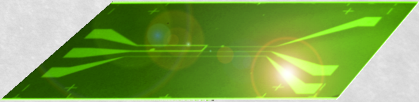
Long coherence times for Rydberg qubits on a superconducting atom chip

Physical Review A **90**, 040502(R) (2014)

Thanh Long NGUYEN

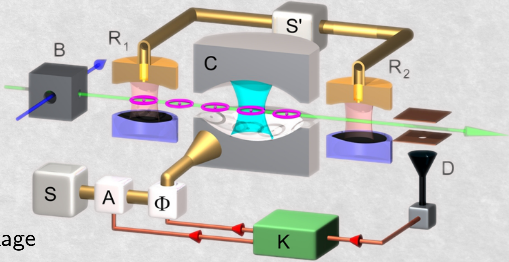
QuantumGDR
Lyon 2014



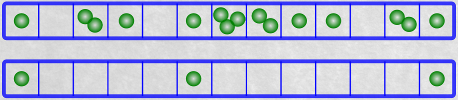
Introduction

CQED experiment

- QND measurement
- Fock state in a box
- Schrödinger cat



Hypothesis: single atome on each package



Poisson distribution

$\bar{n} \ll 1 \Rightarrow$ long data acquisition time

A deterministic single atom source

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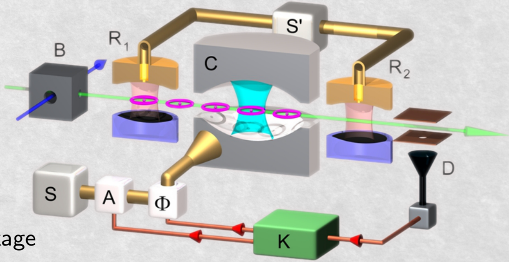

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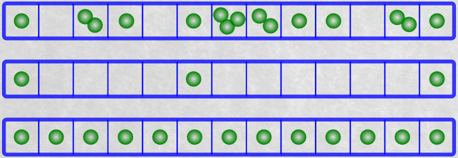

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Introduction

VOLUME 87, NUMBER 3 PHYSICAL REVIEW LETTERS 16 JULY 2001

Dipole Blockade and Quantum Information Processing in Mesoscopic Atomic Ensembles

M. D. Lukin,[1] M. Fleischhauer,[1,2] and R. Cote[3]
[1]*ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138*
[2]*Fachbereich Physik, Universität Kaiserslautern, D-67663 Kaiserslautern, Germany*
[3]*Physics Department, University of Connecticut, Storrs, Connecticut 06269*

L. M. Duan, D. Jaksch, J. I. Cirac, and P. Zoller
Institut für Theoretische Physik, Universität Innsbruck, A-6020 Innsbruck, Austria
(Received 7 November 2000; published 26 June 2001)

We describe a technique for manipulating quantum information stored in collective states of mesoscopic ensembles. Quantum processing is accomplished by optical excitation into states with strong dipole-dipole interactions. The resulting "dipole blockade" can be used to inhibit transitions into all but singly excited collective states. This can be employed for a controlled generation of collective atomic spin states as well as nonclassical photonic states and for scalable quantum logic gates. An example involving a cold Rydberg gas is analyzed.

DOI: 10.1103/PhysRevLett.87.037901 PACS numbers: 03.67.Lx, 03.75.Fi, 42.50.Gy, 73.23.–b

Recent advances in quantum information science have opened a door for a number of fascinating potential applications ranging from the factorization of large numbers and

optical wavelengths. Combined with the exceptional degree of control that is typical for quantum optical systems and long coherence times, this allows one to

Blockade of Rydberg excitation on a superconducting atom chip

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PHYSICAL REVIEW A **66**, 065403 (2002)

Creating single-atom and single-photon sources from entangled atomic ensembles

M. Saffman and T. G. Walker
Department of Physics, University of Wisconsin, 1150 University Avenue, Madison, Wisconsin 53706

(Received 14 March 2002; published 16 December 2002)

We discuss the application of dipole blockade techniques for the preparation of single-atom and single-photon sources. A deterministic protocol is given for loading a single atom in an optical trap, as well as ejecting a controlled number of atoms in a desired direction. A single-photon source with an optically controlled beamlike emission pattern is described.

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Quantum-information science builds on the laws of quantum mechanics to transmit, store, and process information in varied and powerful ways. Advances in this field rely on our ability to manipulate coherently isolated quantum objects while eliminating incoherent interactions with the surrounding environment. It was proposed two decades ago that the

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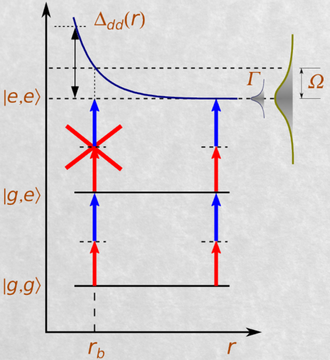
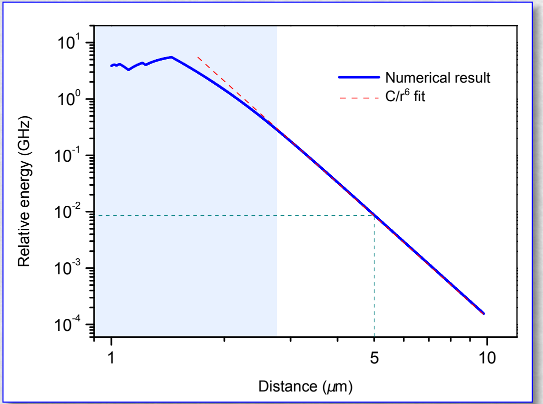
Taming electric field near a superconducting atom chip

Dipole blockade

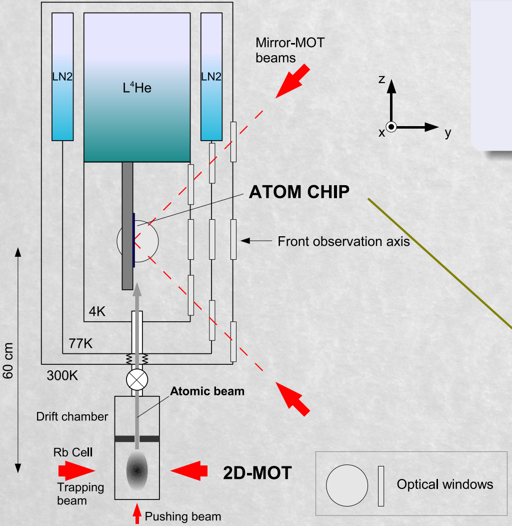


$|60s60s\rangle$



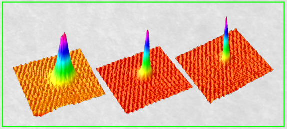
- Rydberg atoms: $n \gg 1 \Rightarrow$ huge electric dipole matrix element $d \propto n^2$
- Dipole interaction $\Rightarrow$ shift of energy levels
- $\Delta_{dip} >$ excitation line-width $\Rightarrow$ blockade regime
- Radius of blockade r_b

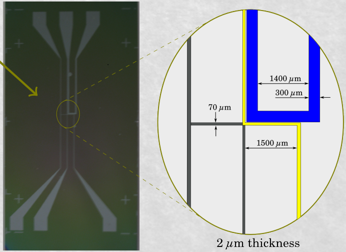
Experiment setup



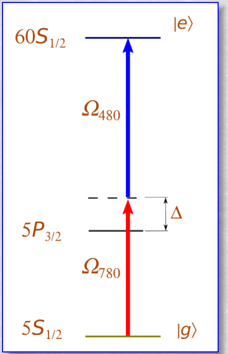
Superconducting atom chip

- Nb wires: superconducting
- Gold coated
- On chip 3D MOT & IP magnetic trap
- Varied position and temperature

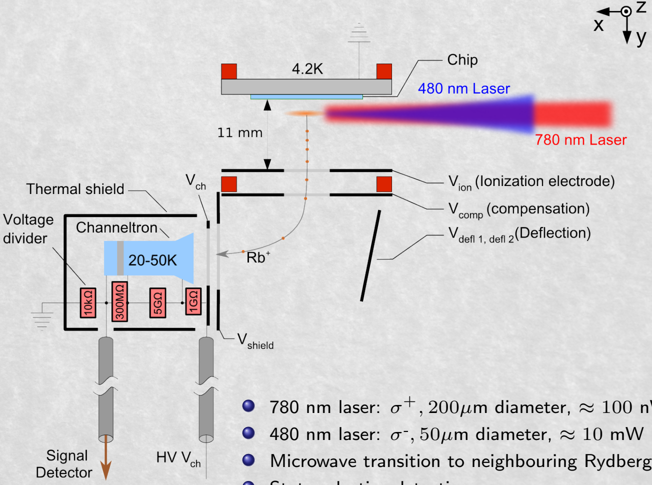




Rydberg excitation & detection



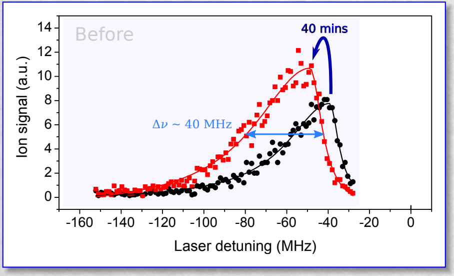
$\Delta = 540\text{MHz}$

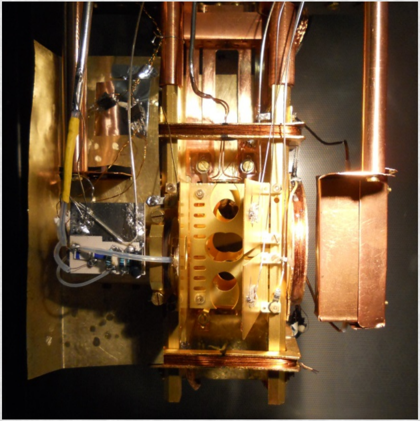


- 780 nm laser: σ^+, 200μm diameter, ≈ 100 nW
- 480 nm laser: σ^-, 50μm diameter, ≈ 10 mW
- Microwave transition to neighbouring Rydberg levels
- State selective detection
- Compensation for perpendicular residual electric field

Stark effect and optical transition

Spatial and temporal fluctuation of stray field due to accumulation of charges on chip surface





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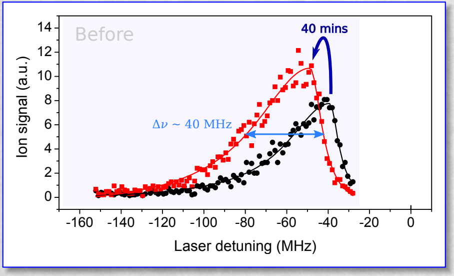

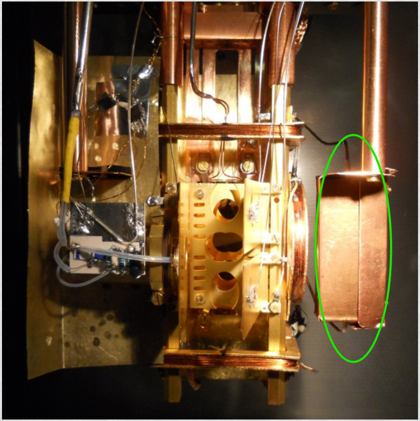

Solution in our case

Installation of **Rb dispensers inside the cryogenic environment** for Rb deposition on a large surface of the chip $\longrightarrow$ saturation of the slow Rb deposit (~ 90 nm layer)

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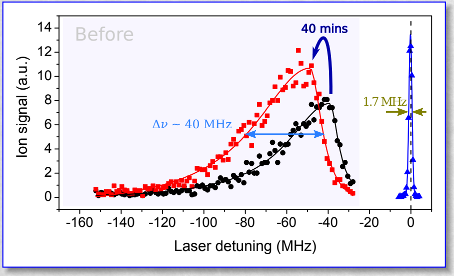

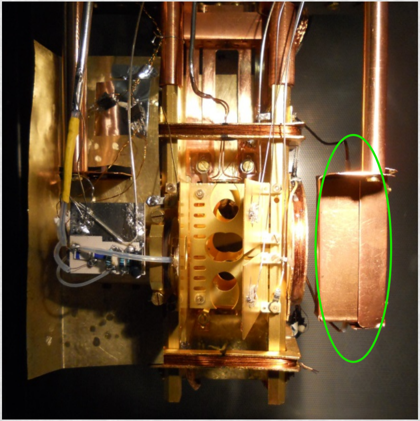

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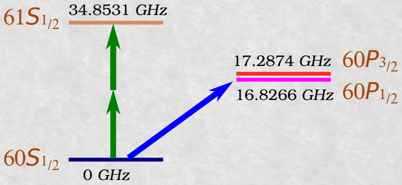
Electric field measurement using microwave

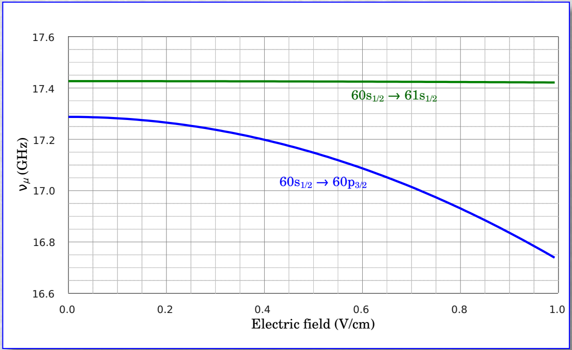
Precise knowledge of Stark shift allows to measure the residual electric field

$$\hat{\mathcal{H}}\psi = \hat{\mathcal{H}}_0 + e\vec{F}\cdot\vec{r}$$
$$\Delta\nu = A|\vec{F}|^2,\ A \propto n^7$$

$$A_{60s1/2} = -92.2 \text{ MHz}$$
$$A_{61s1/2} = -102.8 \text{ MHz}$$
$$A_{60p3/2} = -649.6 \text{ MHz}$$

Microwave spectroscopy allows accurate probe of energy shifts
$\longrightarrow$ precise tool to measure electric field





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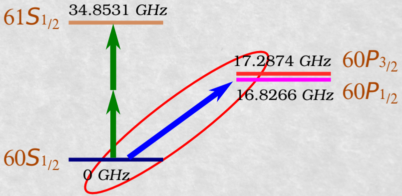
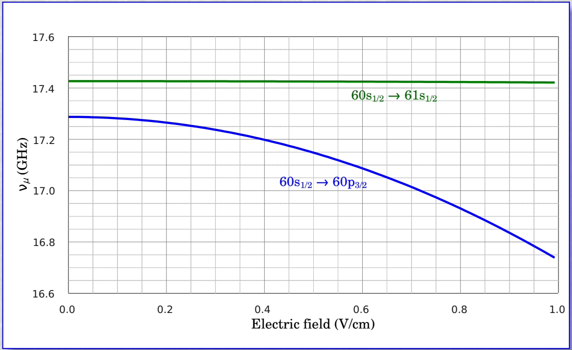
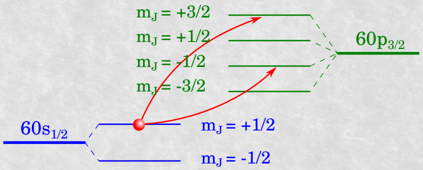




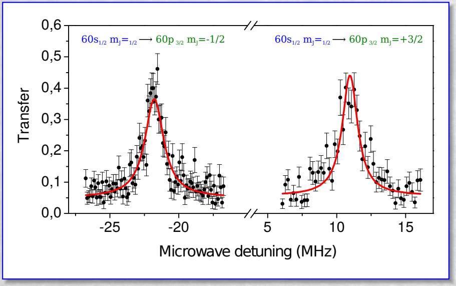
Electric field measurement using microwave

- Thermal cloud in a magnetic trap
- Taking into account Zeeman splitting $\longrightarrow$ We can deduce the electric field with certain precision

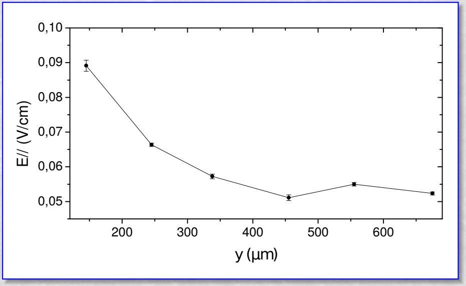
$60s_{1/2} \longrightarrow 60p_{3/2}$ transition



@455 μm from the chip surface

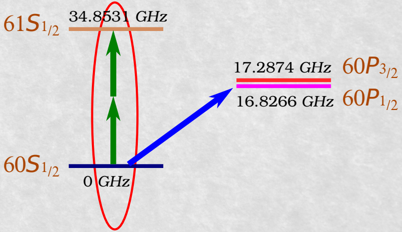


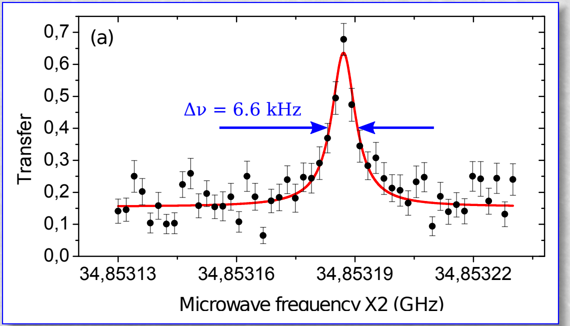
Residual electric field as fuction of distance to chip



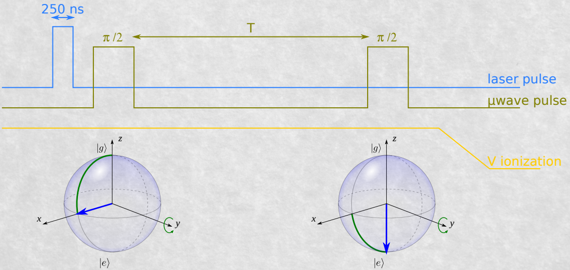
Coherence - Spectrum

- Thermal cloud in a magnetic trap
  @450 μm from the chip
  $T \sim 1\,\mu$K
  $\sim 60\,\mu$m $\times 30\,\mu$m $\times 30\,\mu$m

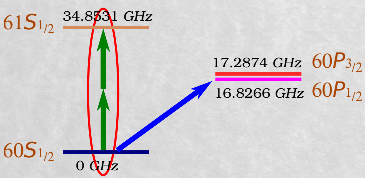


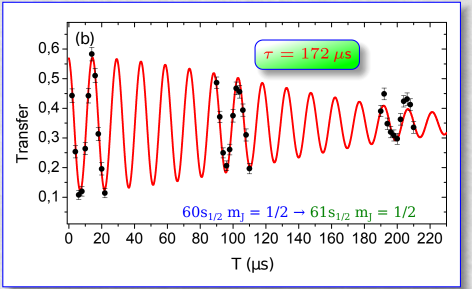


Coherence-Ramsey interference

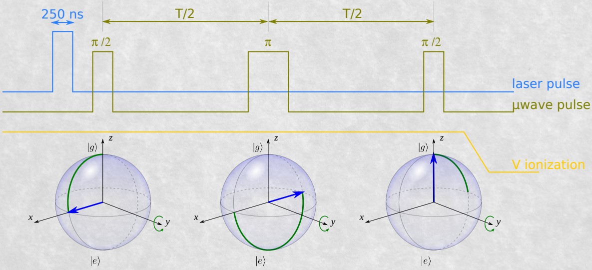


Thermal cloud @450 μm from the chip
$\Delta\nu = 70$ kHz



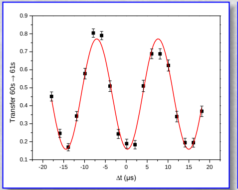


Coherence-Spin echo

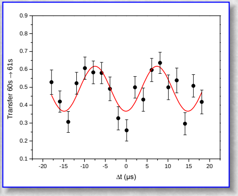


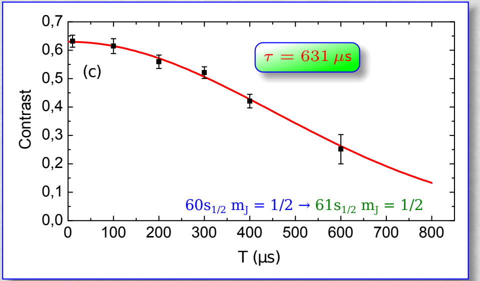
Thermal cloud @450 μm from the chip
Rydberg lifetime $\sim 210\,\mu$s
$\Delta\nu = 2 \times 35$ kHz

$T = 100\,\mu$s



$T = 600\,\mu$s





Conclusion

- **Rb dispenser** inside the cryogenic environment allowed a good **control of residual electric field** close to the chip surface
- Residual electric field were probed from **microwave spectroscopy** of nearby Rydberg transition
- **Coherence** times bigger than the Rydberg lifetime were demonstrated

A step forward deterministic excitation of single Rydberg atoms

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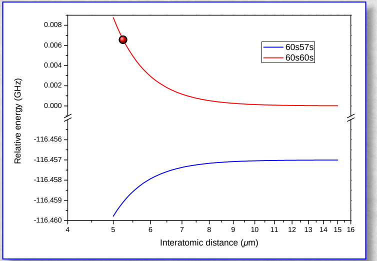
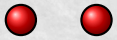
Expansion of a cloud of Rydberg atoms





- Detune laser to give initial potential
- Use microwave to map the spatial distribution of the Rydberg cloud

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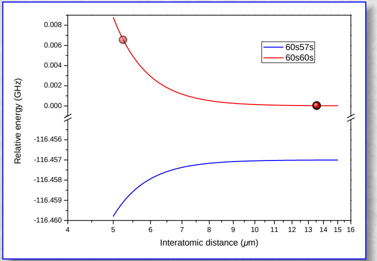

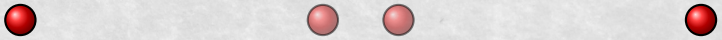

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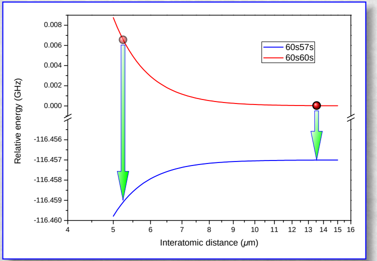

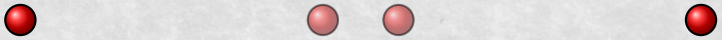

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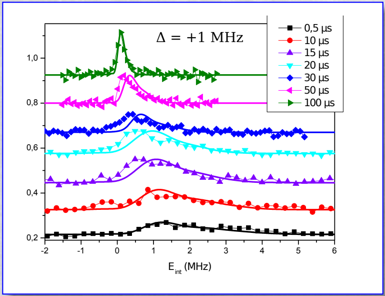
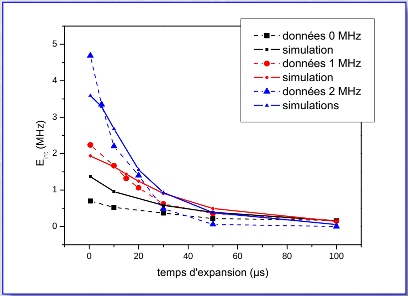
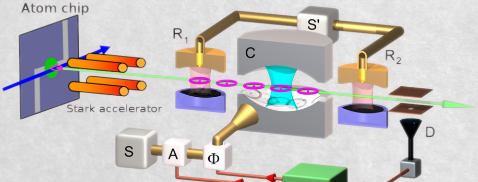
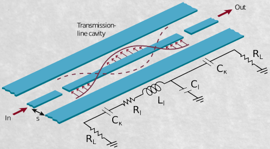


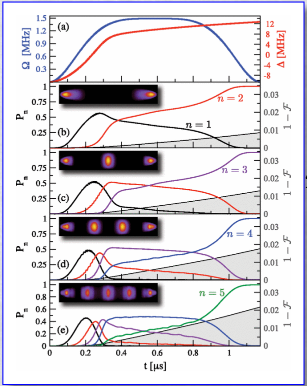


Long term aims





- Couple deterministic single Rydberg atom source and CQED/circuit QED Experiment



$Rx =$

15 μm

22.5 μm

35 μm

45 μm

- Adiabatic passage:

  Excitation on an elongated BEC, depending on the size of BEC and appropriate detuning $\longrightarrow 1D$ crystal of Rydberg atoms

  T. Pohl *et al.*, PRL **104**, 043002 (2010)

Team

PhD students

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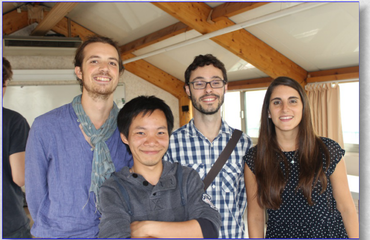

Permanents

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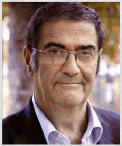

Thank you for your attention!