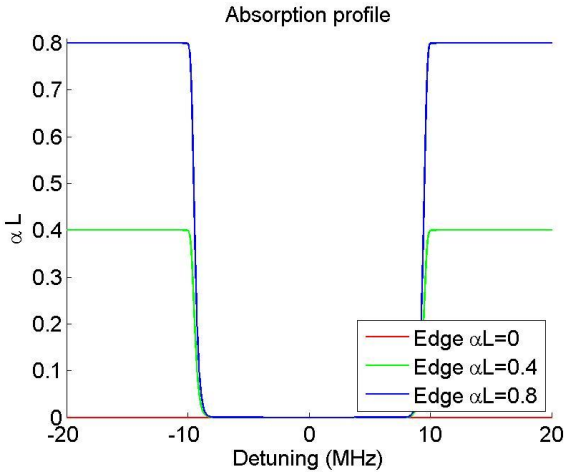
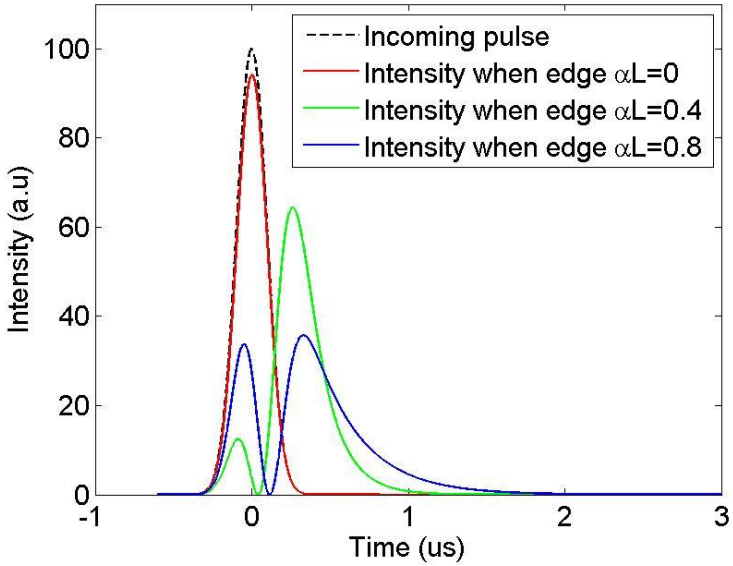
Slow light

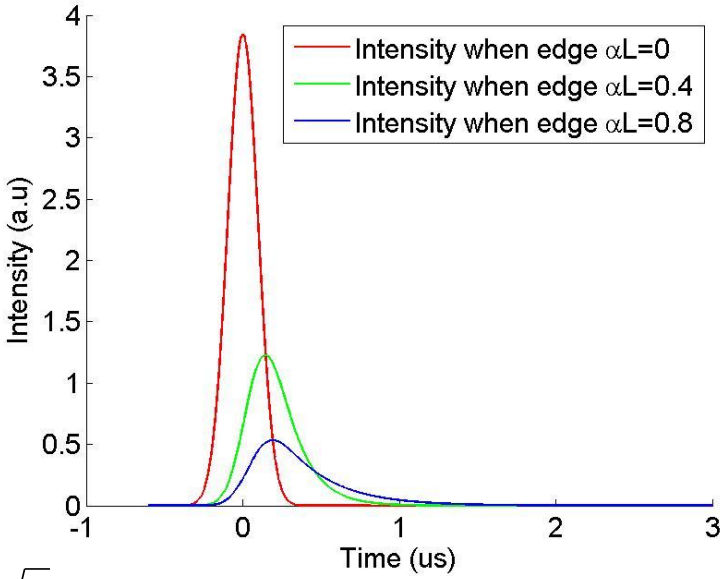




Reflection

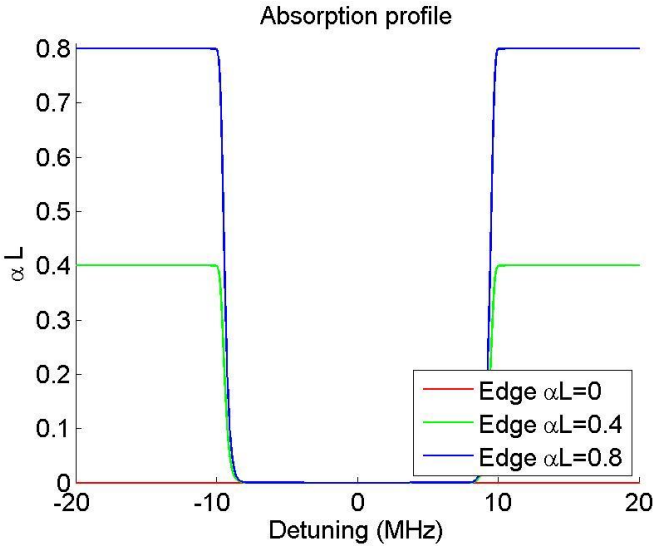


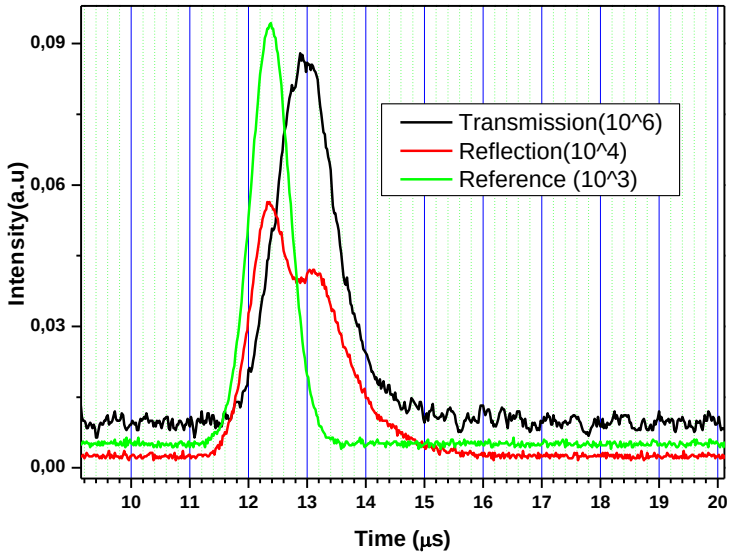
Transmission



$$E_{out} = -\sqrt{R_1}E_{in} + \sqrt{T}E_{cavity}$$

Slow light





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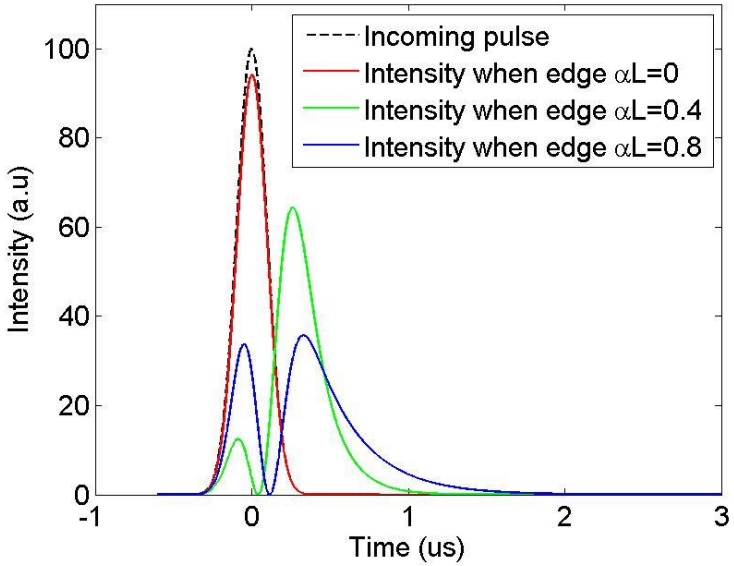

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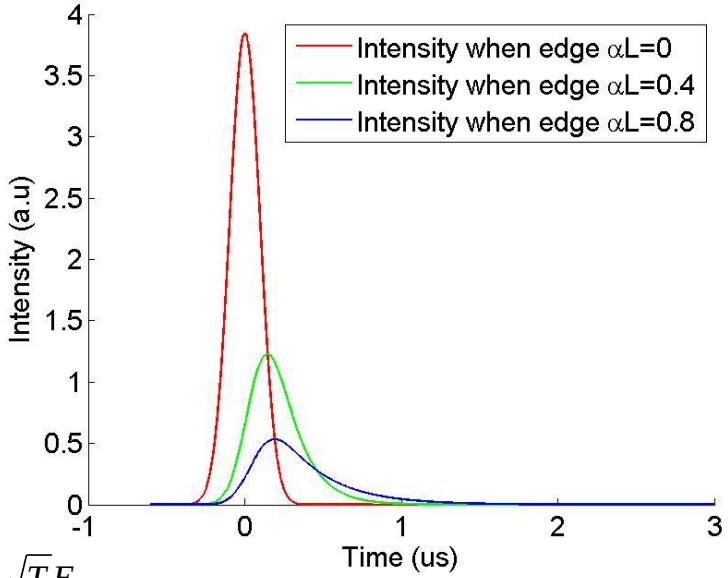

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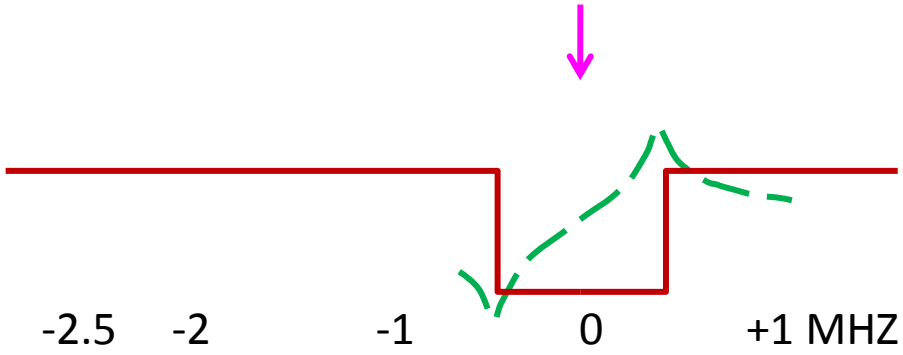
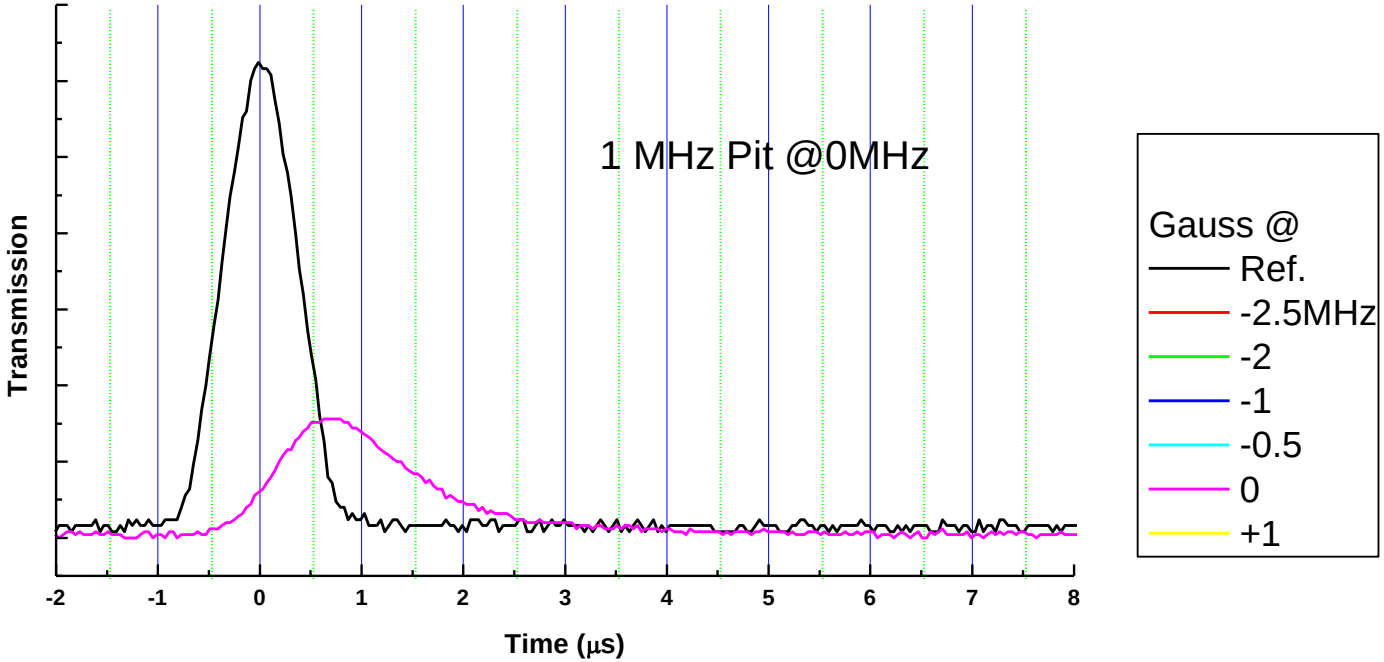
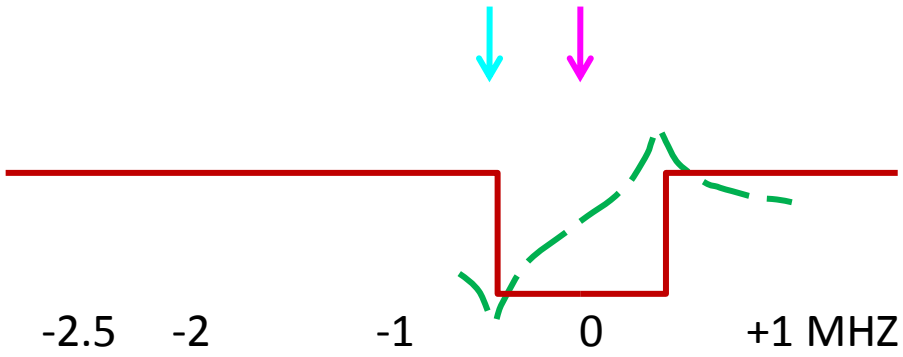

-2.5
-2
-1
0
+1 MHZ


1 MHz Pit @0MHz
Transmission
Time (μs)
-2
-1
0
1
2
3
4
5
6
7
8
Gauss @
Ref.
-2.5MHz
-2
-1
-0.5
0
+1

Slow light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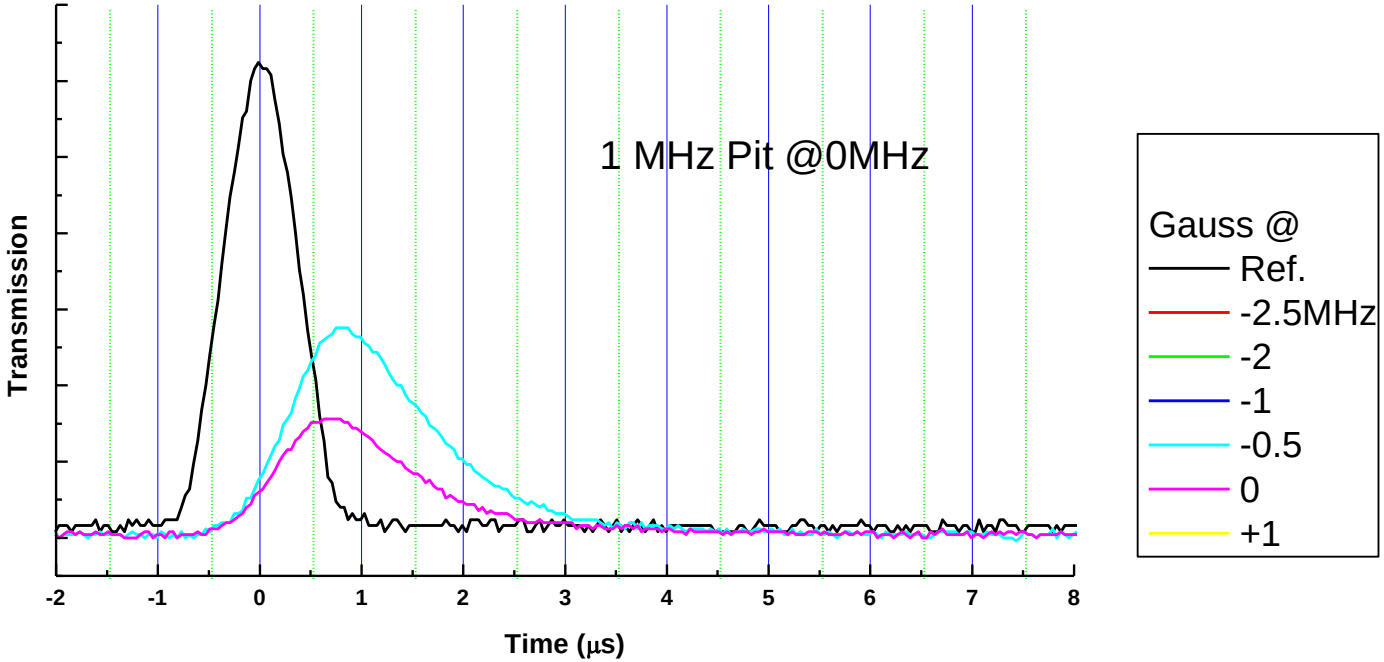
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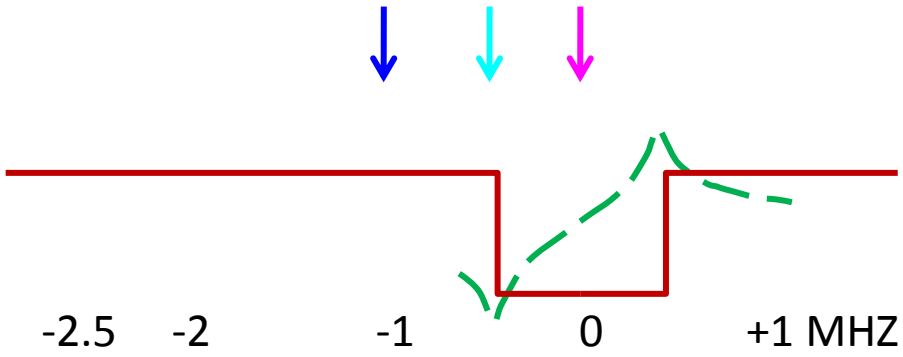
Slow light


-2.5
-2
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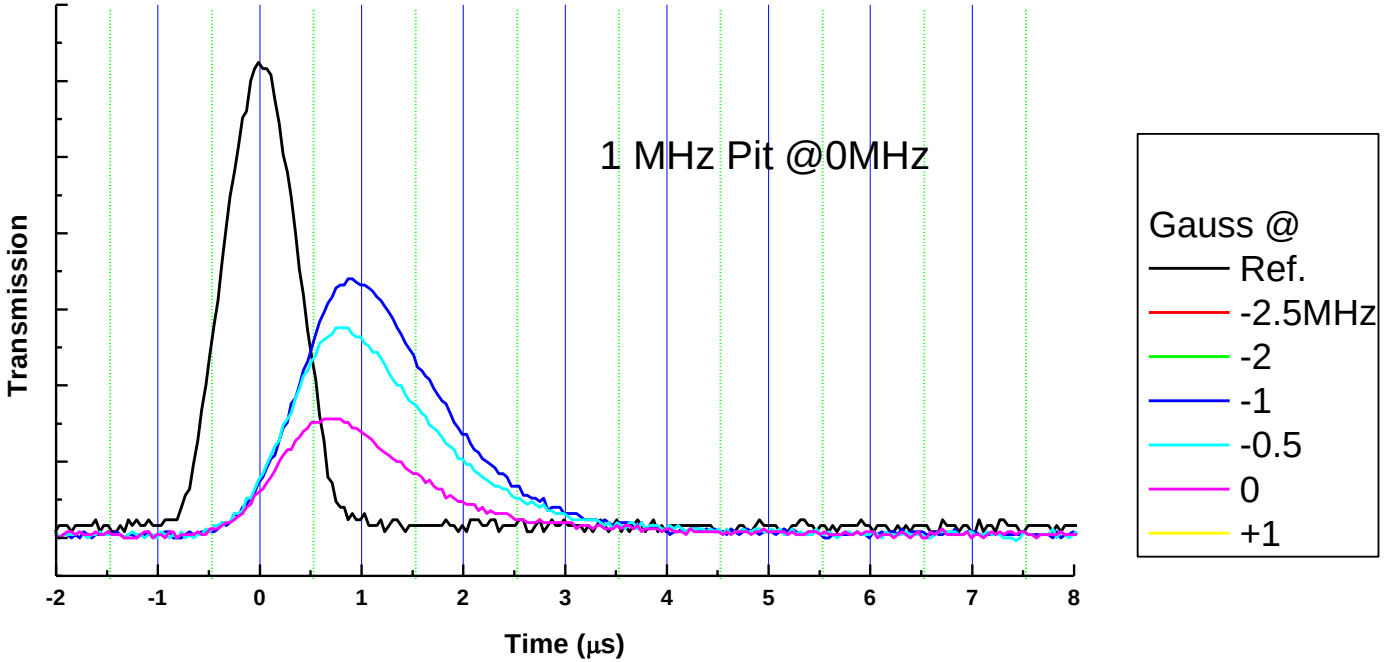
1 MHz Pit @0MHz
Transmission
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-2
-1
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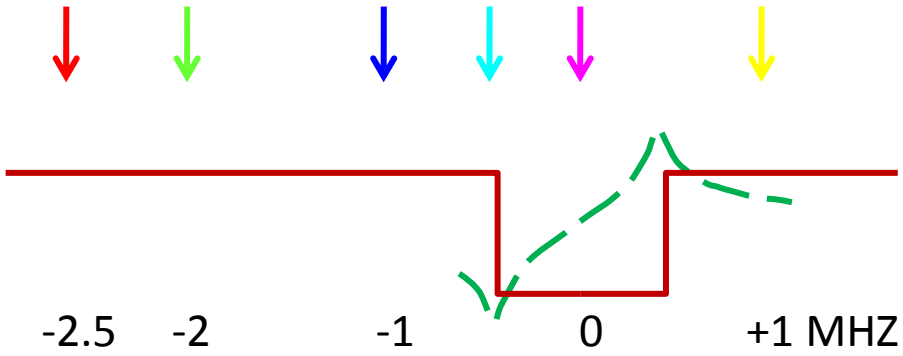
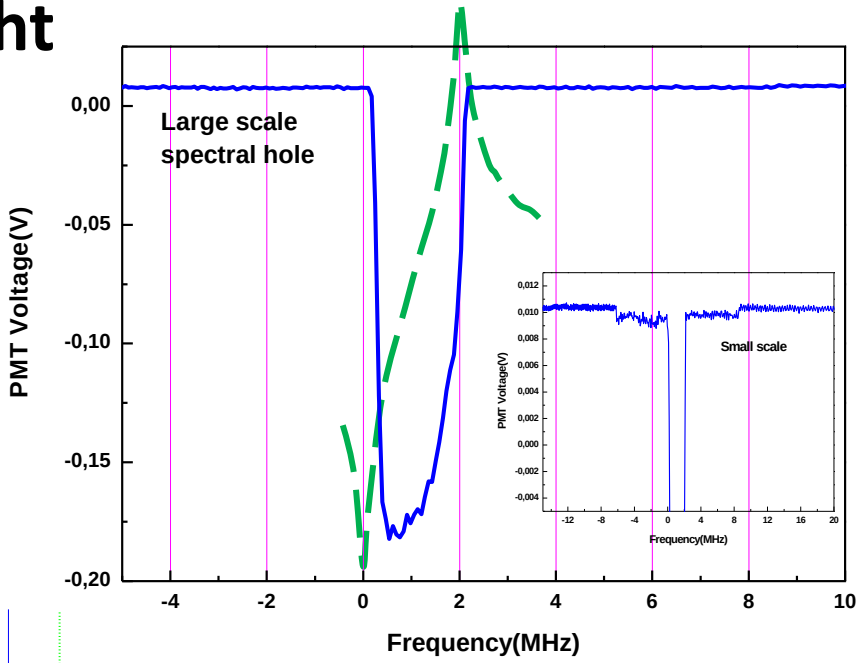
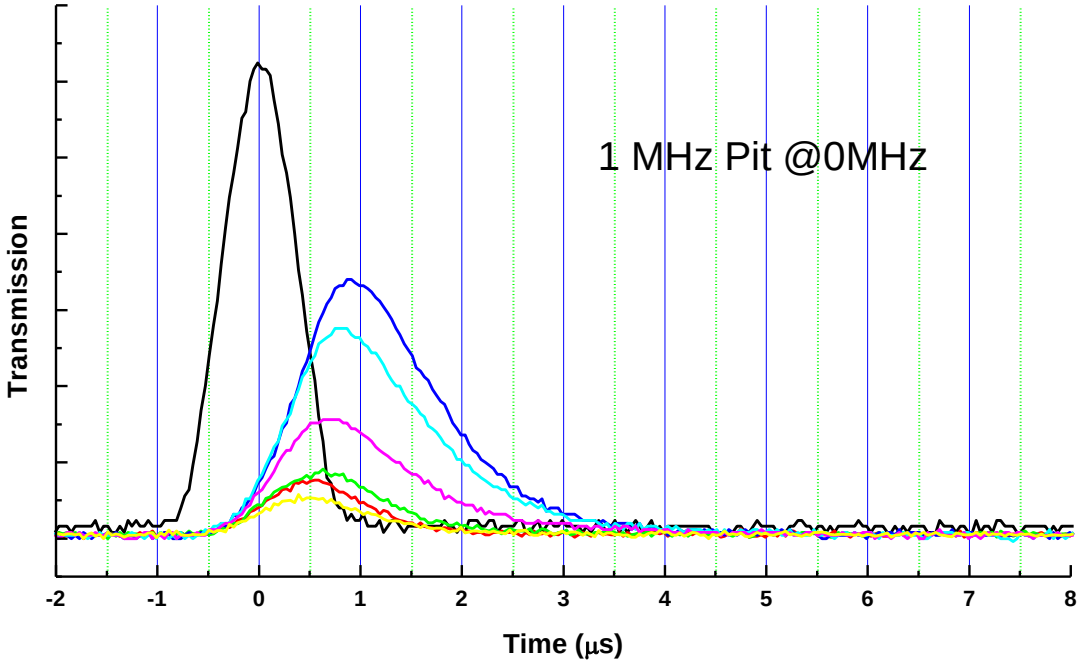
Slow light







Gauss @
- Ref.
- -2.5MHz
- -2
- -1
- -0.5
- 0
- +1

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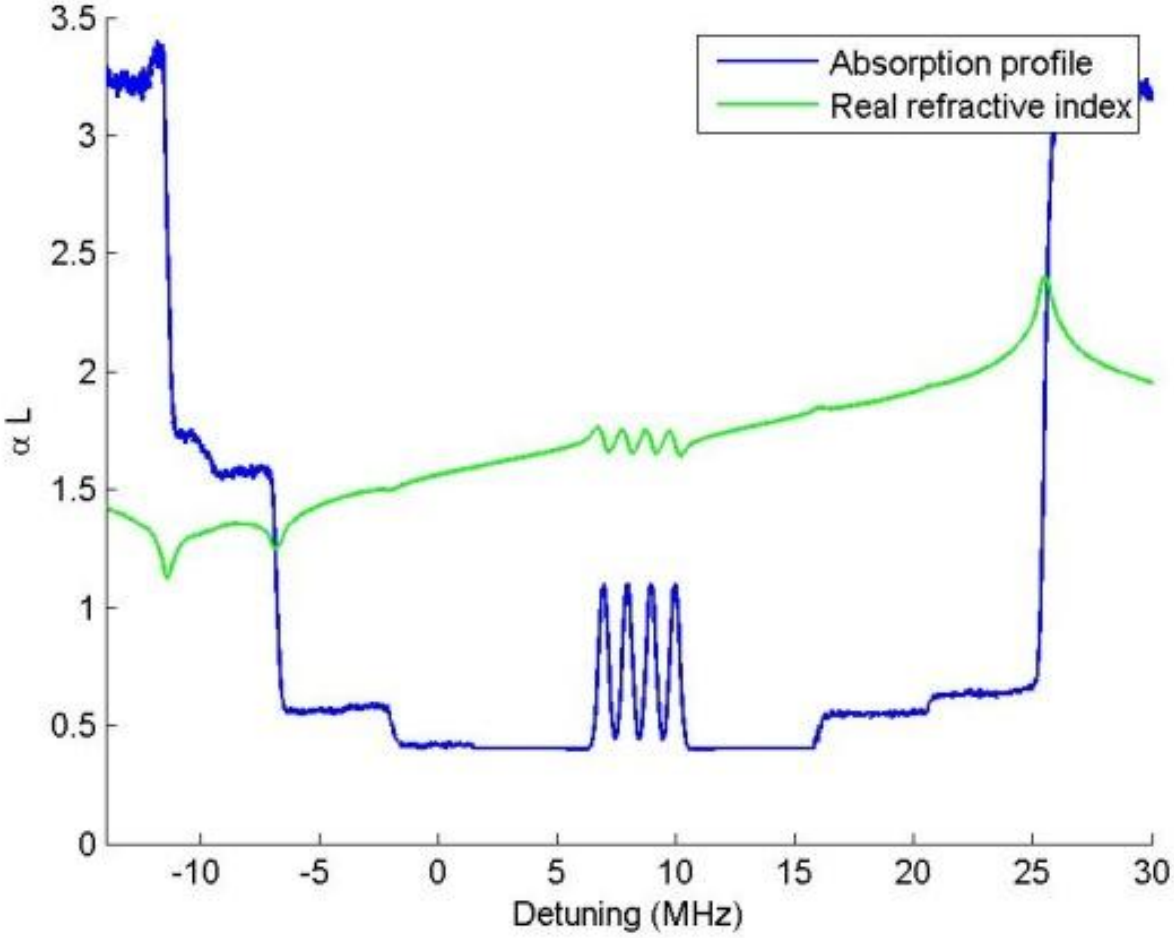
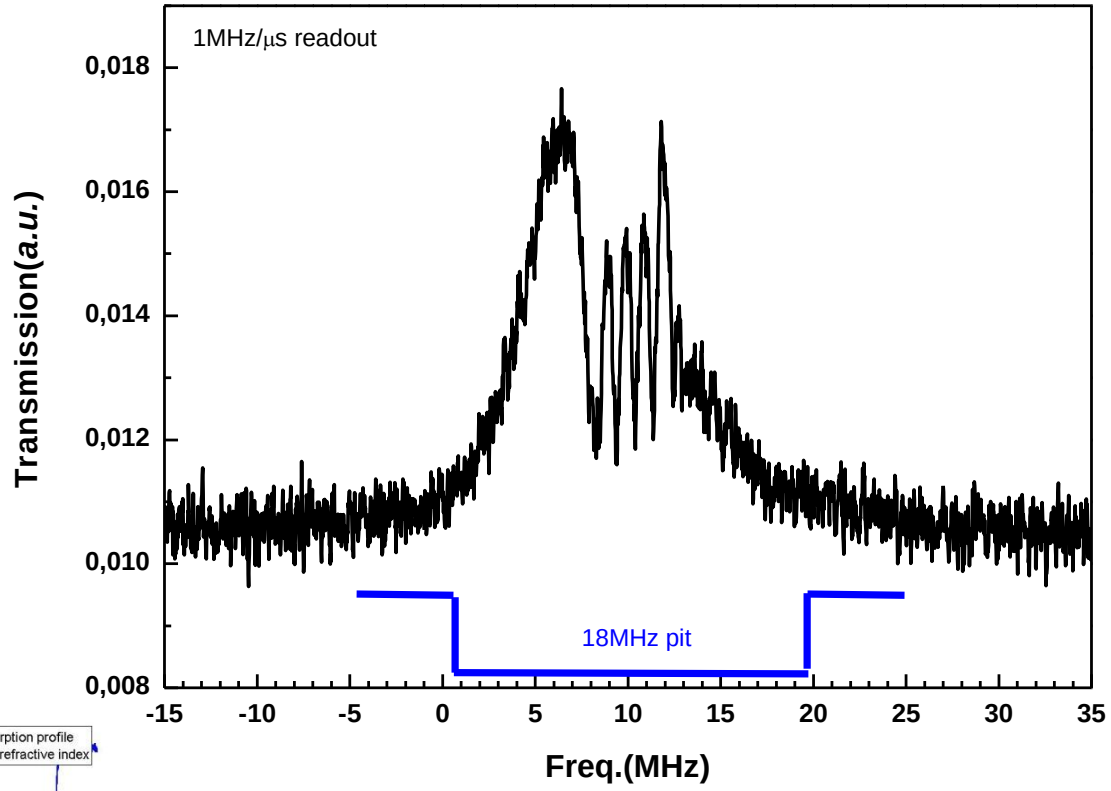
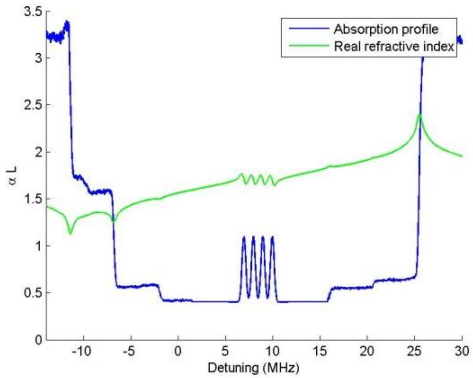
Storage experiment & AFC structure



Storage experiment & AFC structure





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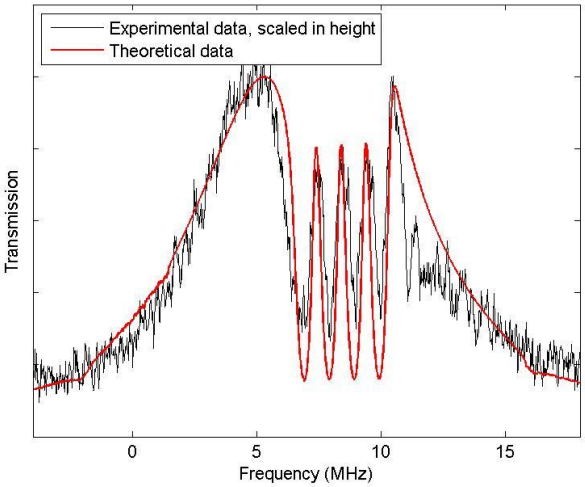
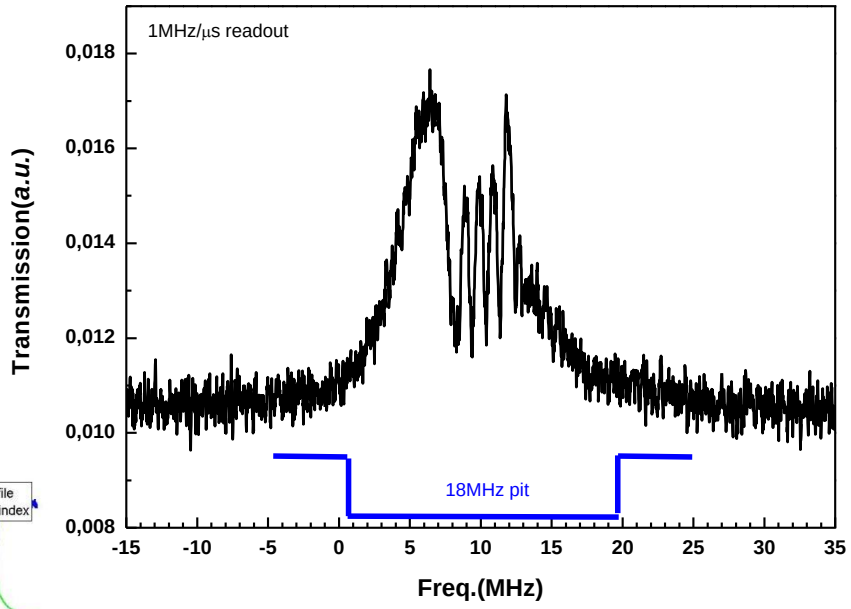
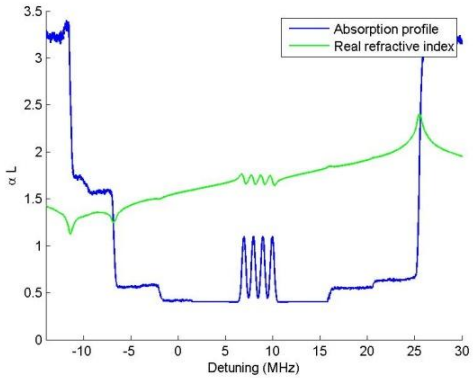
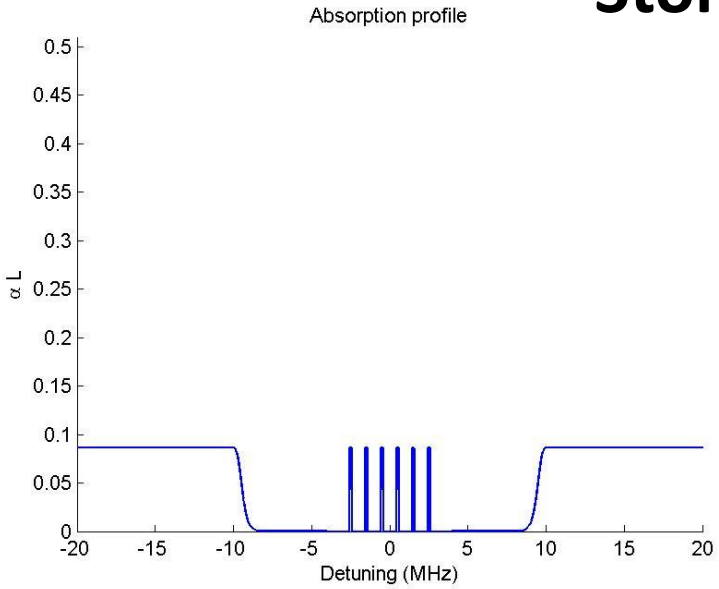
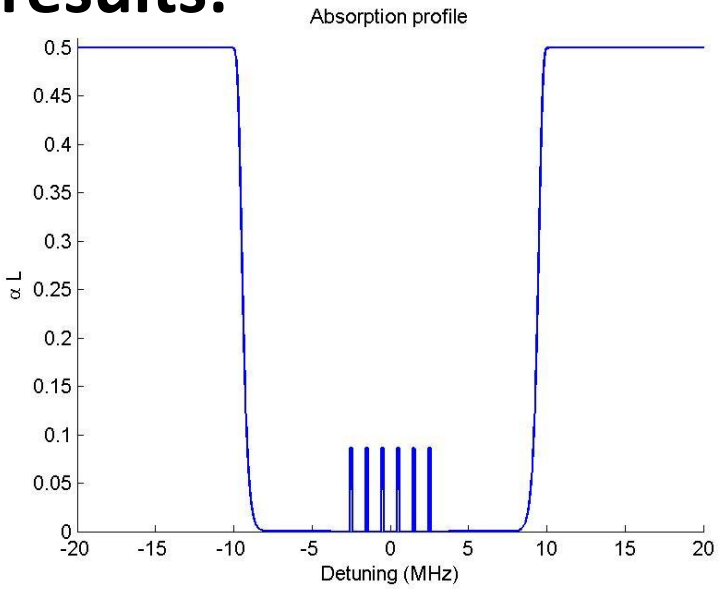


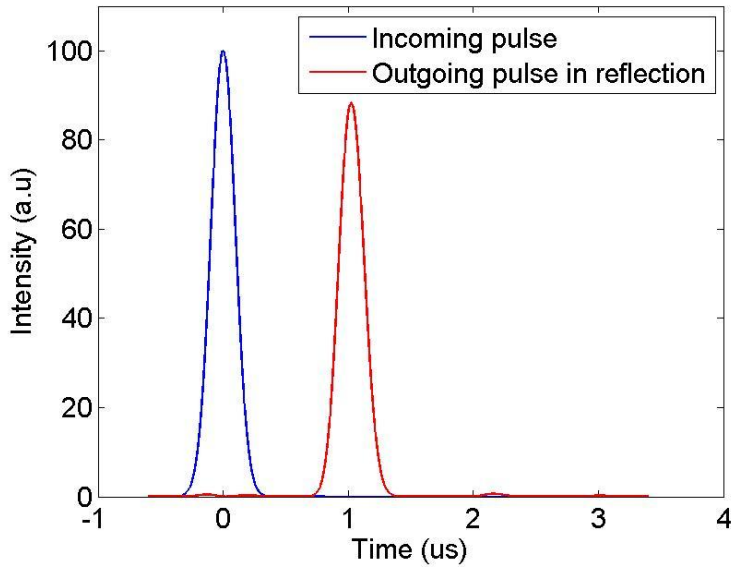


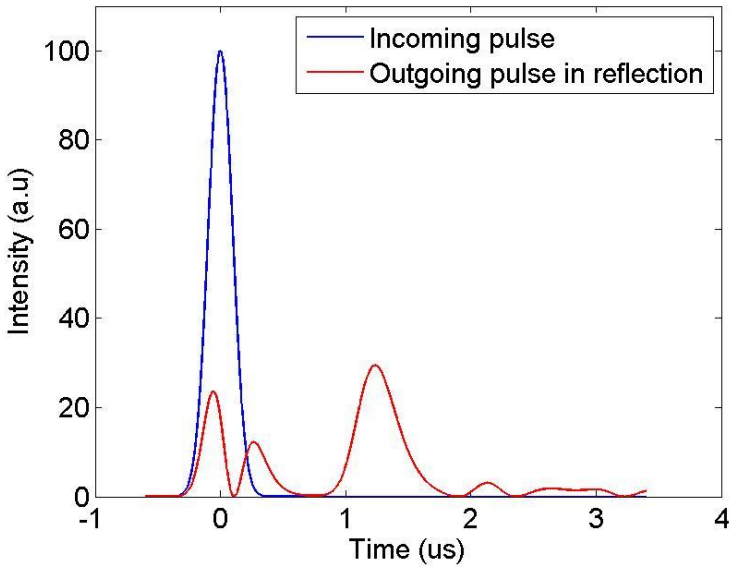


Storage results:









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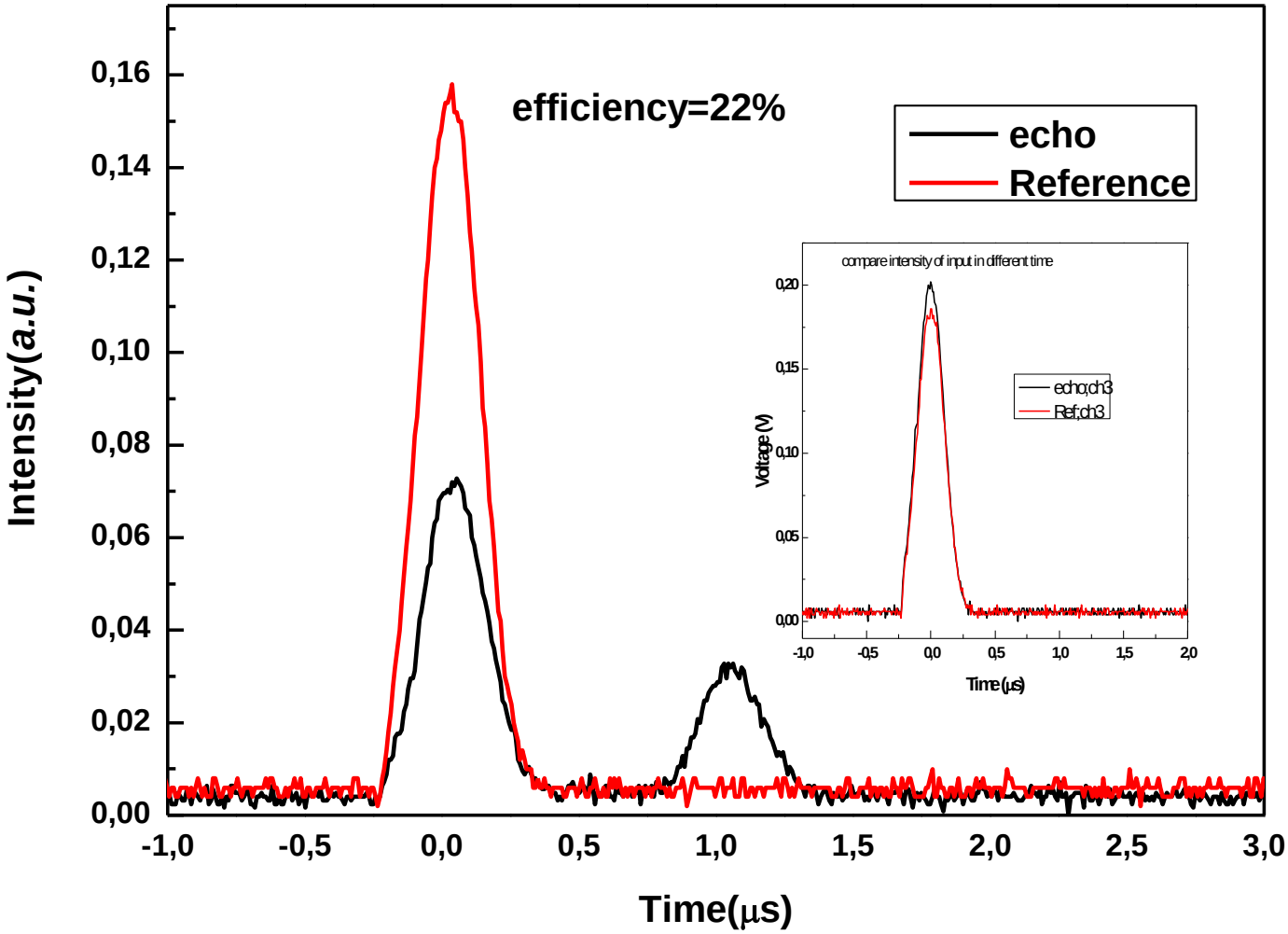

Note: Since we have almost half of the input in the reflection seems cavity is not match properly. But WHY?

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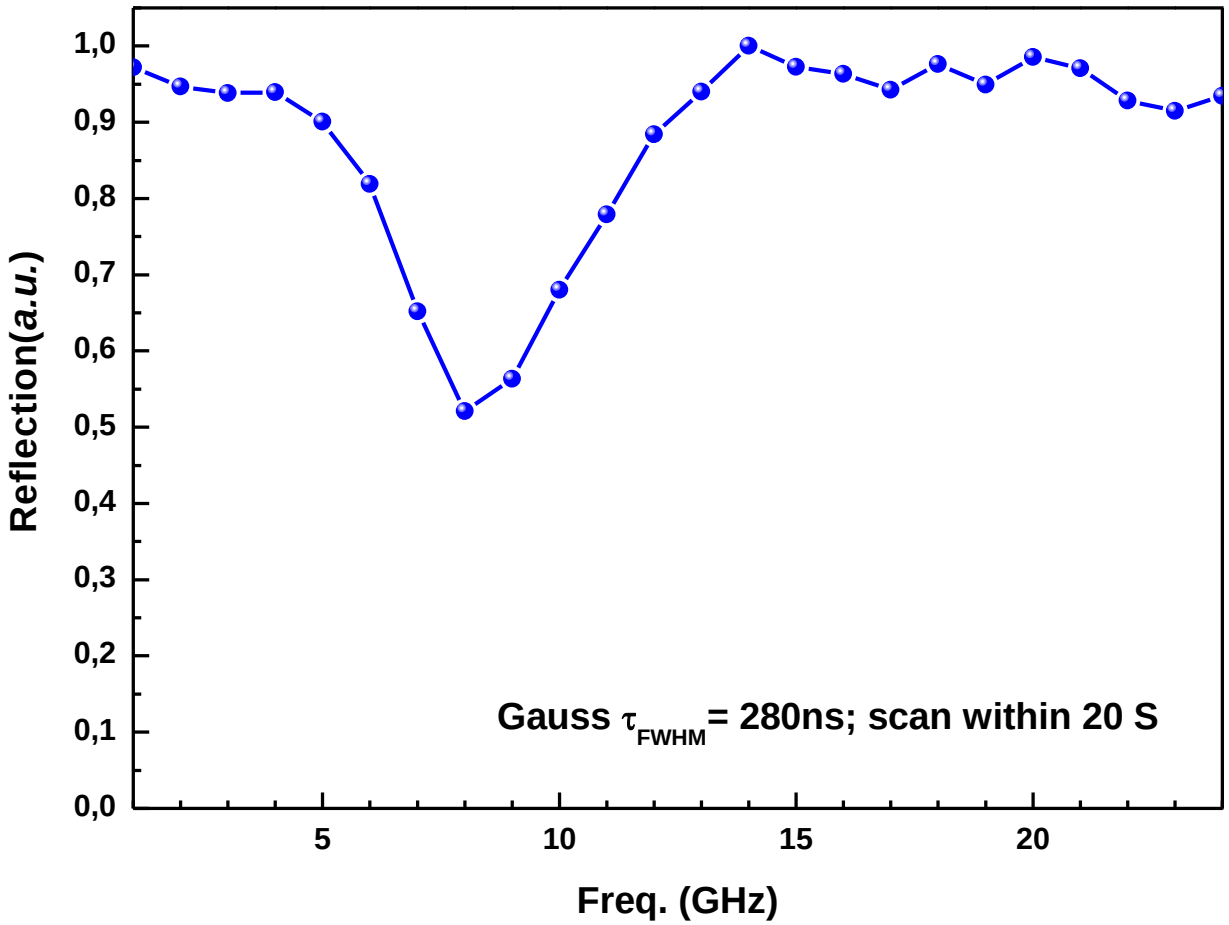
What is the best absorption?

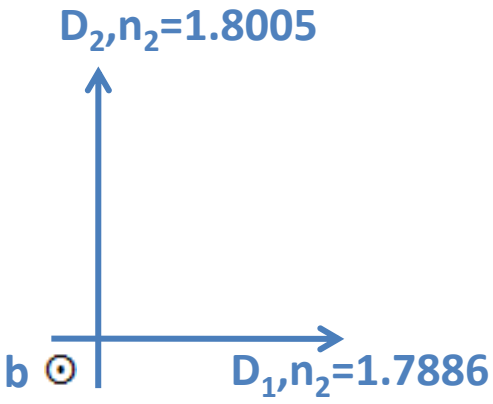


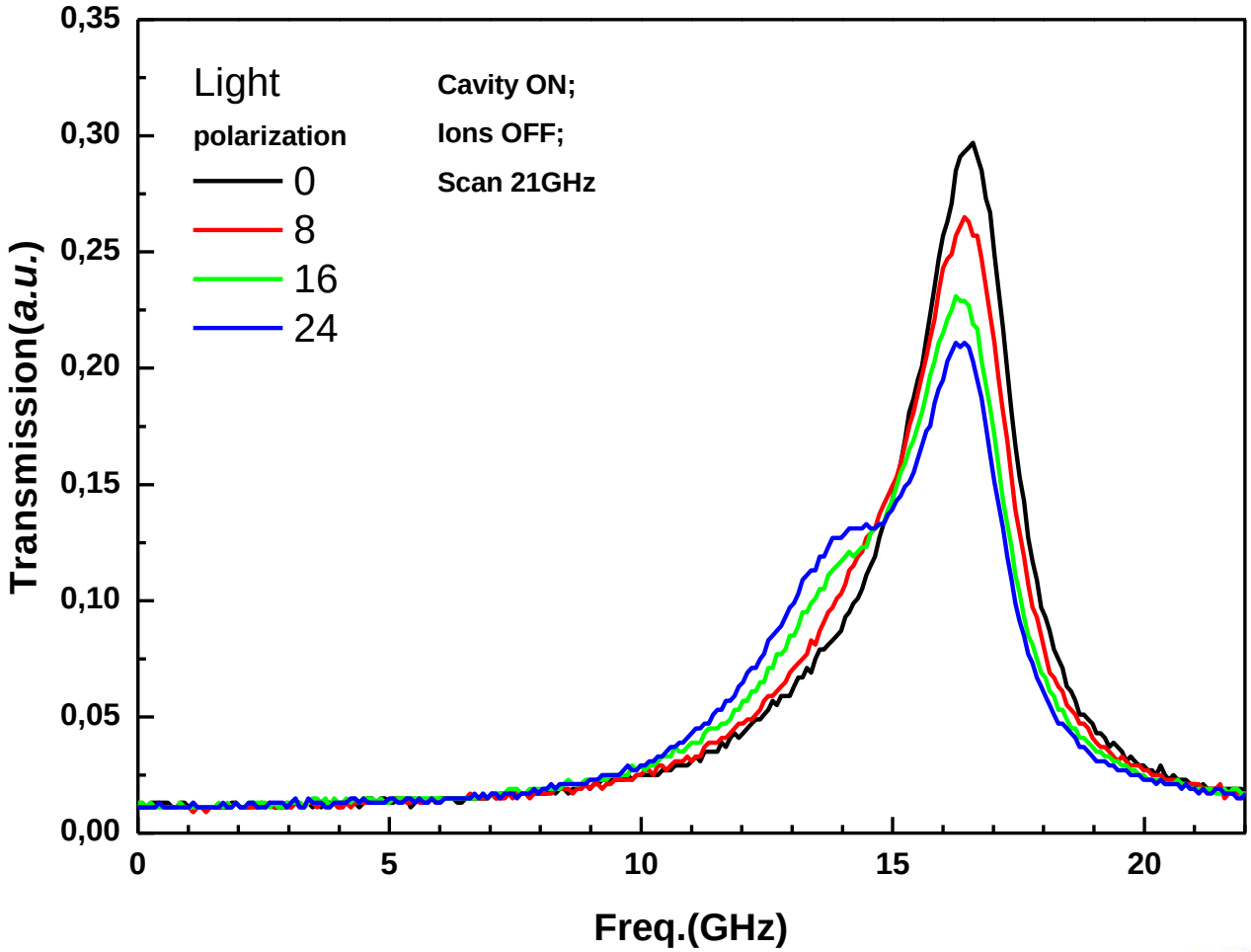
Note: Scan laser and cavity length with low intensity Gaussian to find best absorption.

Why is the absorption not 100%?

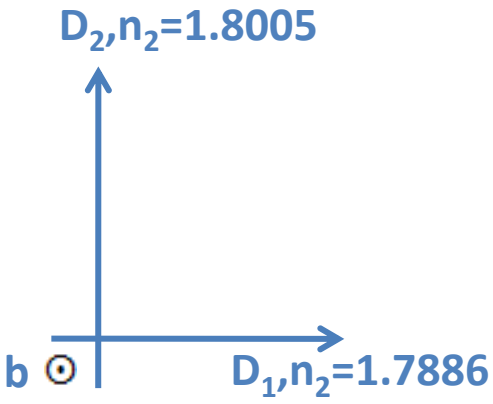
1. Transition dipole moment & Refractive indices axis orientation
2. Gaussian spatial laser mode is not fit with the cavity.
3. Wedge losses is more than we expected?
4. Bulk loss of the YSO crystal is considered? [Opt. Exp. **18**, No. 23 23763 (2010)]

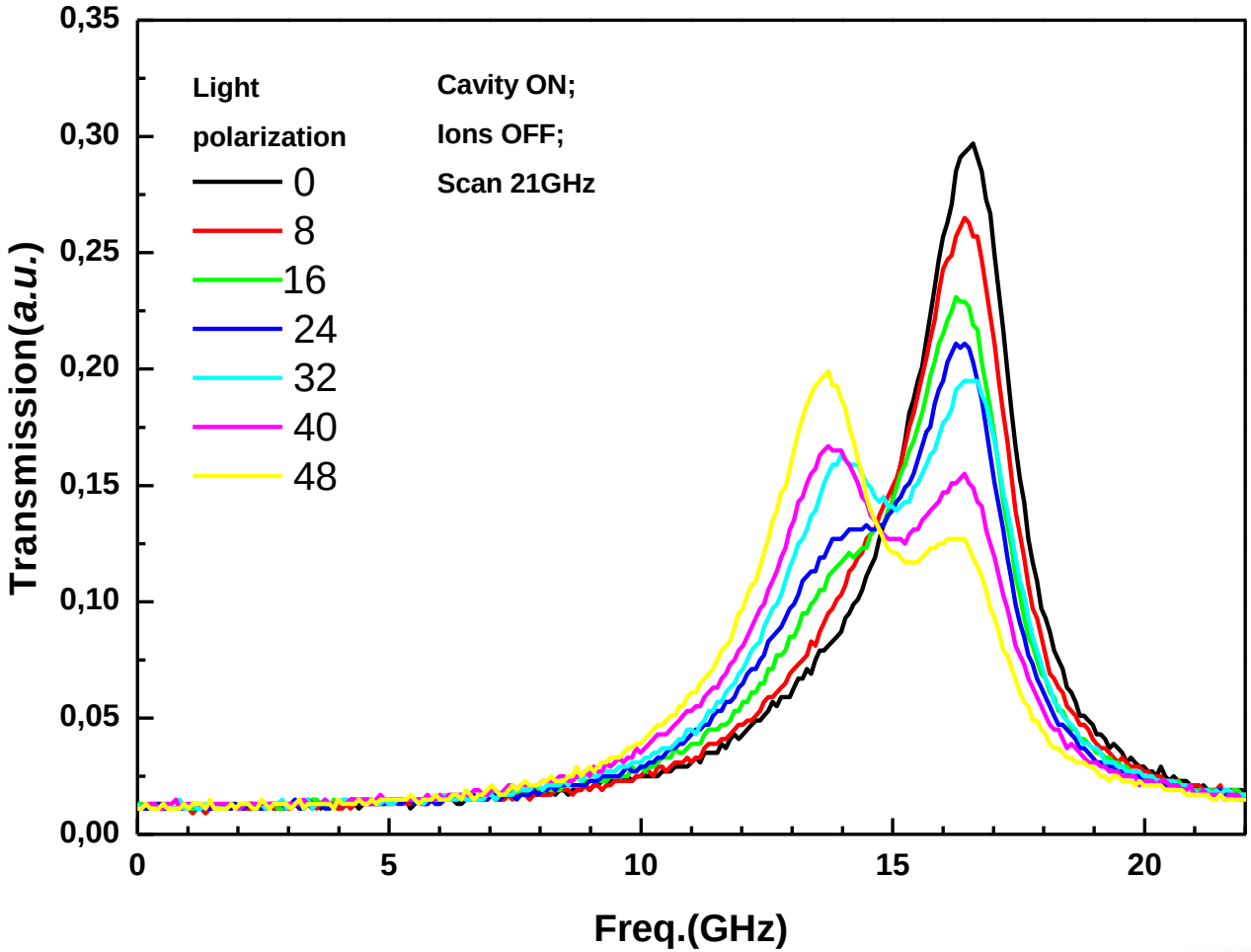
Cold cavity transmission VS polarization





Cold cavity transmission VS polarization





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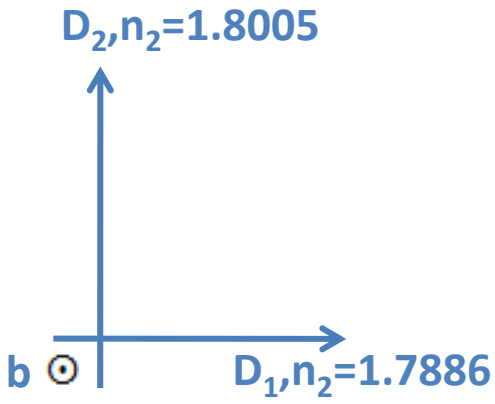
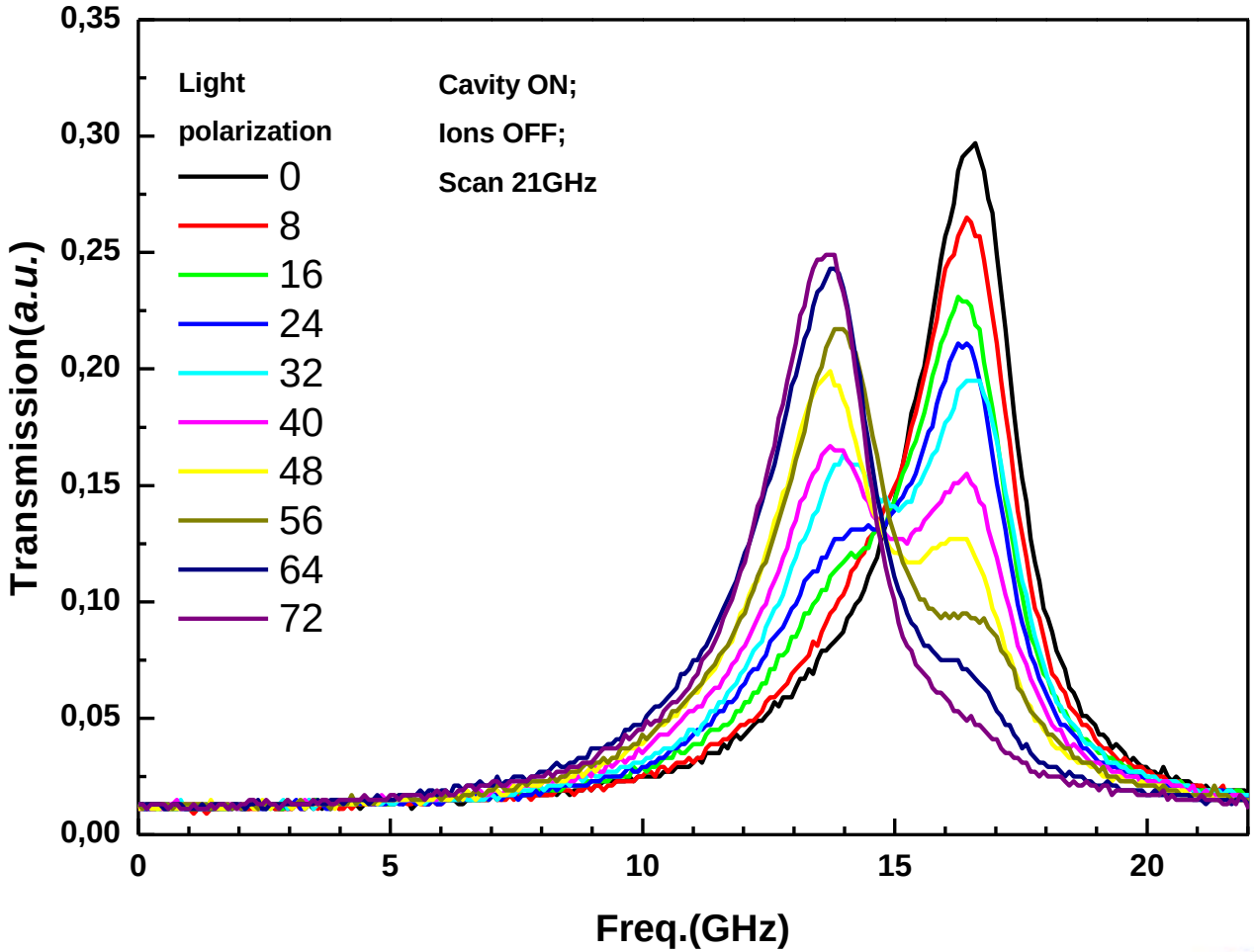
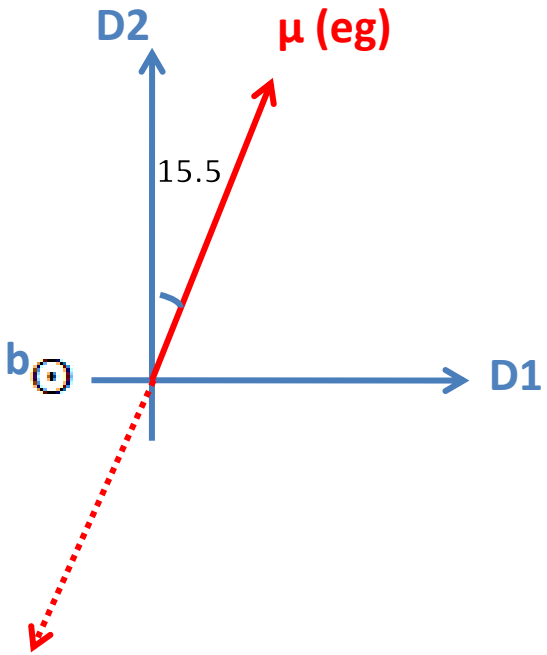




Transition dipole moment & Refractive indices axis orientation



Ref:

1. PRB **68,** 085109 (2003).
2. Discussion with Prof. Y. Sun

Summary:

- Line-width narrowing ≈ 3 orders of magnitude
- Slow light experiment $v_g \approx 2000$m/s
- Storage efficiency ≈ 22%
- Optimizing absorption line-width parameters is in progress.
- Good agreement to cavity Maxwell-Bloch simulation

Axel Thuresson

Samuel Kometa

Lars Rippe

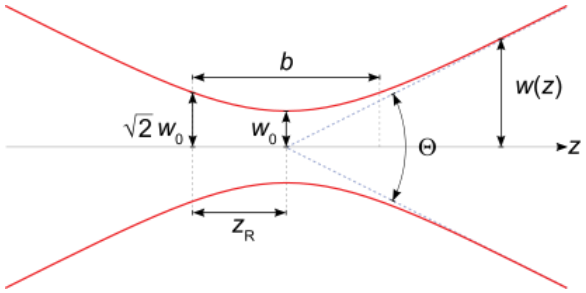
Thanks for your attention

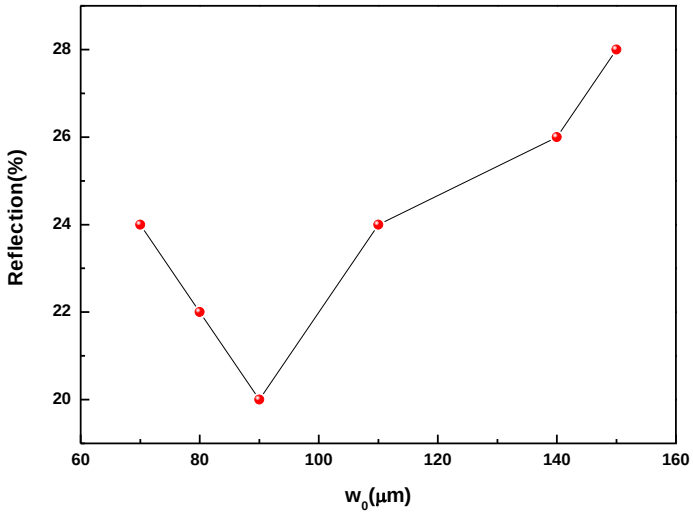
Wedge losses larger than expected?

(FRED simulation)

$w_0 = 150\ \mu m$ ⇨ $z_R = 29.1\ mm$

$$z_{\mathrm{R}} = \frac{\pi w_0^2}{\lambda}$$



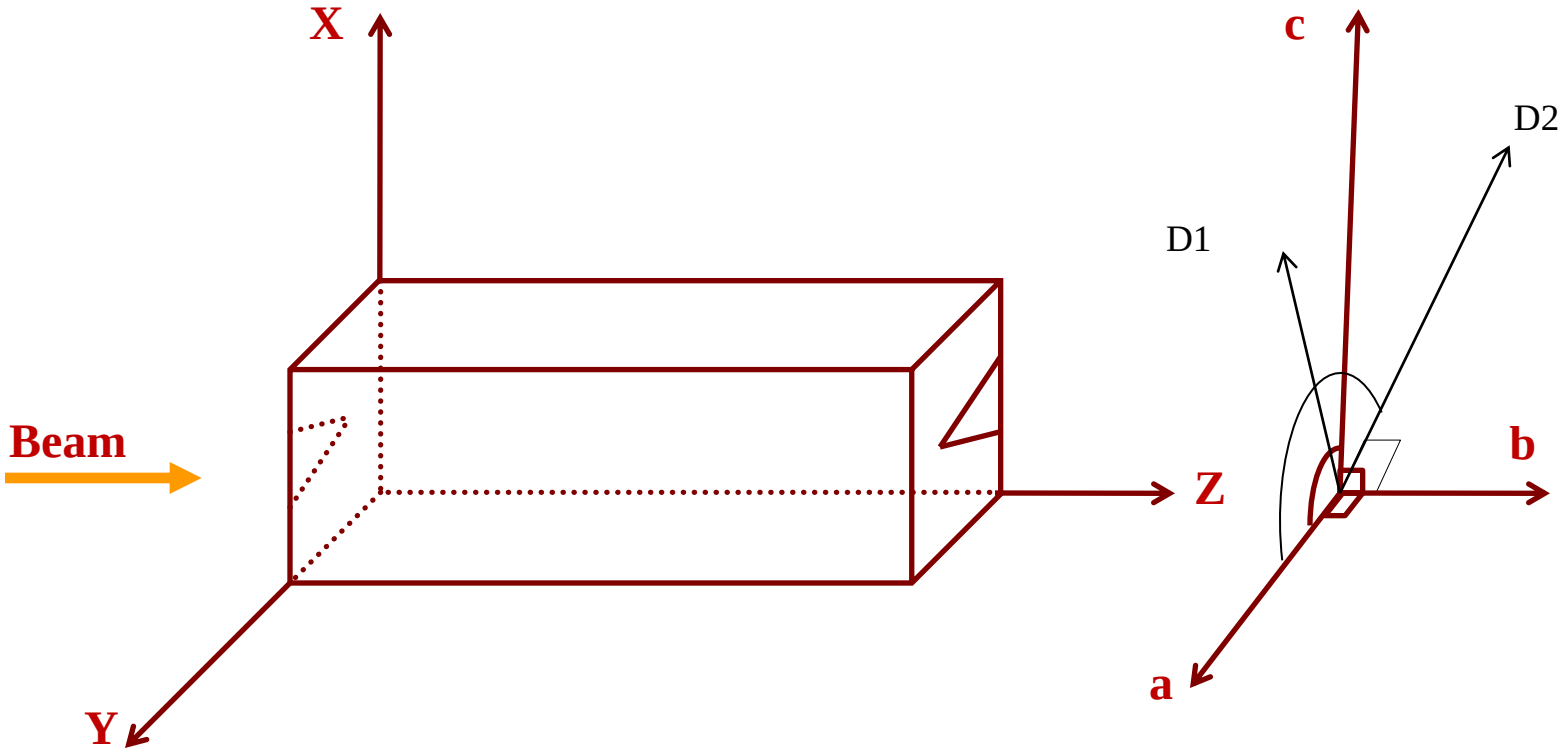


Cavity storage idea DONE
AFC in cavity DONE
Matching cavity & absorption peak- frequency pulling
Pit creation-slow light-mode spacing (possibiliy previous work on slow light in cavity)
Comparison theory & experiment DONE
Matching cavity & AFC [at low absorption side of inhom. profile] DONE
Storage experiment DONE
Obtaining 100% absorption DONE
Polarization effects DONE

1. inhom. Profile of the cavity 2011-03-25 **DONE**
2. Cold cavity – experiments (2010-12-29)& theory
3. Polarization (2011-01-19) (2011-04-06) cold cavity **DONE**
4. Possibility to move cavity transmission (2011-01-21)(2011-01-26) **DONE**
5. Gauss in different frequency position in the pit 2011-01-25 **DONE**
6. AFC cavity transmission(2011-01-26) (2011-03-24 104, 094)(2011-04-06;009) **DONE**
7. Cavity transmission width VS pit width (2011-01-27) & height(2011-03-24) trans. & refl. DATA 031 (nothing special found!!)
8. Slow light effect-2011-03-22 -041 **DONE**
9. Storage result 2011-03-25 076 2011-03-24 095 **DONE(check for others)**
10. Gaussian scan 2011-04-05 100% absorption **DONE**
11. latest paper about FSR of warm cavity
12. two cavity transmission peaks should be included (2011-01-27)
13. check the best echo that we had

Cavity Idea:

1. From what paper? Bring AFC cavity idea also here!!! DONE
2. How is look like our cavity? Wedges and dimension and picture & Pr:YSO DONE
3. Discuss about R1=R2 condition (matching condition) DONE
4. How we control resonance frequency?
5. Experimental setup

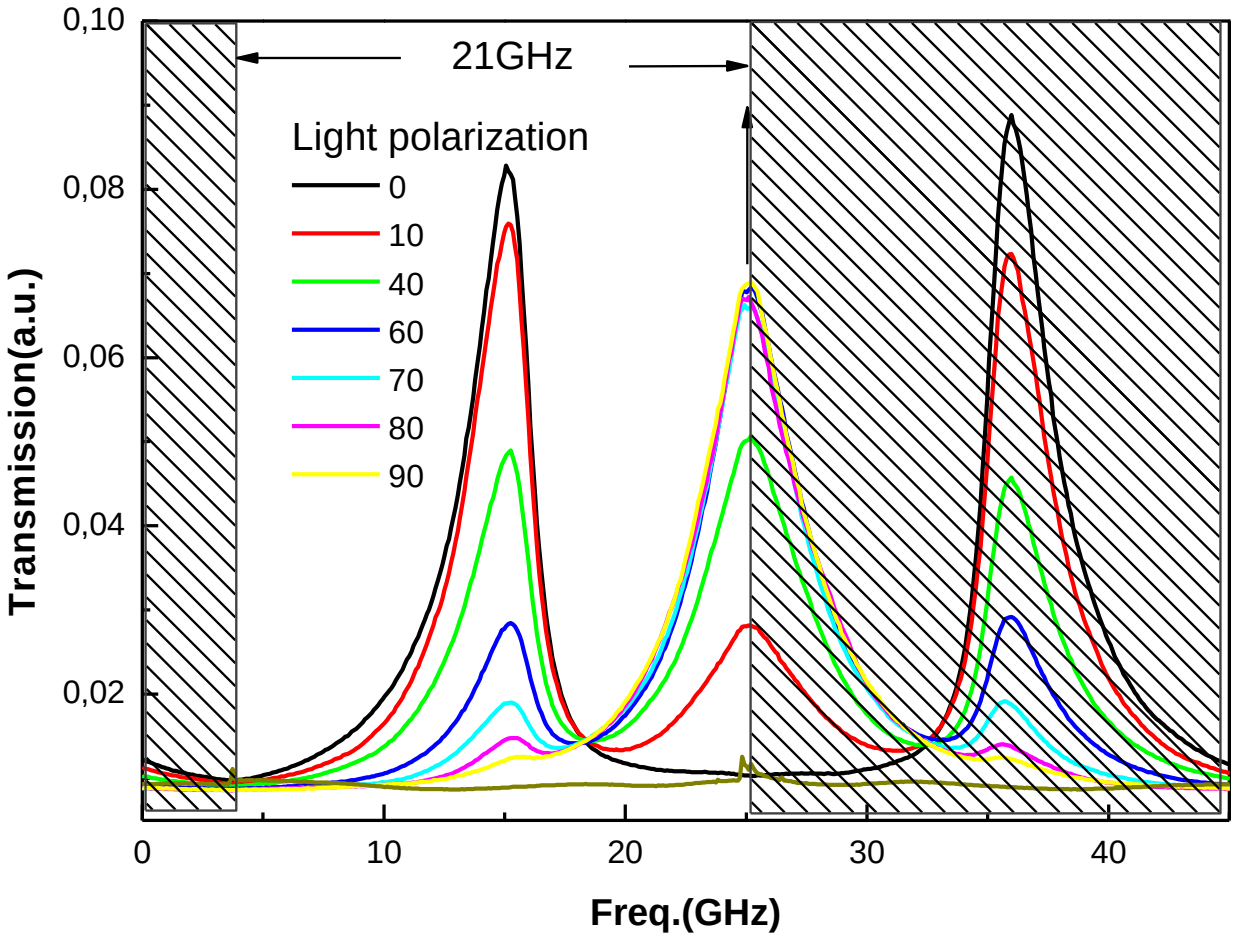


Crystal Parameters

Crystal Dimensions =10x10x20 mm

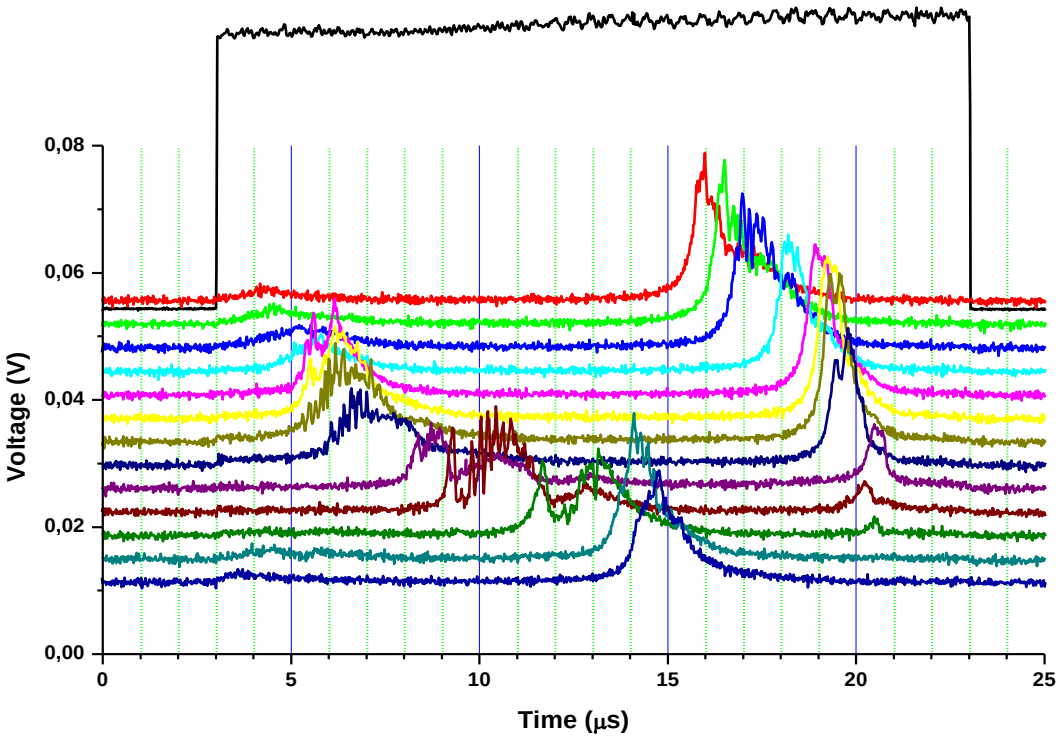
Two end surfaces curved with radius= 200mm

Cold cavity transmission VS polarization

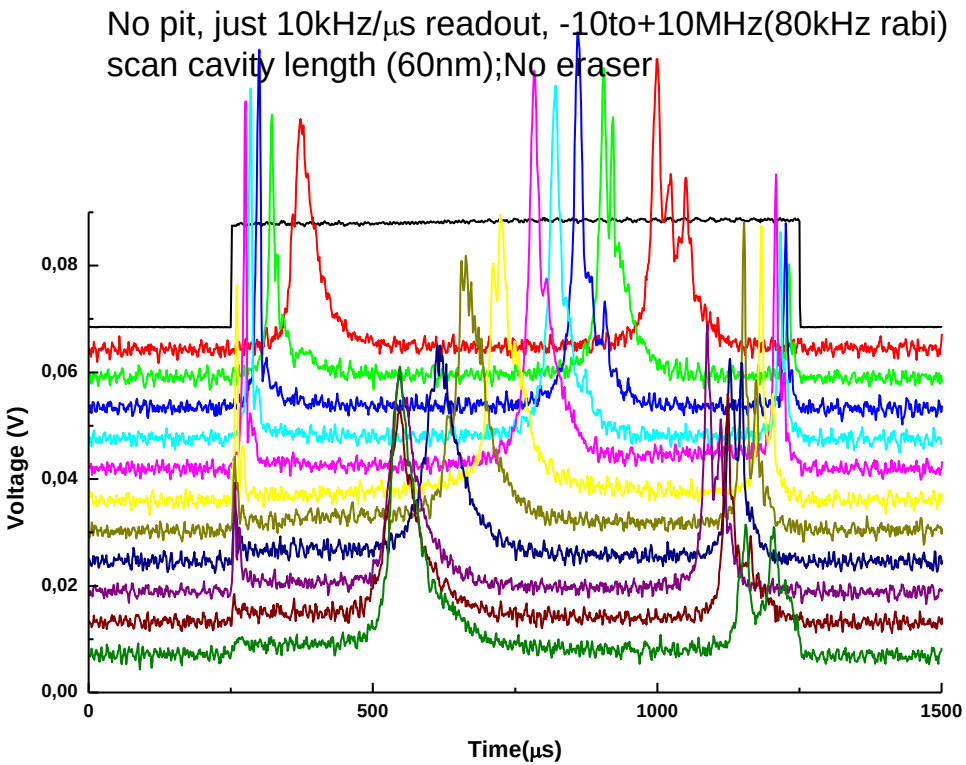


Tuning the cavity transmission frequency

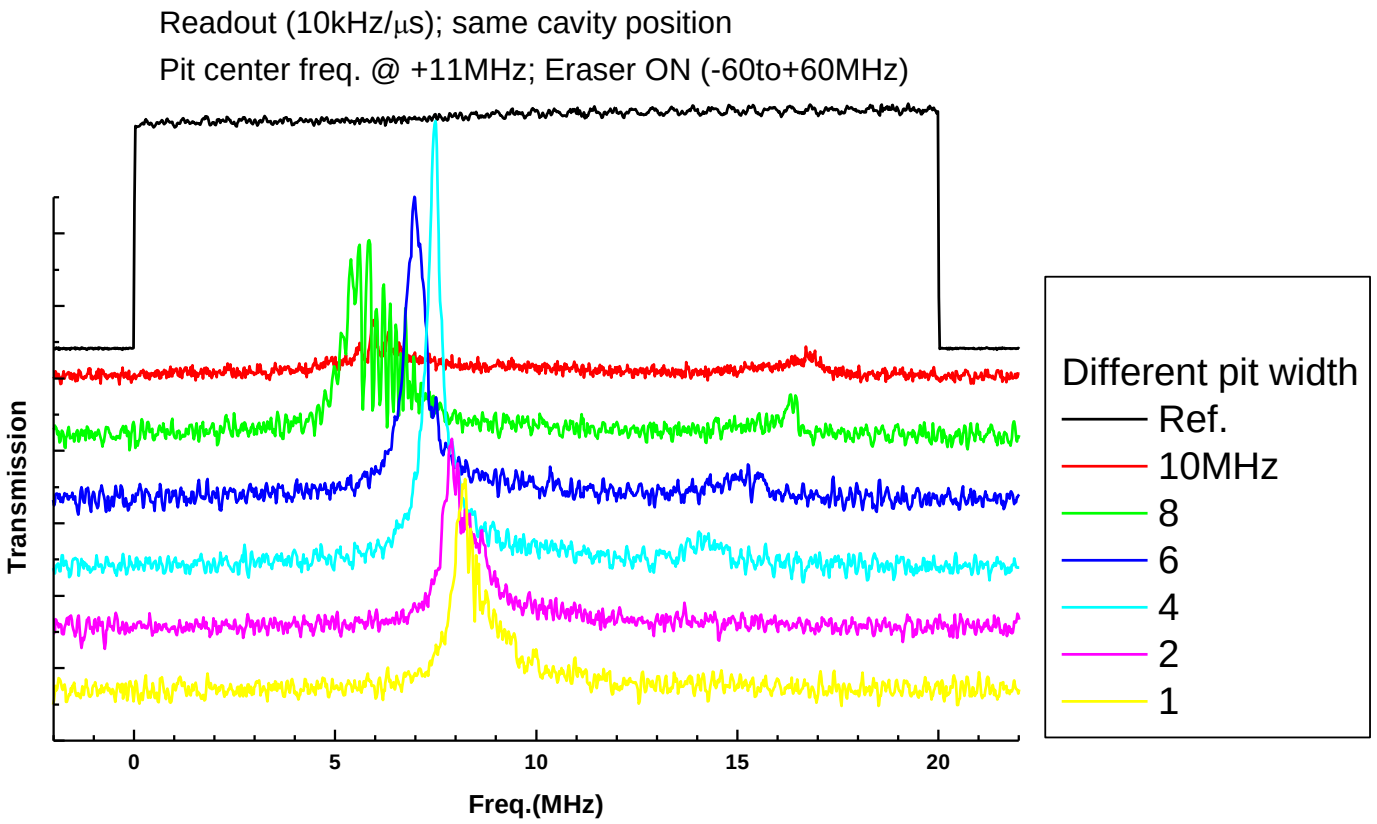
Transmission; scan cavity width (5mm)
1 peak is included @0; pit 16MHz @0



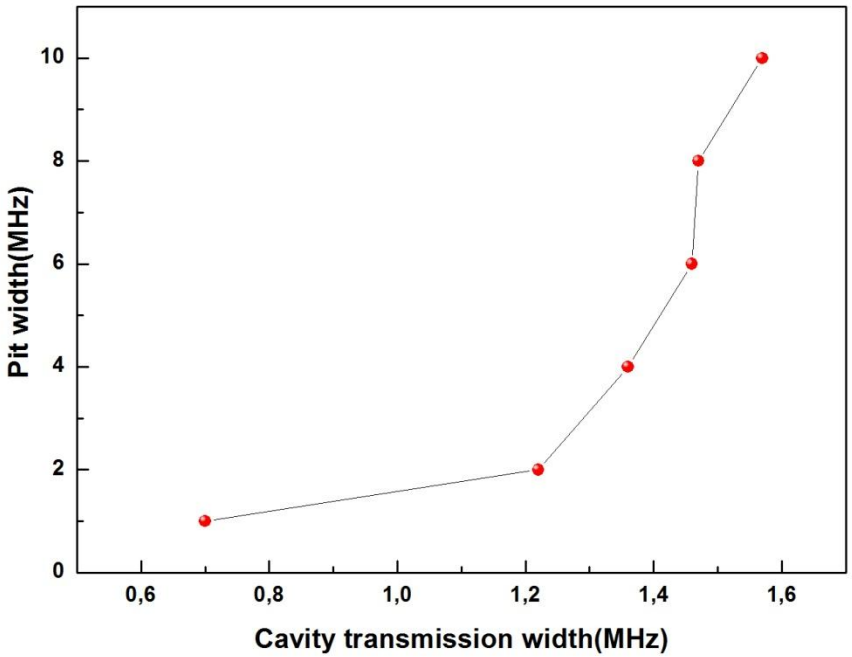
Tuning the cavity transmission frequency



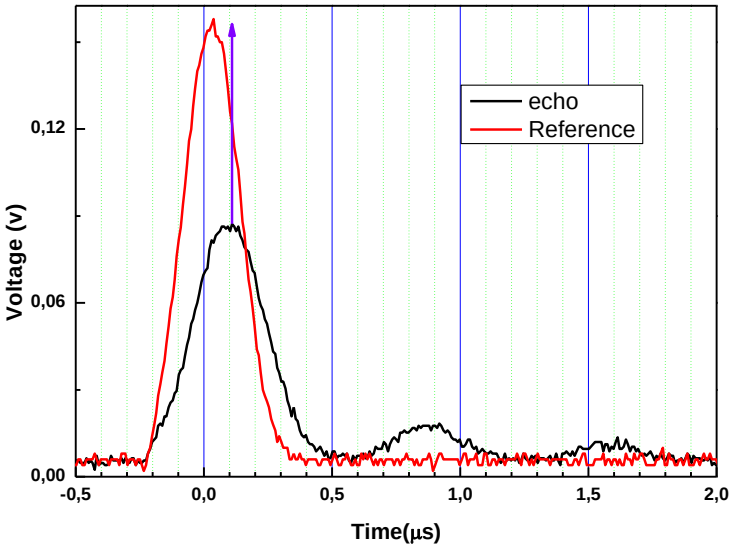
Tuning the cavity transmission frequency

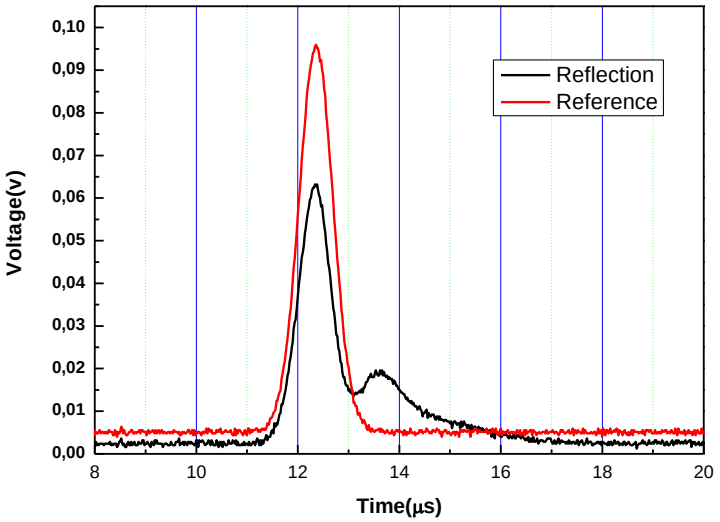


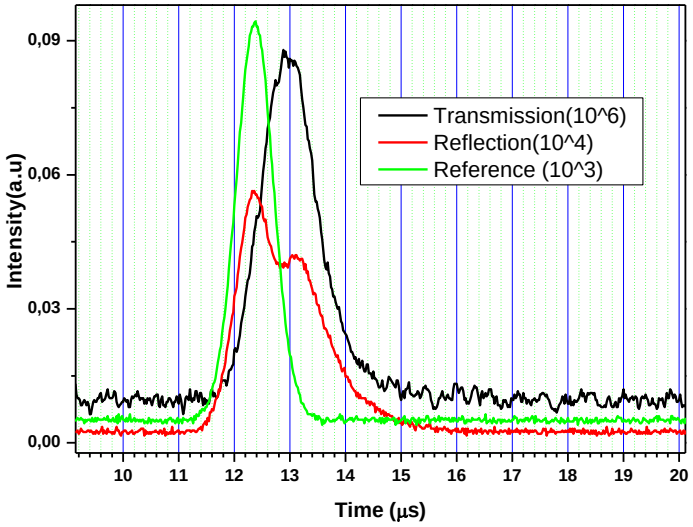
Cavity transmission width VS pit width



Slow light?

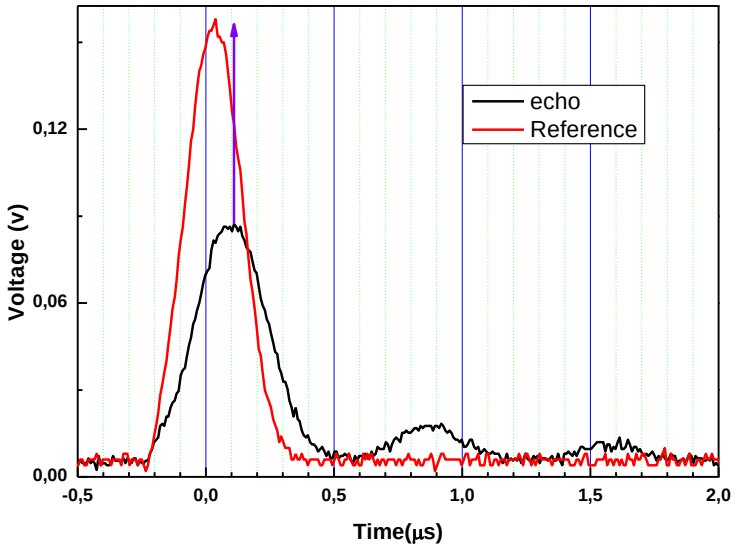


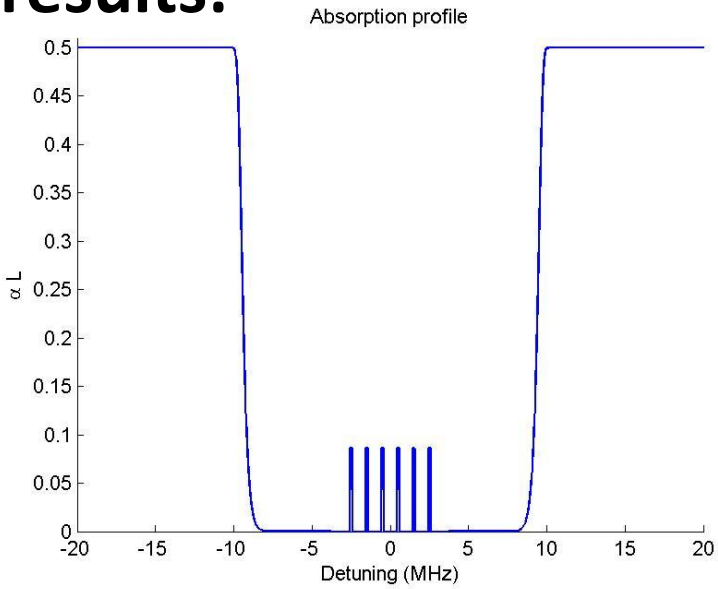


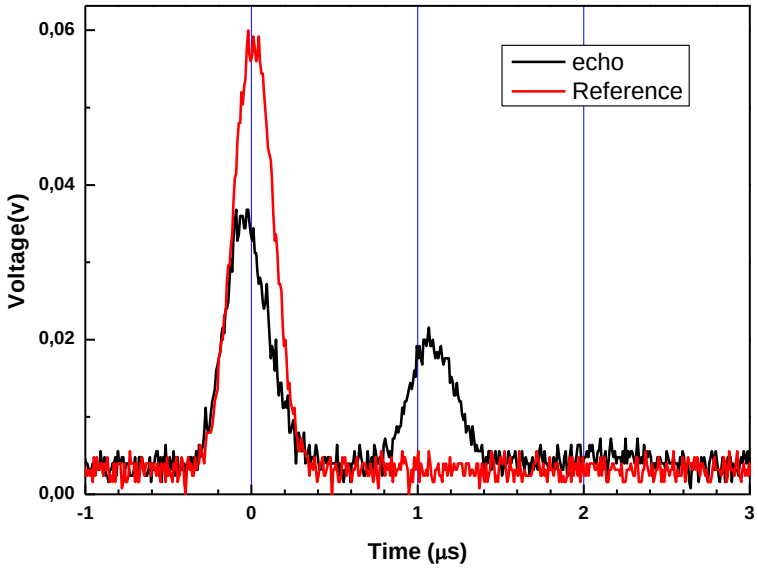


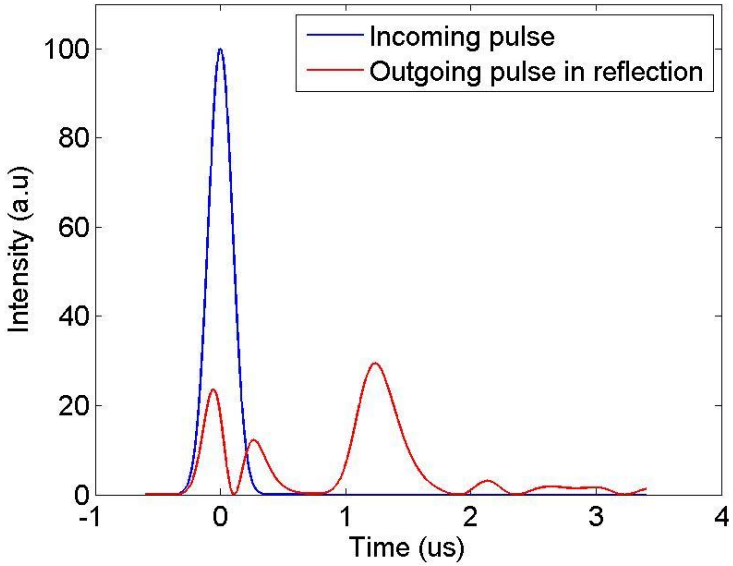
$$E_{out} = -\sqrt{R_1}E_{in} + \sqrt{T}E_{cavity}$$

Storage results:



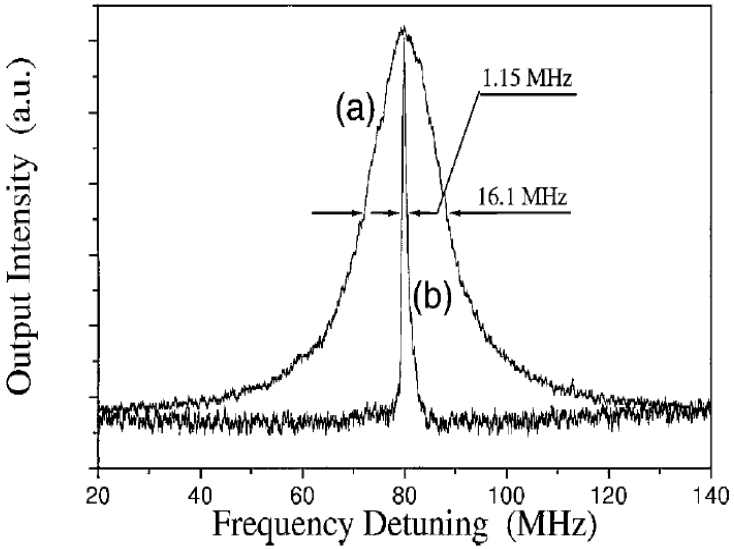






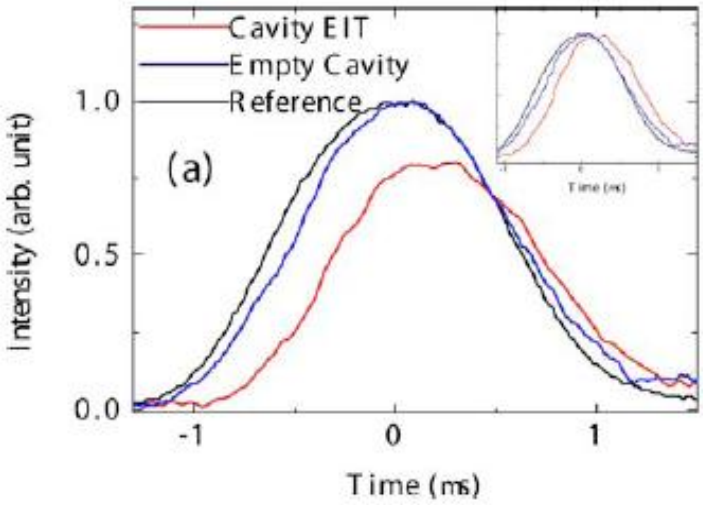
Line-width narrowing

Opt. Lett. **25**, No.23, 1732(2000).
Rb atom vapor, EIT



Slow light

Opt. Lett. **33**, No.1, 46(2008).
Rb atom vapor, EIT
Time delay=200ns



Opt. Lett. **32**, No.21, 3122(2007).

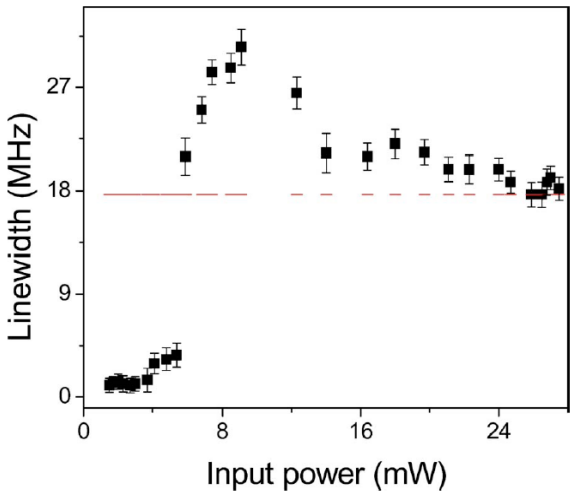


Fig. 3. (Color online) Experimentally measured cavity linewidth versus the input power. Dotted line corresponds to the empty cavity linewidth. Squares are the linewidths measured under the same experimental conditions as in Fig. 2.