# NONCLASSICAL LIGHT USING RYDBERG ATOMS

David Paredes

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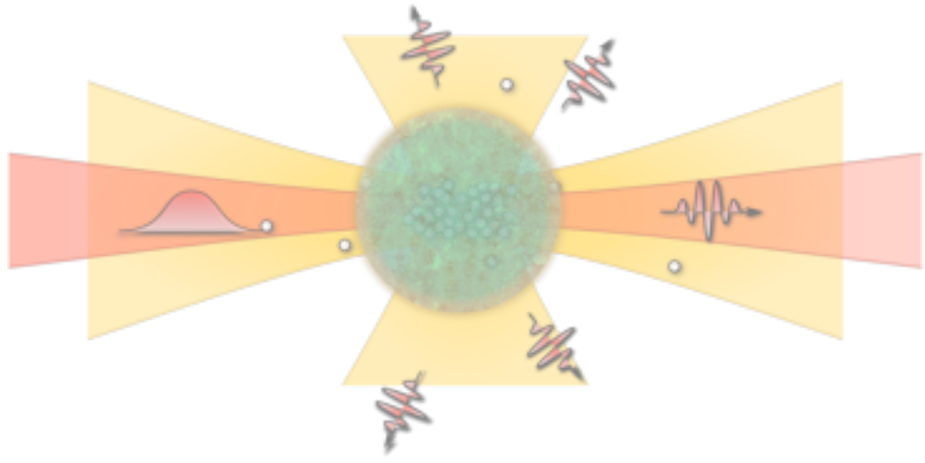

ICFO - 03/07/12

# Trouble with photons


# Solution:

- Map into atomic excitations with strong interactions


# Outline

1. Essential physics

   1.1. Polariton propagation

   1.2. Blockade

2. Our experiment

3. Future

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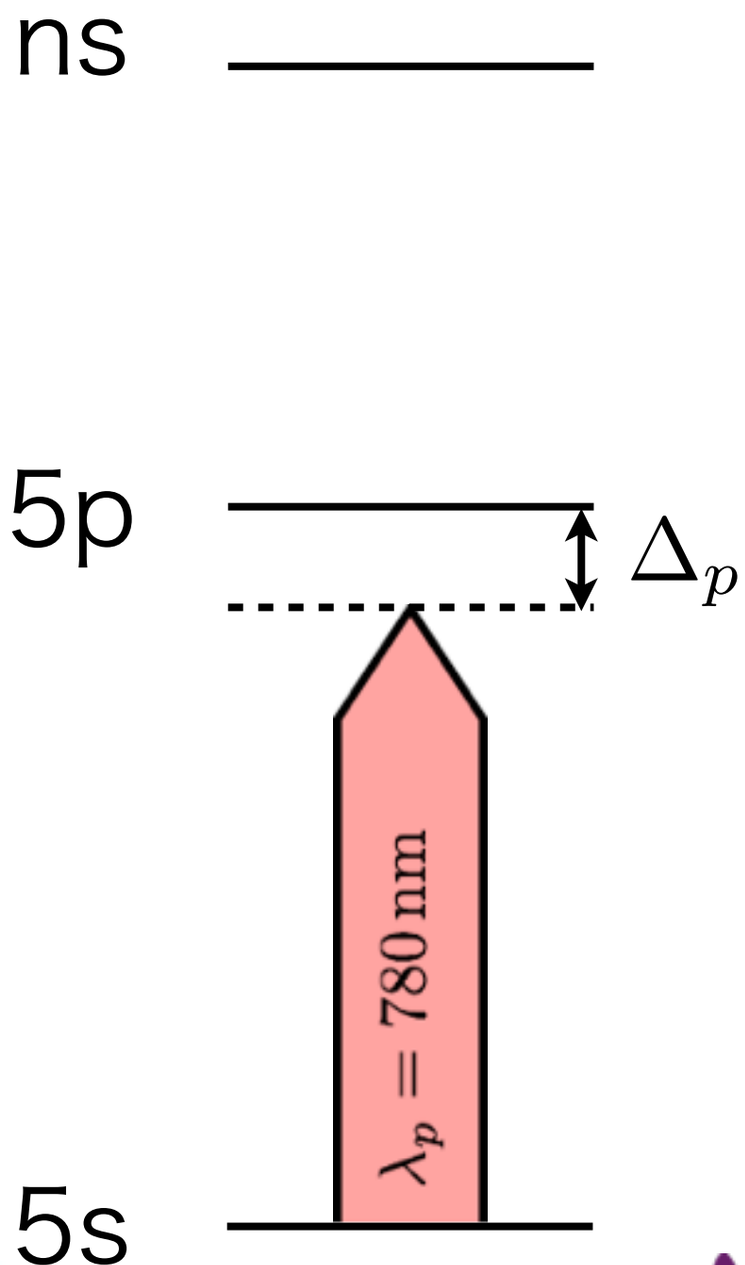
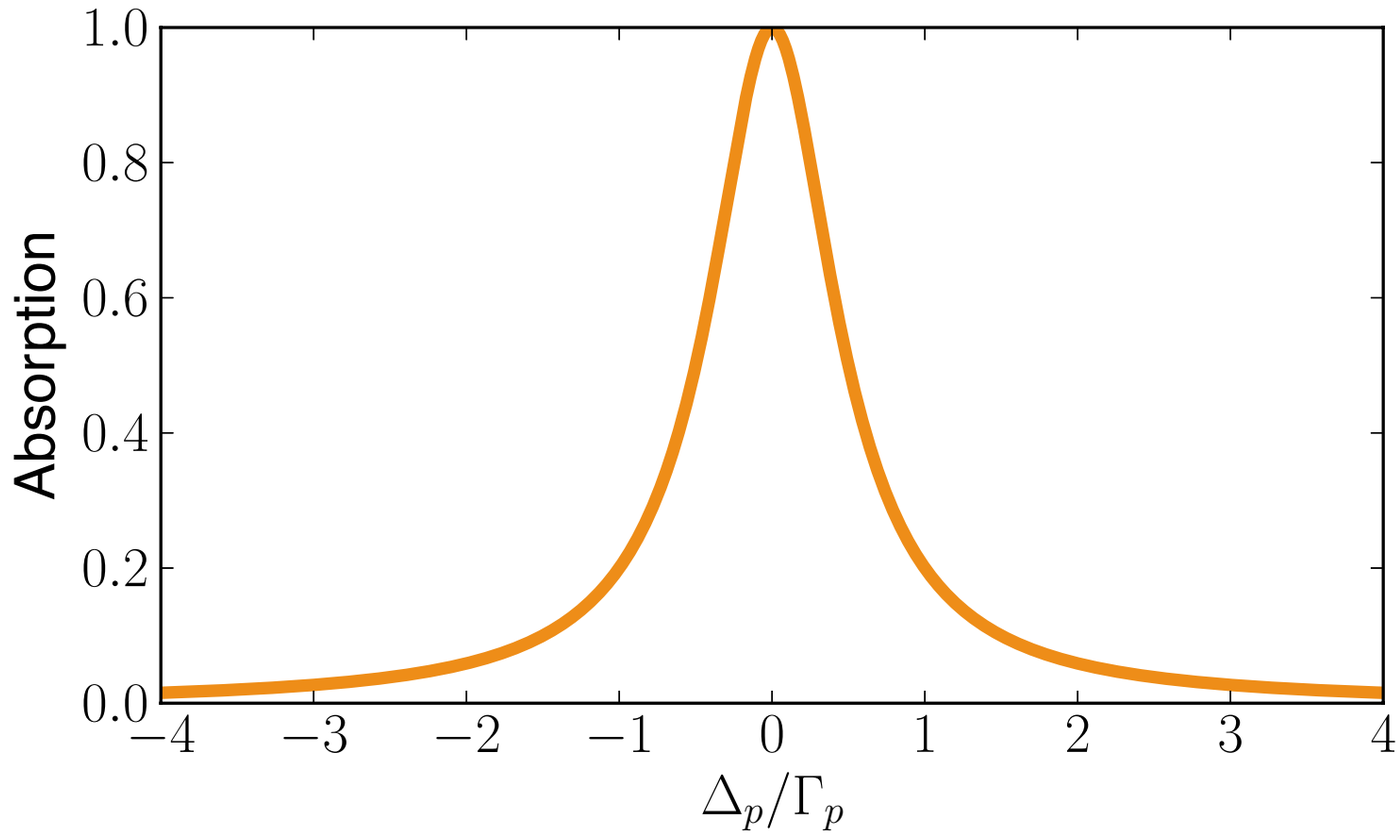
# EIT: Effect on light

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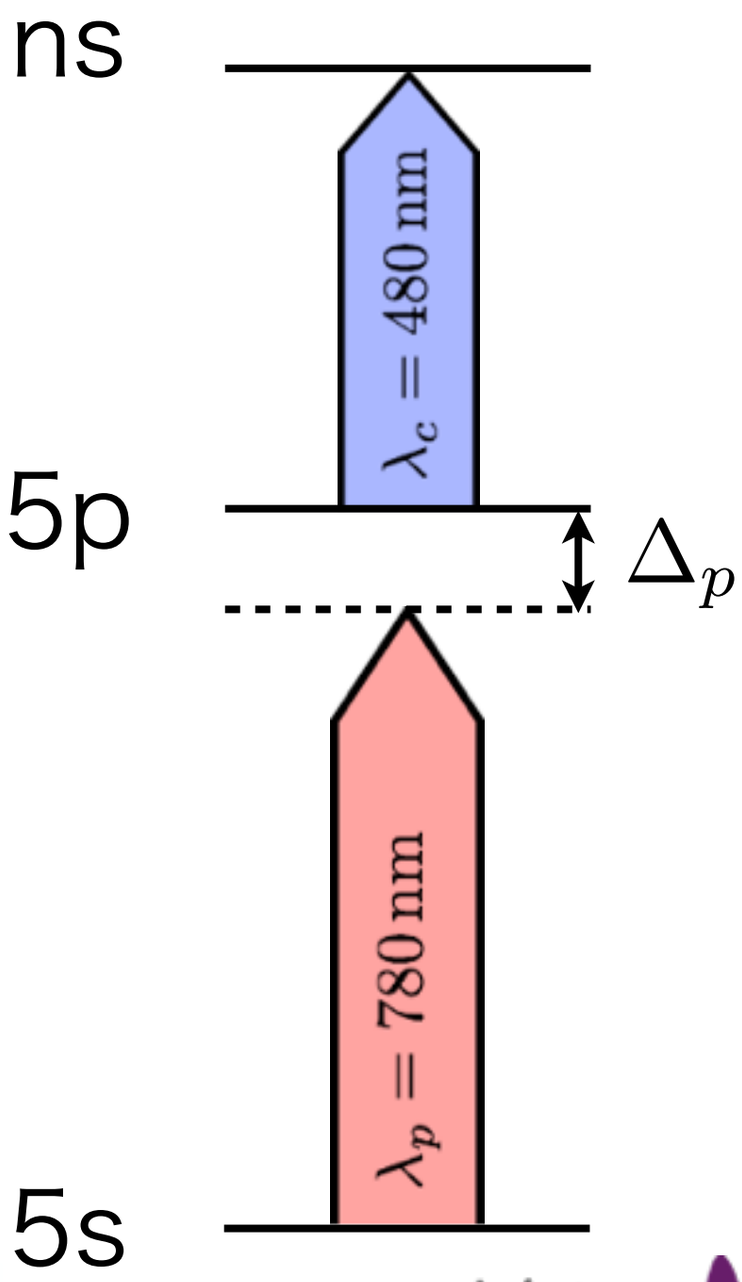
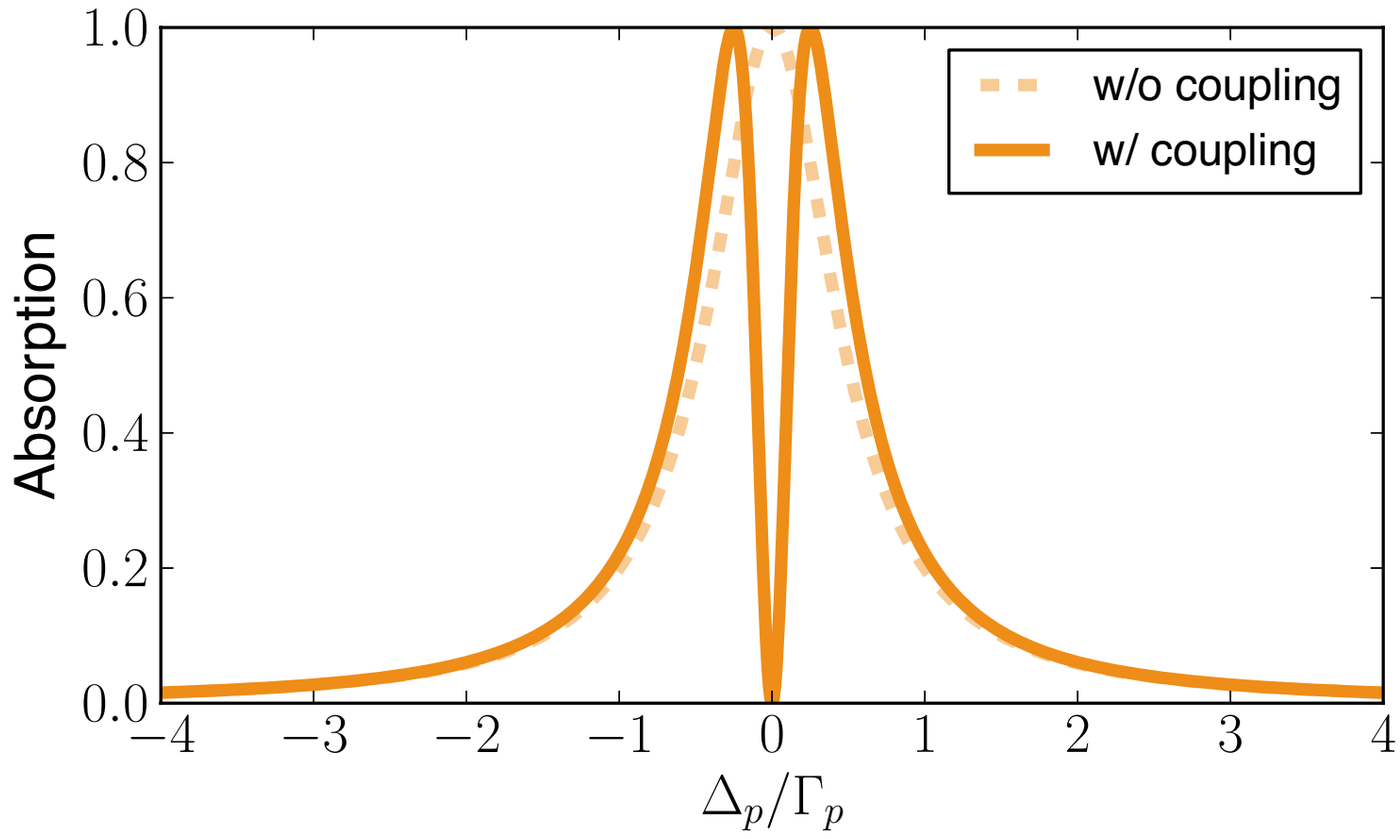
Fleischhauer et al., Rev. Mod. Phys. **77**, 633 (2005)

# EIT: Effect on light

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# Dark State Polaritons

Photons propagating through matter polarize it

Maxwell-Bloch equations $\longrightarrow$ EM field + matter

# Particular solution: **Polariton**

$$\Psi(z,t) = \cos\theta(t)E(z,t) - \sin\theta(t)\sqrt{(N)}\sigma_{gr}(z,t)$$

$$\cos\theta(t) = \frac{\Omega_c(t)}{\sqrt{\Omega_c^2(t) + g^2 N}}$$

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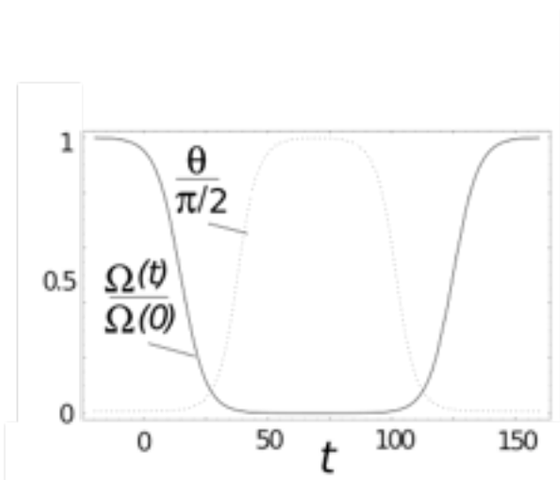
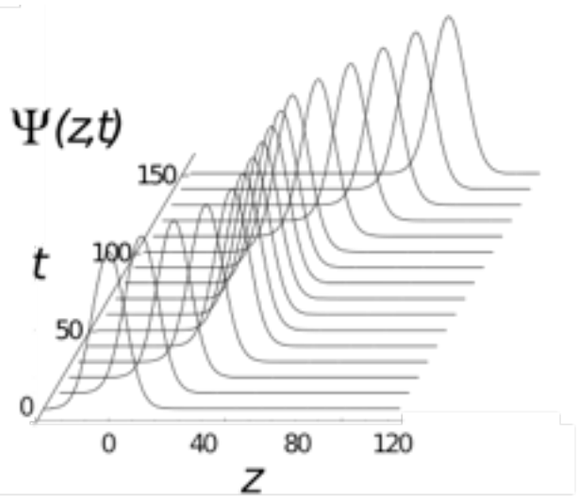
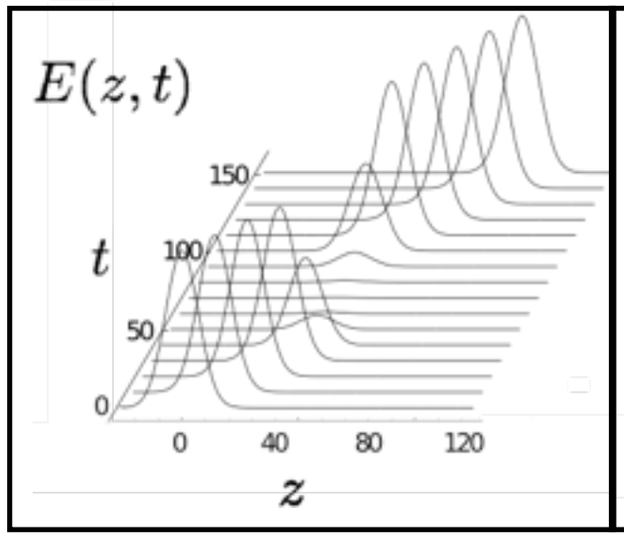
Fleischhauer & Lukin, PRL **84**, 5094 (2000)

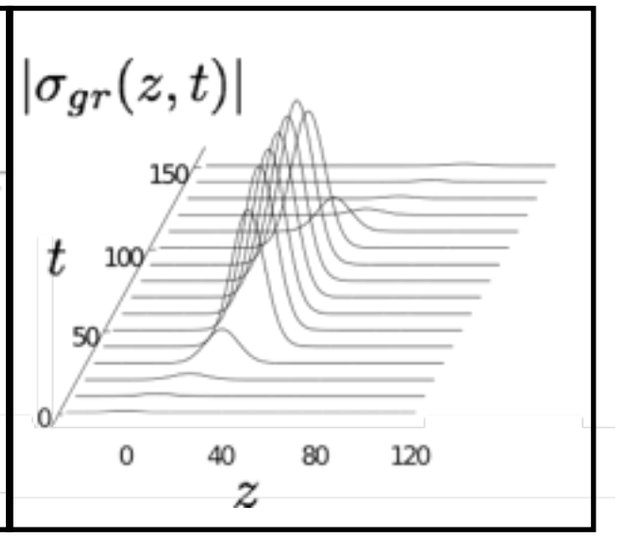
$$\Psi(z,t) = \cos\theta(t)E(z,t) - \sin\theta(t)\sqrt{N}\sigma_{gr}(z,t)$$




EM field




Spin-wave

$$\cos\theta(t) = \frac{\Omega_c(t)}{\sqrt{\Omega_c^2(t) + g^2N}} \qquad v_g = c\cos^2\theta(t)$$

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Fleischhauer & Lukin, PRL **84**, 5094 (2000)

# Rydberg physics 101

High principal quantum number, n

**Exaggerated properties**

Dipole moment $\mu \propto n^2$

Dipole-dipole interactions $V(r) \propto \frac{C_6}{R^6}$

$C_6 \propto n^{11}$

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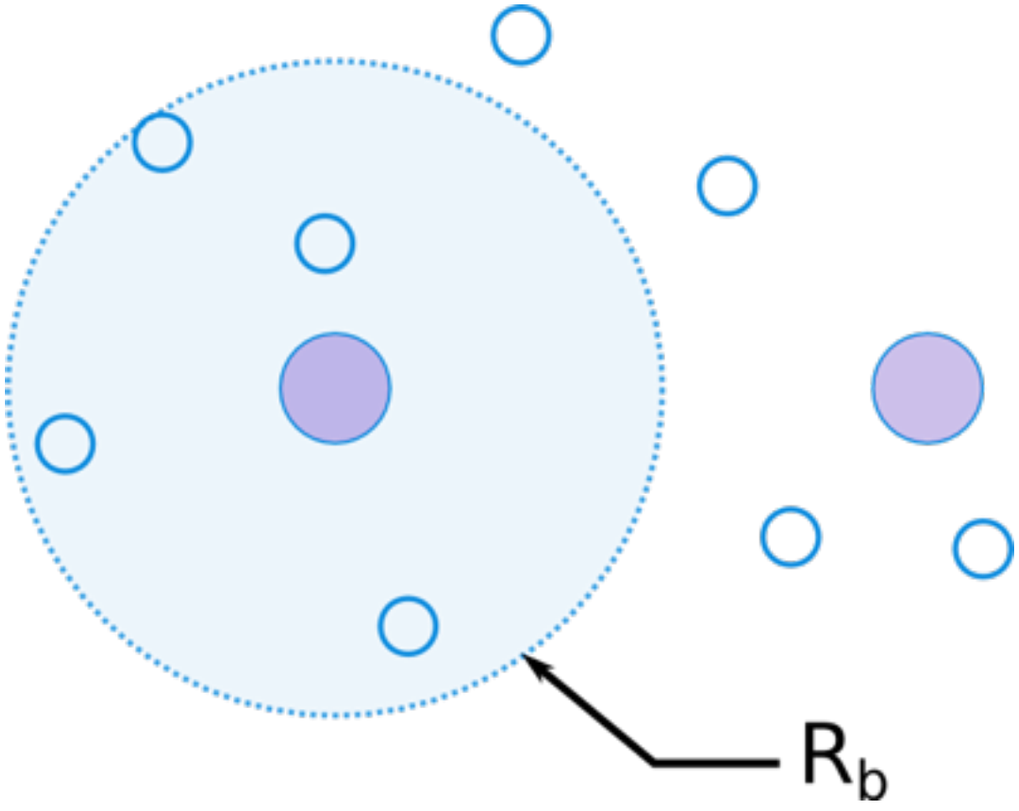
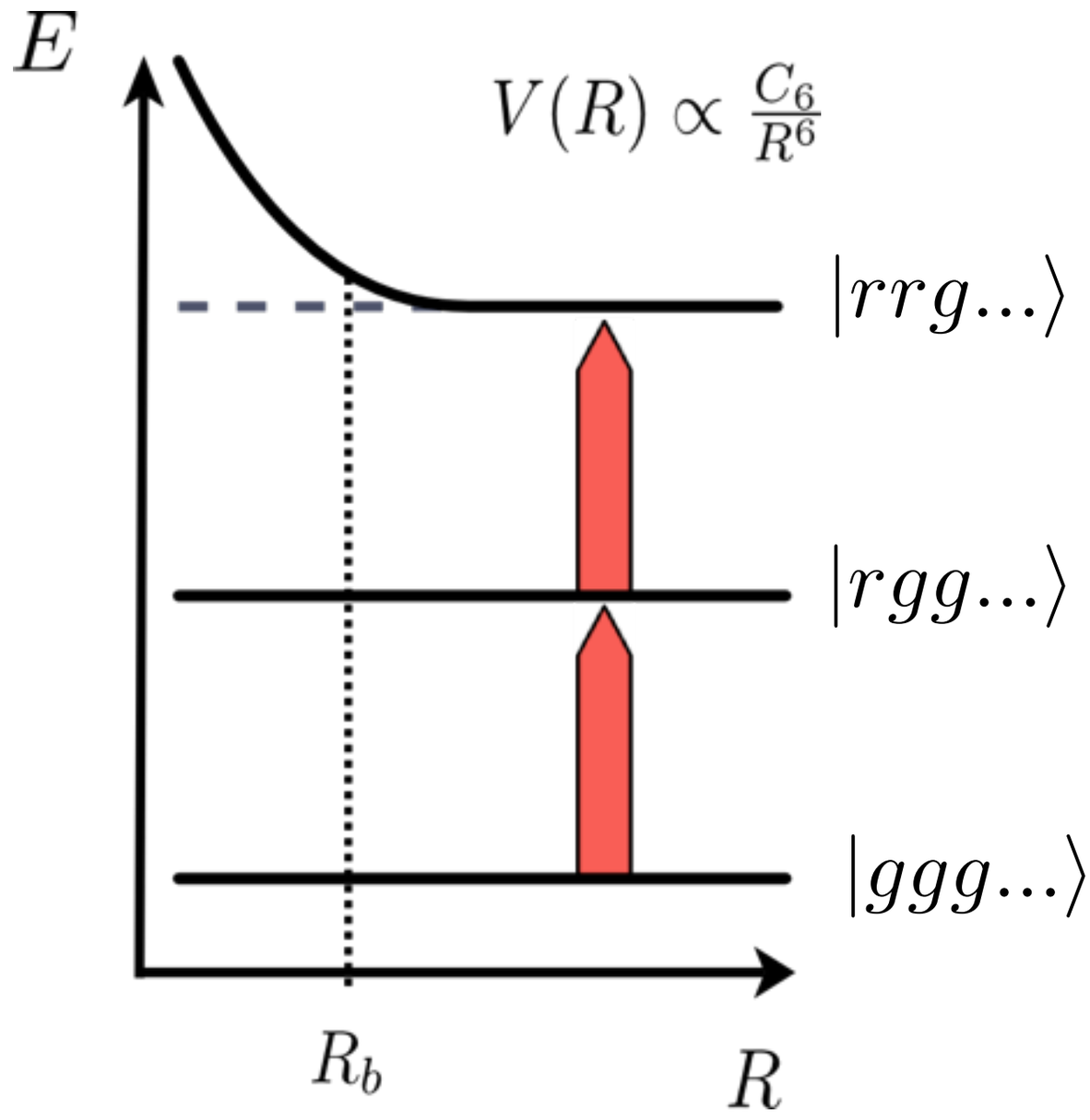
Gallagher, 1994

# Dipole blockade




Blockade radius

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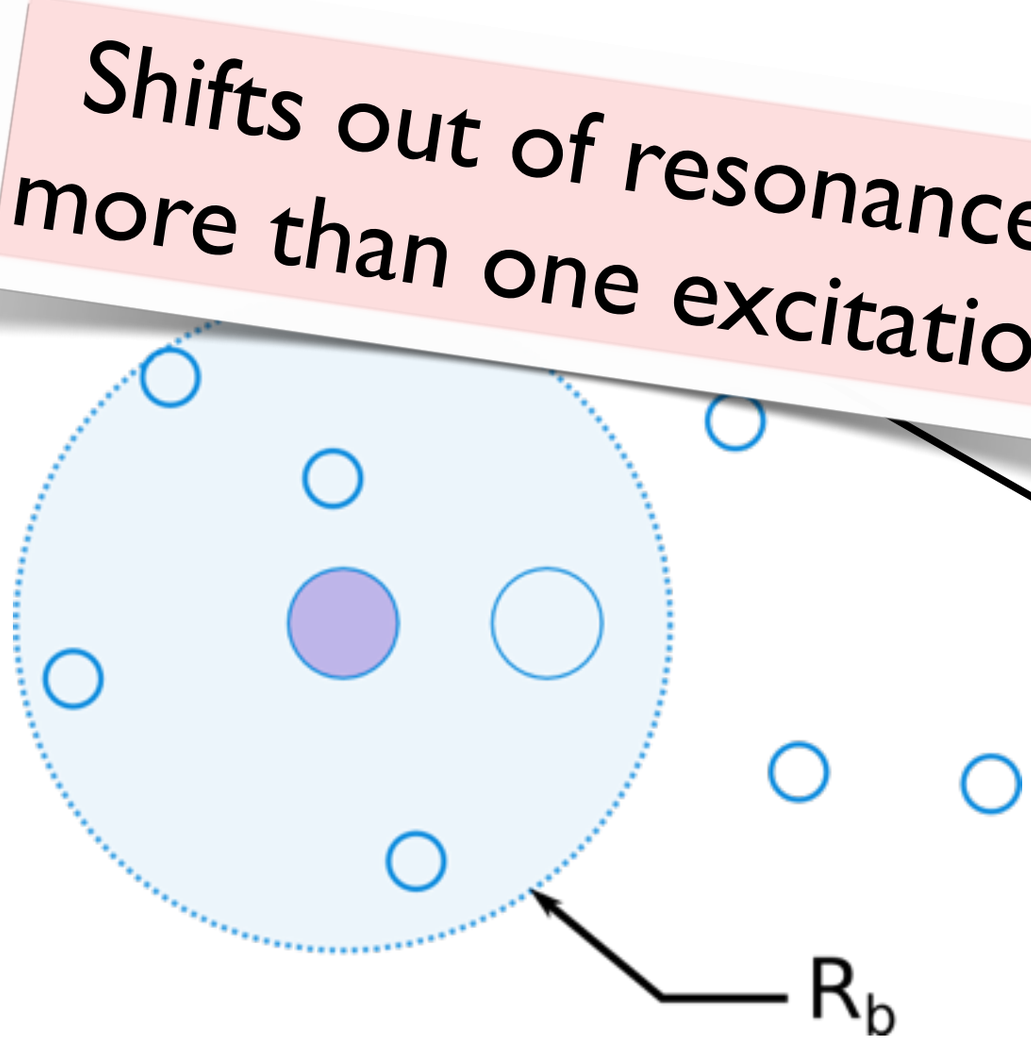
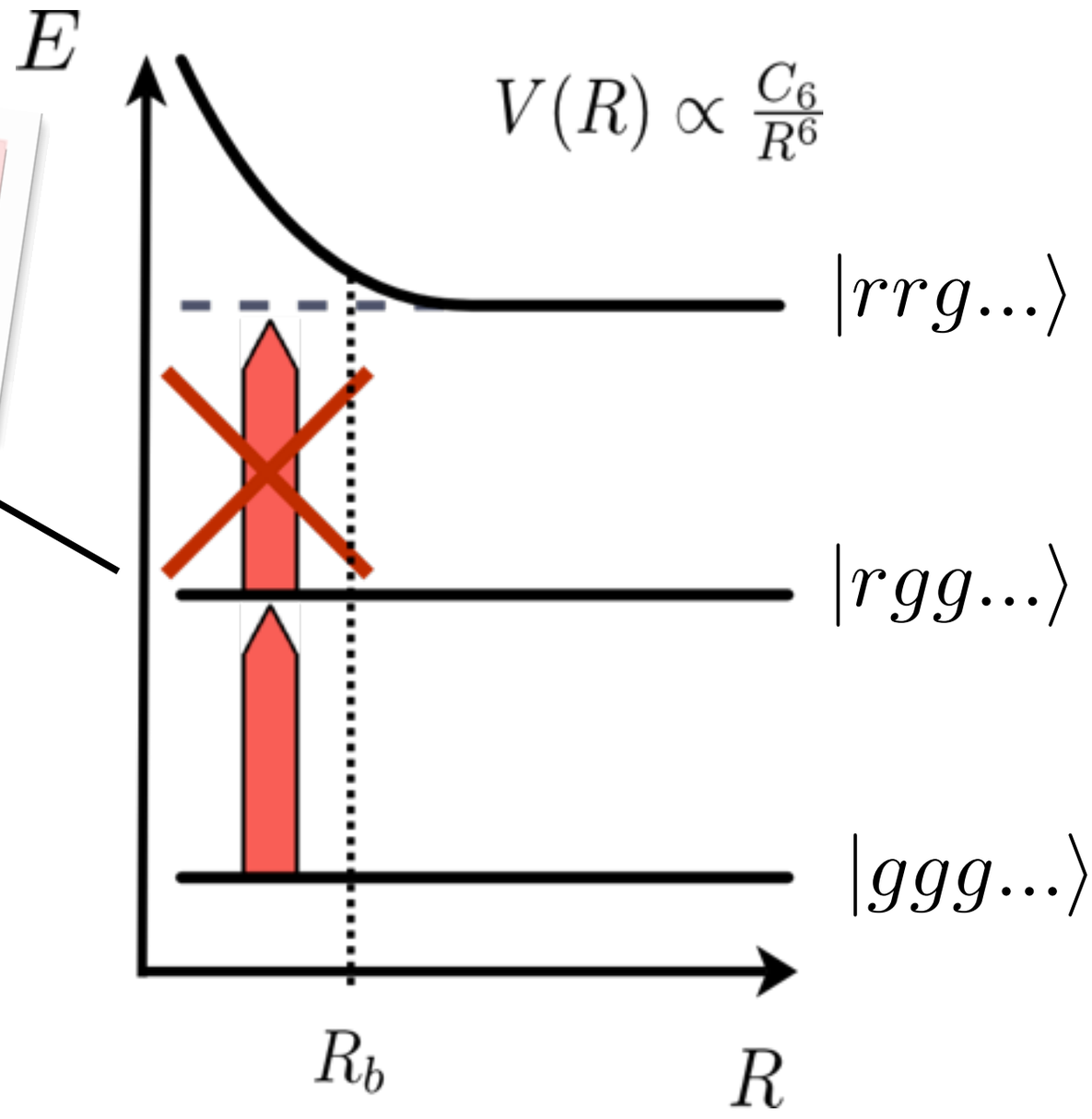
# Dipole blockade

Shifts out of resonance more than one excitation




Blockade radius

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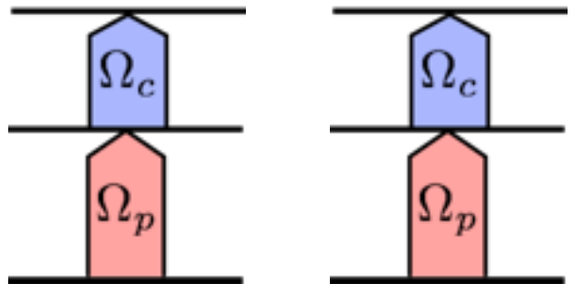
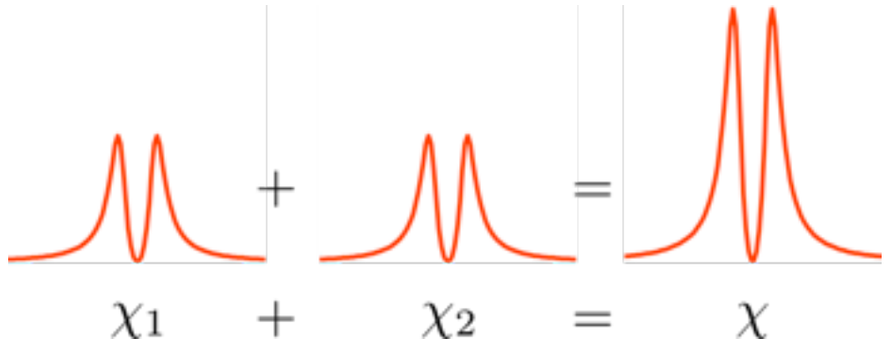
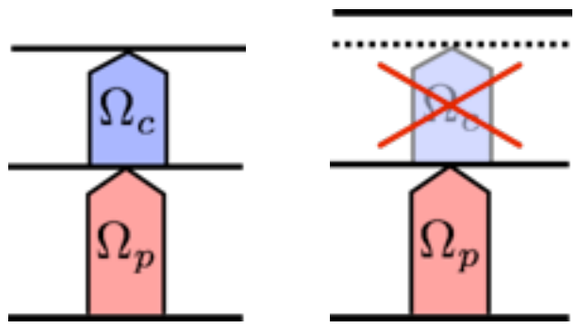
# Combine effects

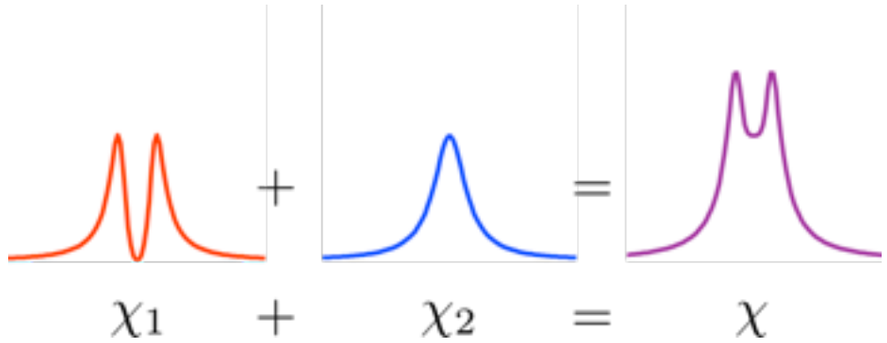
Non-interacting system




Blockaded system




Single photons out?

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# Outline

1. Essential physics
2. Our experiment
   - 2.1. Cooperative nonlinearity
   - 2.2. Tightly focused beams
   - 2.3. Photon storage
   - 2.4. Nonclassical-light
3. Future

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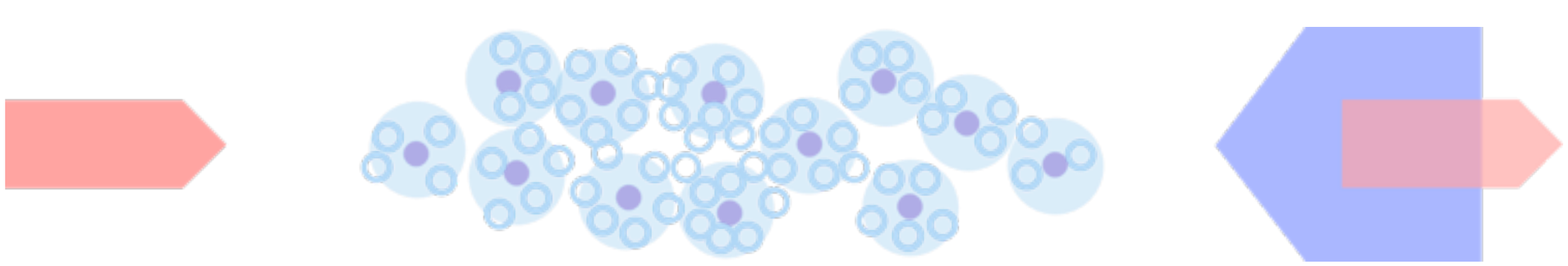
Laser cooled $^{87}$Rb atoms from MOT

$\mathrm{T} \sim 20\mu\mathrm{K}$ $N = 1.2 \times 10^{10}\mathrm{cm}^{-3}$

Probe 5s–5p, Coupling 5p–60s



$w_0 = 10\mu\mathrm{m}$

0.5mm

$\mathrm{R_b} = 5\mu\mathrm{m}$

$\langle \mathrm{N_b} \rangle \sim 10$

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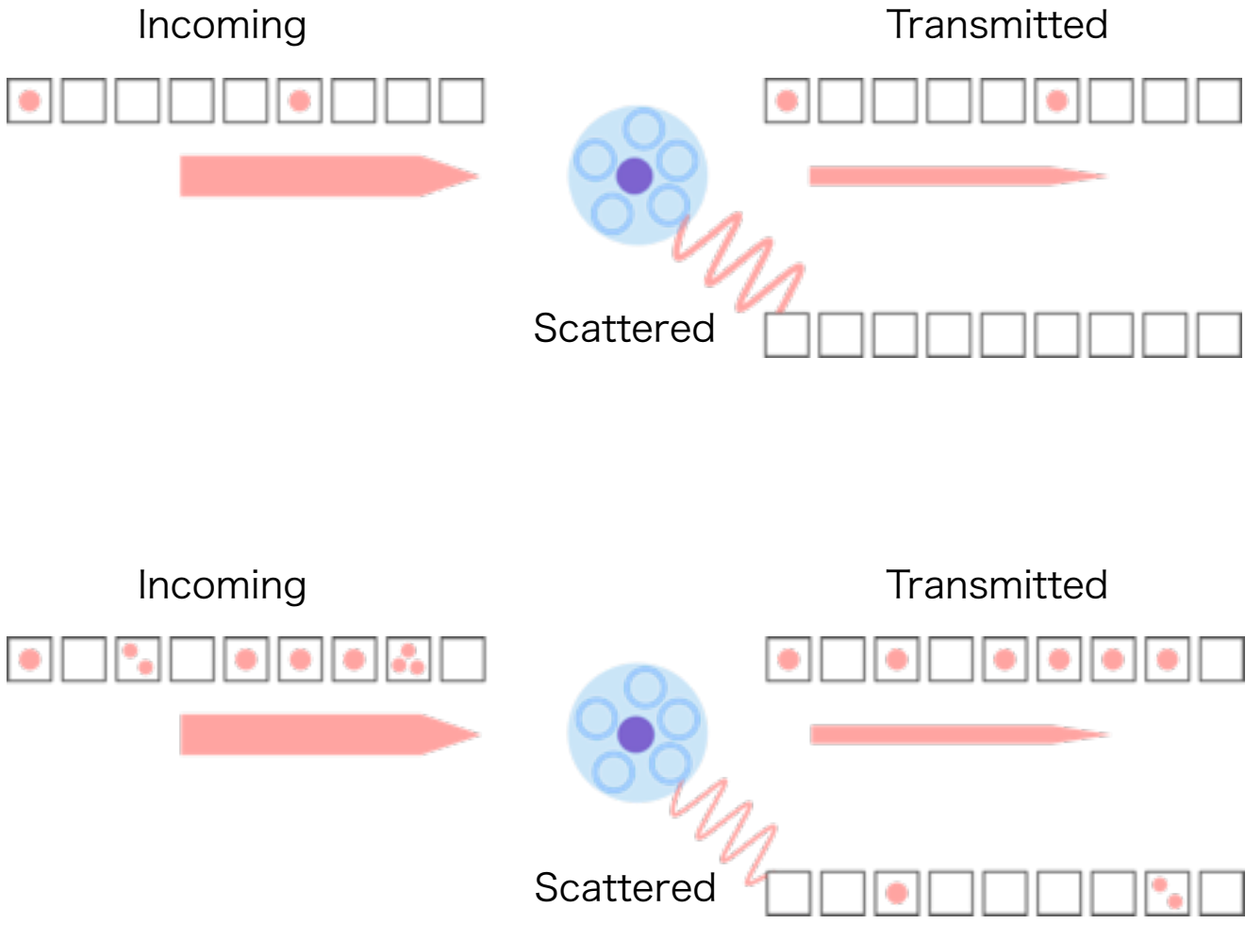
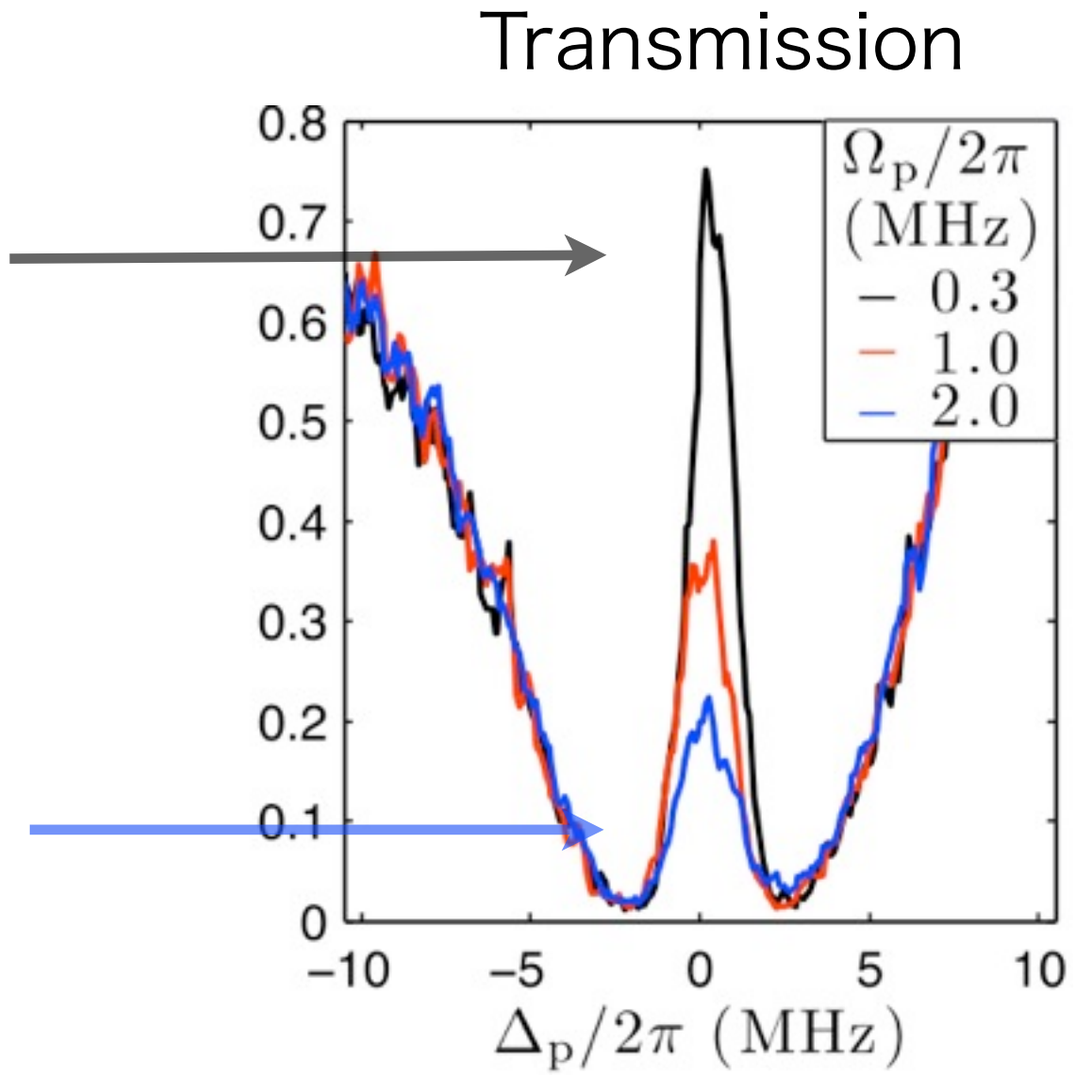
# Cooperative nonlinearity

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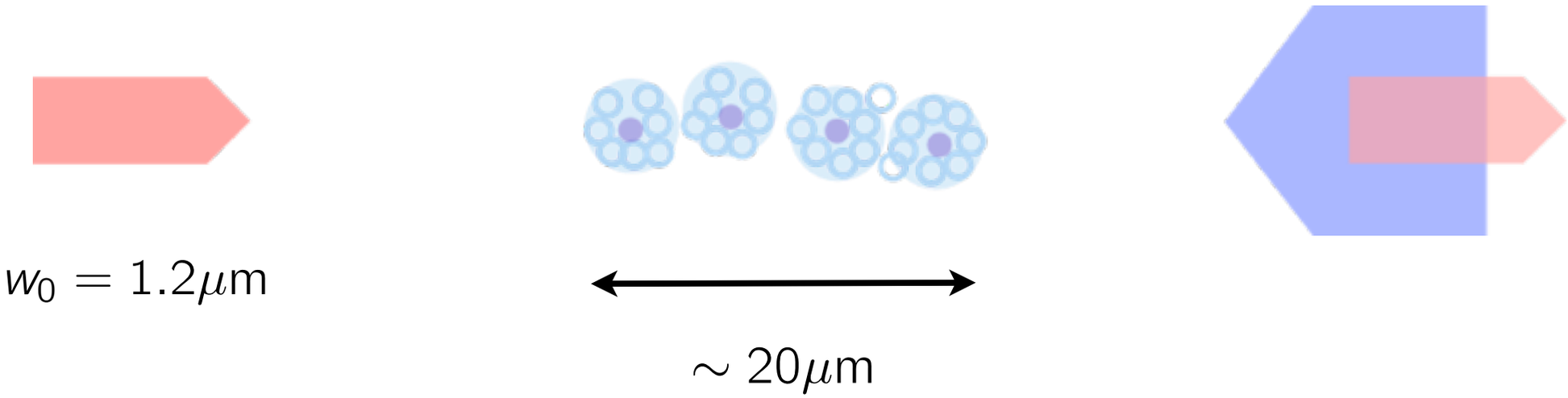
Pritchard et al. Phys. Rev. Lett. **105**, 193603 (2010)




Cold $^{87}$Rb **T ~ 150$\mu$K**

Tightly focused dipole trap (aspheric lenses in vacuum).

Optical depth **OD ~0.5**

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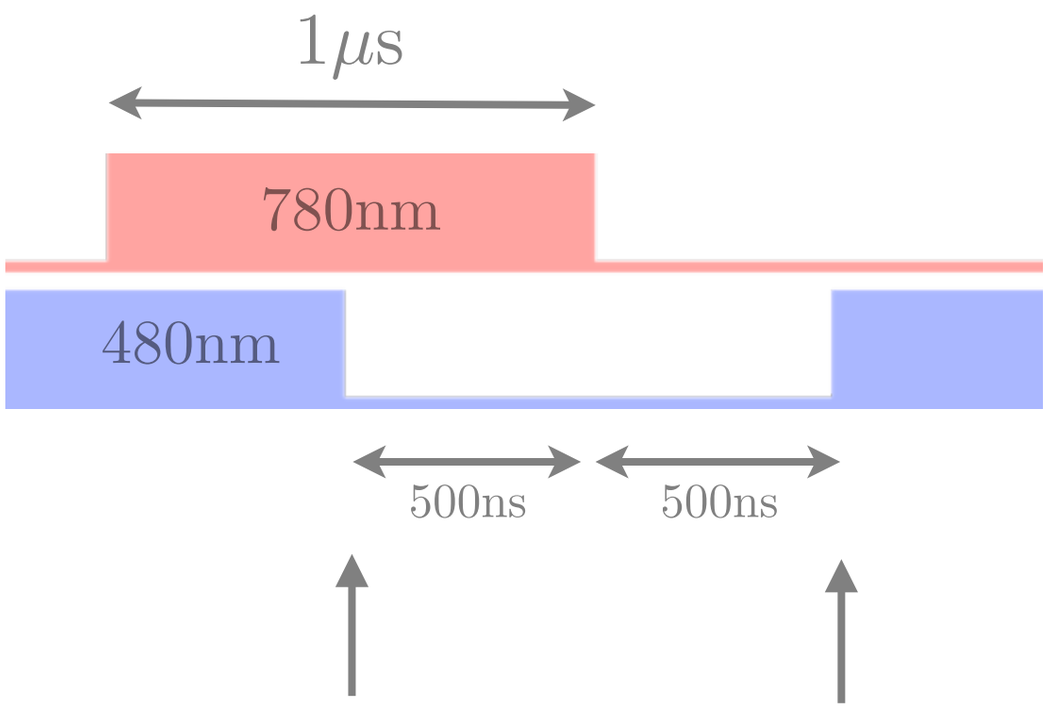
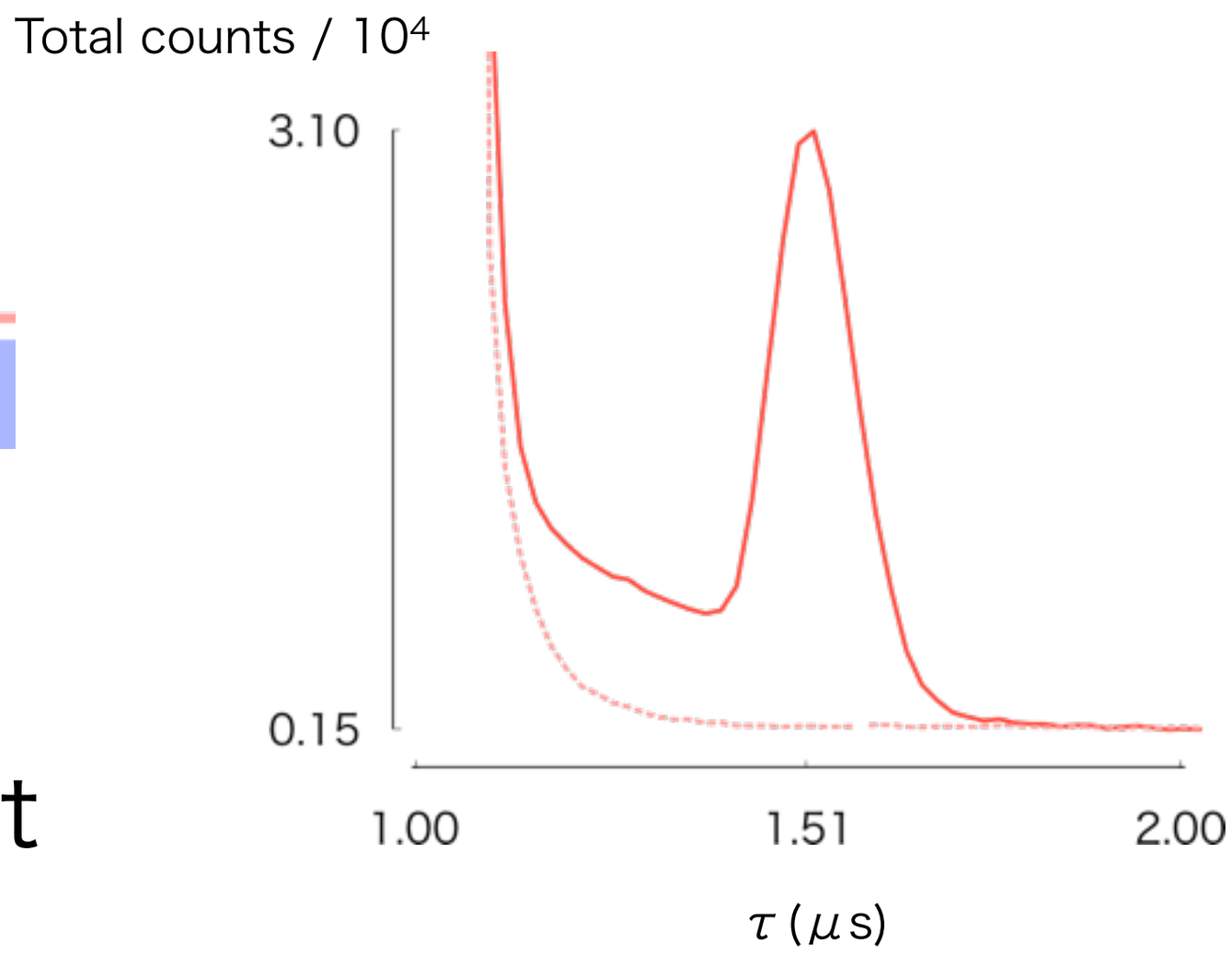
# Stored photons

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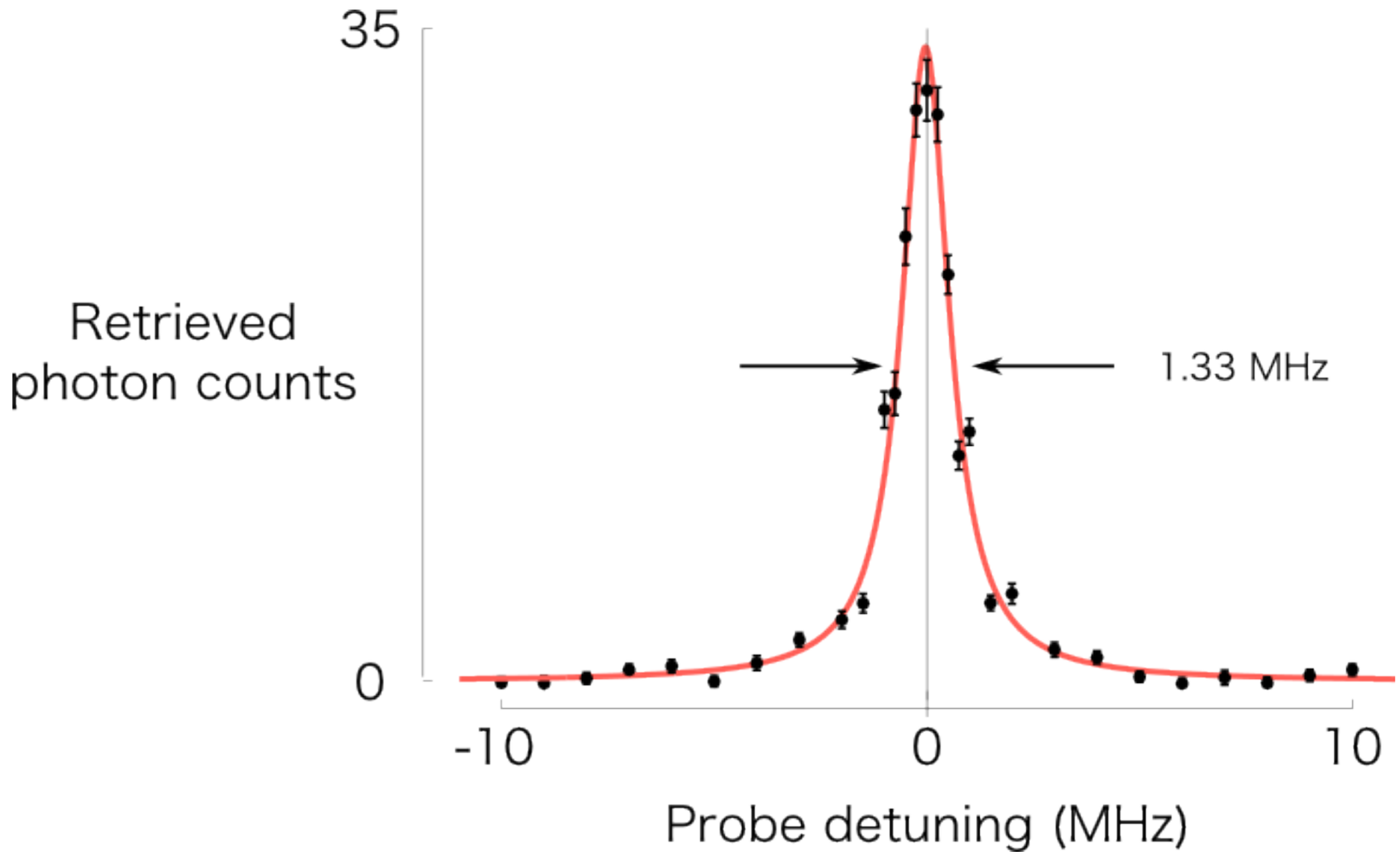
# Retrieved pulse: detuning dependence

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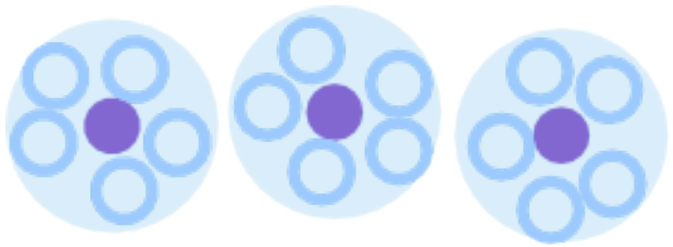
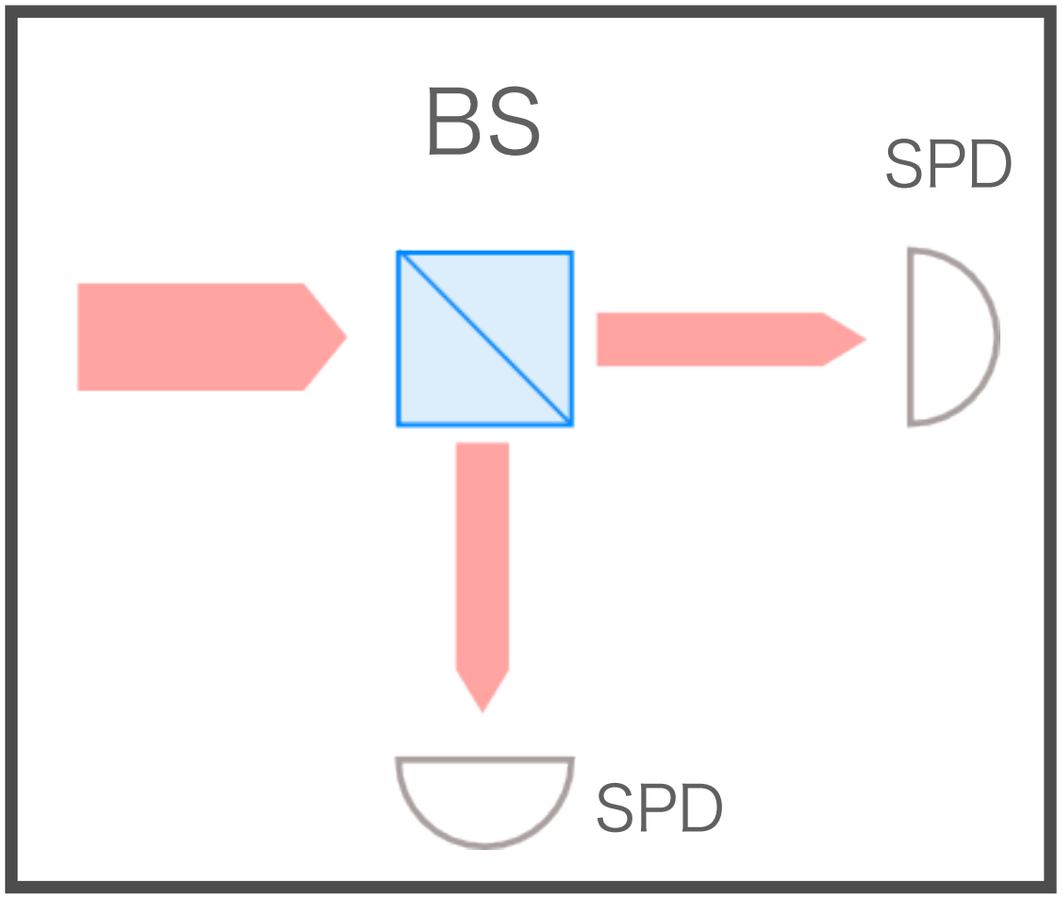
# Measure statistics

Hanbury Brown-Twiss
(HBT) interferometer



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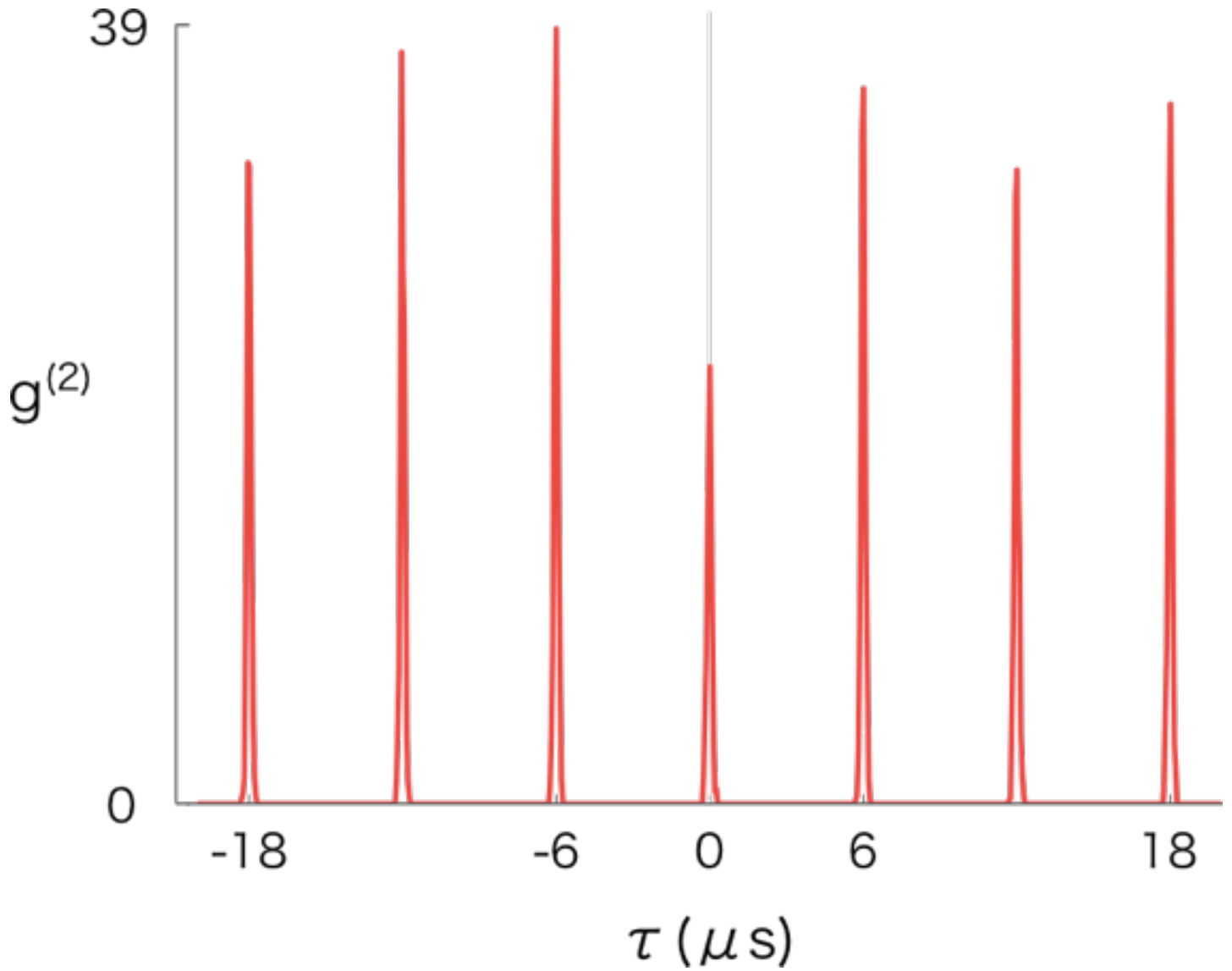
# Non-classical light

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# Outline

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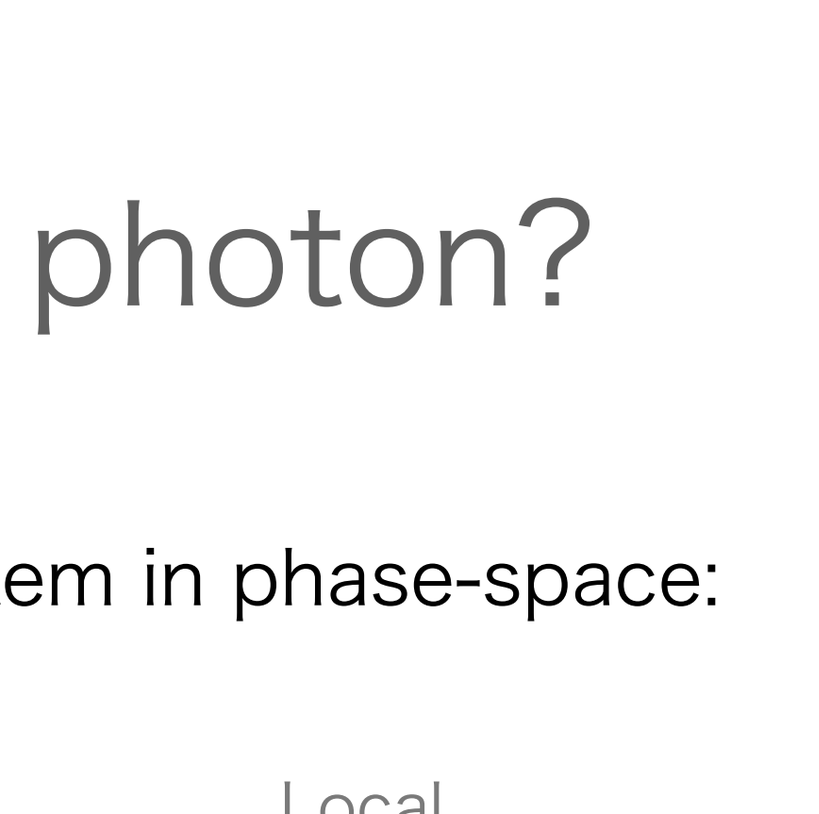
2. Our experiment
3. Future

# Is there a single photon?

Characterize the system in phase-space:

TOMOGRAPHY

Local Oscillator



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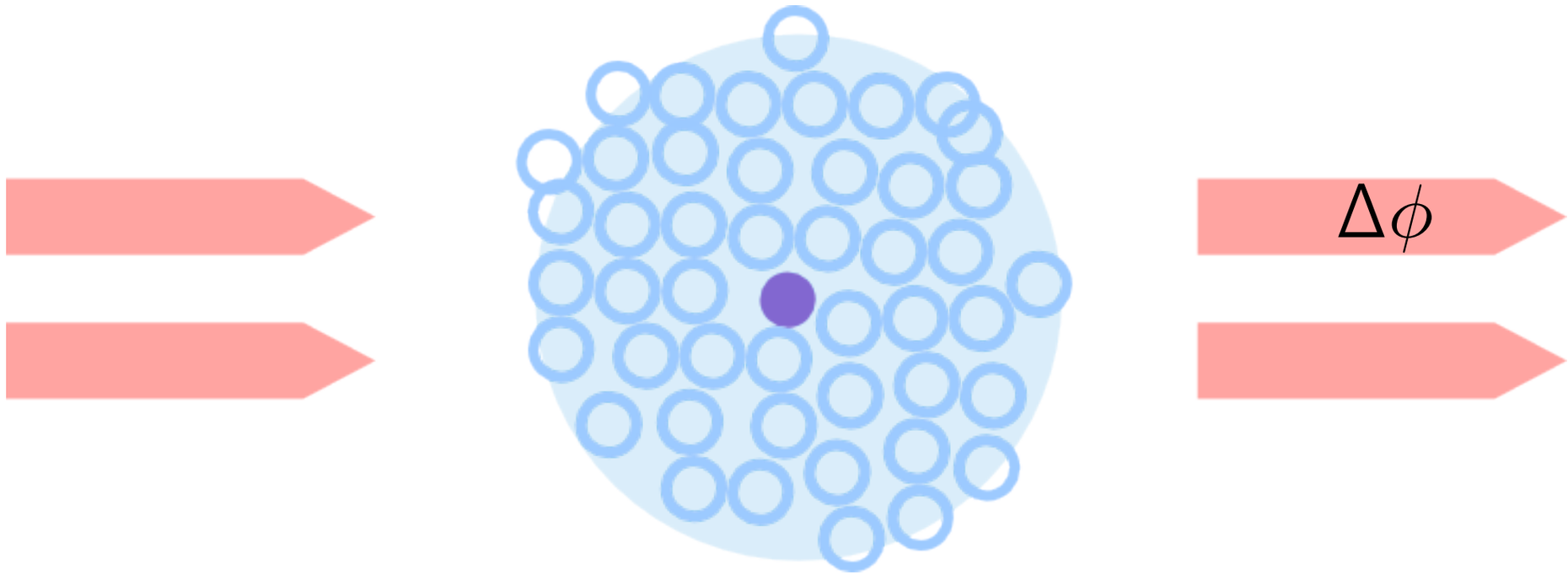
# Control photon interactions

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Gorshkov, PRL 107, 133602 (2011)

# Conclusion

Making use of the **dipole-dipole interactions** we can affect the propagation of light in form of a **dark state polariton** through ensemble of cold **Rydberg atoms** to generate **nonclassical light**.

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