Efficient storage at telecom wavelength for optical quantum memory

Julian Dajczgewand
Jean-Louis Le Gouët
Anne Louchet-Chauvet
Thierry Chanelière

Collaboration with:

Philippe Goldner's group

Laboratoire Aimé Cotton
Université Paris-Sud XI

4ème Colloque du GDR – IQFA:
Paris, November 20 to 22, 2013

Motivation: Memory + telecom wavelength

Don't lose information = Efficiency

Retrieve information = On-demand

Storing capacity = Bandwidth

1.5 μm

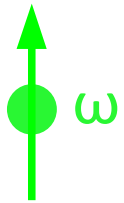
Process classical and quantum information

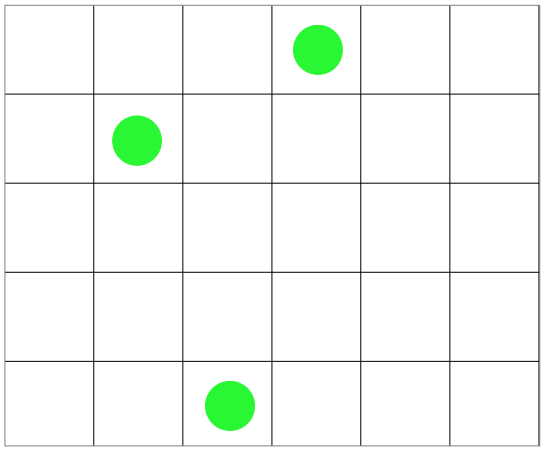
Outline

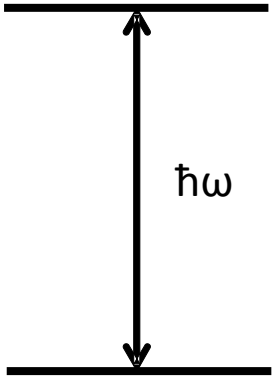
- Where do we store information ?
- ROSE protocol
- Efficiency of ROSE
- ROSE bandwidth

Where do we store information?

Ions are placed into a host matrix







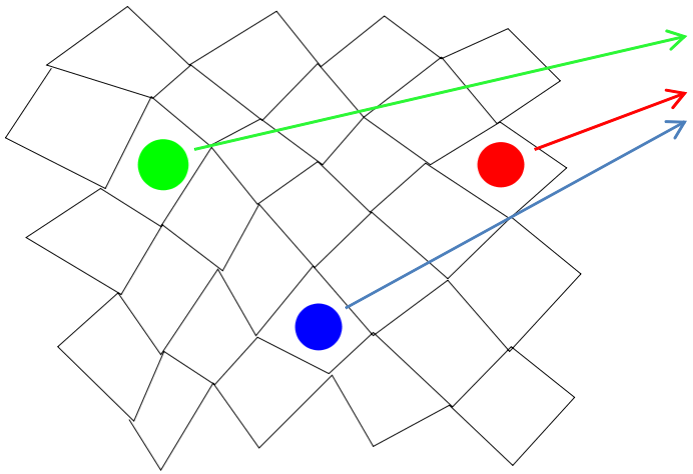
Where do we store information?

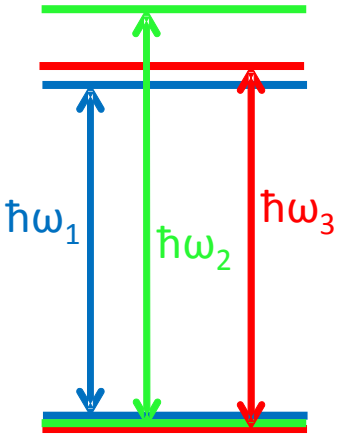
Ions are placed into a host matrix

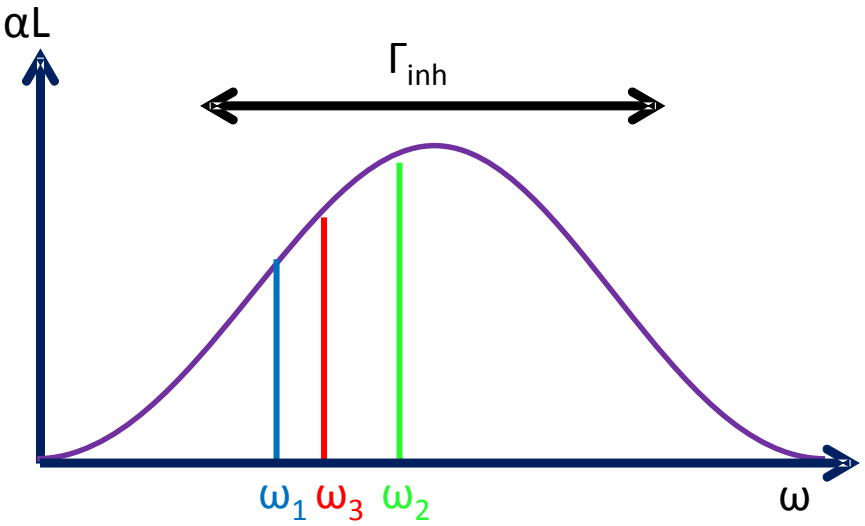
ω

ħω

Because of local strains each ion has a slightly different environment

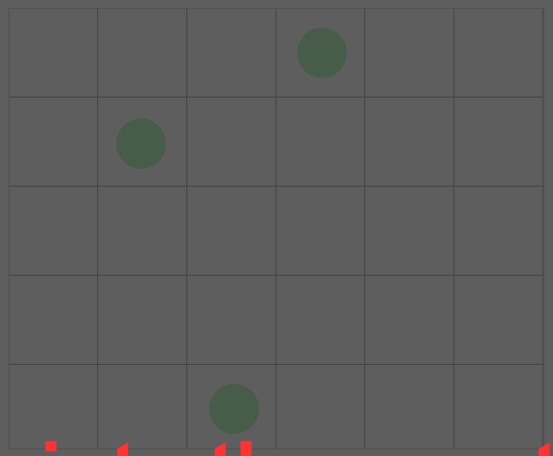




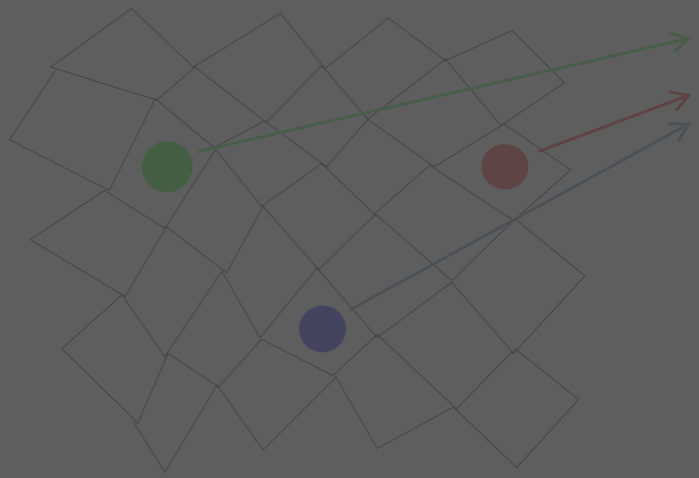


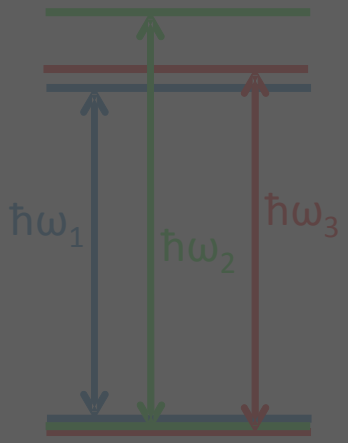
Where do we store information?

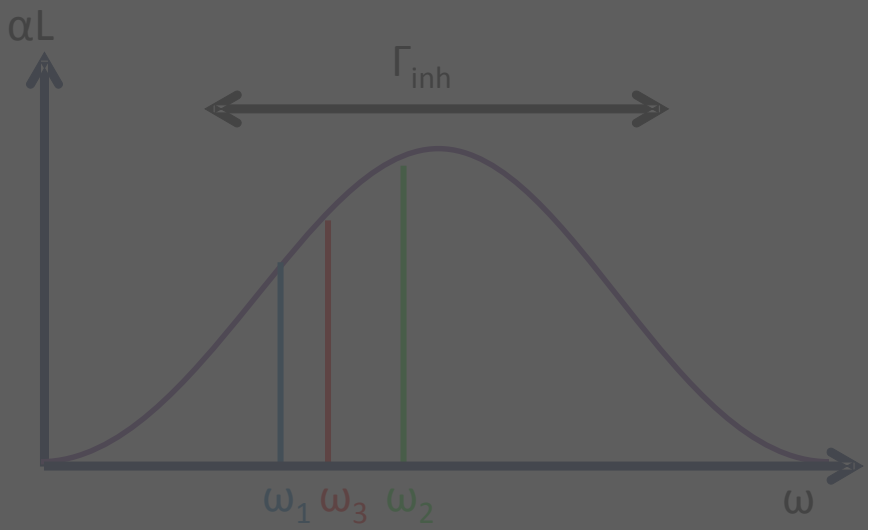
Ions are placed
into a host matrix



We map the information into the spectral dimension





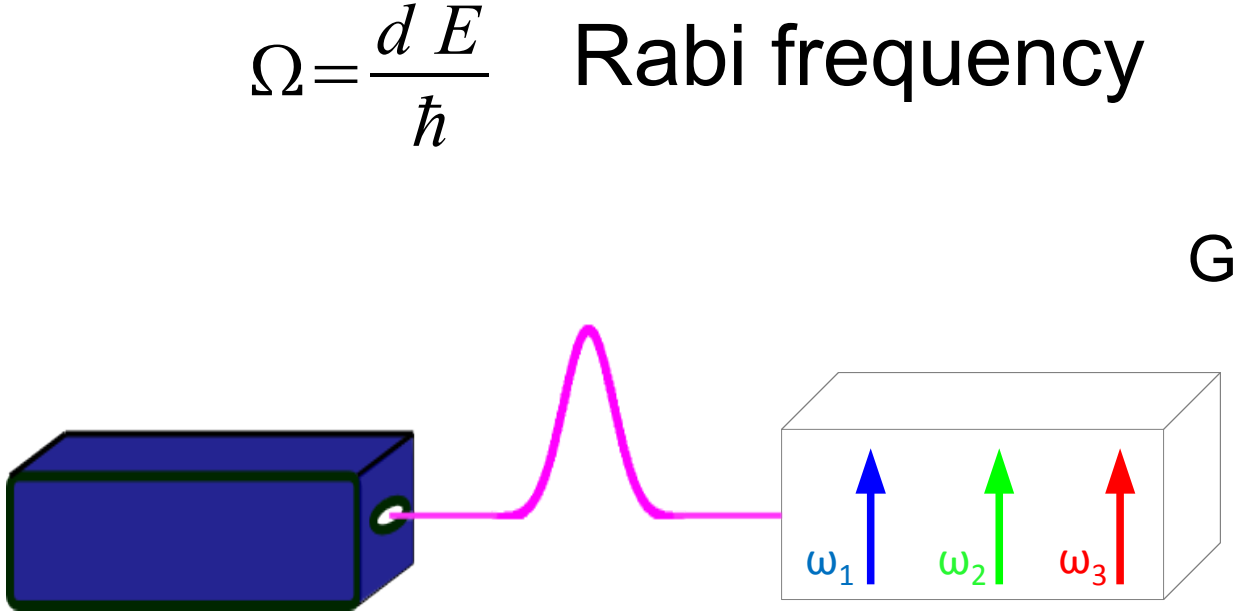


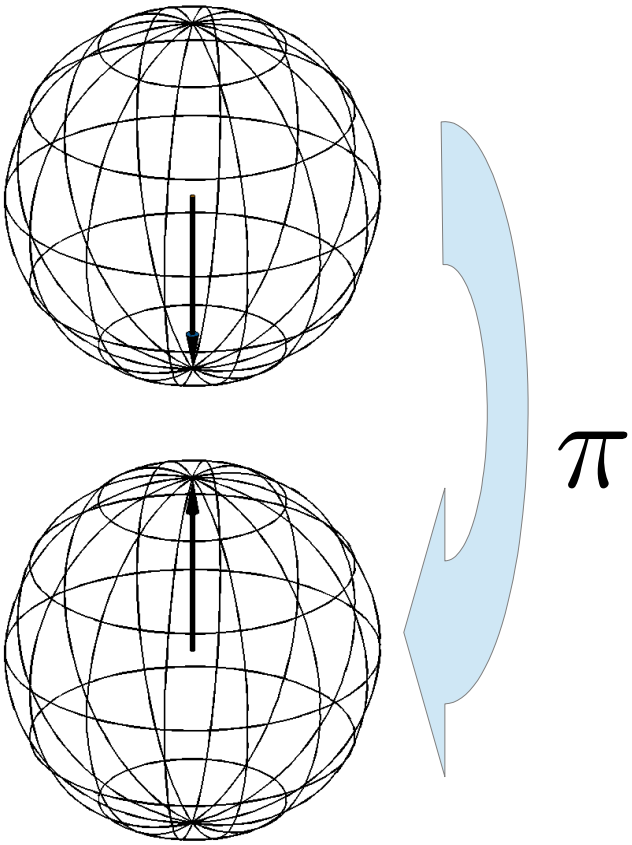
Photon echo protocols

Photon echo

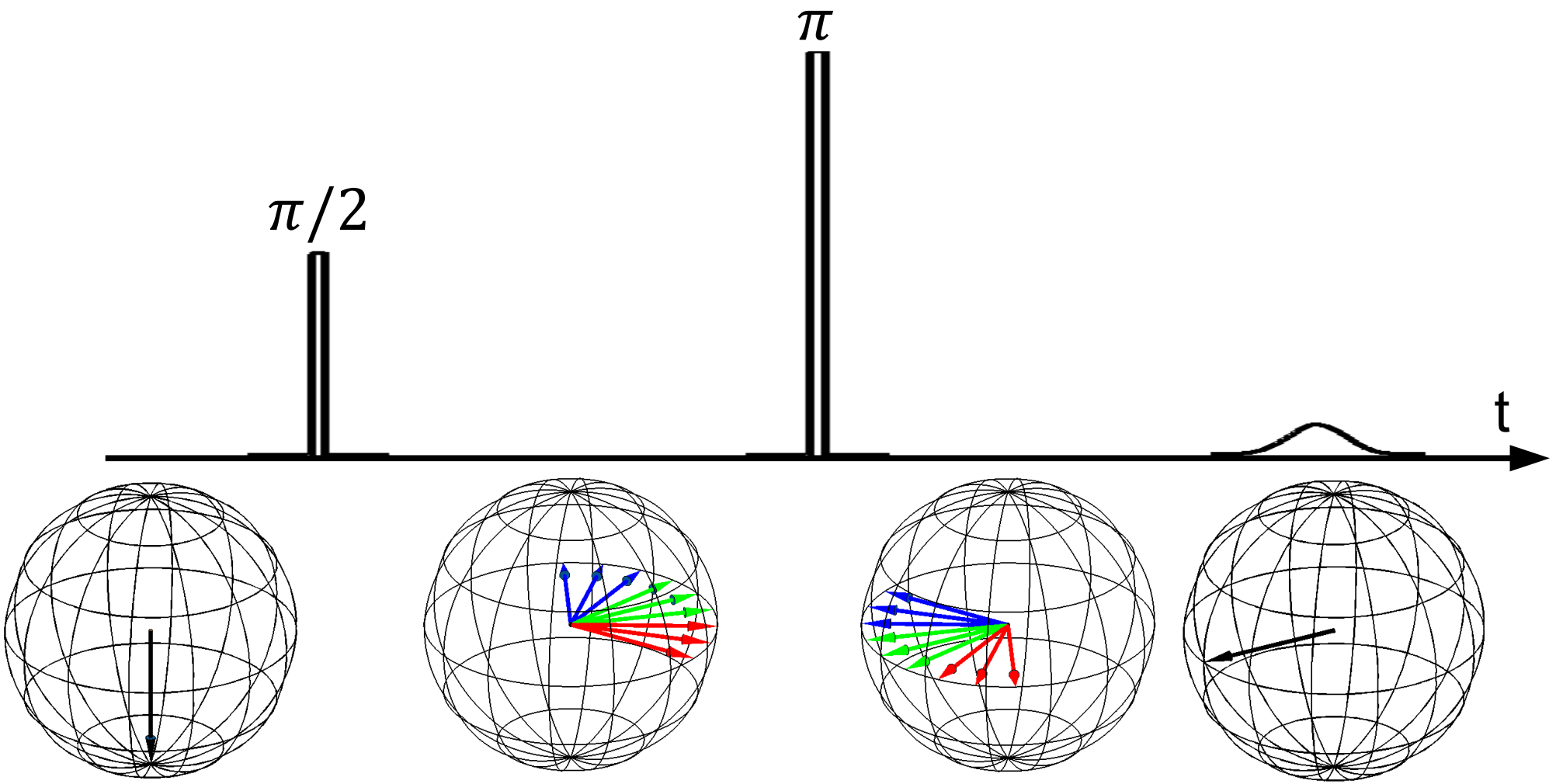
It is based on the interaction between dipoles and an electromagnetic field:

$$\Omega = \frac{\vec{d}\,\vec{E}}{\hbar}$$ Rabi frequency

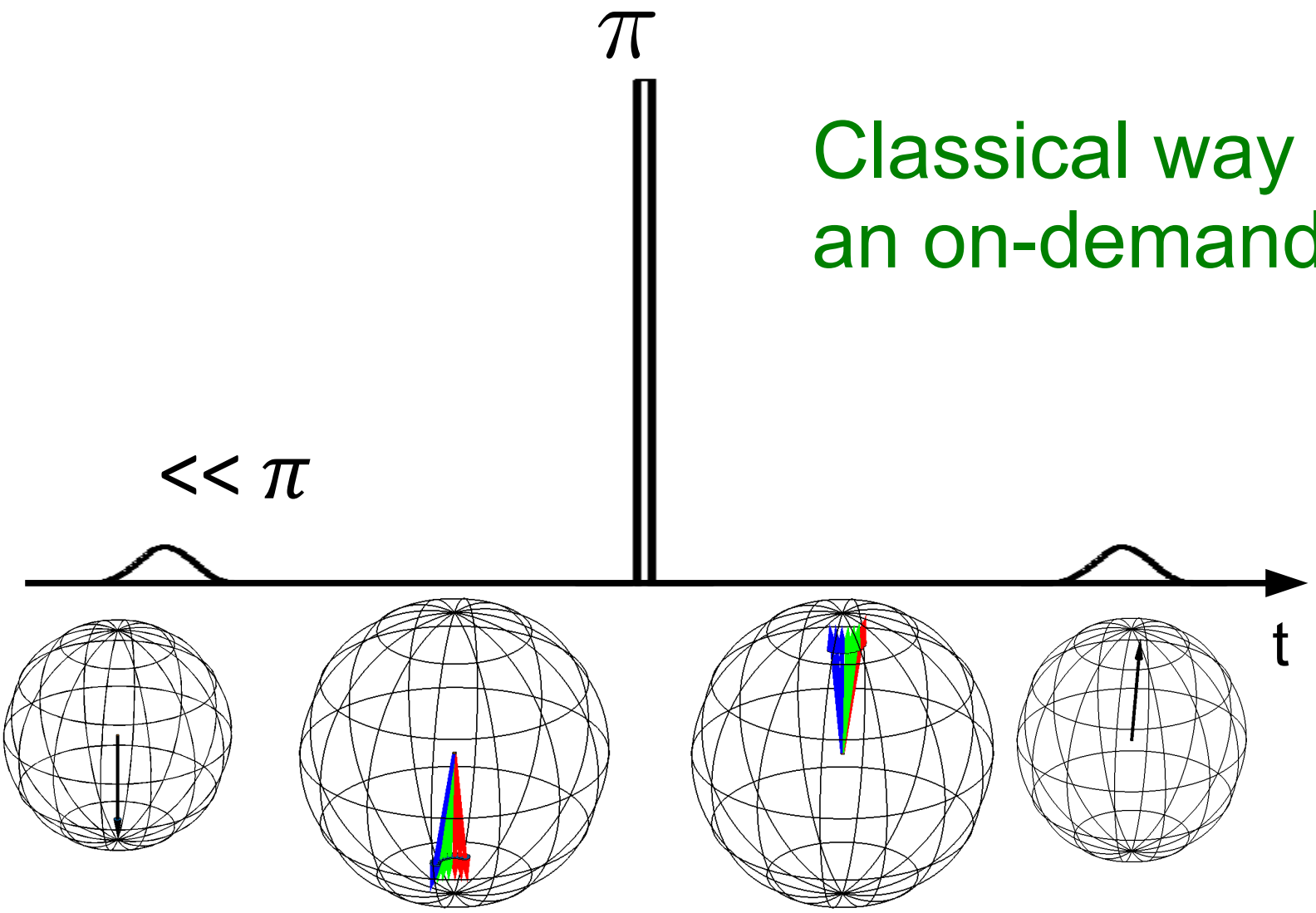




2-pulse photon echo

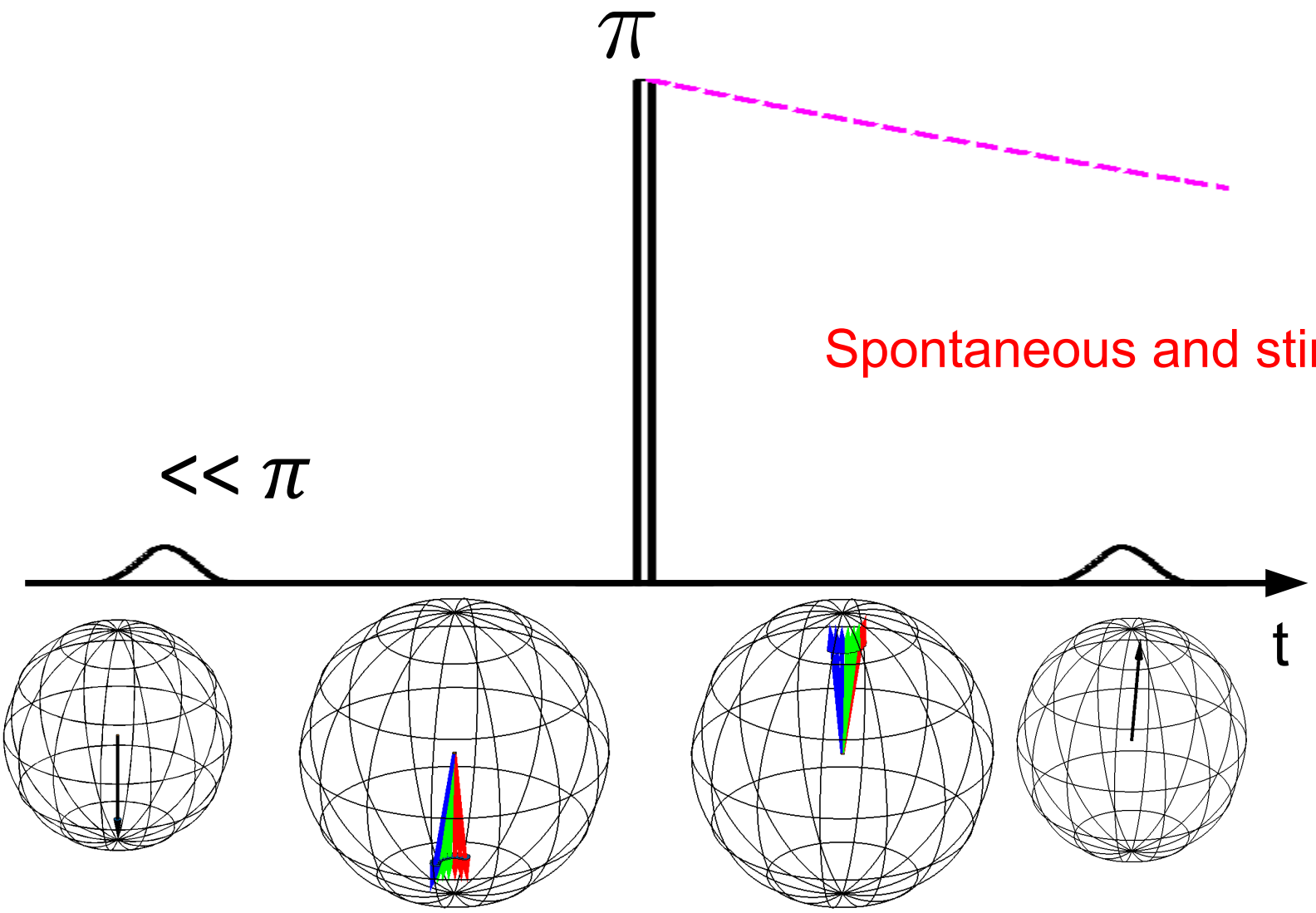


2-pulse photon echo memory



Classical way to set up an on-demand memory

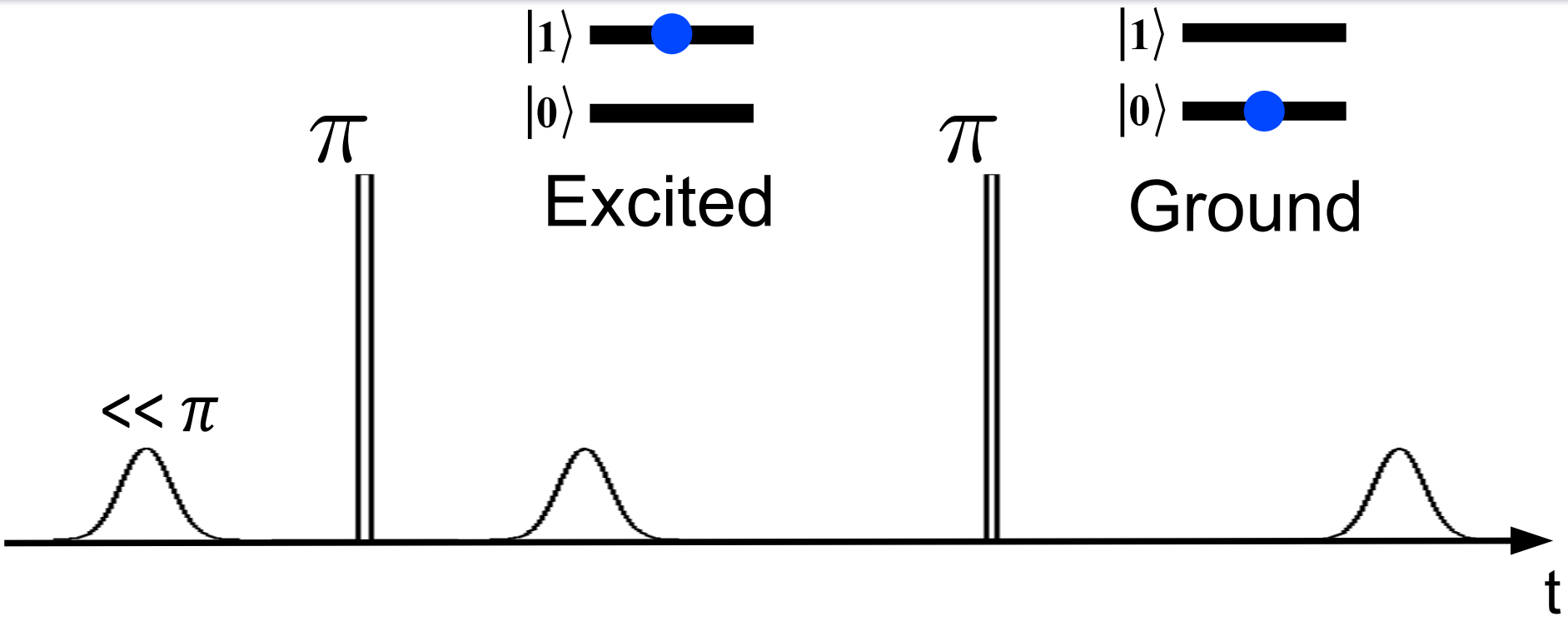
2-pulse photon echo memory(*)



Spontaneous and stimulated emission

(*) J.Ruggiero et al, "Why the two-pulse photon echo is not a good quantum memory protocol", Phys. Rev. A, 79(5):053851, 2009.

Double π rephasing

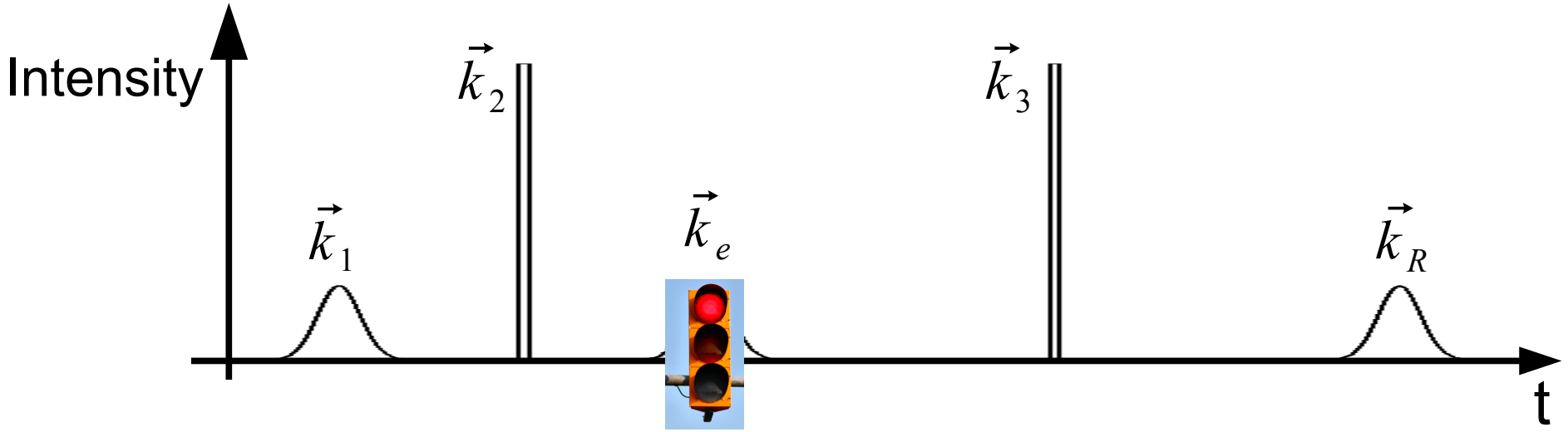


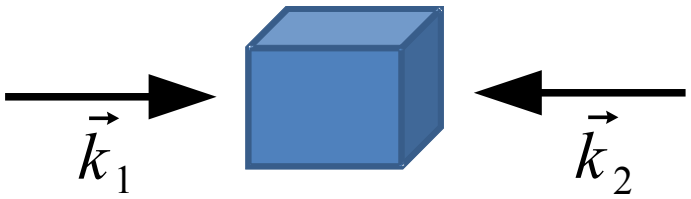
+ Avoid working in the excited state

- Loss of information due to rephasing after the first π pulse

ROSE (revival of silenced echo)(*)

It is based on the spatial phase mismatching





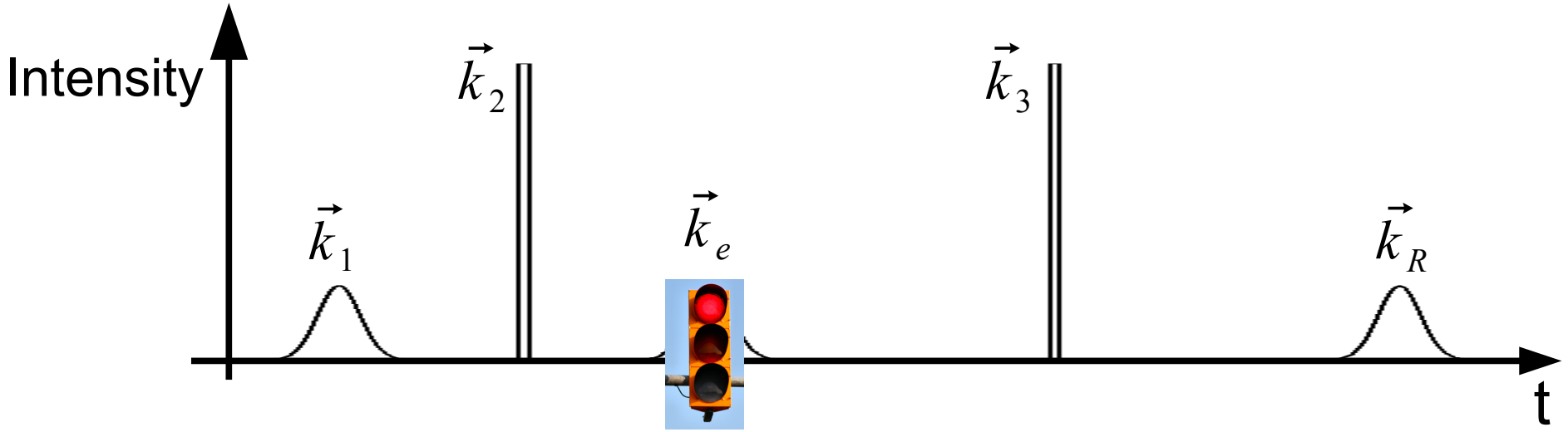
No primary echo due to phase matching condition

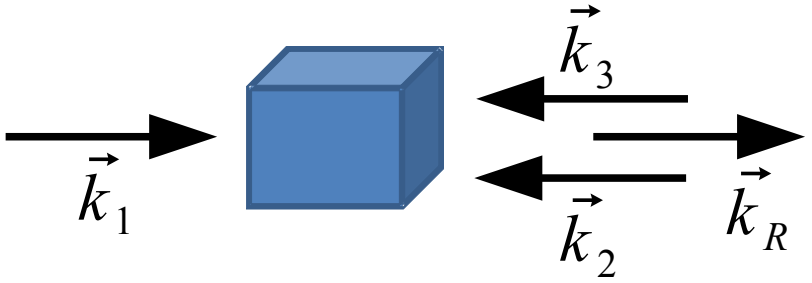
DOES NOT AFFECT THE ATOMIC COHERENCE

(*) V. Damon et al, "Revival of Silenced Echo and Quantum Memory for Light", , New J. Phys., 13:093031, 2011.

ROSE (revival of silenced echo)(*)

It is based on the spatial phase mismatching



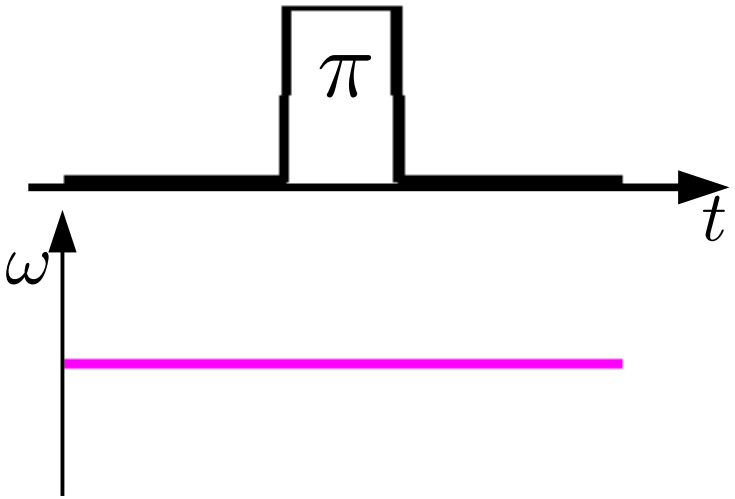


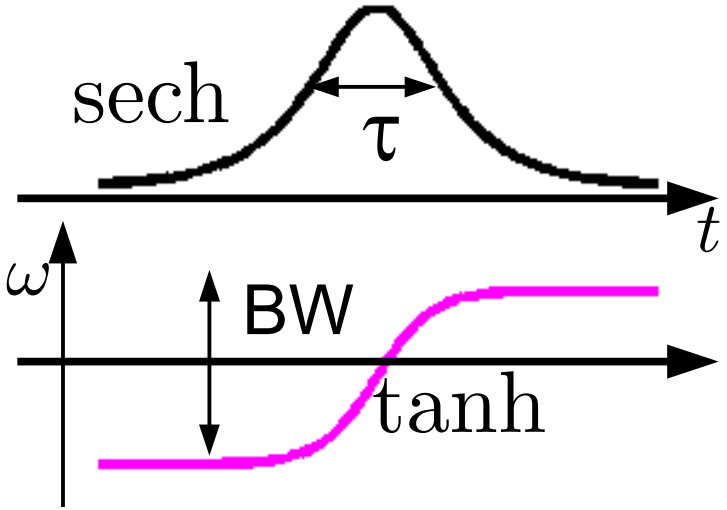
ROSE echo emitted without losing information in the primary echo

(*) V. Damon et al, "Revival of Silenced Echo and Quantum Memory for Light", , New J. Phys., 13:093031, 2011.

ROSE (revival of silenced echo)

In addition we replace π pulses by chirped pulses called CHS(*)





+ Increase bandwidth

+ Less distortion of the pulse

(*) M. F. Pascual-Winter et al, "Securing coherence rephasing with a pair of adiabatic rapid passages", New J. Phys., 15:055024, 2013.

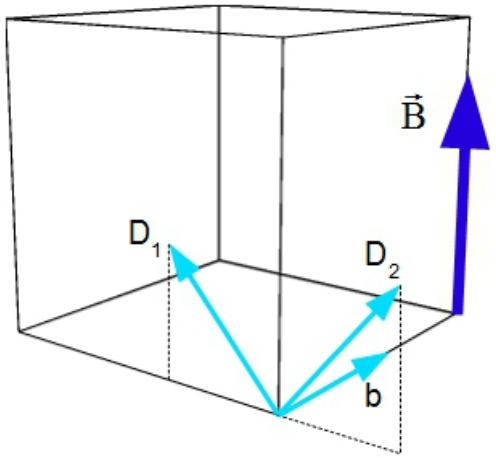
ROSE advantages

- Avoid contamination by spontaneous and stimulated emission
- Chirped pulses are more efficient than π pulses
- No need for spectral preparation of the sample
- Multimode storage

ROSE performance

$Er^{3+}:Y_2SiO_5$ main characteristics

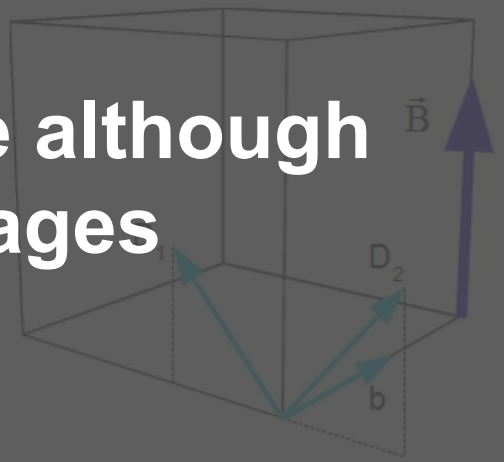
- 3 perpendicular optical extinction axes **(birefringent)**.



- Erbium ions substitute Y ions.
- Y_2SiO_5 has a small magnetic moment **(increase T_2)**.
- Low symmetry C_1 sites leading to anisotropic splitting of the Zeeman levels **(anisotropic T_2)**.

$Er^{3+}:Y_2SiO_5$ main characteristics

- 3 perpendicular optical extinction axes **(birefringent)**.
- Erbium ions substitute Y ions.
- Y_2SiO_5 has a small magnetic moment **(increase T_2)**.
- Low symmetry C_1 sites leading to anisotropic splitting of the Zeeman levels **(anisotropic T_2)**.



Quite complex crystal to use although it presents many advantages

Gisin's group pioneers using this crystal with CRIB(*):
They showed an efficiency under 1% at single photon level

(*) B. Lauritzen et al, "Telecommunication-Wavelength Solid-State Memory at the Single Photon Level", 2010 Phys. Rev. Lett. 104(8) 080502

Er + ROSE

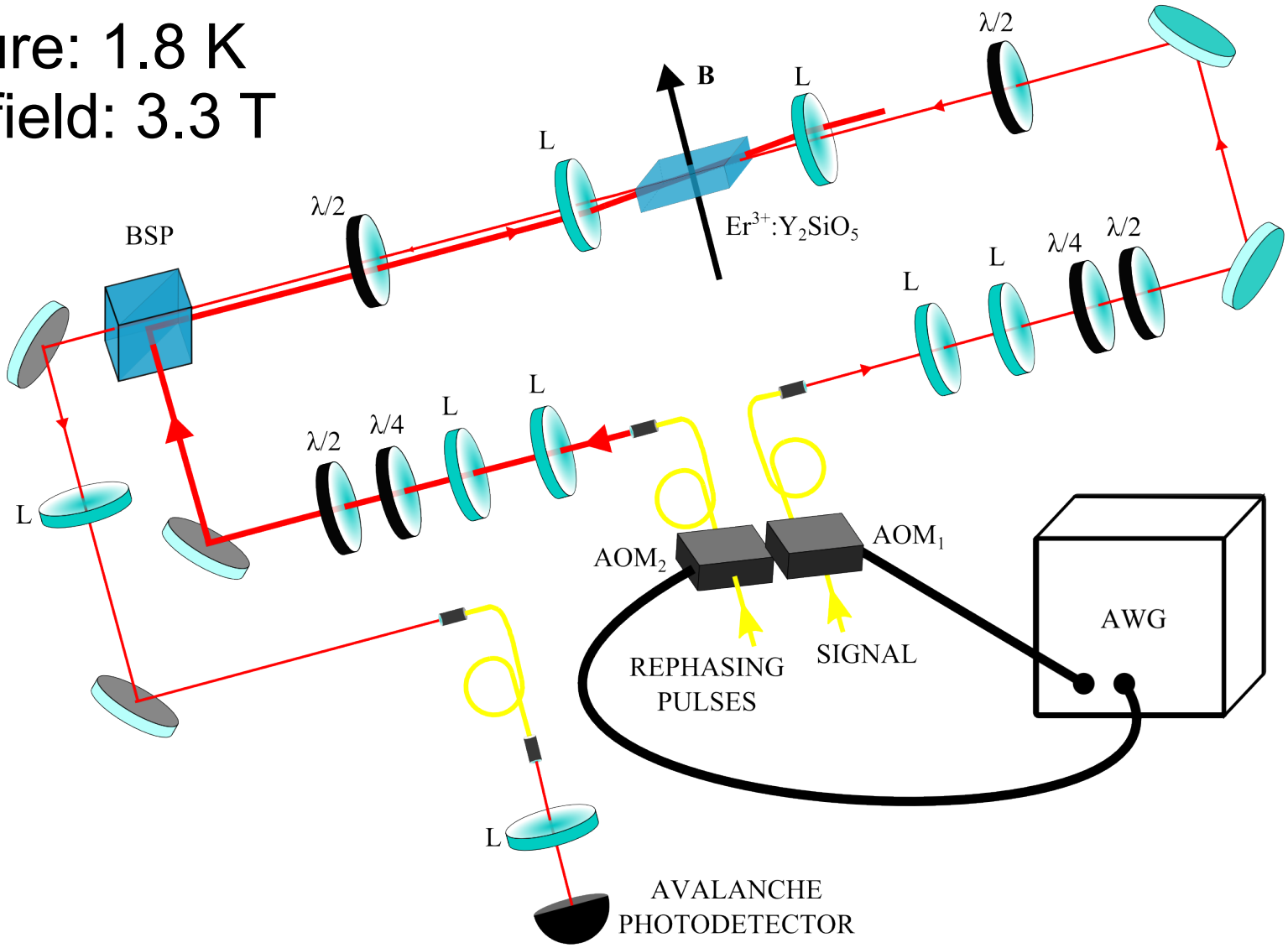
- Coherence lifetime > 1 ms at 3.3 T
- Inhomogeneous linewidth ~ 600 MHz

$$\frac{\Gamma_{inhomog}}{\Gamma_{homog}} \approx 10^6$$

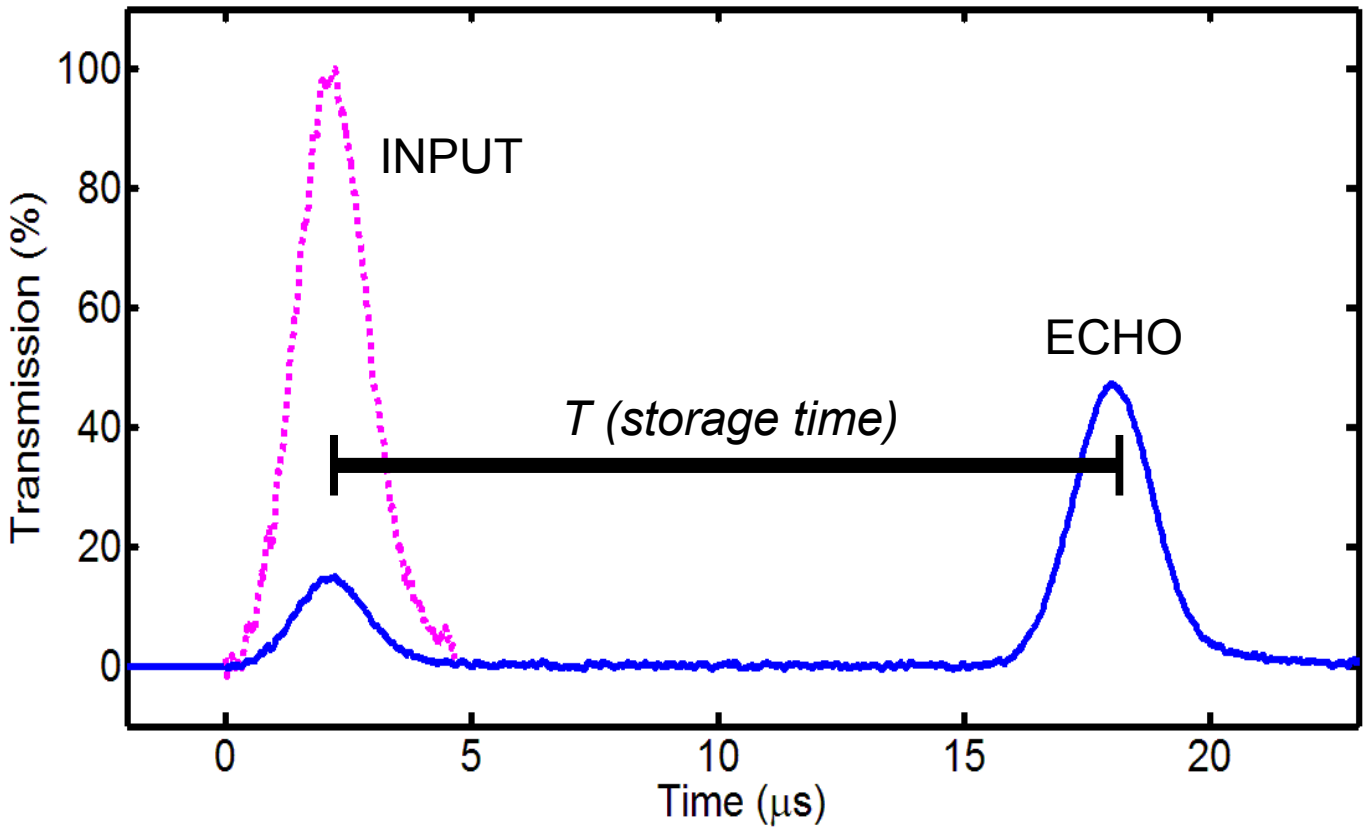
- Transition at telecom wavelength (1.5 μm)

Experimental Set-up

Temperature: 1.8 K
Magnetic field: 3.3 T

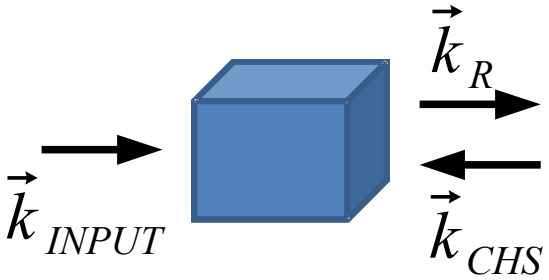


Er + ROSE some results



ROSE with bandwidth of:

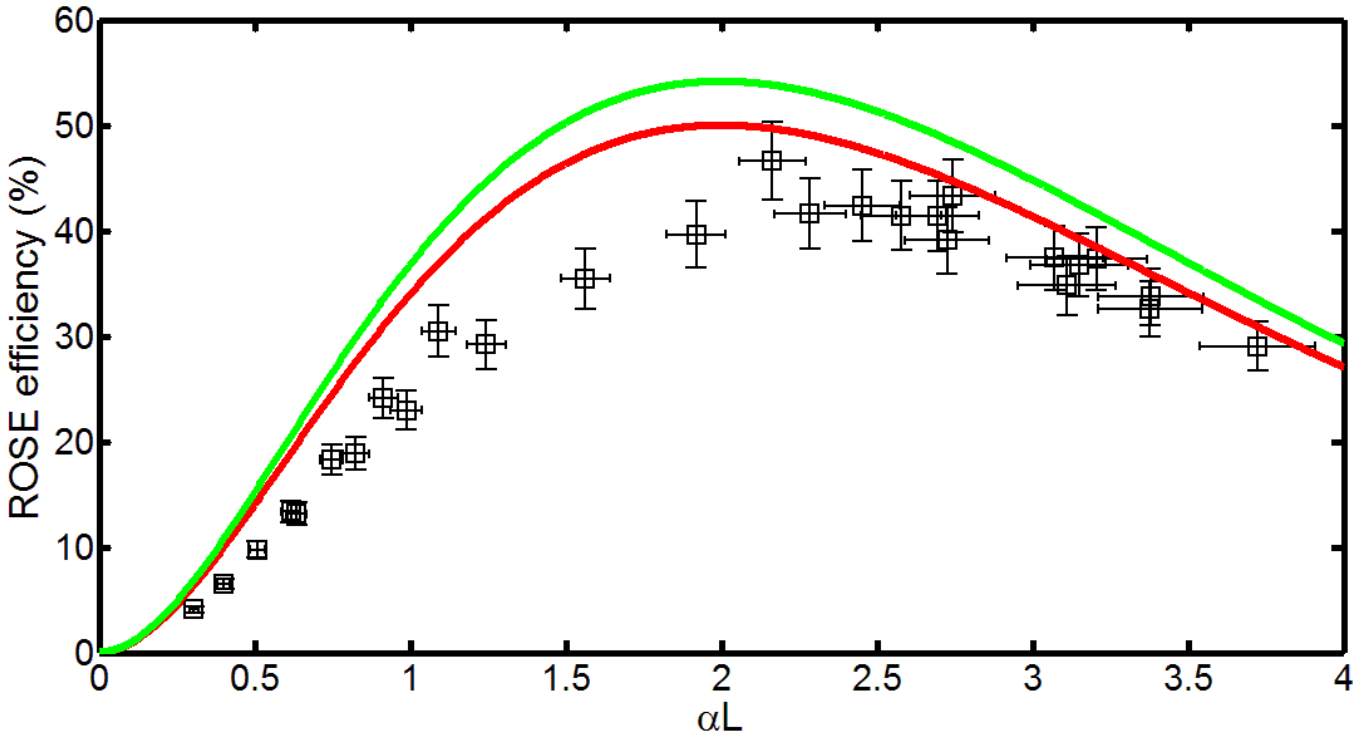
$$BW = 800\,kHz$$



$\eta_{exp} \approx 45\,\%$

$$\eta_{th} = (\alpha L)^2 e^{-\alpha L} e^{-2T/T_2} \approx 50\,\%$$

ROSE efficiency



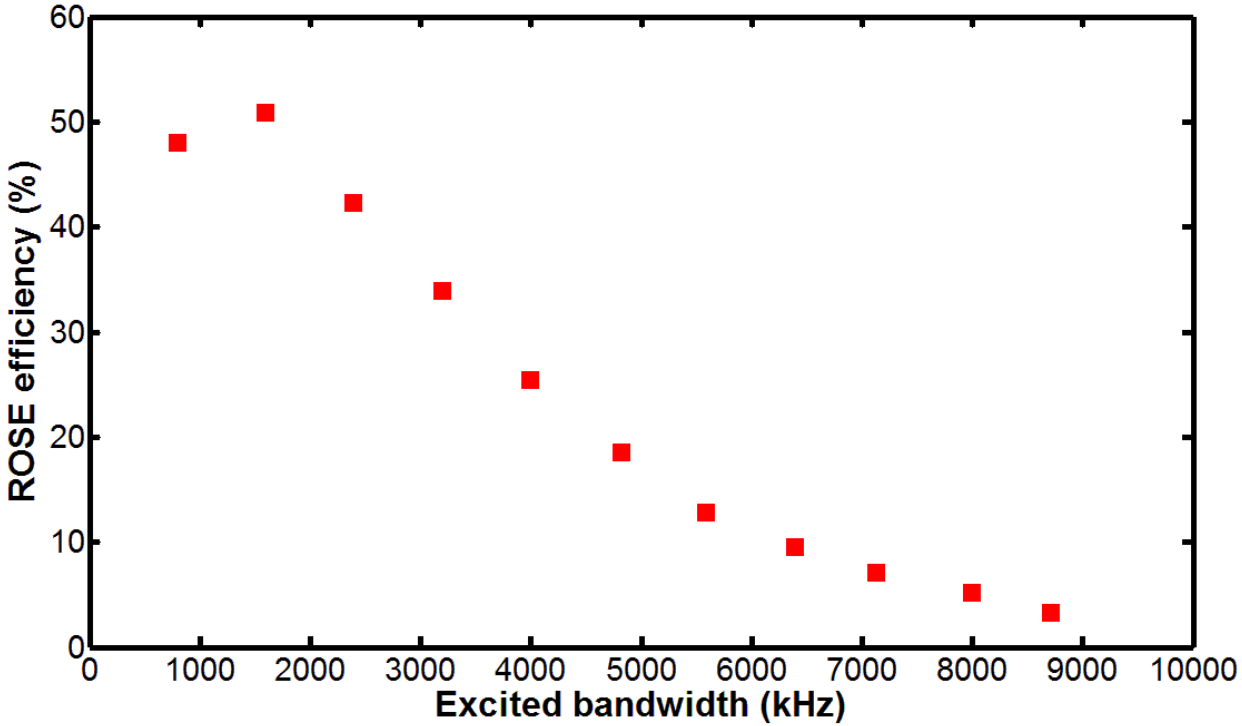
Theoretical efficiency without relaxation: $\eta_{th} = (\alpha L)^2 e^{-\alpha L}$ → **Maximum efficiency 54%**

Theoretical efficiency including relaxation: $\eta_{th} = (\alpha L)^2 e^{-\alpha L} e^{-2T/T_2}$

→ **WE MEASURED OVER 40%!!**

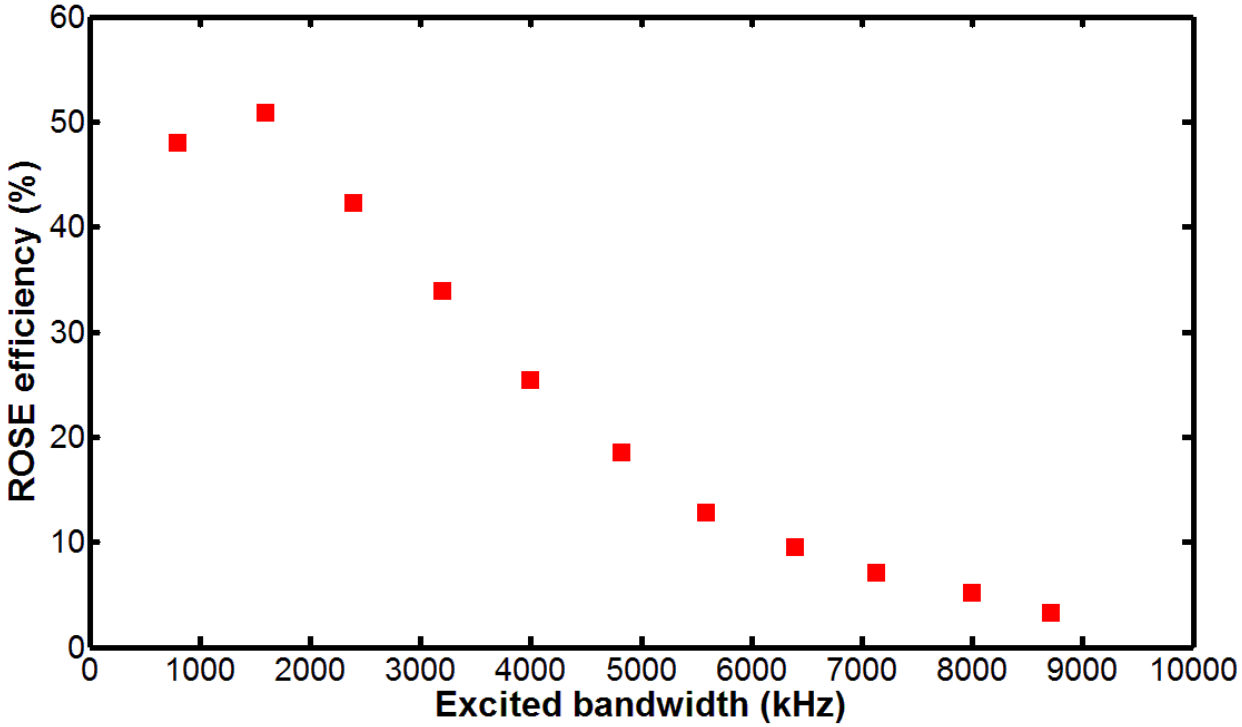
ROSE bandwidth

Er bandwidth efficiency with ROSE



$$(\alpha L)^2 \mathrm{e}^{-\alpha L} e^{\left(-\frac{2T}{T_2}\right)}$$

Er bandwidth efficiency with ROSE

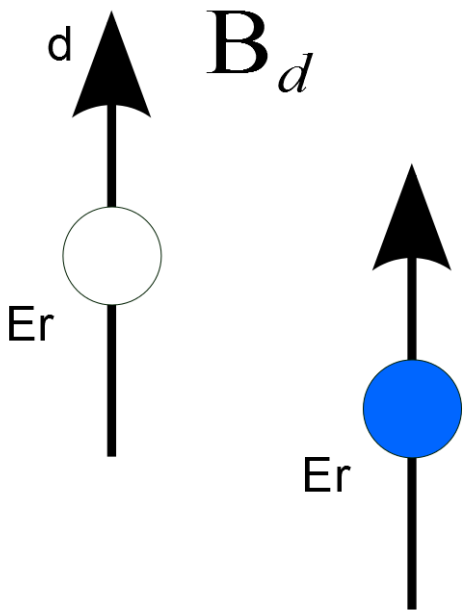


The Instantaneous spectral diffusion (ISD) modifies the coherence time

$$(\alpha L)^2 e^{-\alpha L} e^{\left(-\frac{2T}{T_2}\right)} \rightarrow (\alpha L)^2 e^{-\alpha L} e^{\left(-\frac{2T}{T_2^*(BW)}\right)}$$

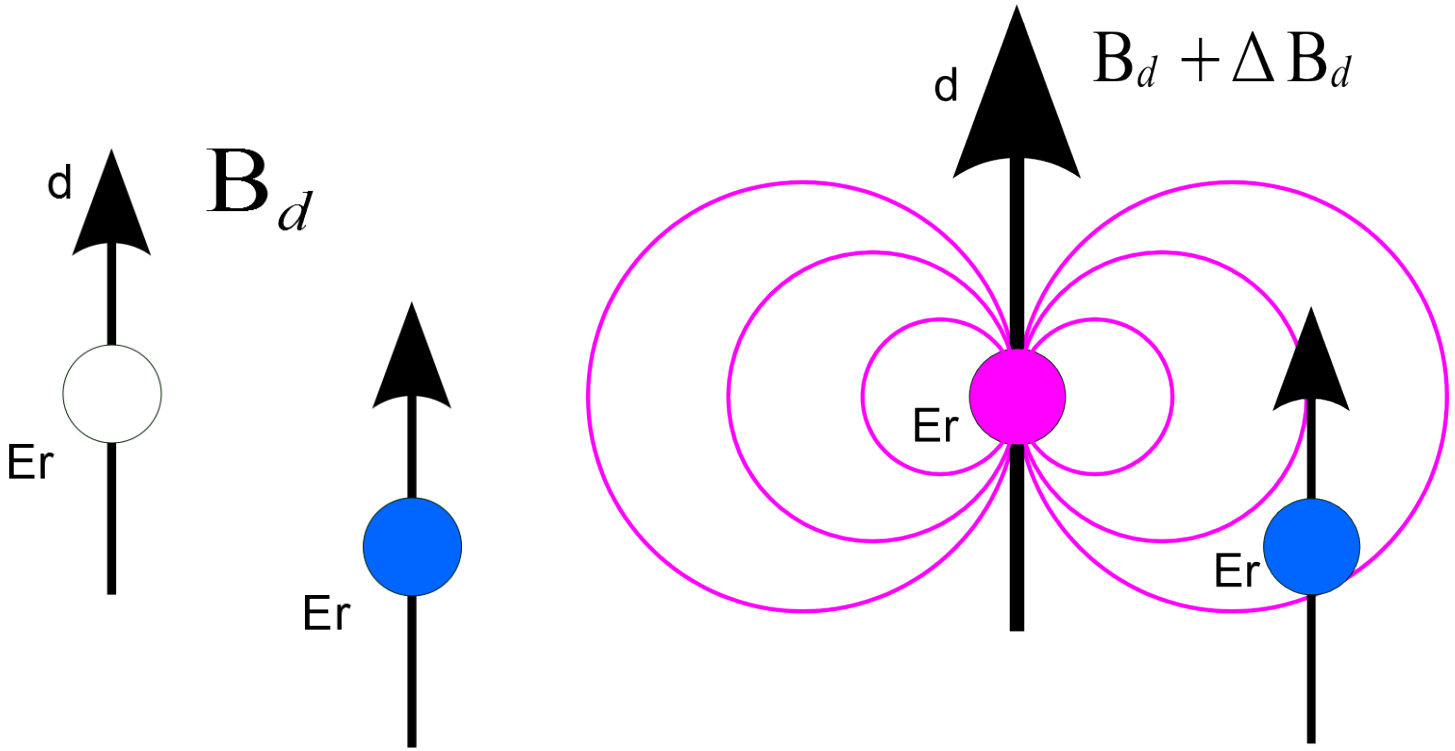
Instantaneous spectral diffusion (ISD)

The ISD appears due to the interaction Er-Er



Instantaneous spectral diffusion (ISD)

The ISD appears due to the interaction Er-Er



$$\Delta B_{d_1} \alpha (g_e - g_g)$$

Instantaneous spectral diffusion (ISD)

Why is it important to evaluate this effect ?

It's a limiting factor to the bandwidth
of the photons that can be used

- Trade-off between channels and efficiency

- Sources SPDC of entangled photons have bandwidth > 10 MHz

Possible solutions to ISD

- Rotate the crystal
- Sacrifice ROSE's bandwidth
- Decrease Er concentration
- Change host matrix (keeping Er)

Philippe Goldner's group at ENSCP (Poster session)

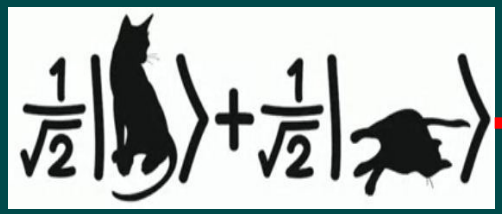
Conclusions and perspectives

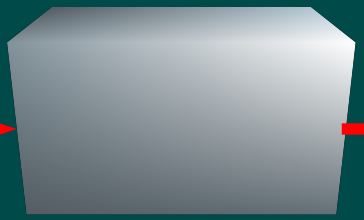
- ROSE efficiency greater than 45 %.

- Evaluate the best way to decrease the effects of ISD.

- Perform experiments at single photon level.

Quantum memory





QUESTIONS ??