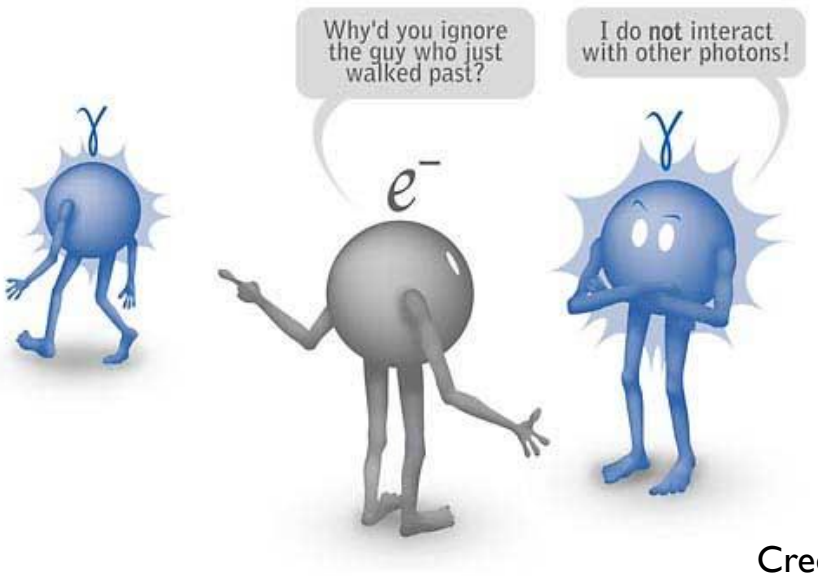

Credits: Mathew Graham

Few photon non-linearities using Rydberg polaritons

Rajiv Boddeda, Imam Usmani, Erwan Bimbard, Andrey Grankin, Etienne Brion, Alexei Ourjoumtsev, Philippe Grangier

Laboratoire Charles Fabry, Institut d'Optique
Palaiseau, France

Outline

- Objective

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- Conclusion

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  - Cavity QED
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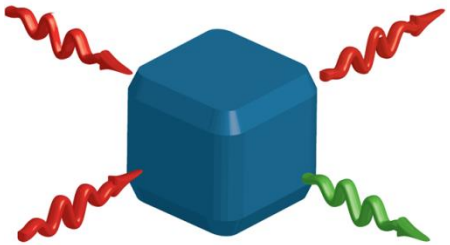
- Existing optical channels for communication.

Building blocks

Building blocks

Control-phase gate



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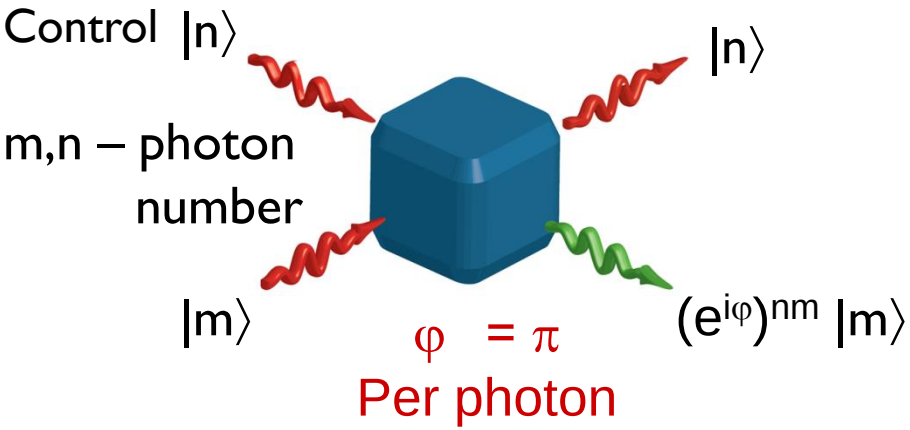
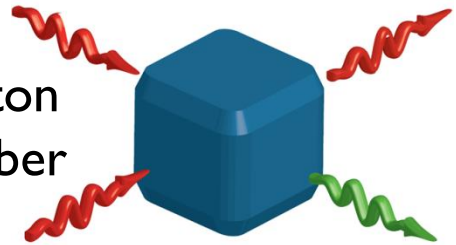


Building blocks

Control-phase gate

Control $|n\rangle$

m,n – photon number



$|n\rangle$

$|m\rangle$

$(e^{i\varphi})^{nm}\,|m\rangle$

$\varphi = \pi$

Per photon

Cross-Kerr effect

$\|n\rangle$	$\|m\rangle$	output
$\|0\rangle$	$\|0\rangle$	$\|0\rangle\|0\rangle$
$\|0\rangle$	$\|1\rangle$	$\|0\rangle\|1\rangle$
$\|1\rangle$	$\|0\rangle$	$\|1\rangle\|0\rangle$
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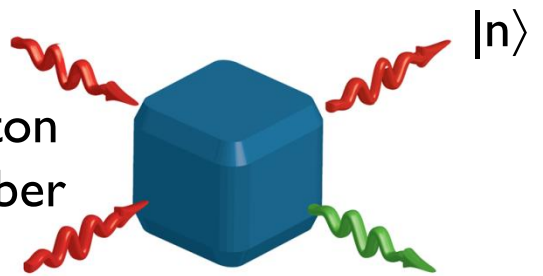

$|n\rangle$

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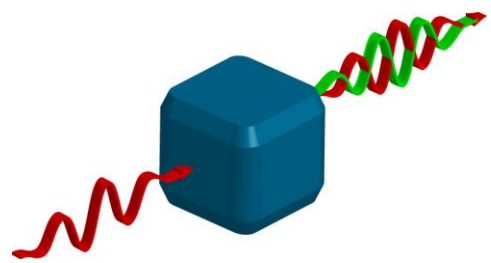
$(e^{i\varphi})^{nm}\,|m\rangle$

$\varphi = \pi$

Per photon

Non-classical state generation



$|\alpha\rangle + |-\alpha\rangle$

$|\alpha\rangle$

$\varphi = \pi$

Cross-Kerr effect

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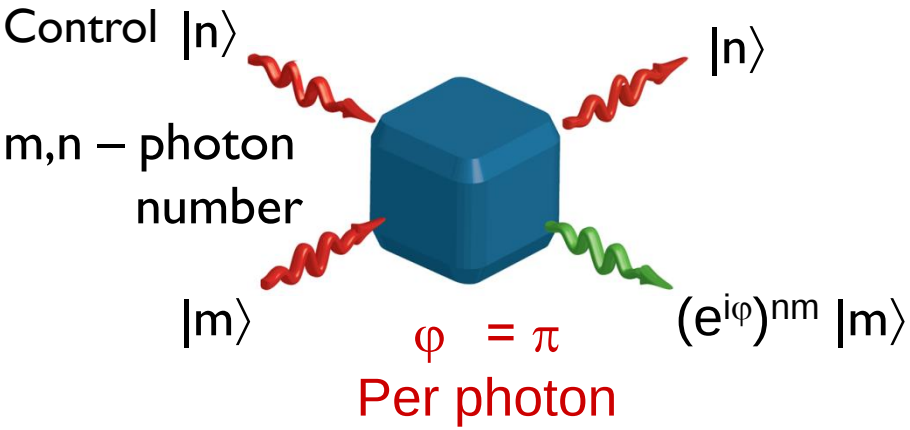
Self-Kerr effect

Building blocks

Control-phase gate



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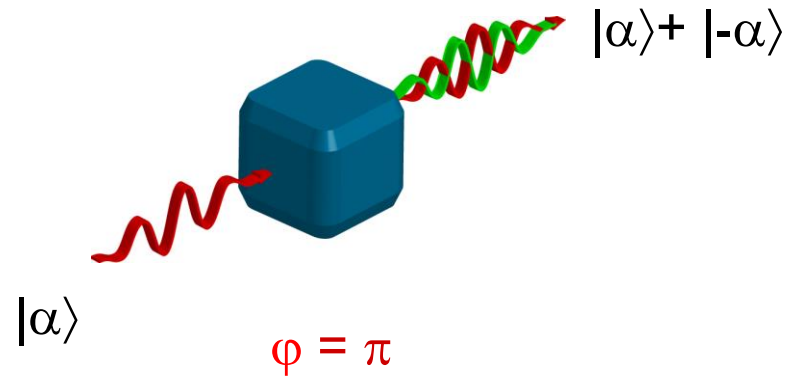

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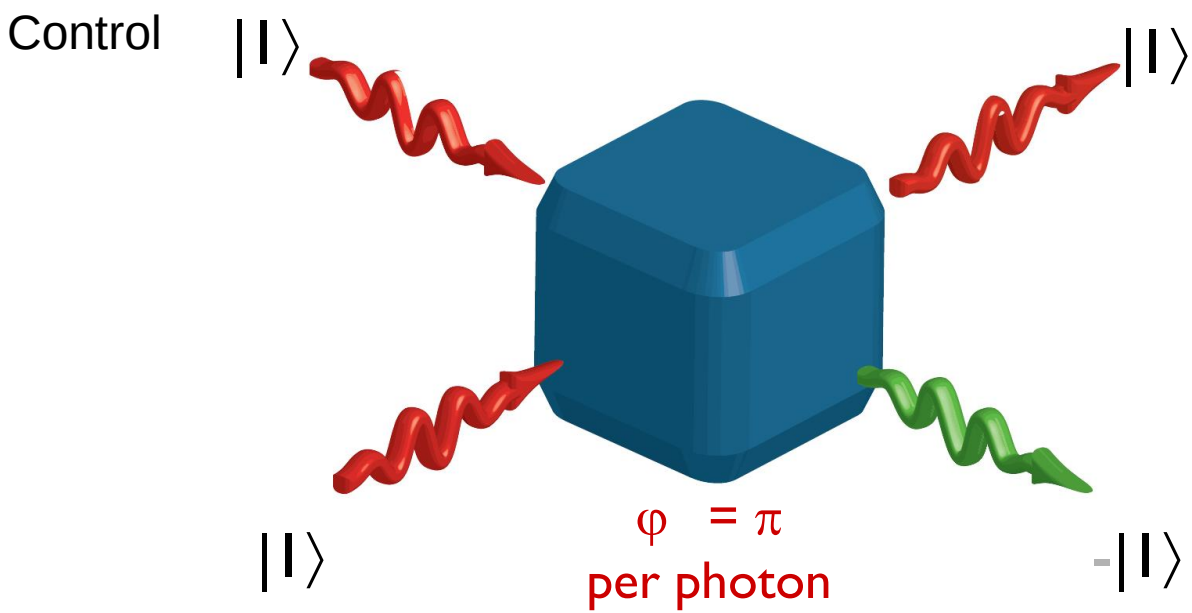
Self-Kerr effect

Classical optical media: $\varphi \approx 10^{-9}$ before photons get lost

Optical non-linearity in a cold Rydberg gas

Control phase gate:



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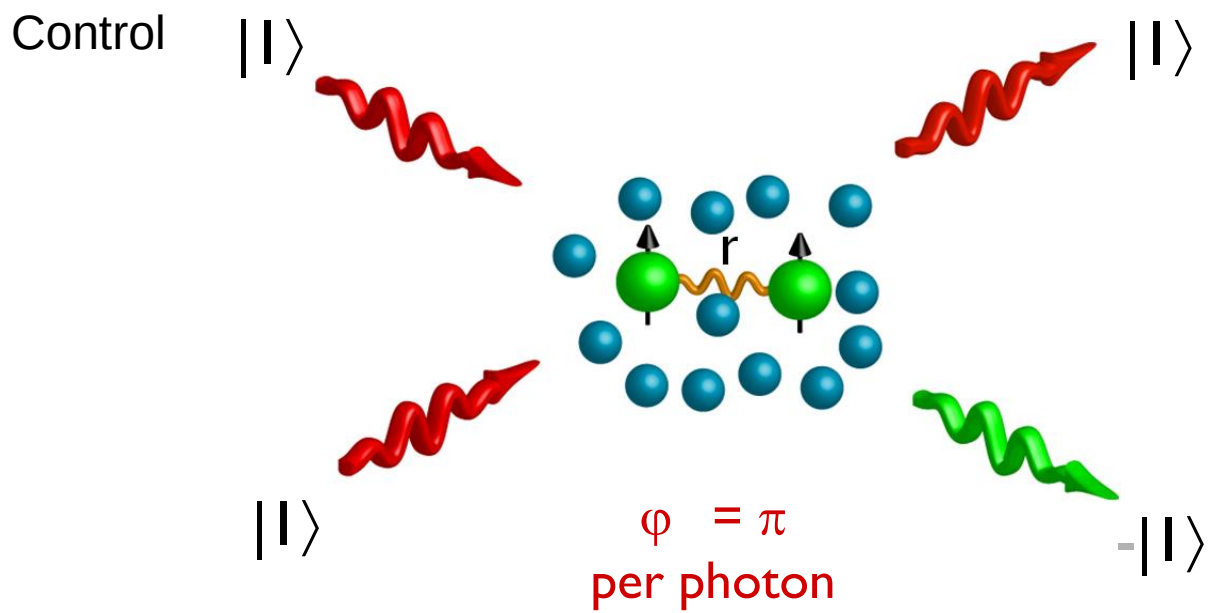

Photons → strongly interacting particles – Polaritons (Collective atomic excitations) involving RYDBERG atoms

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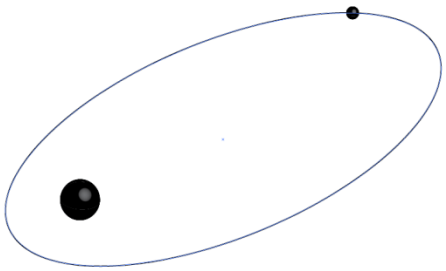

Rydberg atoms n ~ 50-100

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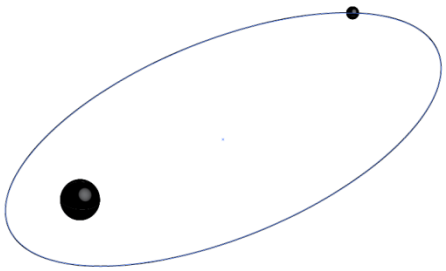

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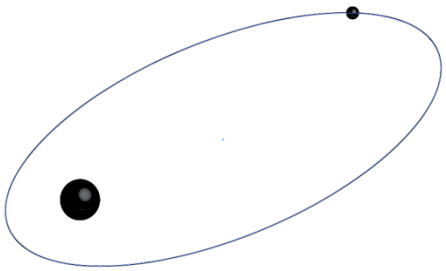

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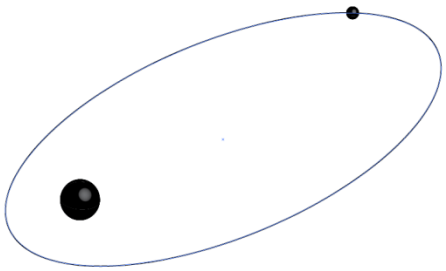

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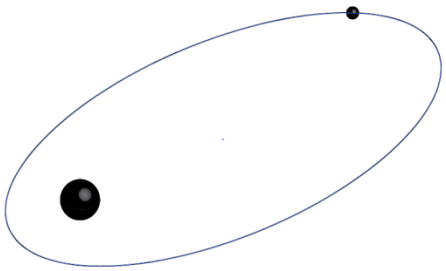

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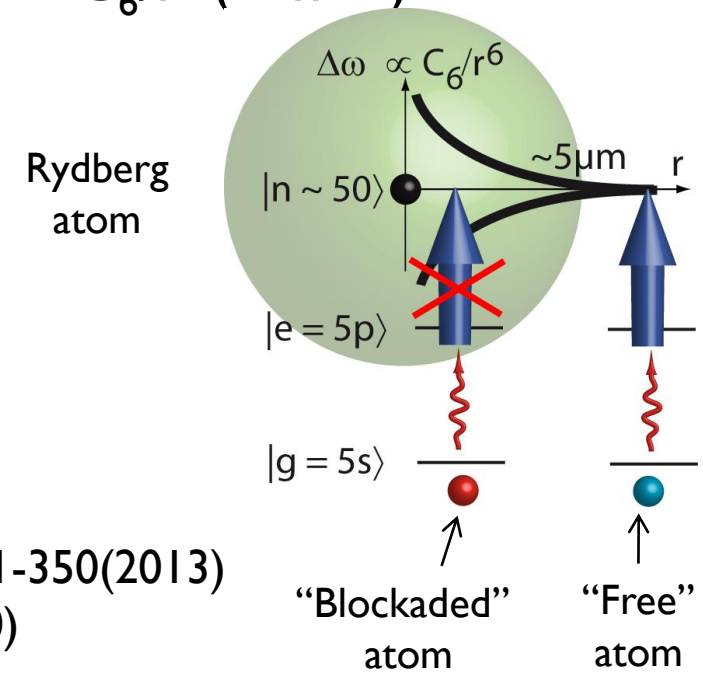

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Rydberg EIT

- EIT – Electromagnetically induced transparency

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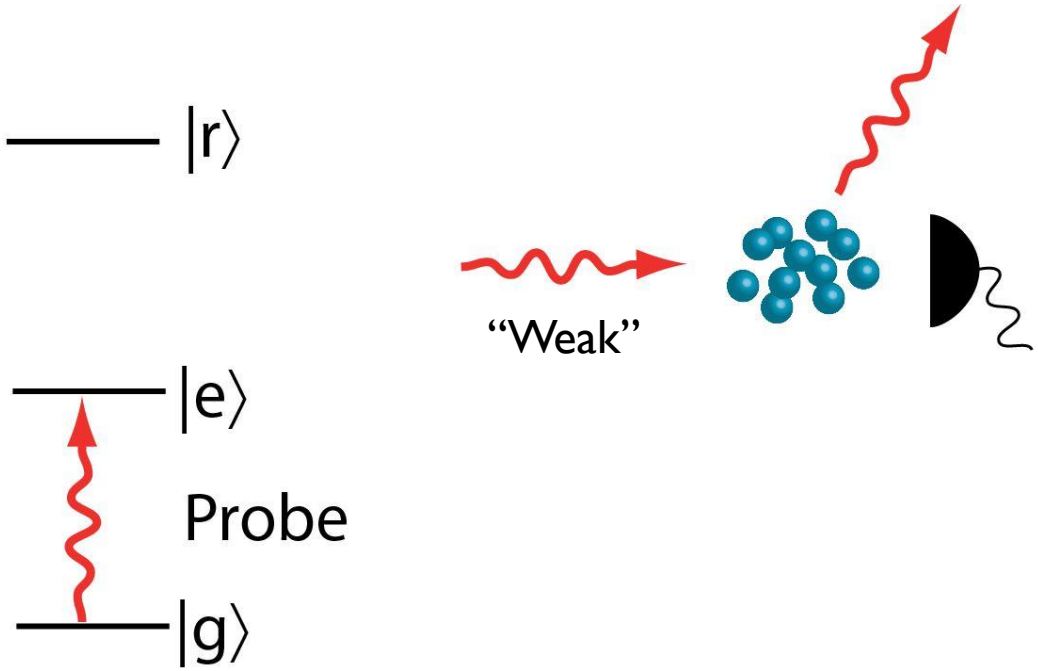

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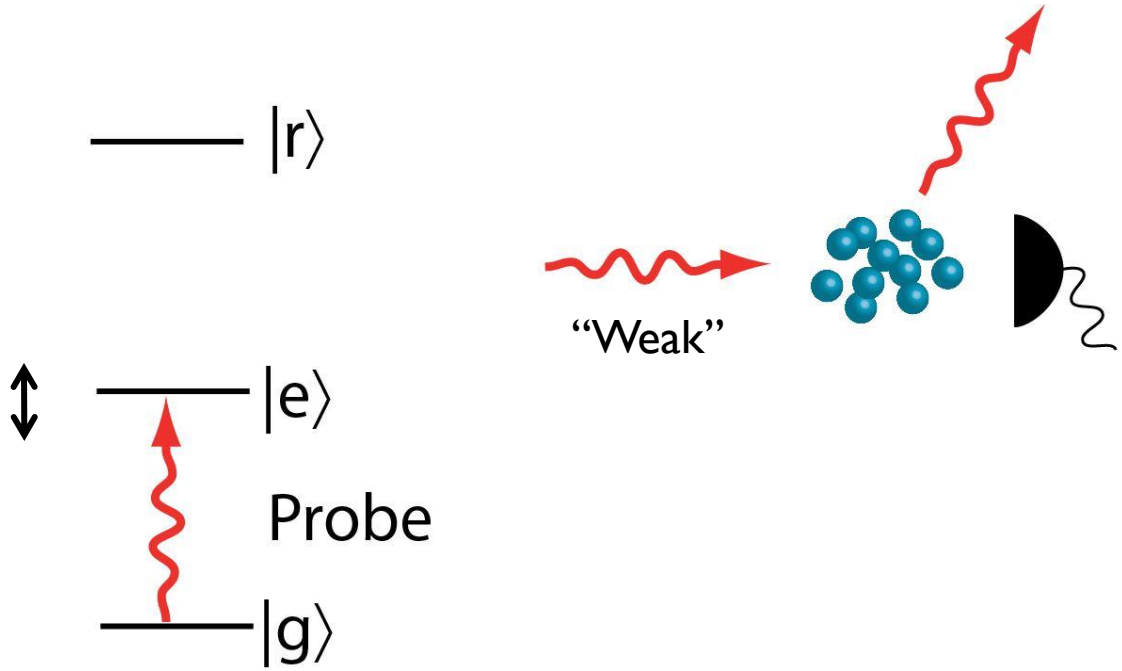

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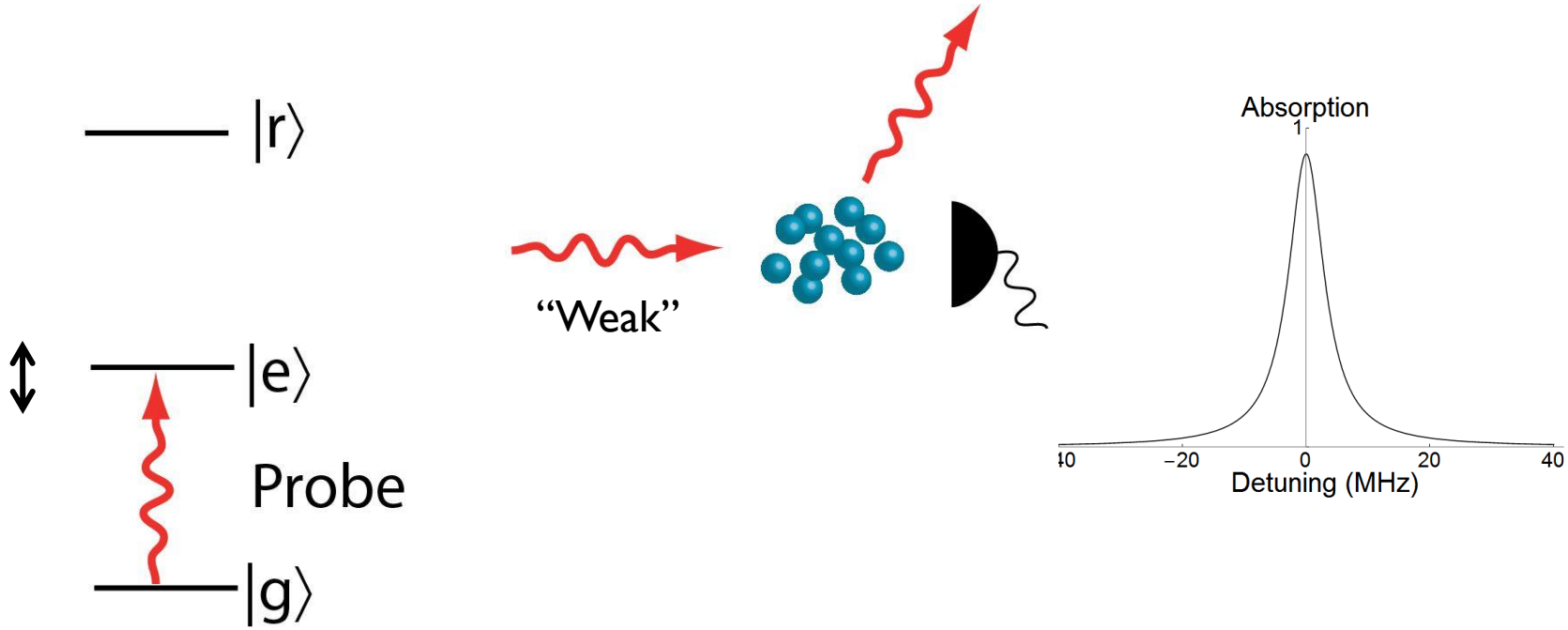

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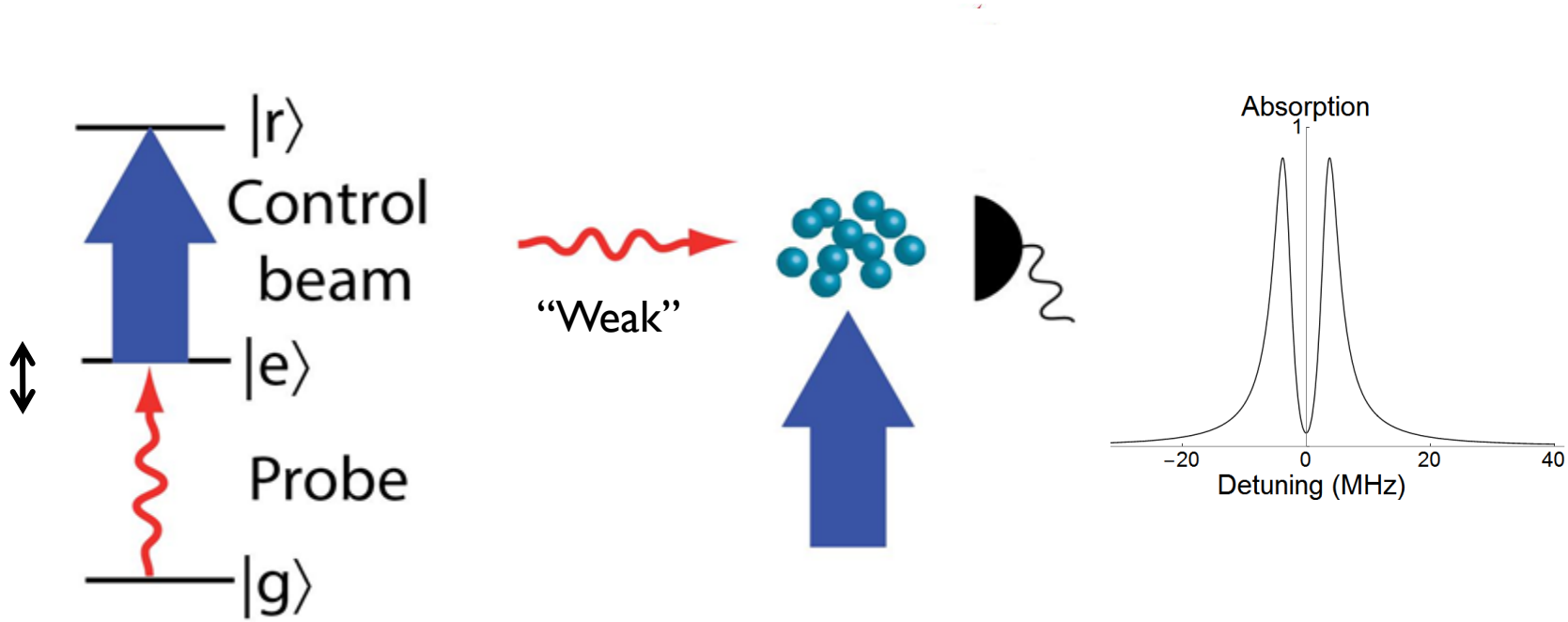

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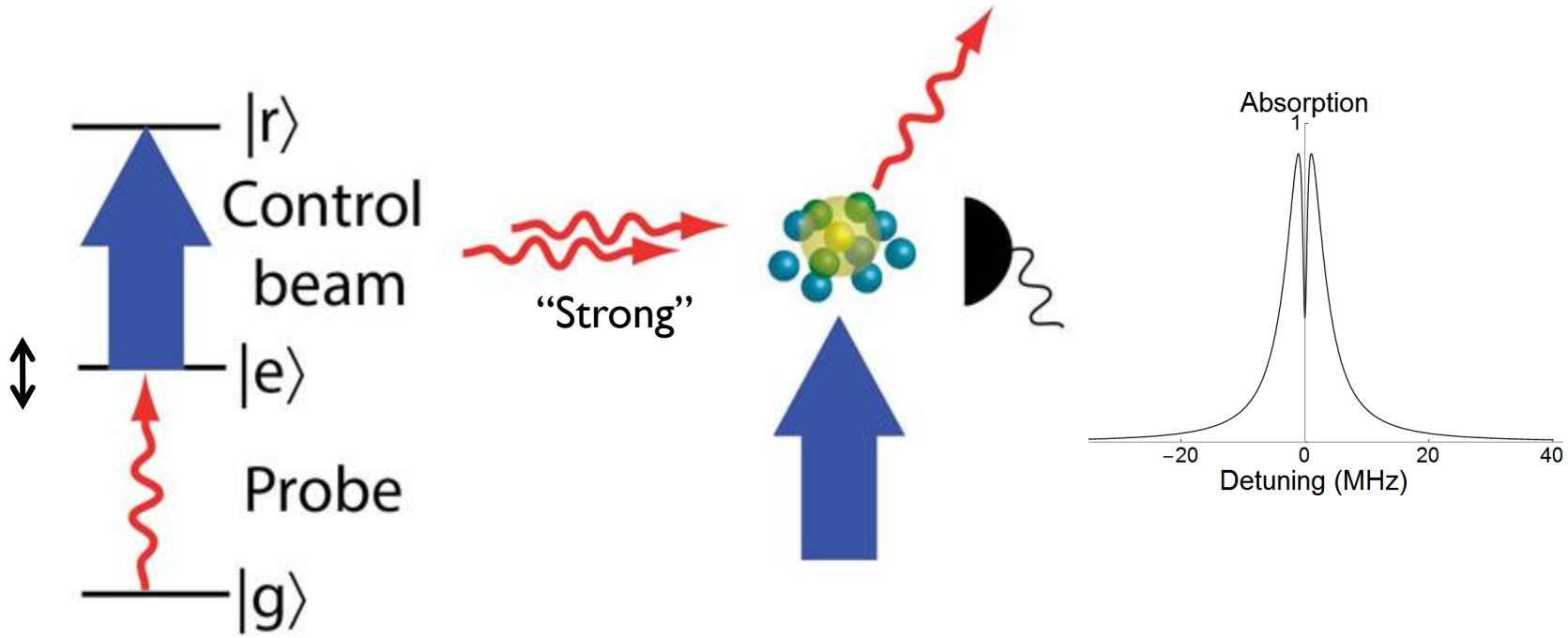

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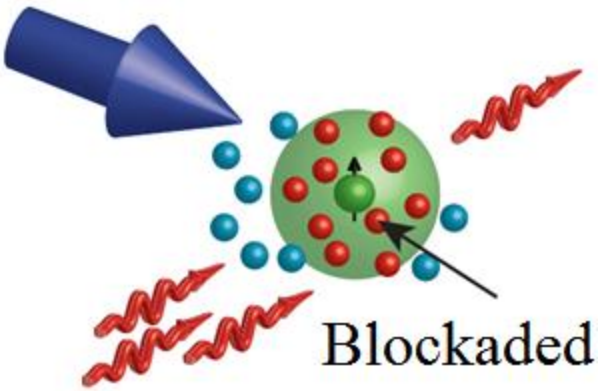
Recent Observations



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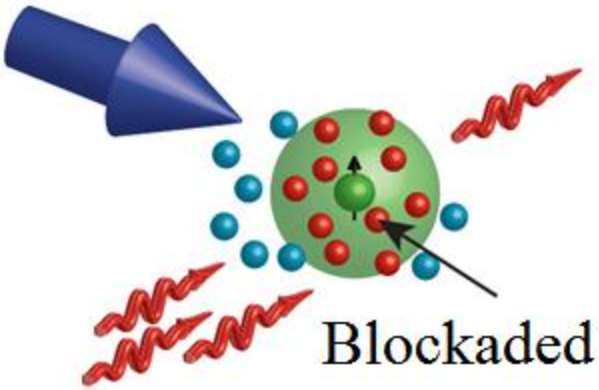

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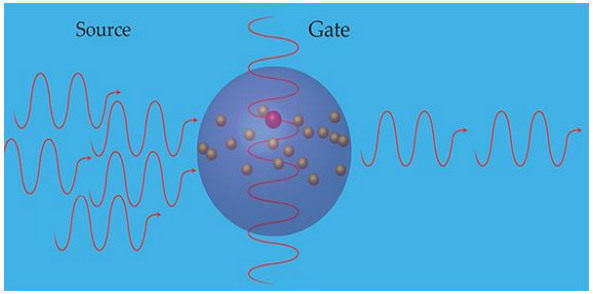

APS/John

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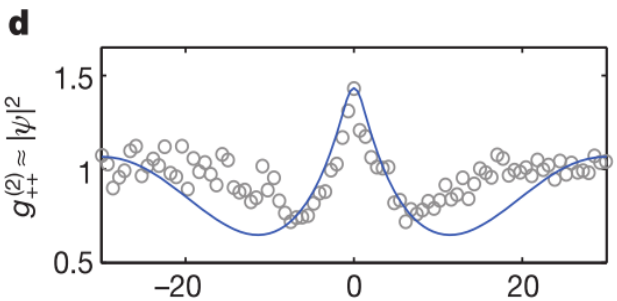

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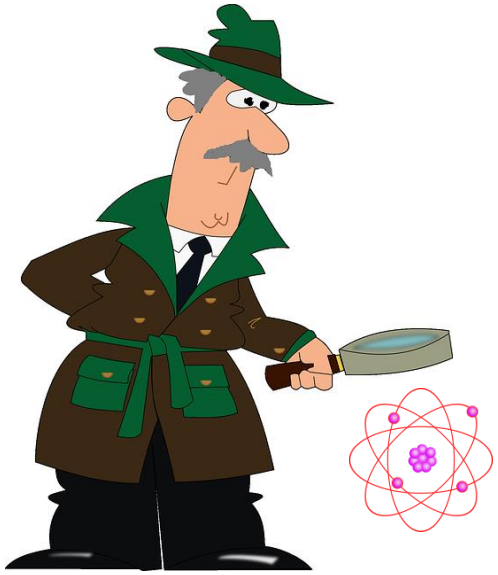
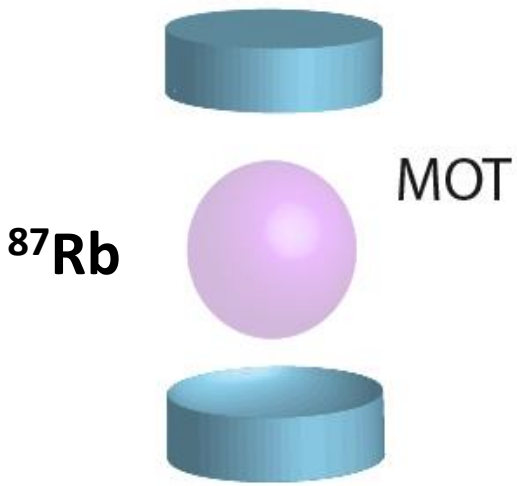
- Attractive photons (off-resonance):
  - Parigi et al, PRL 109, 233602 (2012) (IOGS)
  - Firstenberg et al, Nature 502, 71 (2013)

Optical non-linearities induced by Rydberg excitations in a cavity



Experiment



$$\mathcal{F} = 100$$
$$\gamma_c = 10\text{MHz}$$

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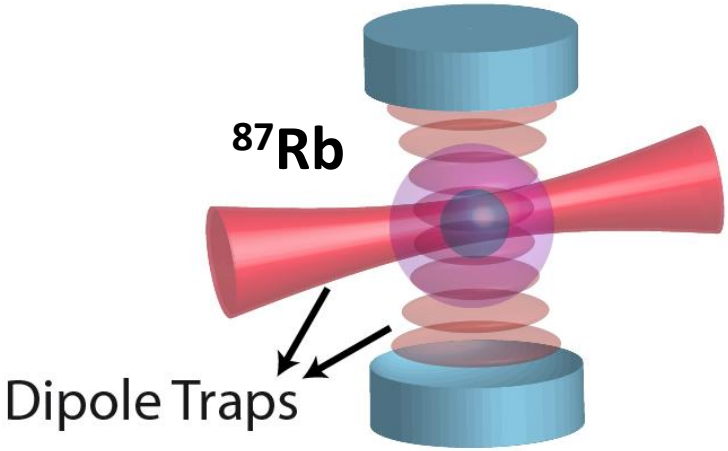

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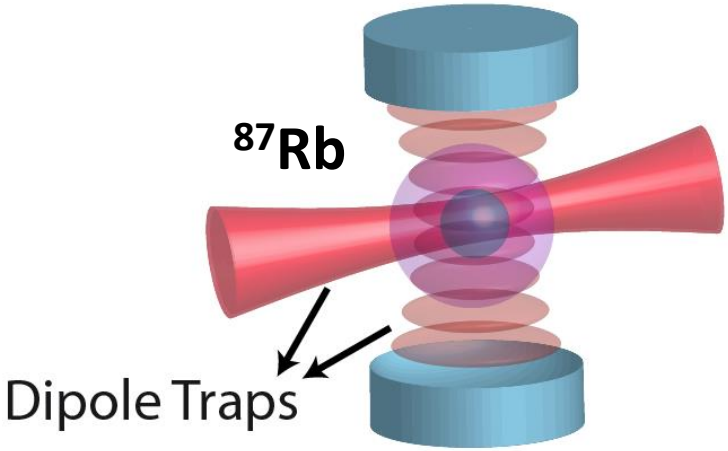

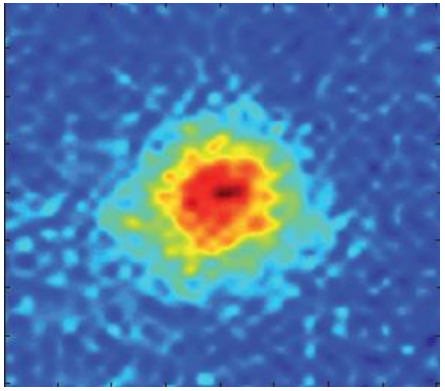

Cloud size ~ 40μm

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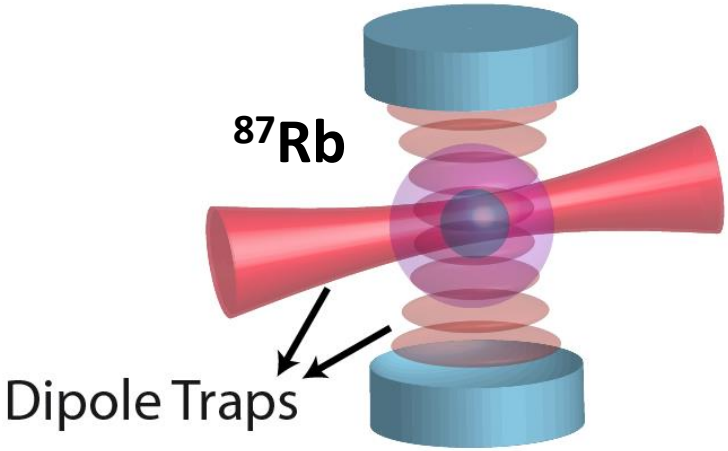

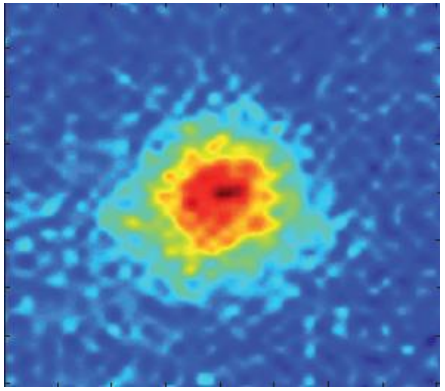

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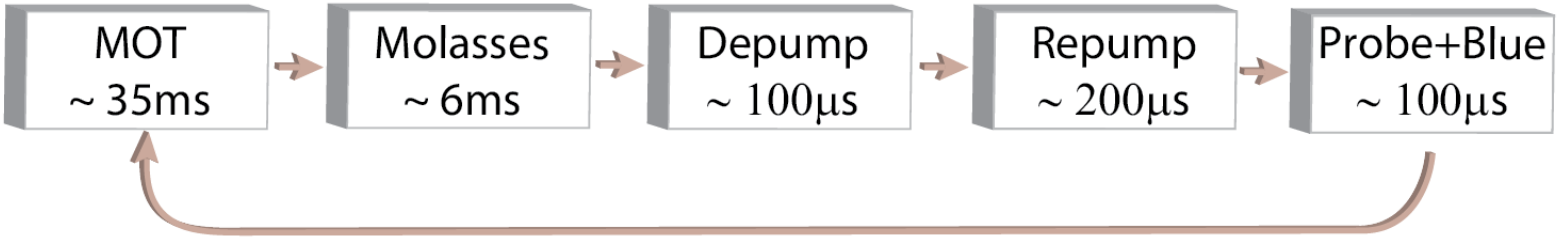

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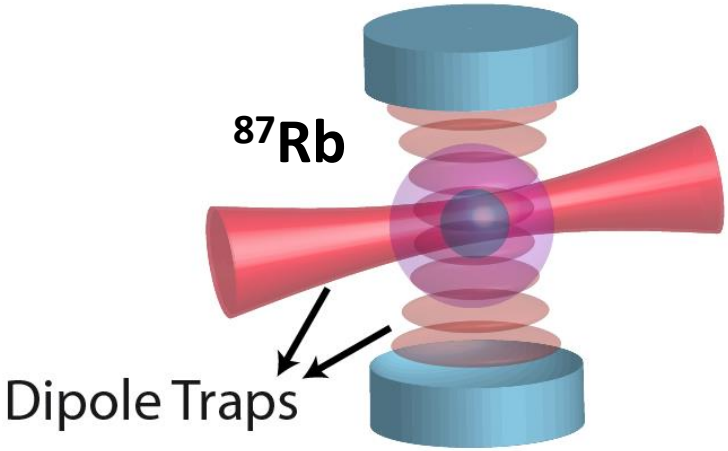

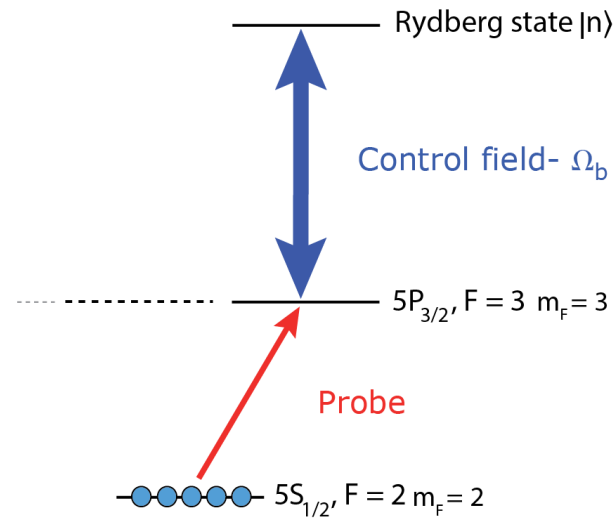

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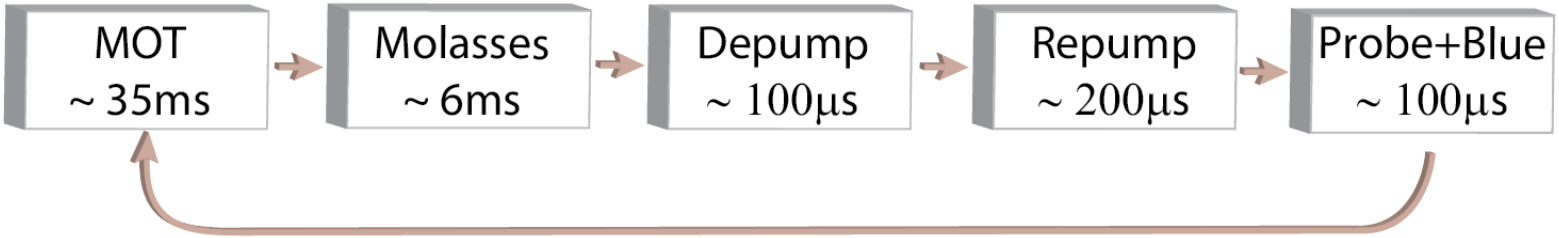

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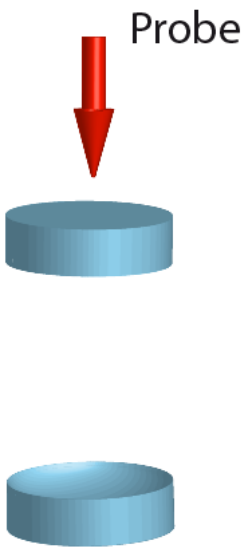

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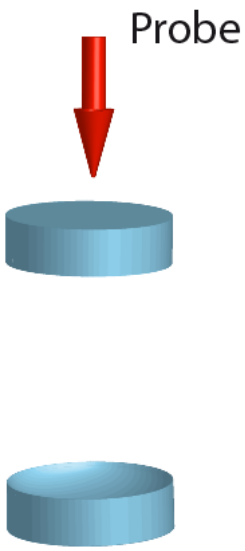
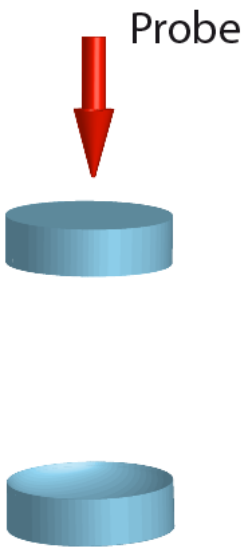


Cavity resonant
with atoms

Results

- Scan probe detuning from -50MHz to +50MHz



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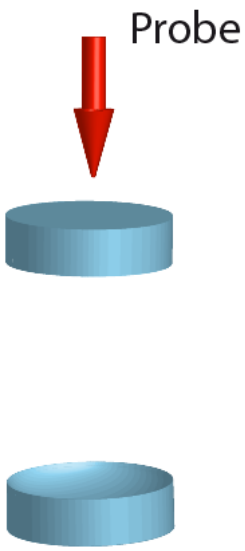

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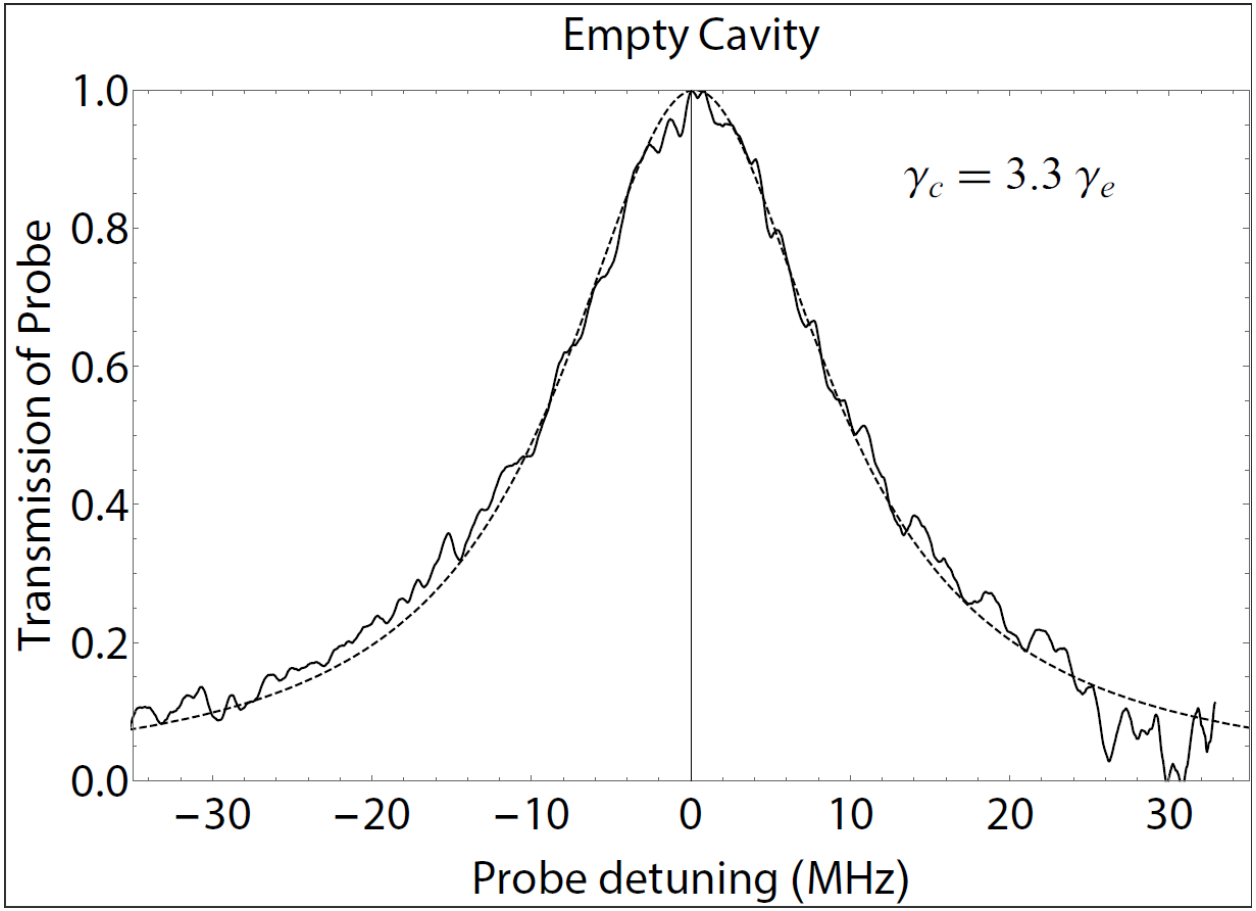

$\gamma_e = 3\text{MHz}$

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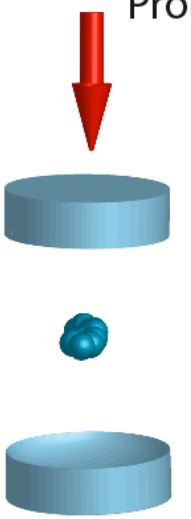

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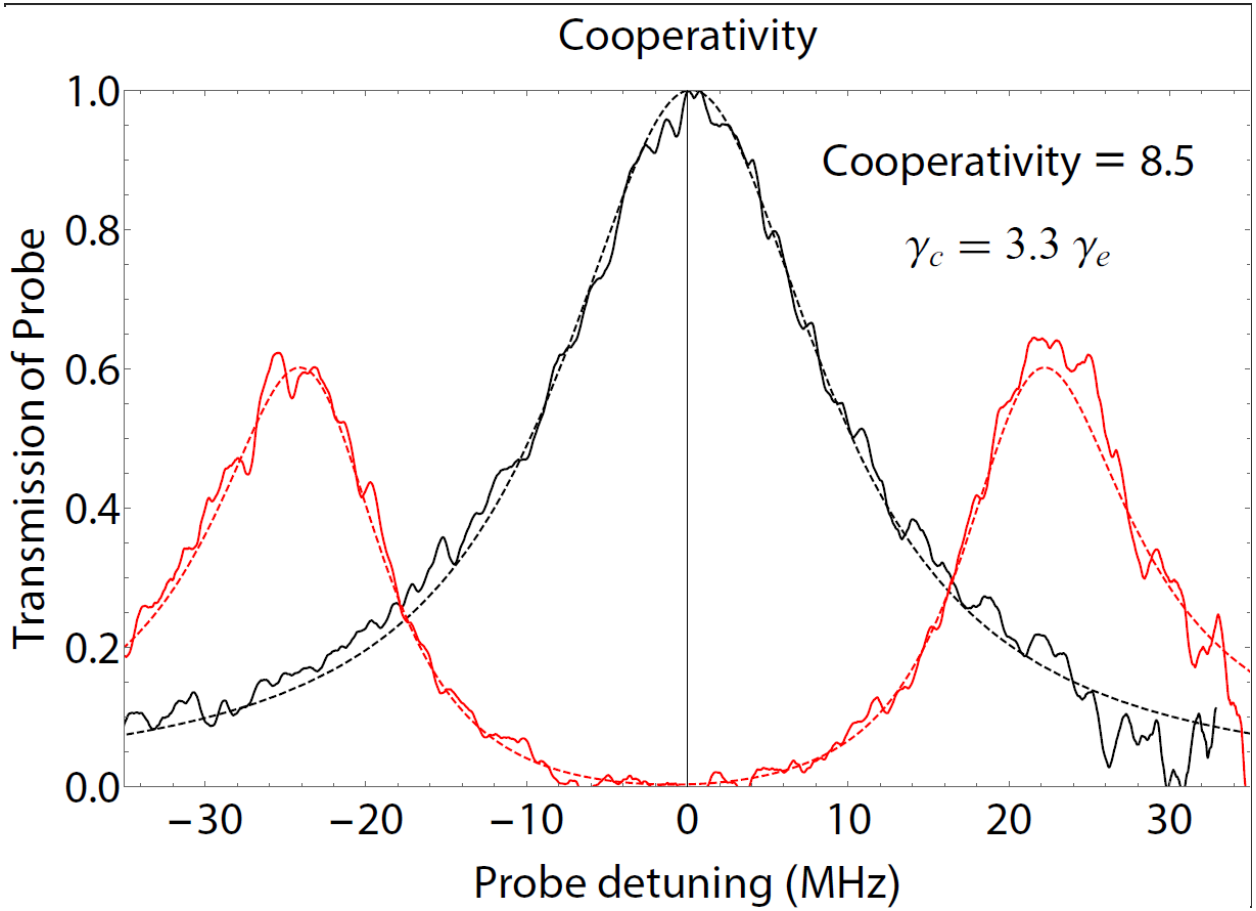

$$= \frac{N_a\, g^2}{\gamma_c \gamma_e}$$

$$\gamma_e = 3\text{MHz}$$

- Few photon non-linearities using Rydberg polaritons – Rajiv Boddeda

Results

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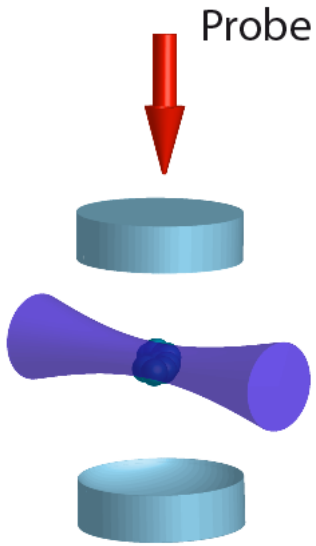
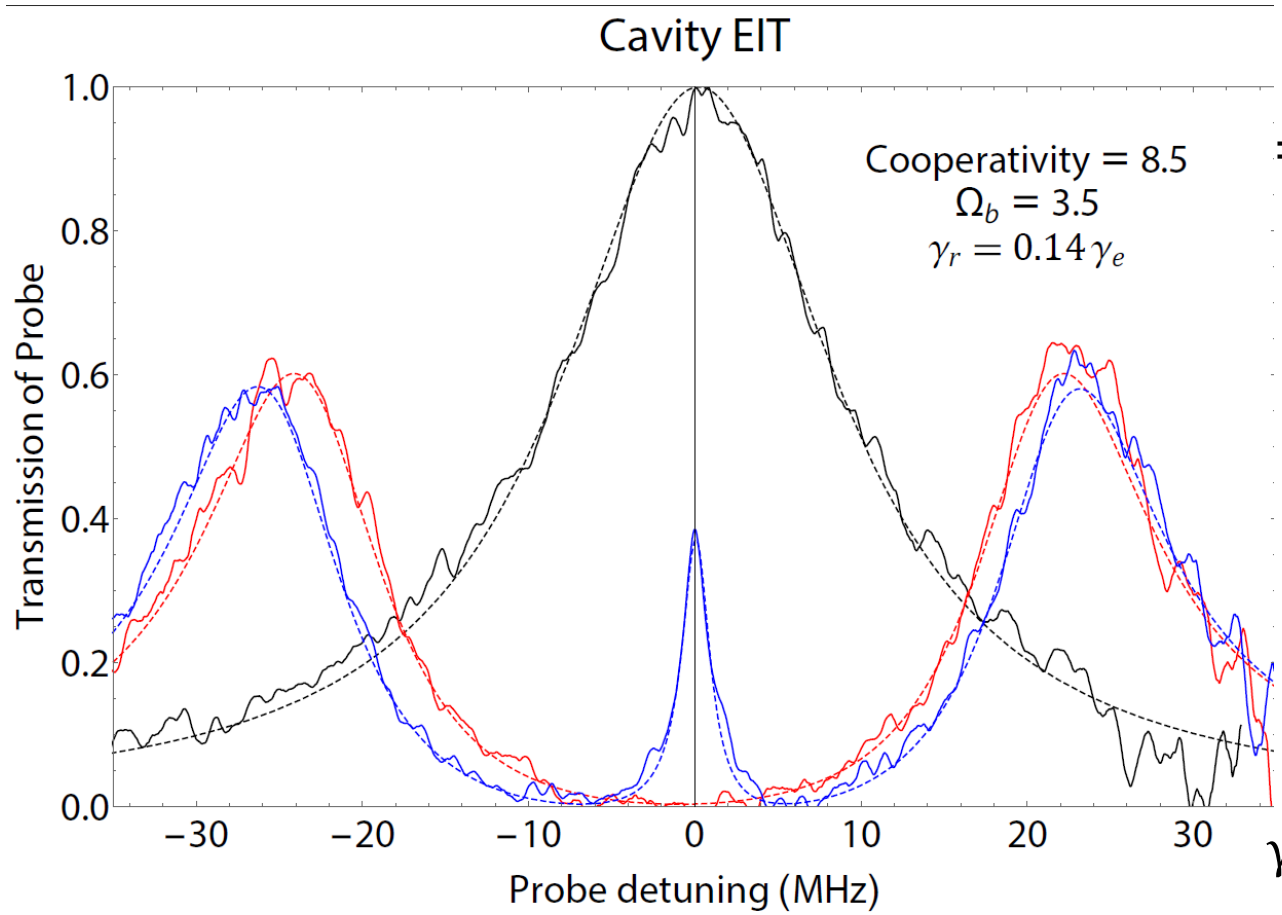


Cavity resonant with atoms



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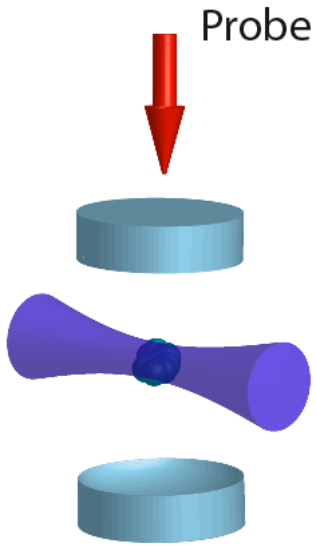

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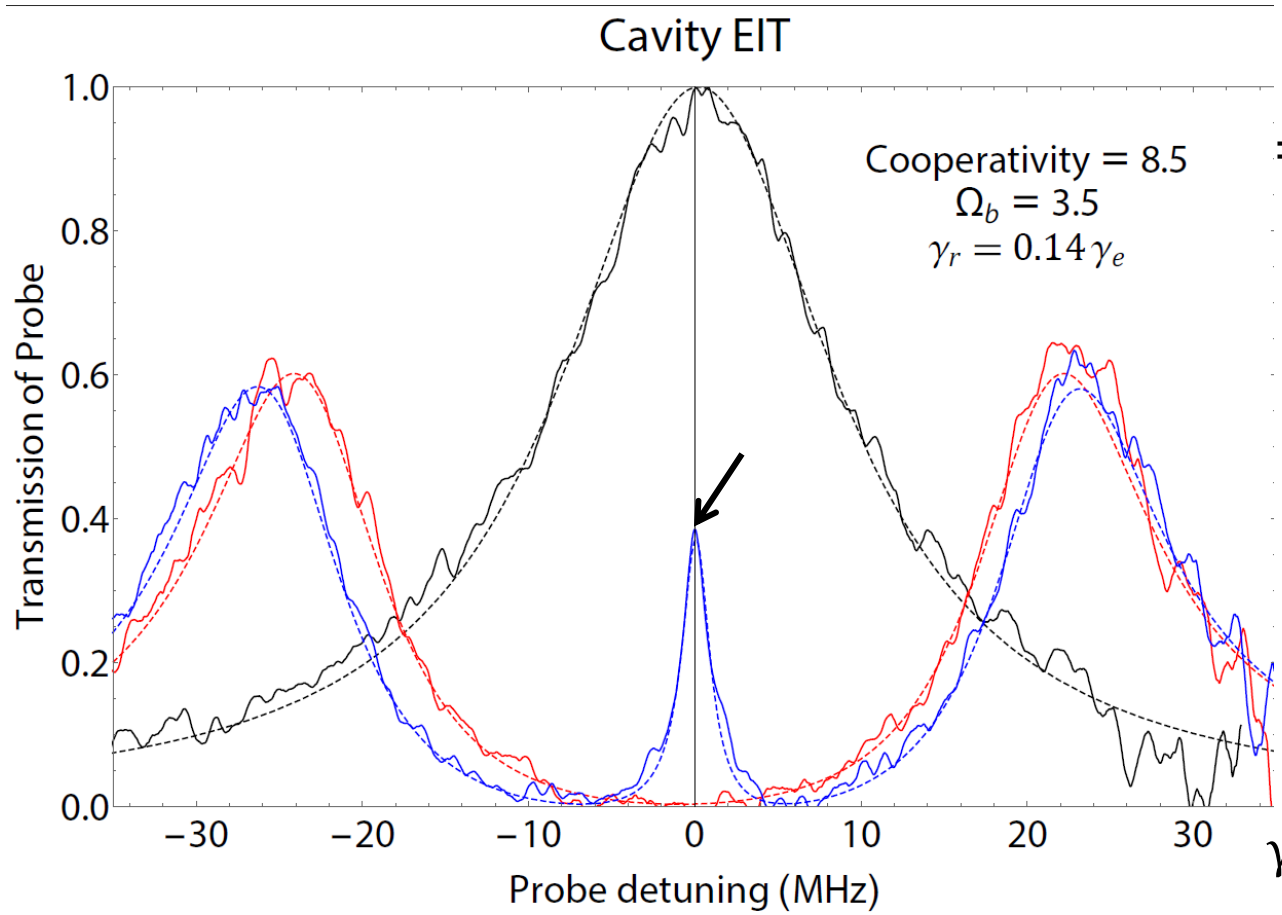

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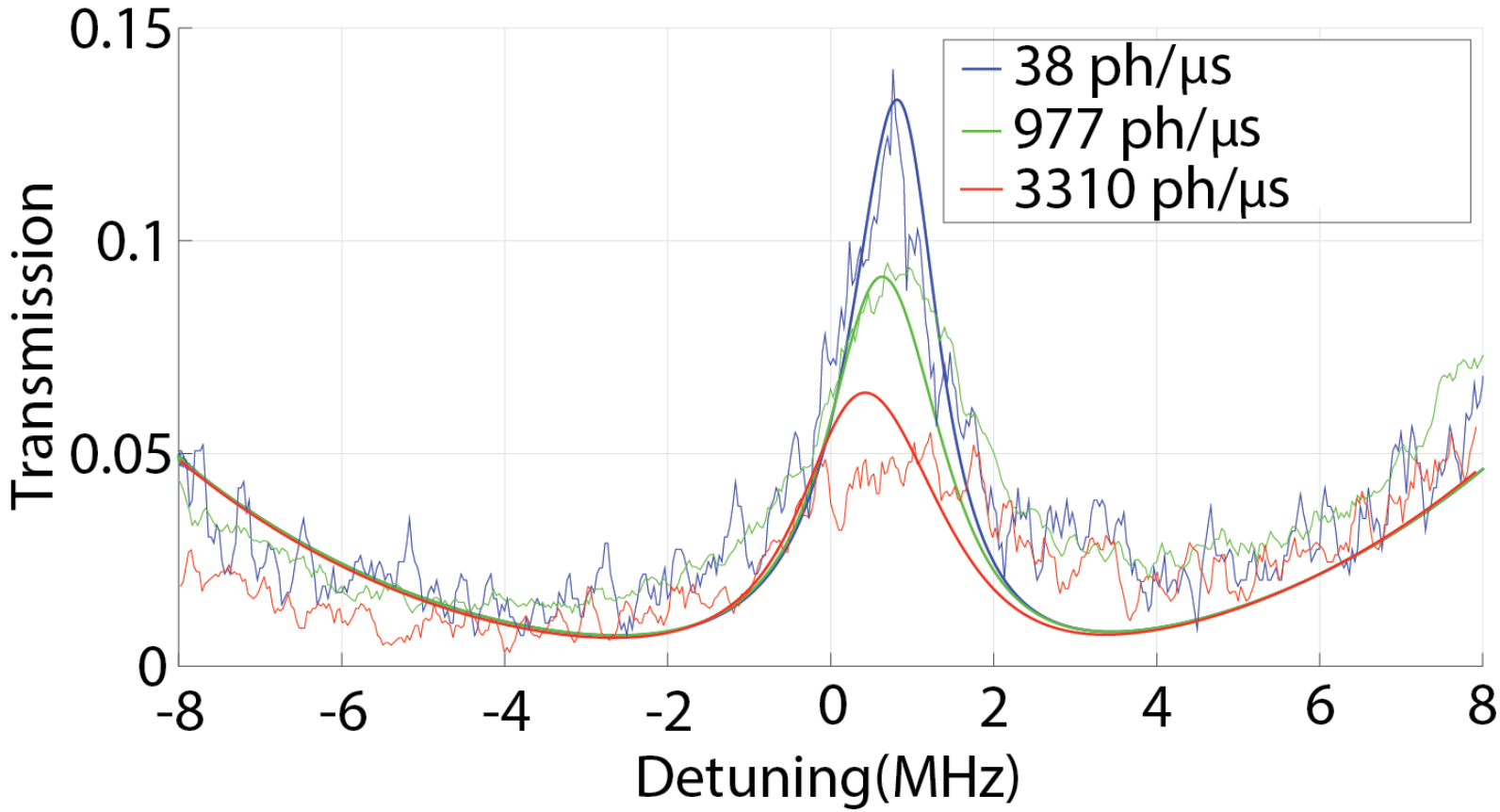
- Few photon non-linearities using Rydberg polaritons – Rajiv Boddeda

Results (S states)



Semi – classical model with no free parameters $C_6 = 20000*(n/56)^{11}\gamma_e\ \mu m^6$

J. Phys. B: At. Mol. Opt. Phys.38(2005)

Few photon non-linearities using Rydberg polaritons – Rajiv Boddeda

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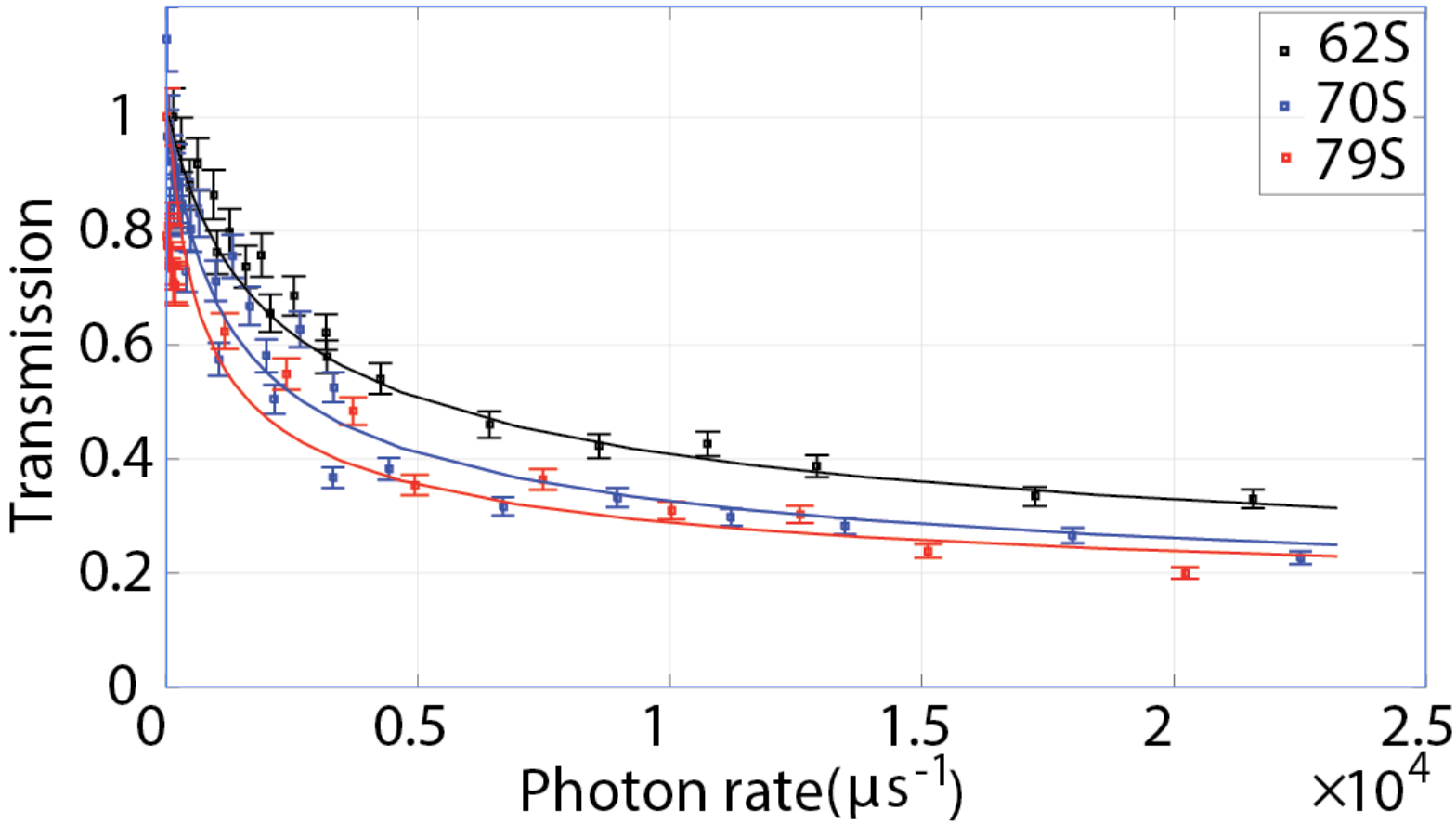

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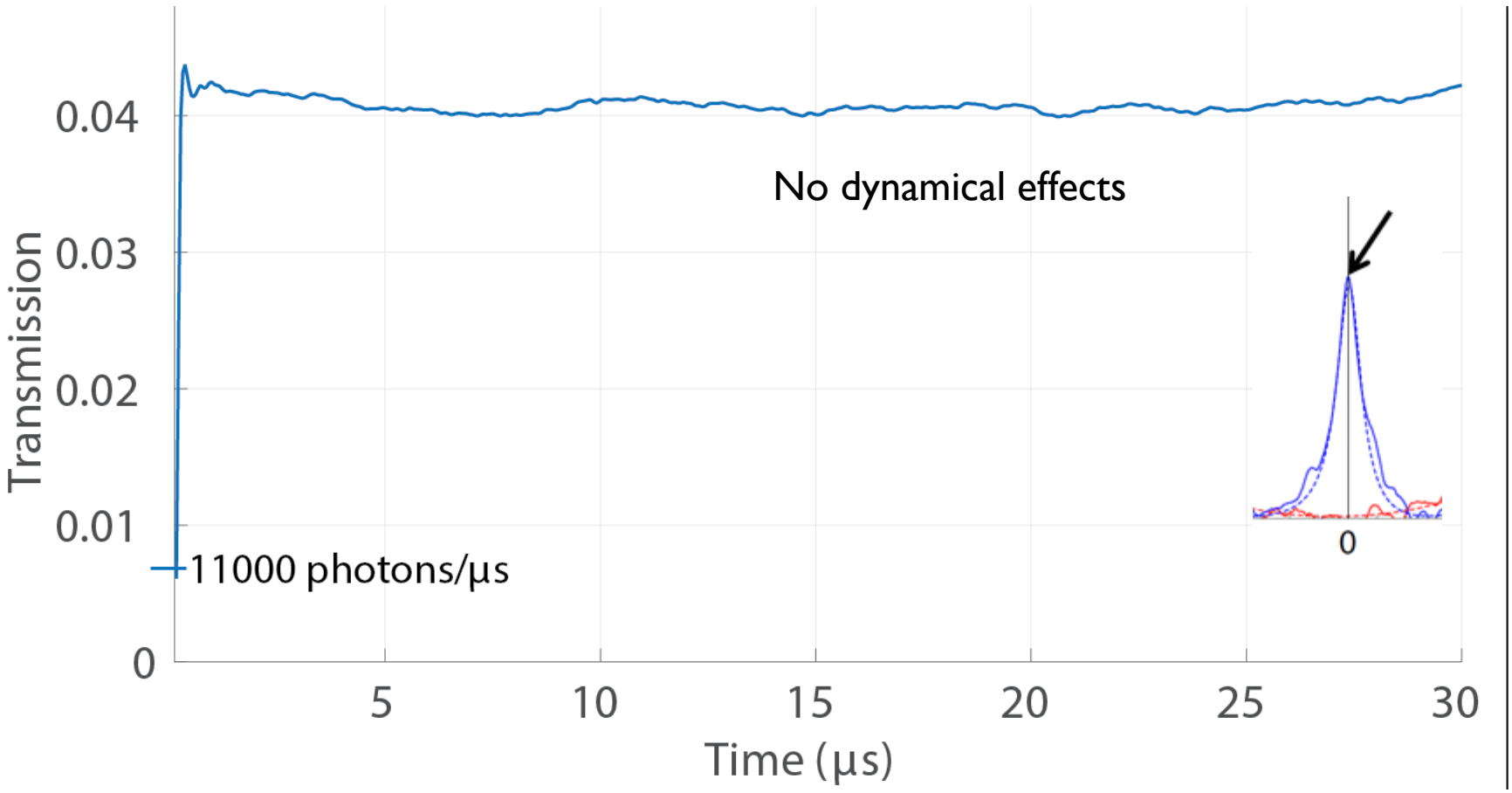
Few photon non-linearities using Rydberg polaritons – Rajiv Boddeda

S states


0.04
0.03
0.02
0.01
0
Transmission
No dynamical effects
11000 photons/μs
0
5
10
15
20
25
30
Time (μs)

Moving to D states

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- Higher dipole moments than S states

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- We can couple to all degenerate m_J levels

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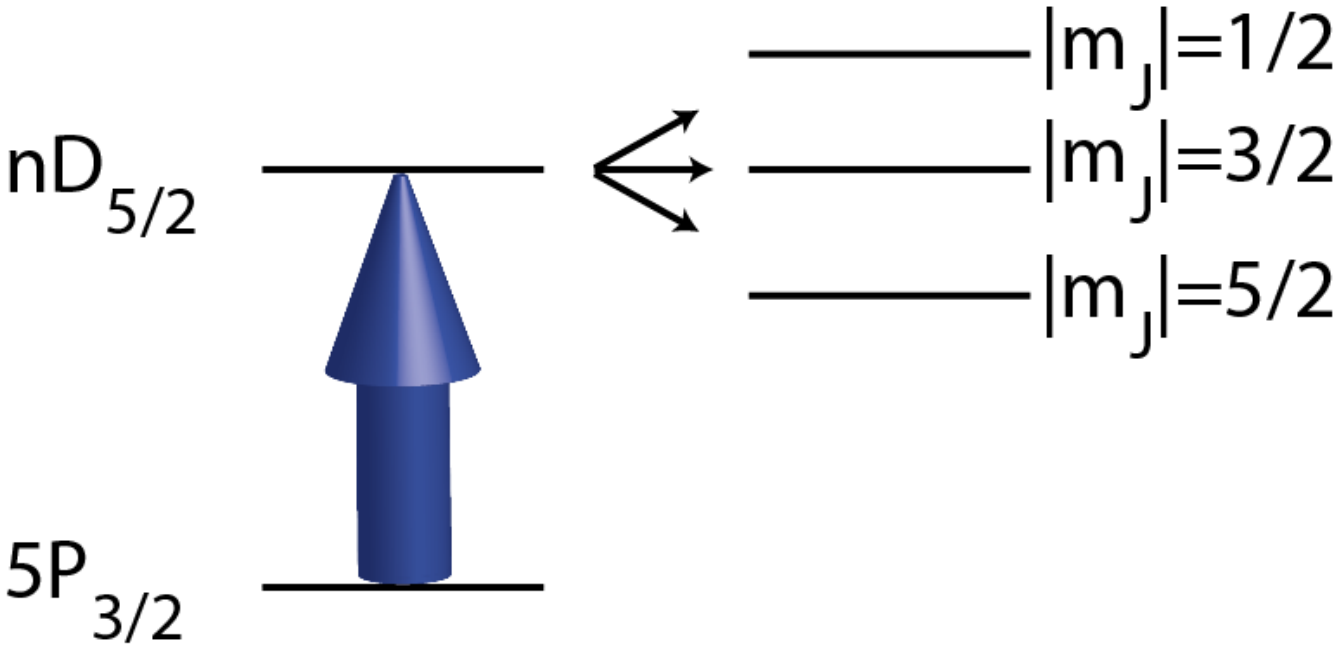

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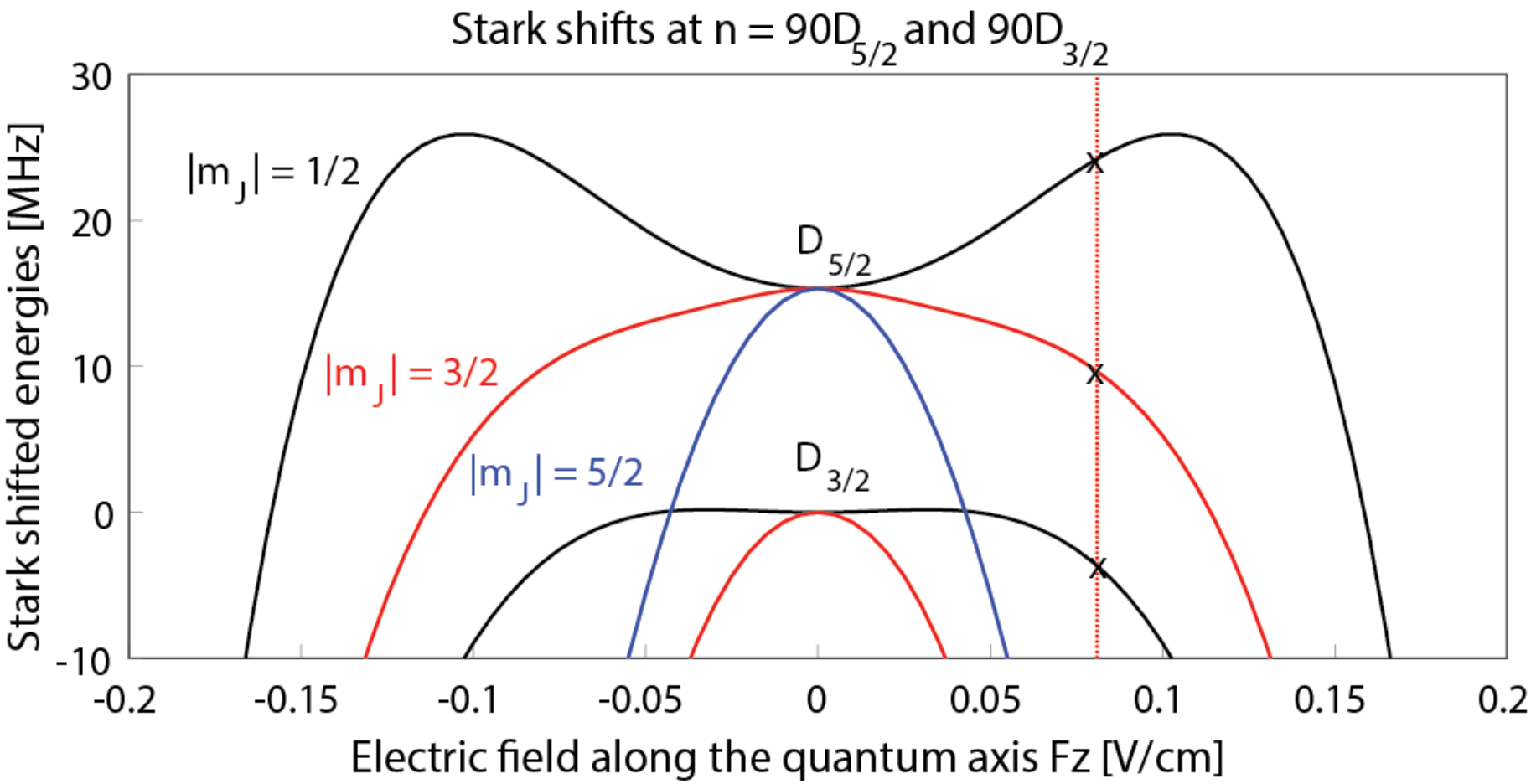
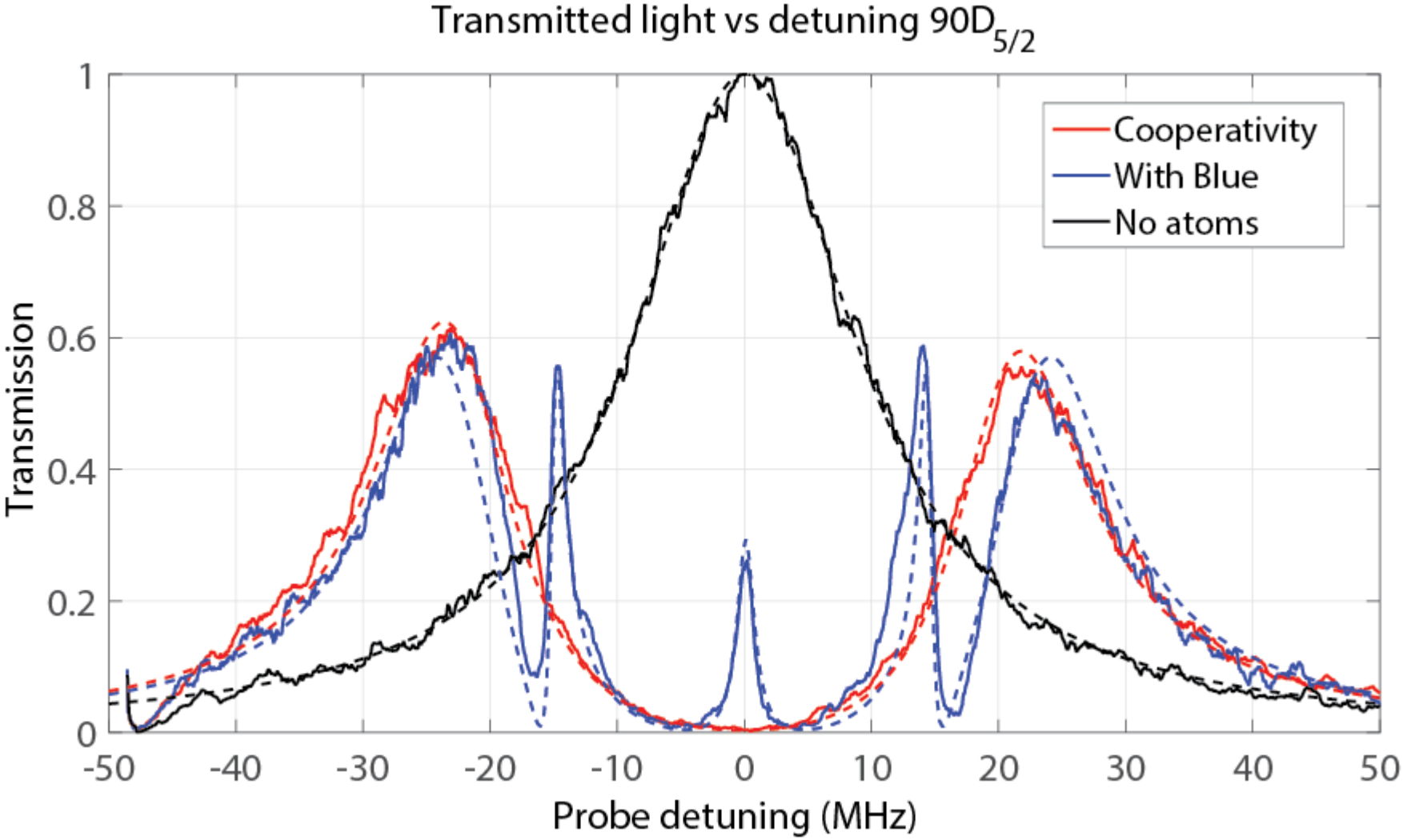
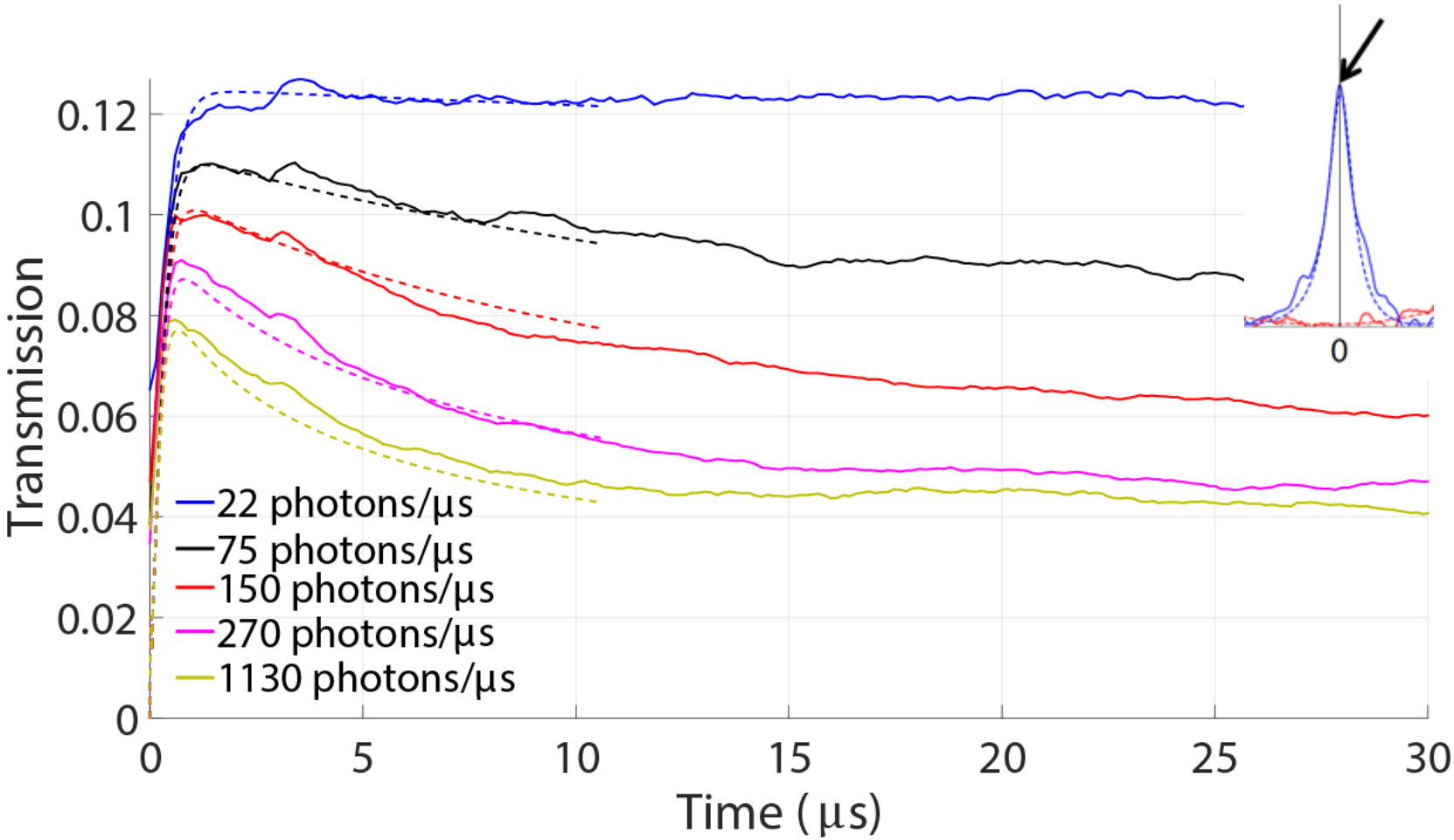


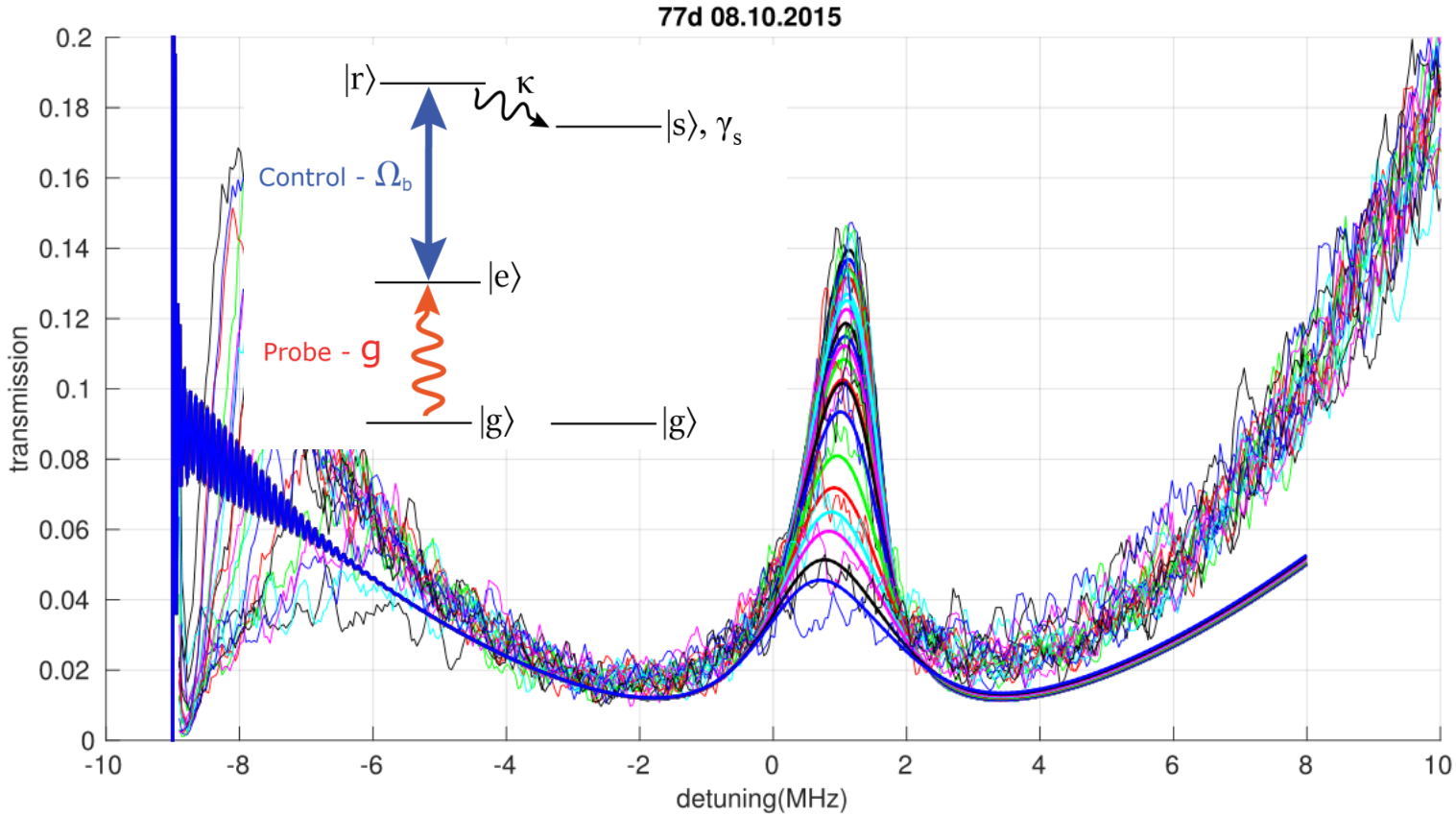
Experiment: Stark Splitting



Dynamical effects

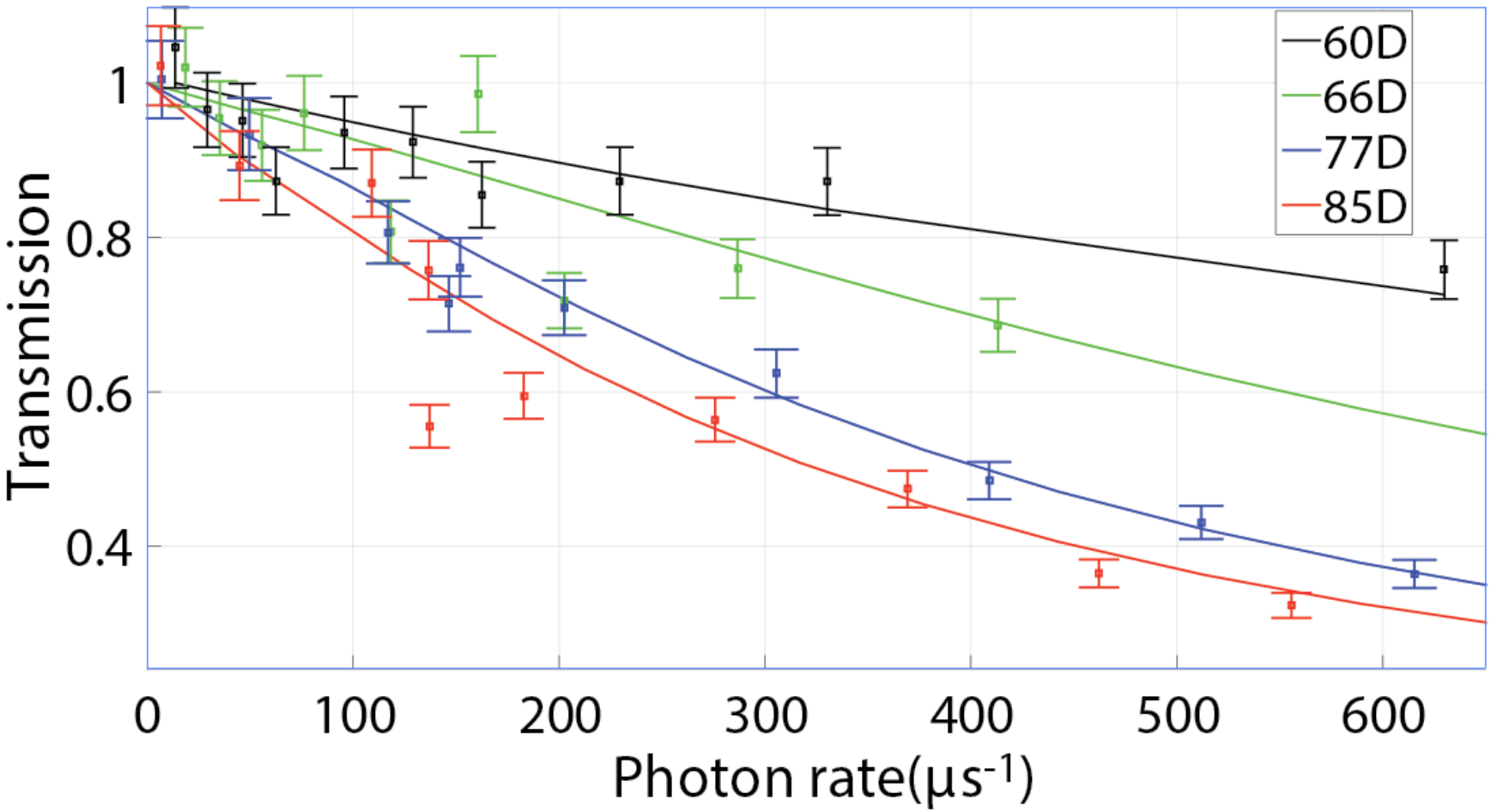


Results



Averaged $C_6 = 15000*(n/56)^{11}\gamma_e$ C. Tresp et. al. PRL 115.083602

Results

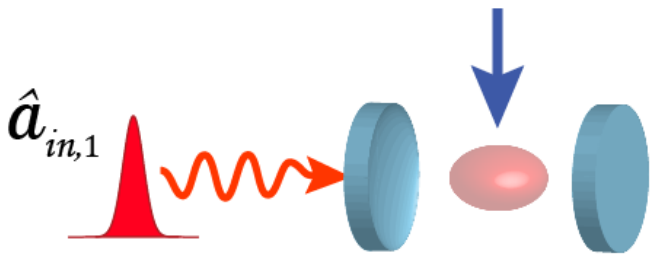


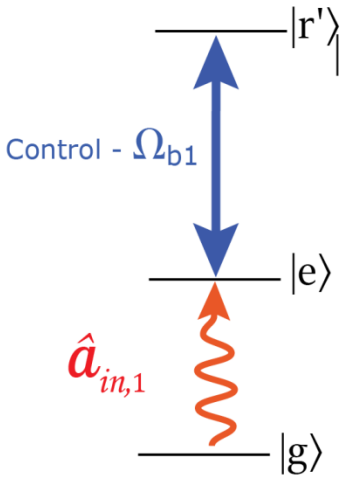
In preparation

Proposal for Photonic Gate

Controlled Phase gate

Single Rail





S.Das, A.Grankin, I.Iakoupov,
E.Brion, J, Borregaard, R.Boddeda,
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A.Sorensen, arXiv: 1506.04300

Controlled Phase gate

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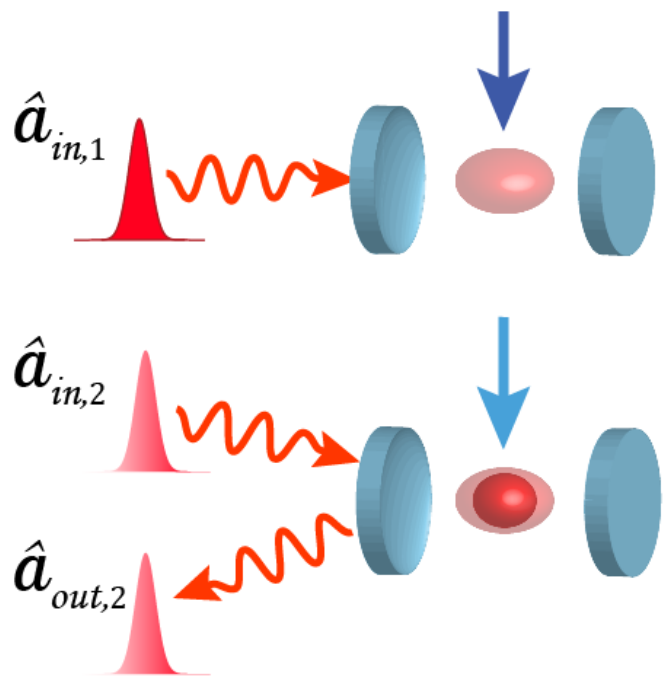

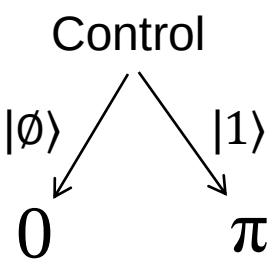

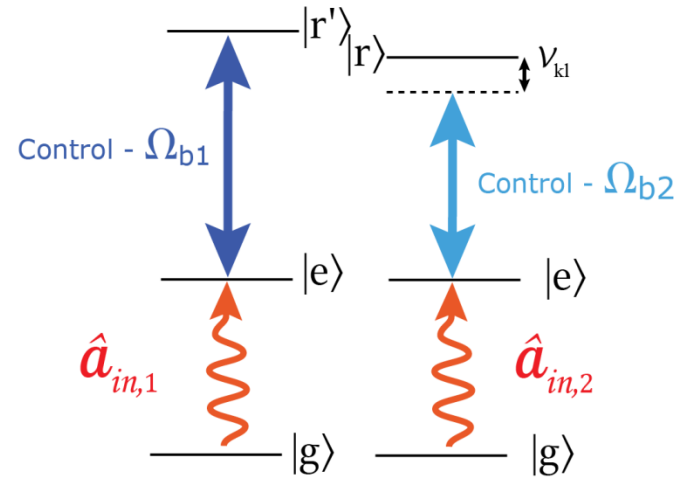

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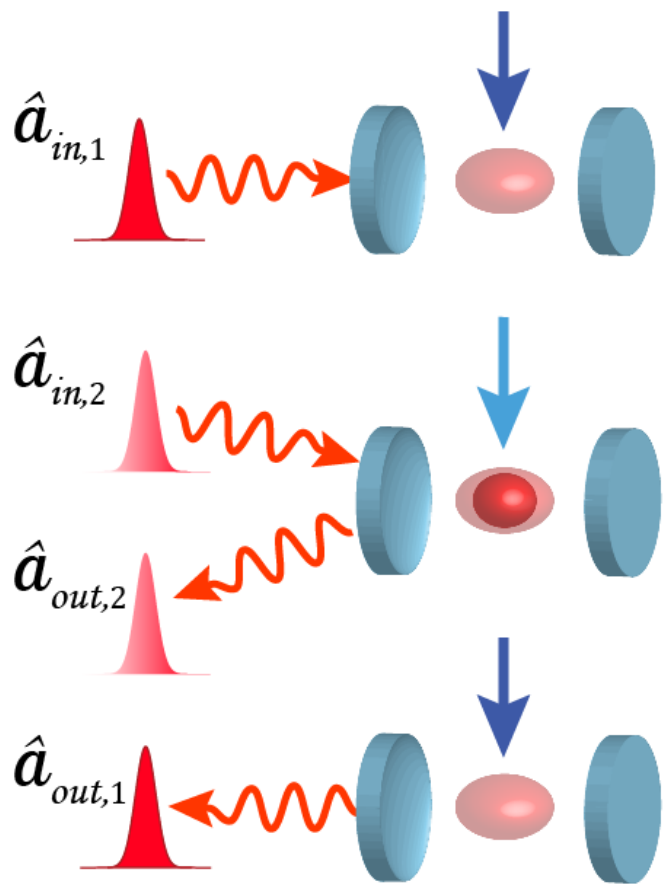

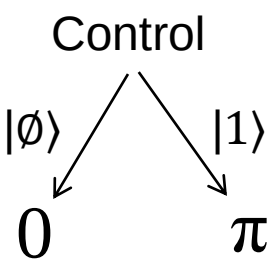

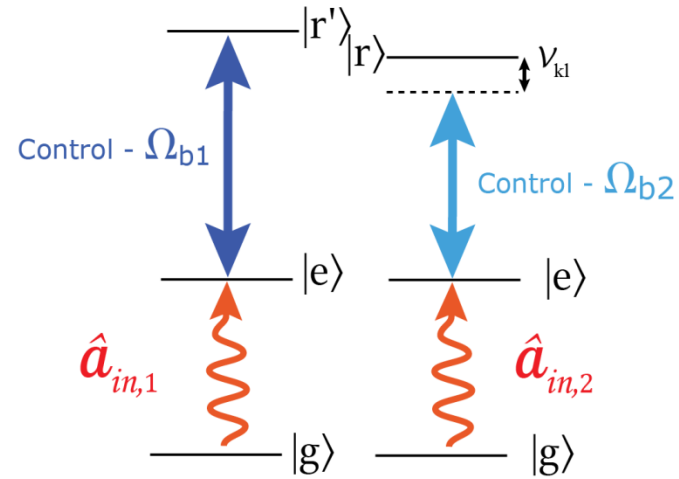

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Gate Fidelity

- Choi – Jamiolkowski fidelity

$$C_b = N_b g^2/\gamma\kappa$$

Eg: For a C_b of 10

N_b = 500

$g^2/\gamma\kappa$ = 0.02

Single atom cooperativity

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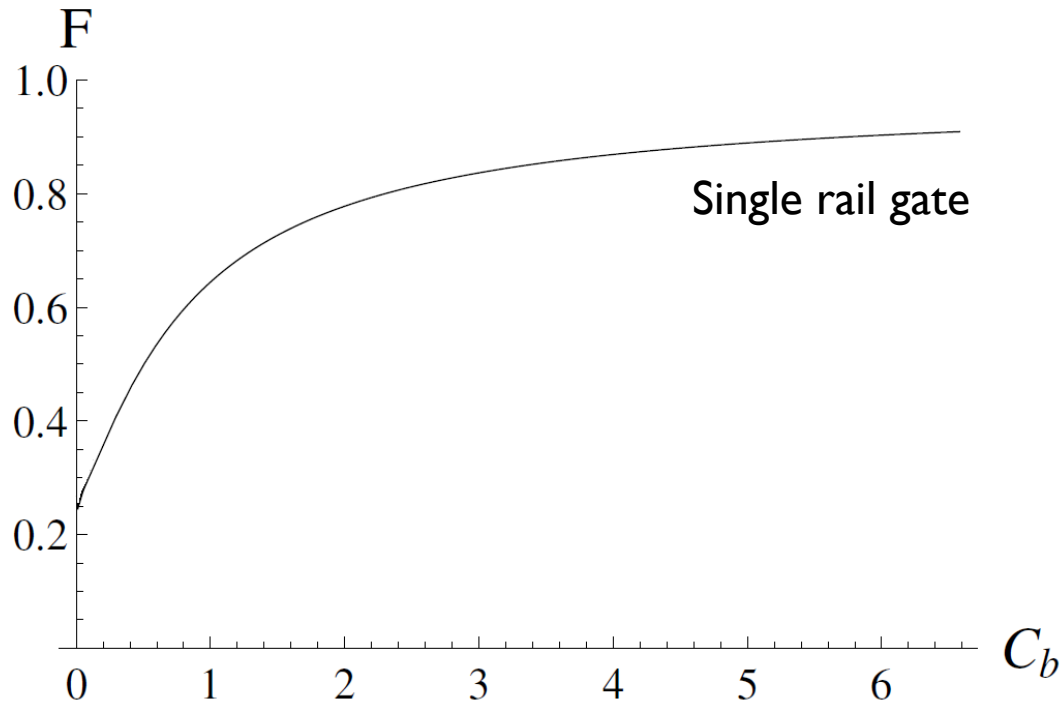


Cooperativity per blockade

Gate Fidelity

$$C_b = N_b g^2/\gamma\kappa$$

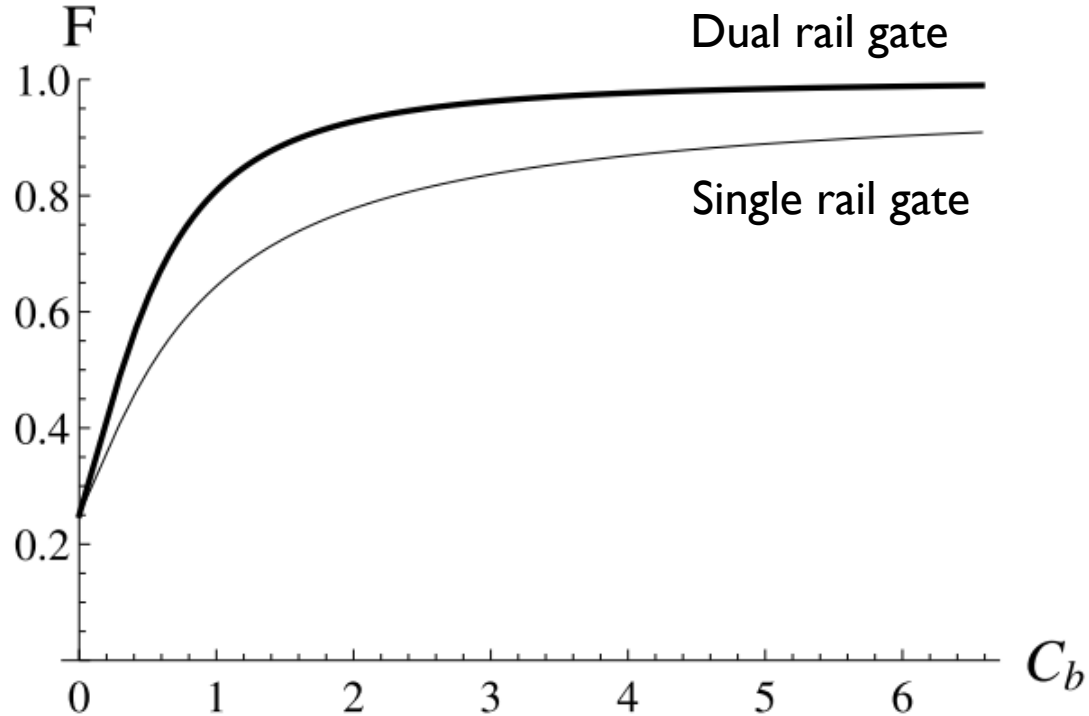
Eg: For a C_b of 10

N_b = 500

$g^2/\gamma\kappa$ = 0.02

Single atom cooperativity

Post selected swap fidelity



Cooperativity per blockade

Conclusion

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- Photons – Ideal candidates

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- Proposal for Controlled Phase gate
- Towards higher finesse cavity

Thank you !

Imam Usmani

Erwan Bimbard

Andrey Grankin

Etienne Brion

Alexei Ourjoumtsev

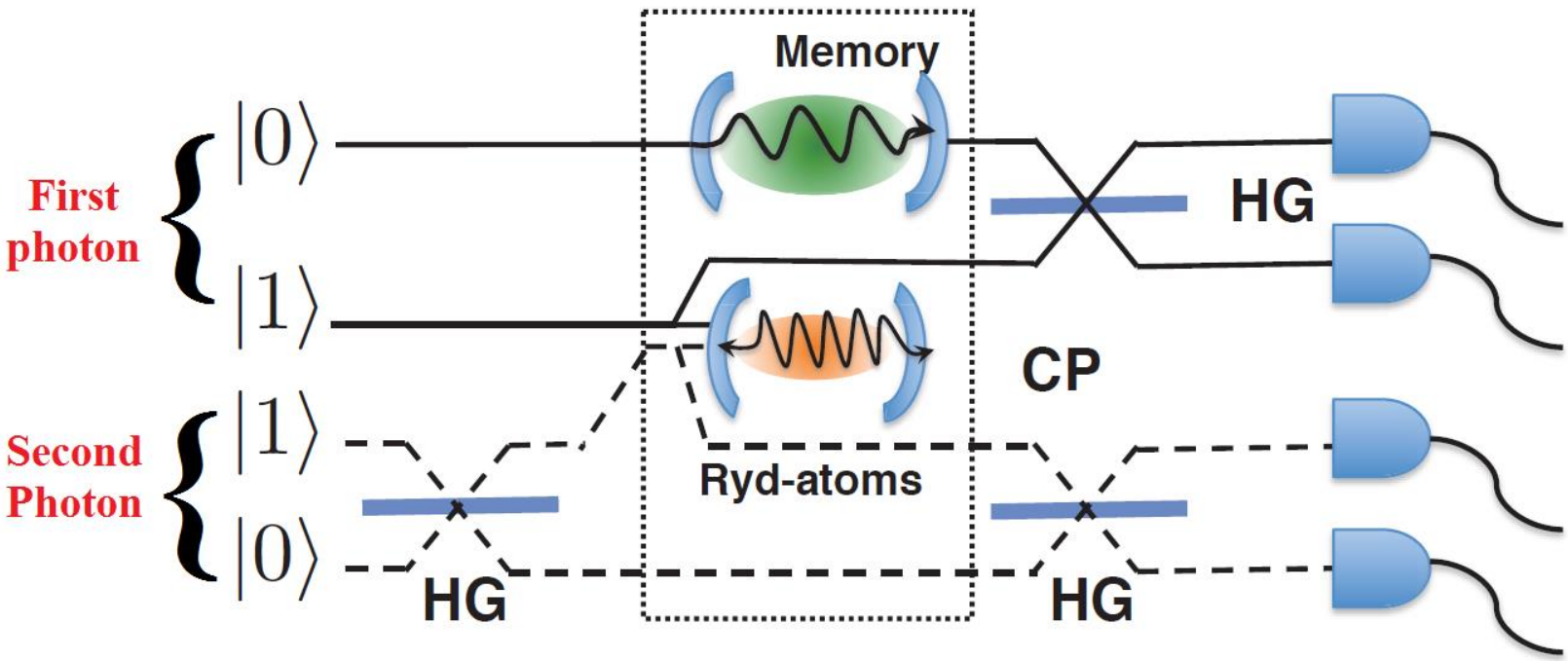
Philippe Grangier

Collaborations:
Anders S Sørensen[1],
Sumanta Das[1],
Ivan Iakoupov[1],
Johannes Borregaard[1,2]
([1]Niels Bohr Institute, Denmark,
[2]Dept. Physics, Harvard University)

Technicians:
Florence Fuchs

Funding:
DELPHI
Deterministic Logical Photon-photon Interactions,
SIQS
Simulators and Interfaces with Quantum Systems

Dual-rail photonic gate



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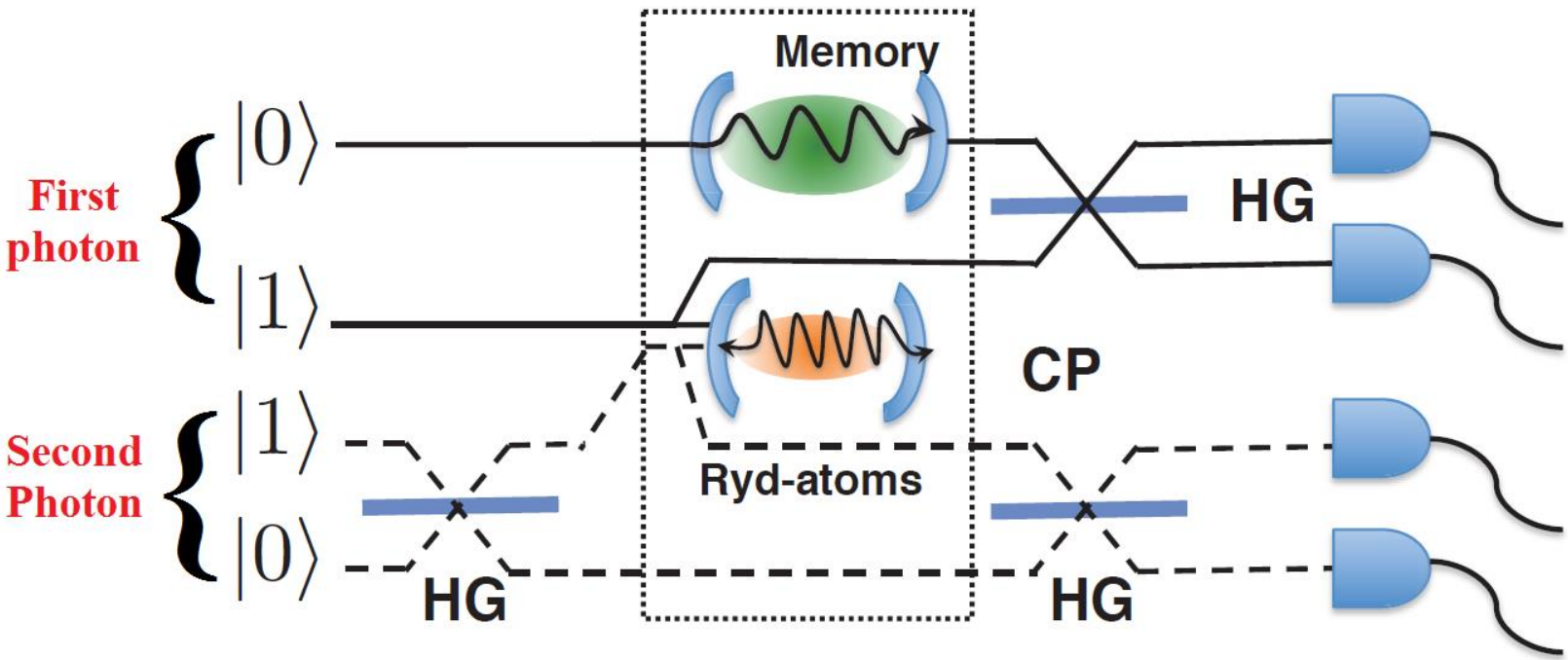

- Significant increase in a quantum repeater scheme
- See also: J. Borregaard et al, arXiv : 1504.03703 (2015)