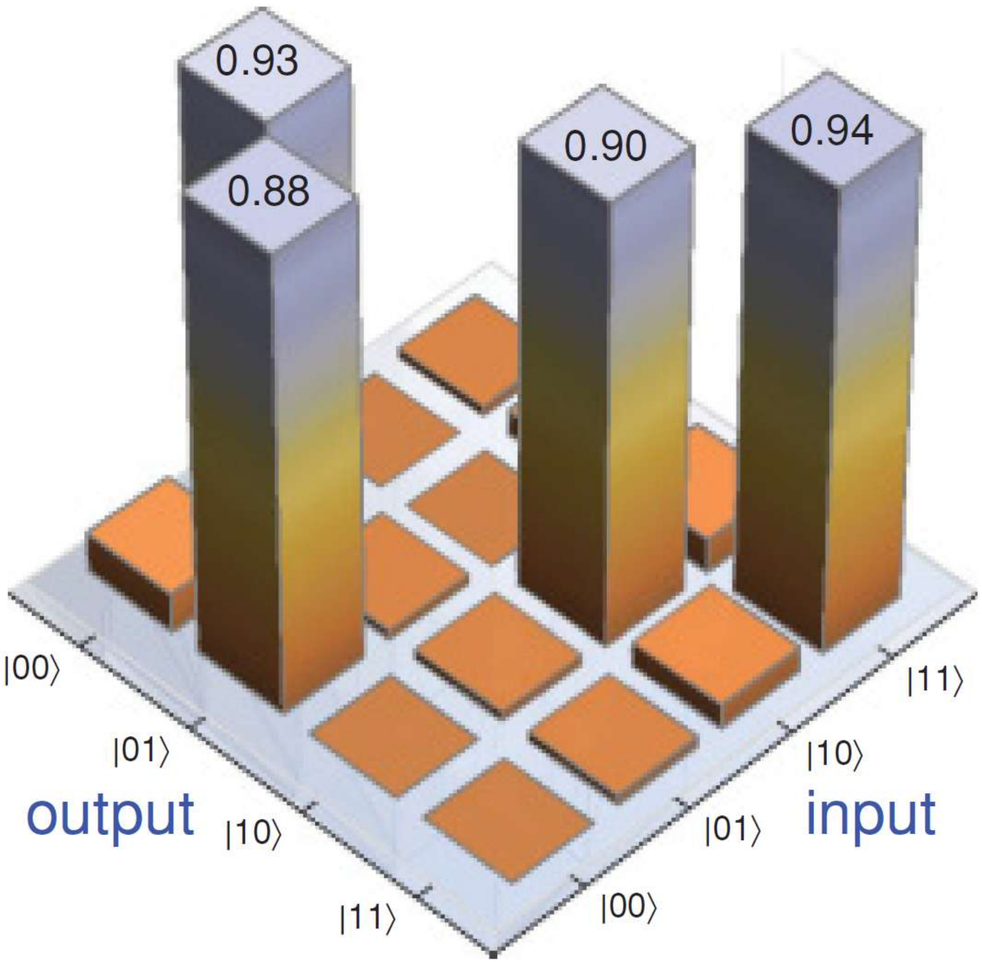
Rydberg blockade



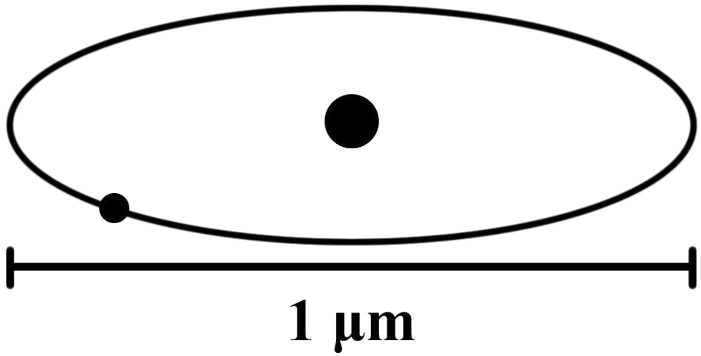
Andreas Schindewolf – TU München

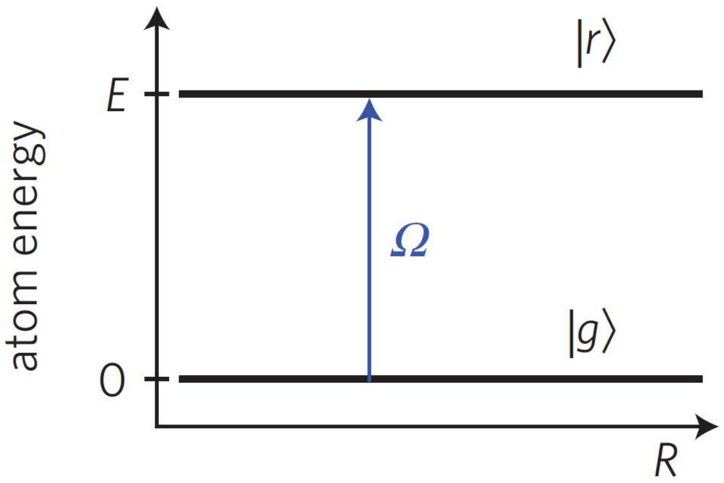
1. Introduction

Rydberg blockade

Highly exited neutral atoms.

Strong long-range dipolar forces.





1. Introduction

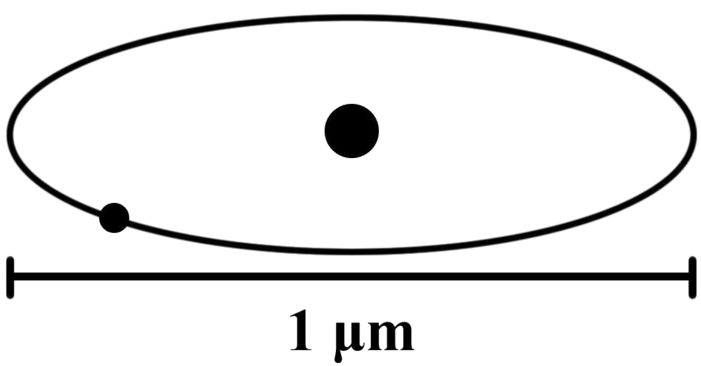
Rydberg blockade

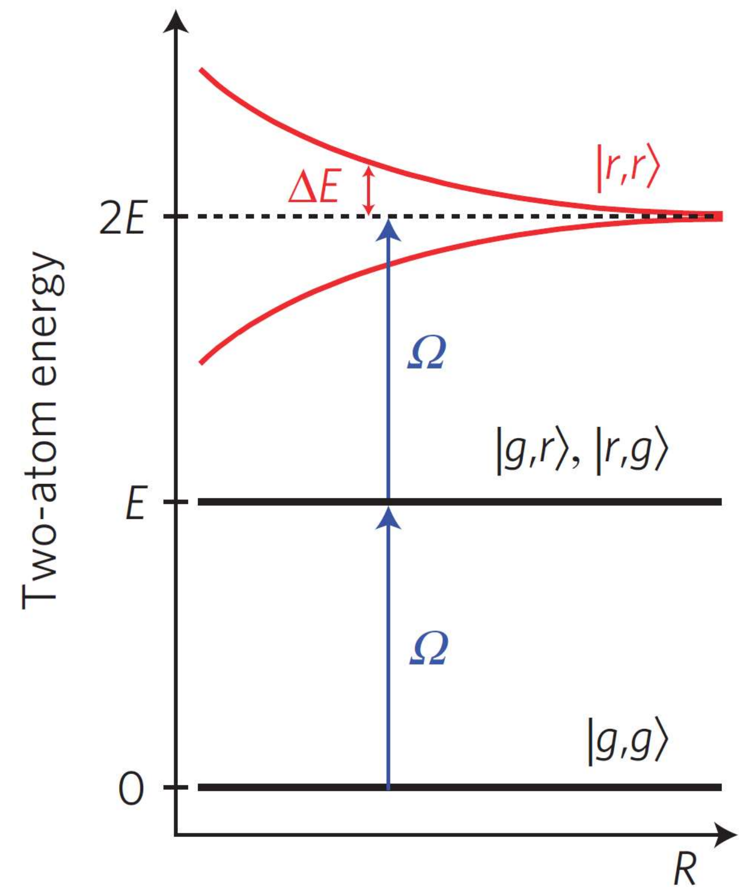
Highly excited neutral atoms.

Strong long-range dipolar forces.

Energy shift ΔE.

$\Delta E > \hbar\Omega \;\rightarrow\;$ blockade.



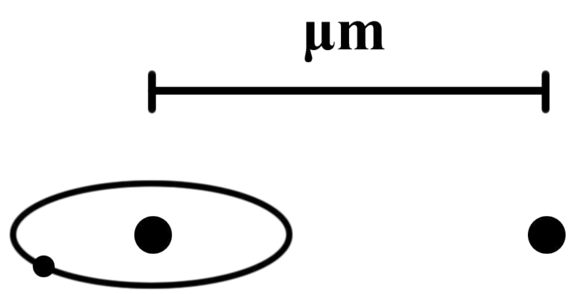


1. Introduction

Motivation

Advantages

- large distance (μm)



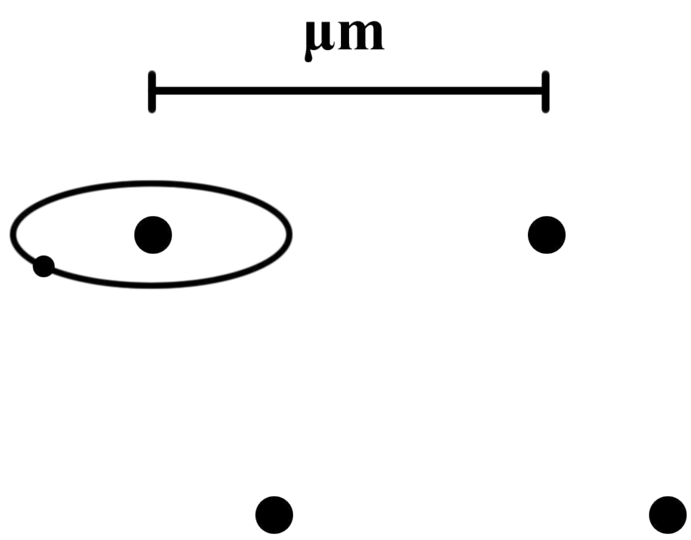
1. Introduction

Motivation

Advantages

- large distance (μm)

- scalable to more atoms

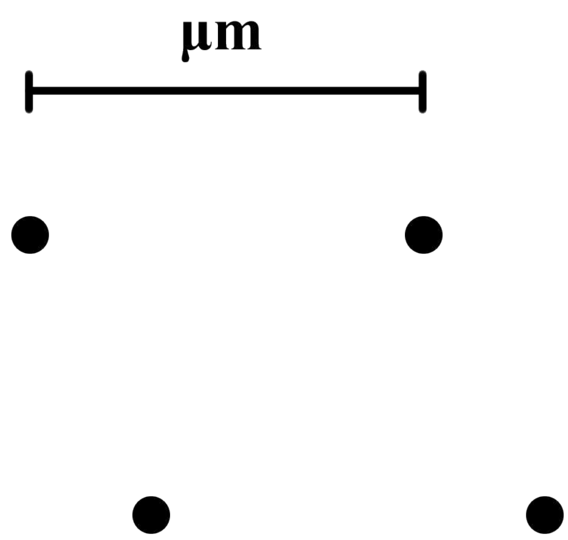


1. Introduction

Motivation

Advantages

- large distance (μm)
- scalable to more atoms
- can be turned on/off



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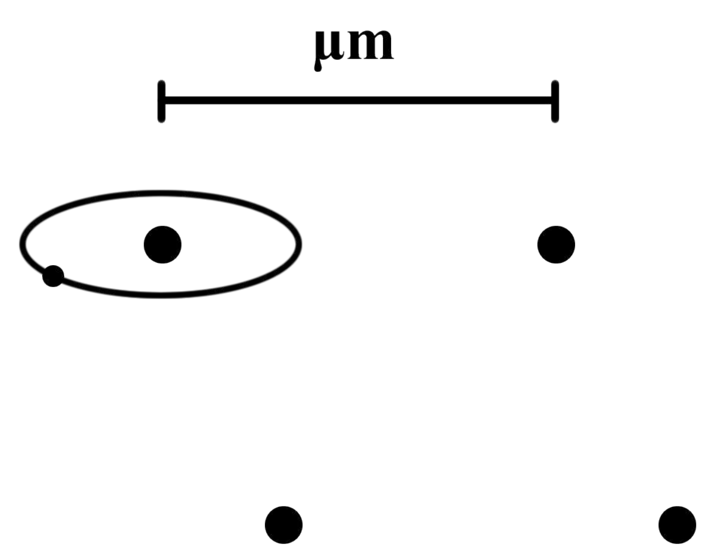

Application

- quantum gates

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3. Entanglement (Wilk *et al*. 2009)

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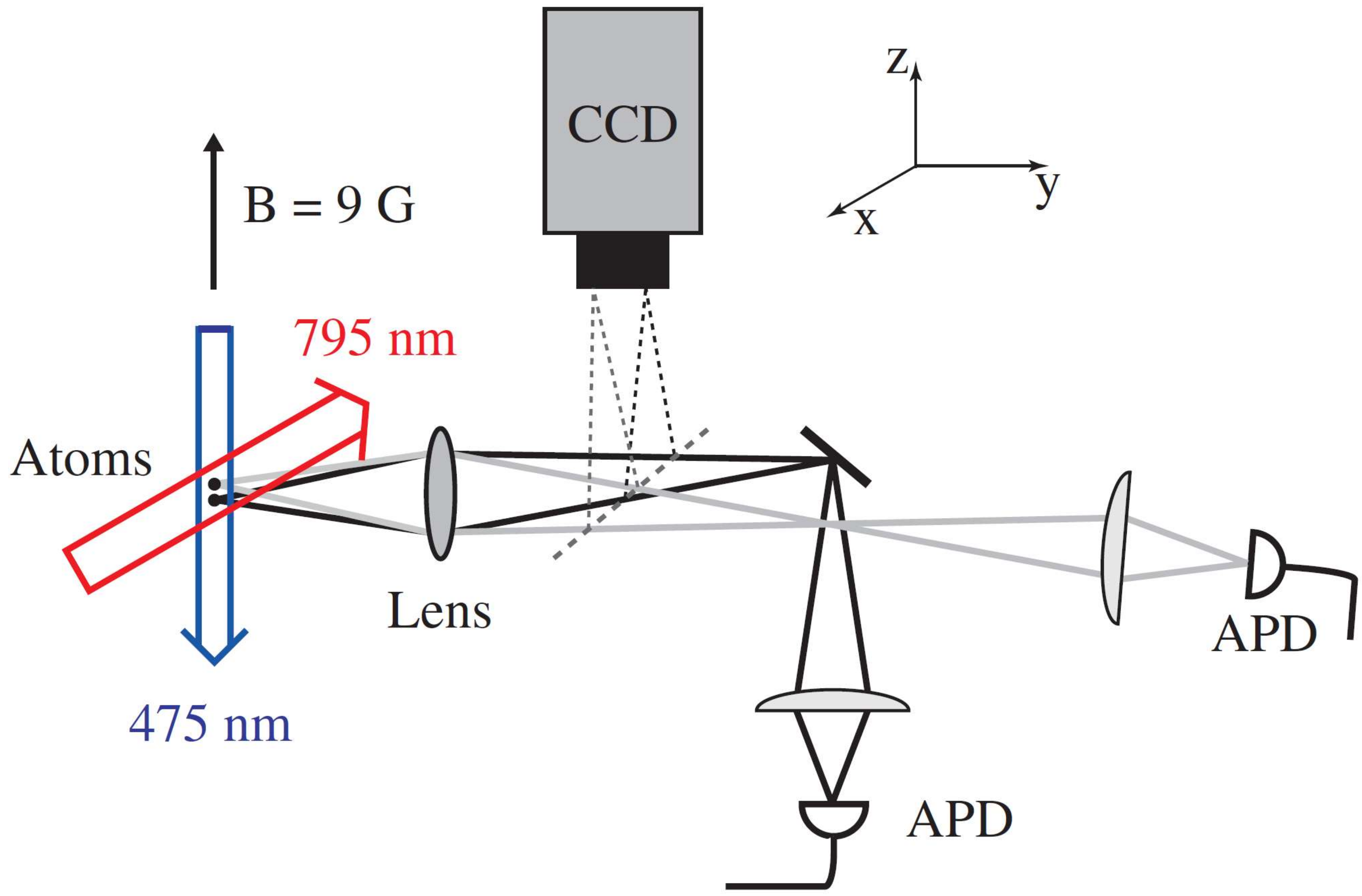
2. Blockade & collective excitation

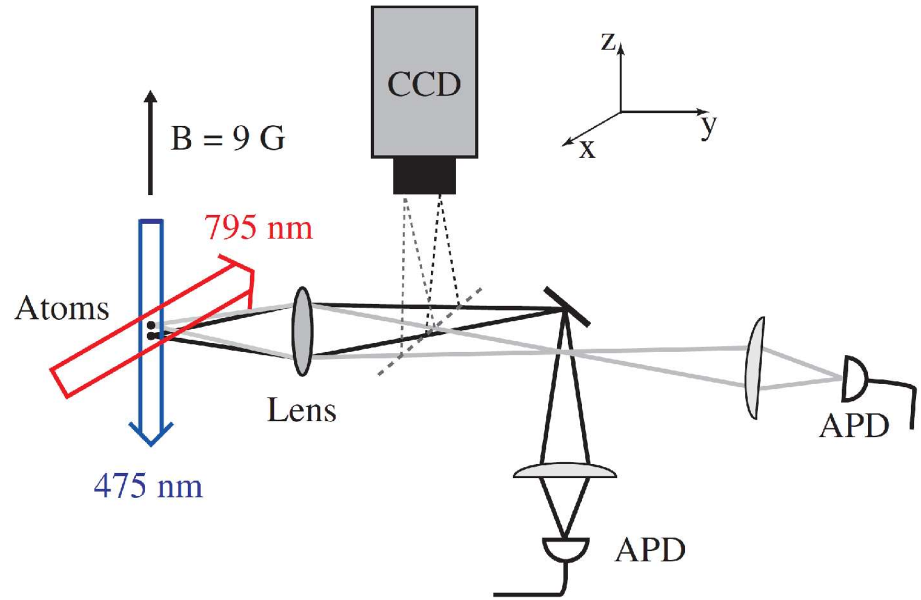
Experimental setup

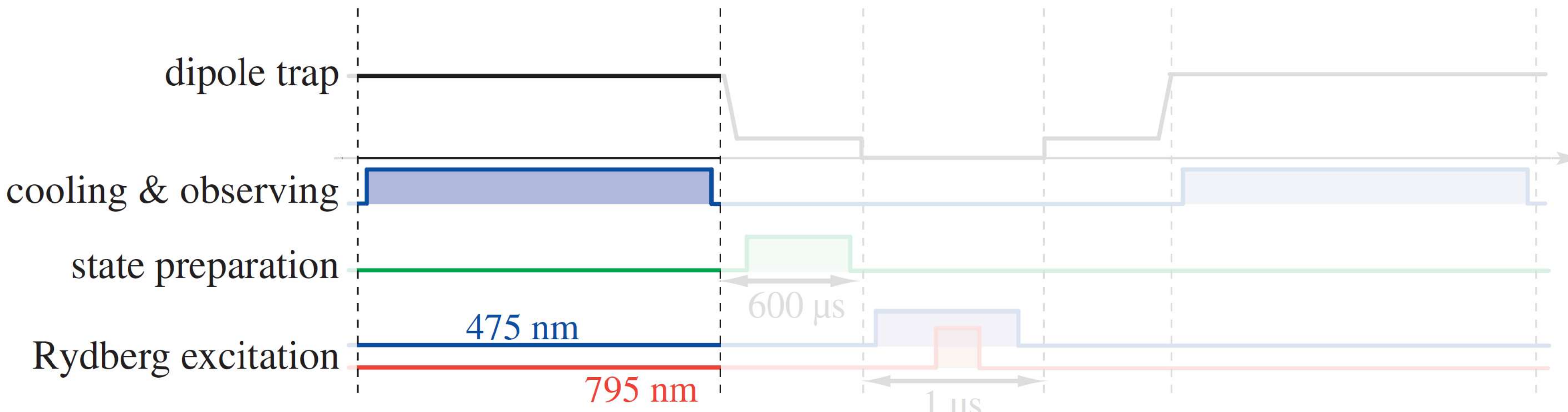


2. Blockade & collective excitation

Dipole traps catch single atoms from an optical molasses.

Magnetic field B defines quantization axis.

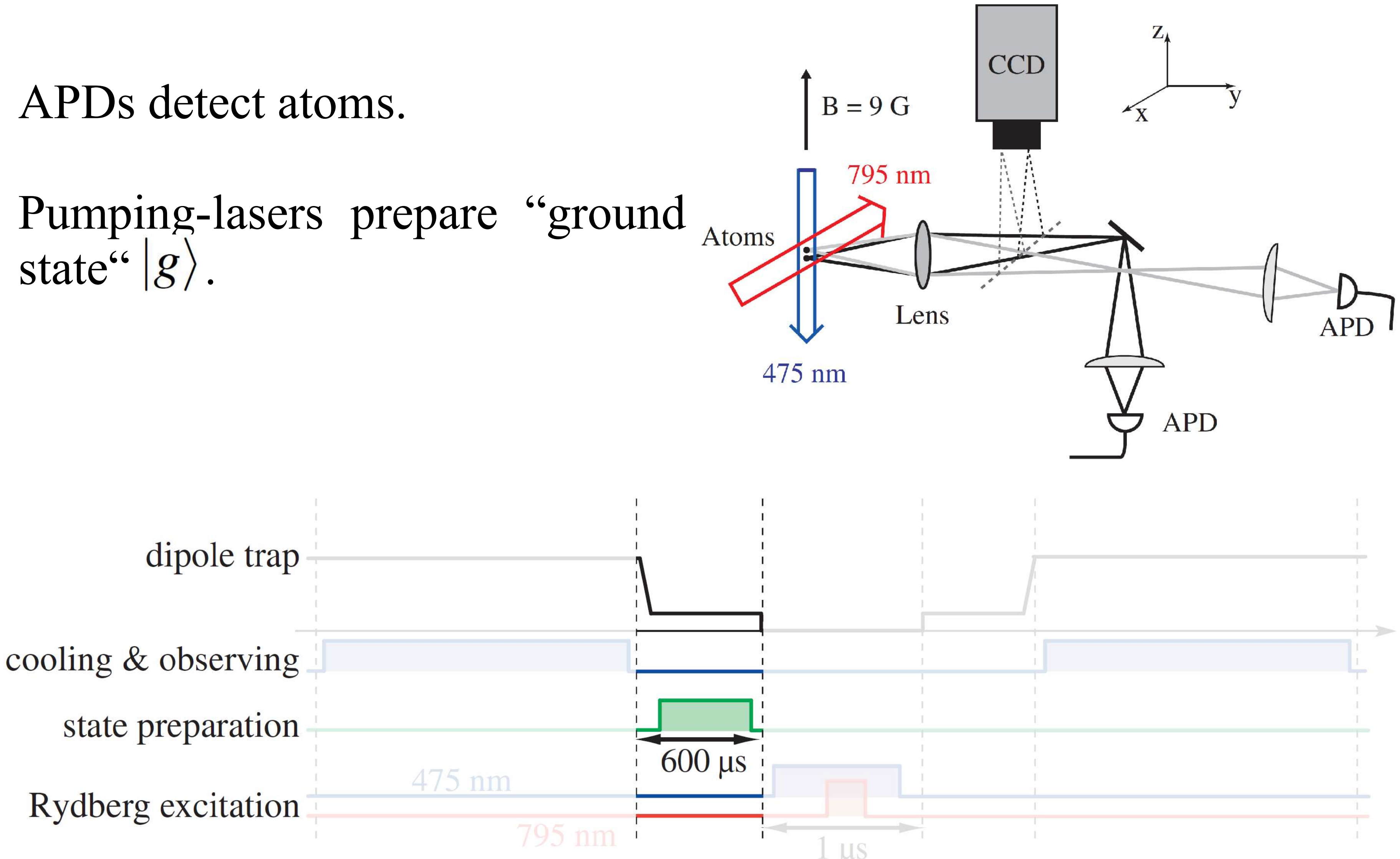




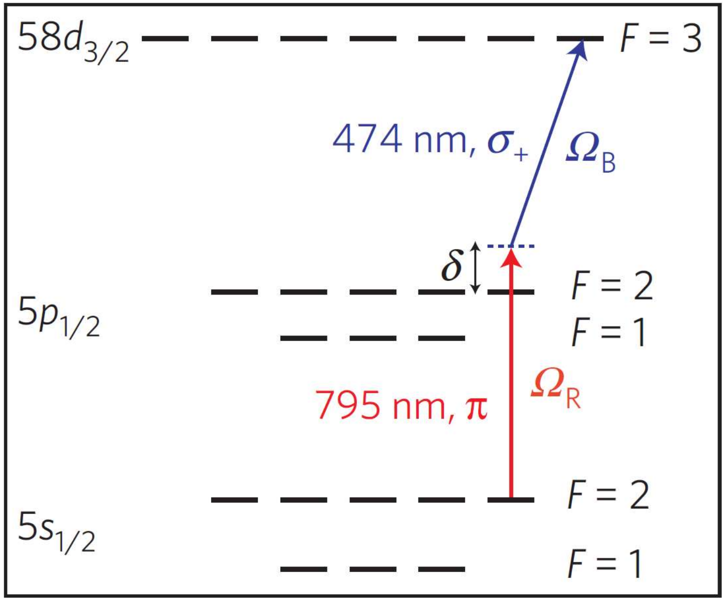
2. Blockade & collective excitation

APDs detect atoms.

Pumping-lasers prepare "ground state" $|g\rangle$.



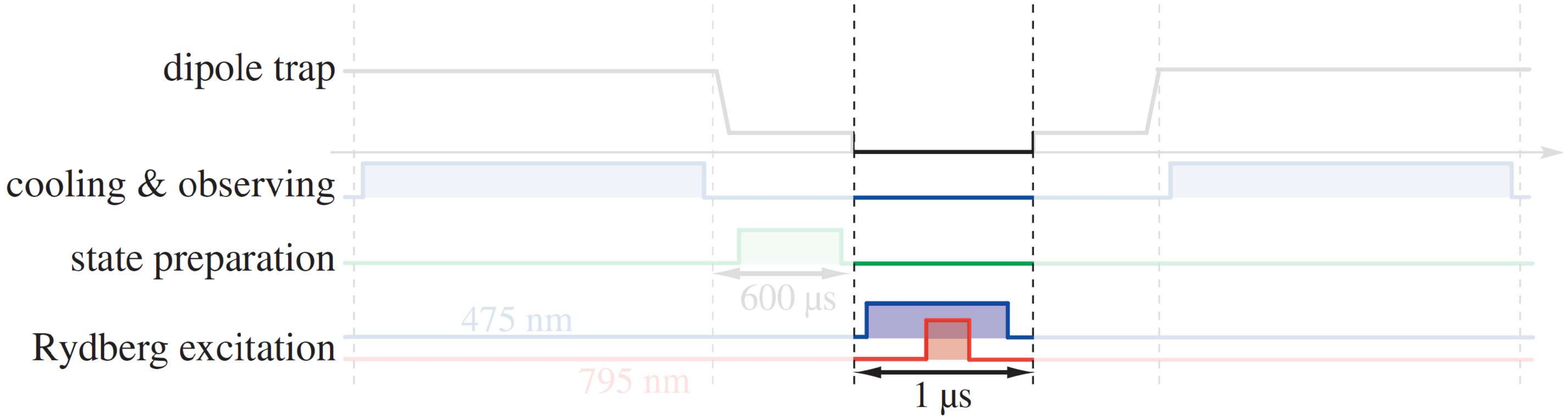
2. Blockade & collective excitation



Traps turned off.

s → d, two-photon transition.

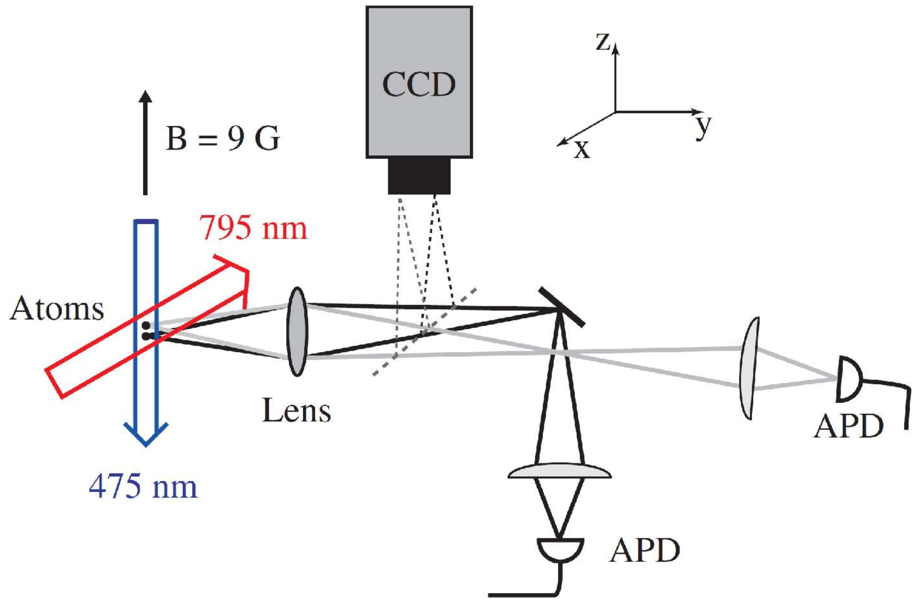
Detuning δ.

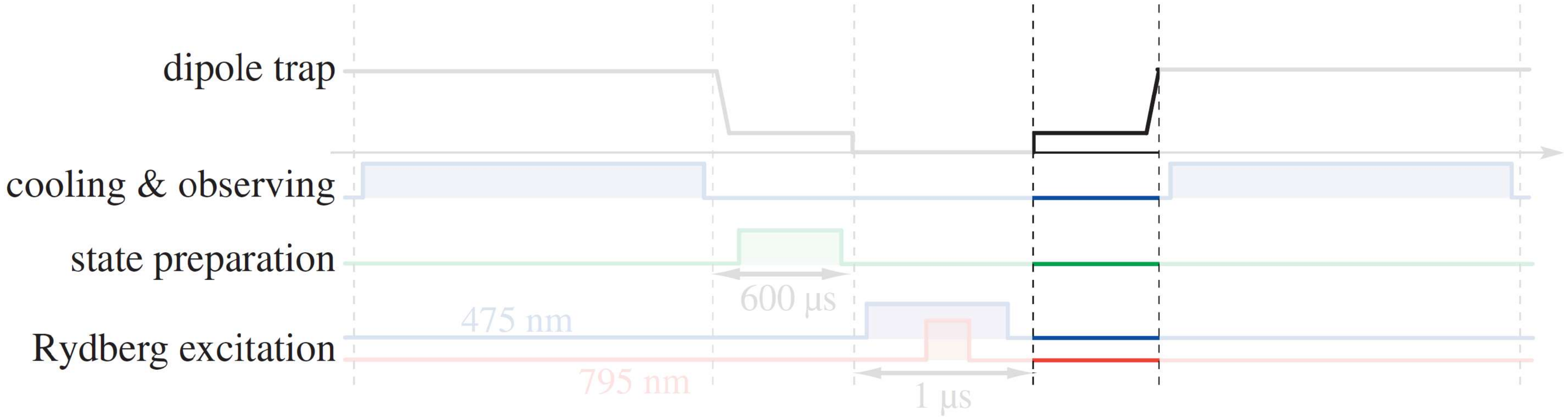


2. Blockade & collective excitation

Rydberg atom cannot be recaptured.

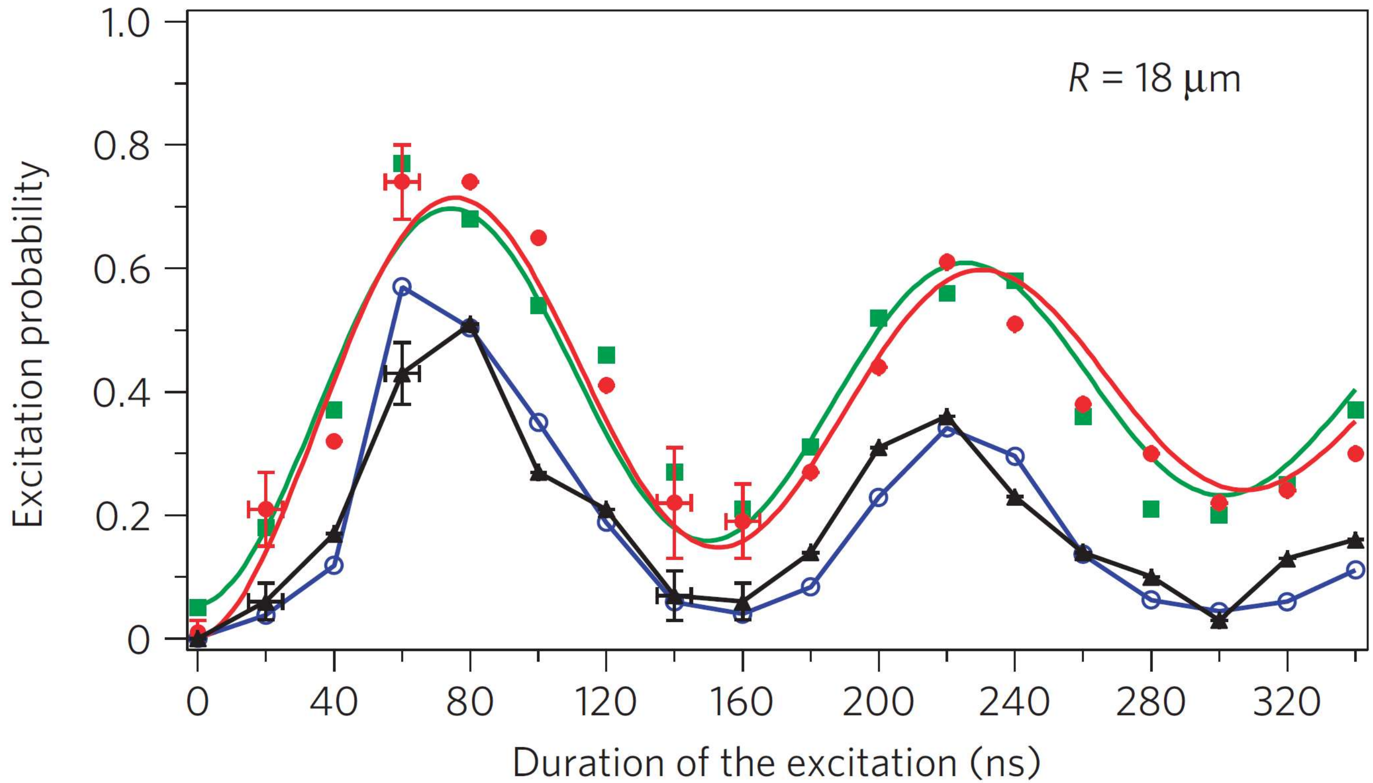
Loss of atom → Rydberg atom.





2. Blockade & collective excitation

Blockade detection



Red, green: Single atom excitation (2. trap empty).

Blue: Product of red and green. Black: Simultaneous excitation.

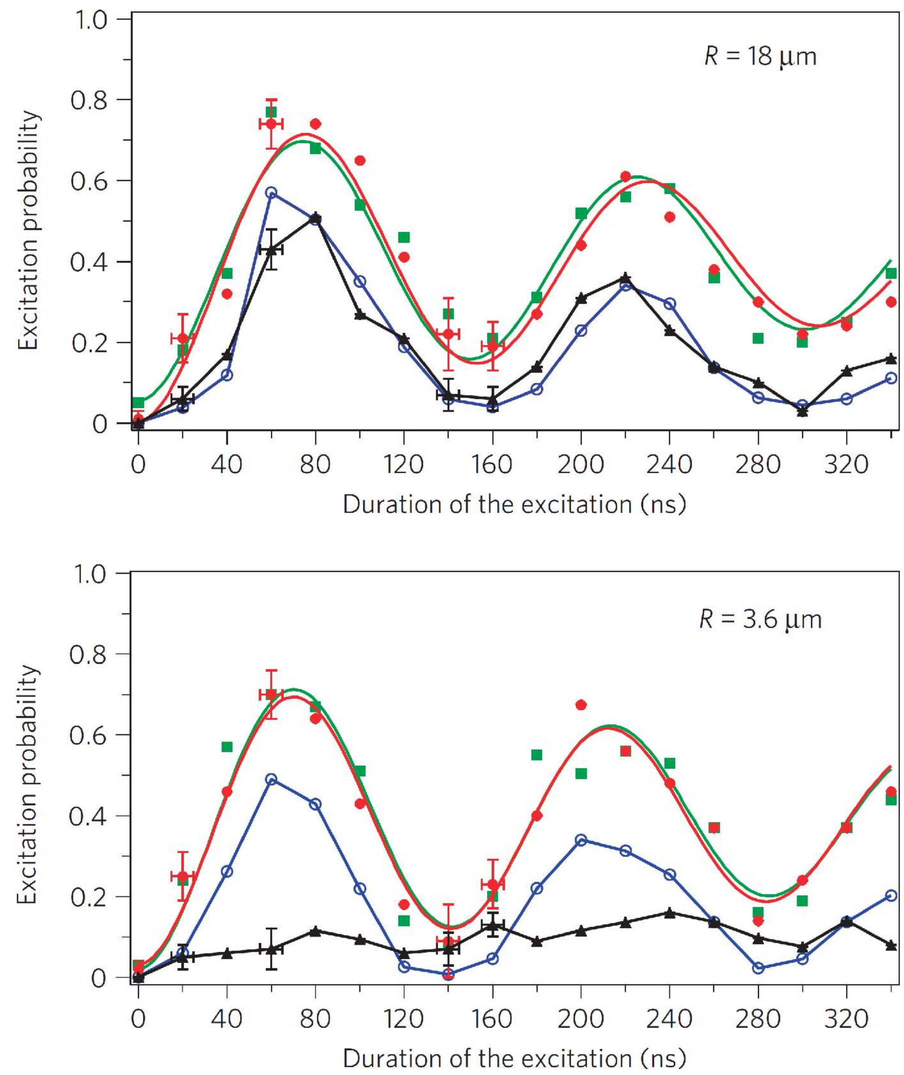
2. Blockade & collective excitation

Blockade detection

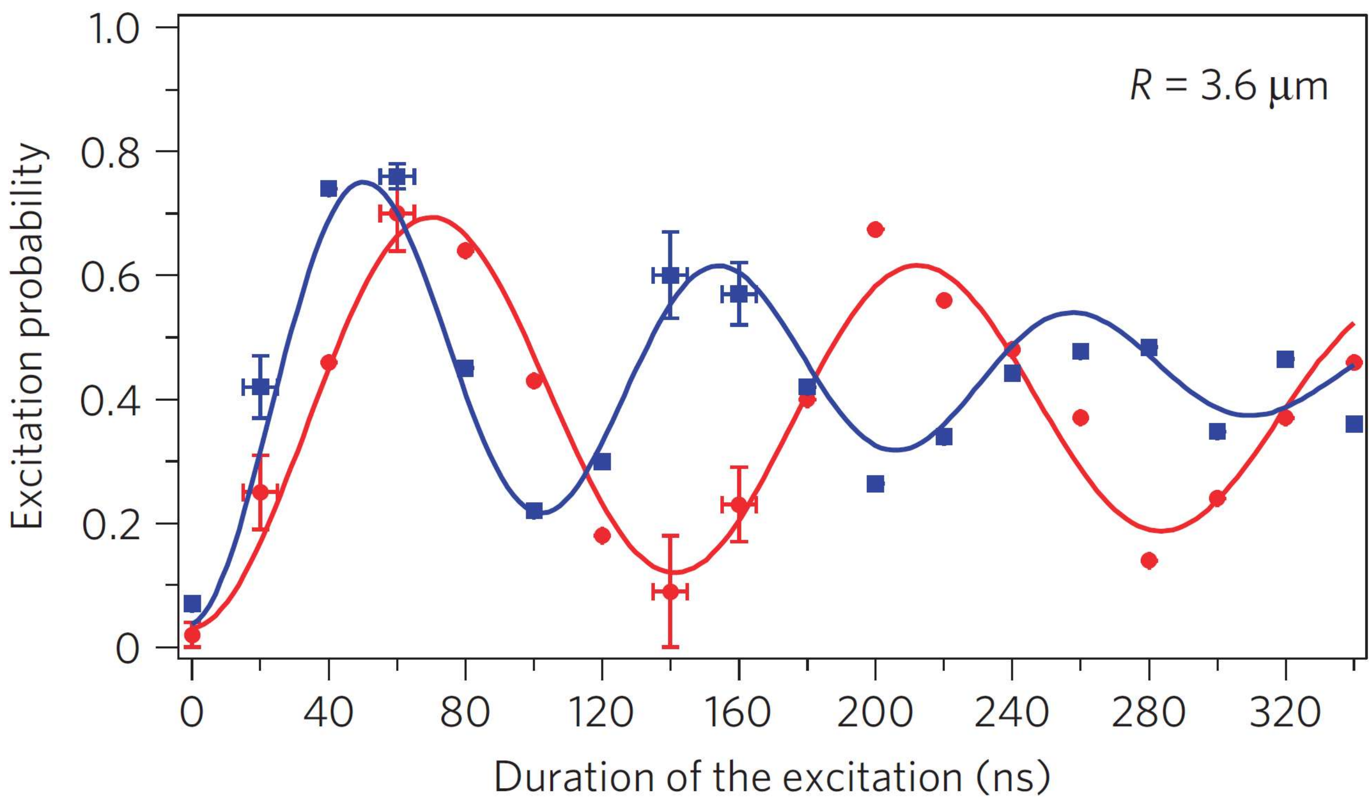
Rabi frequency Ω.

No interaction at 18 μm.

Rydberg blockade at 3.6 μm.



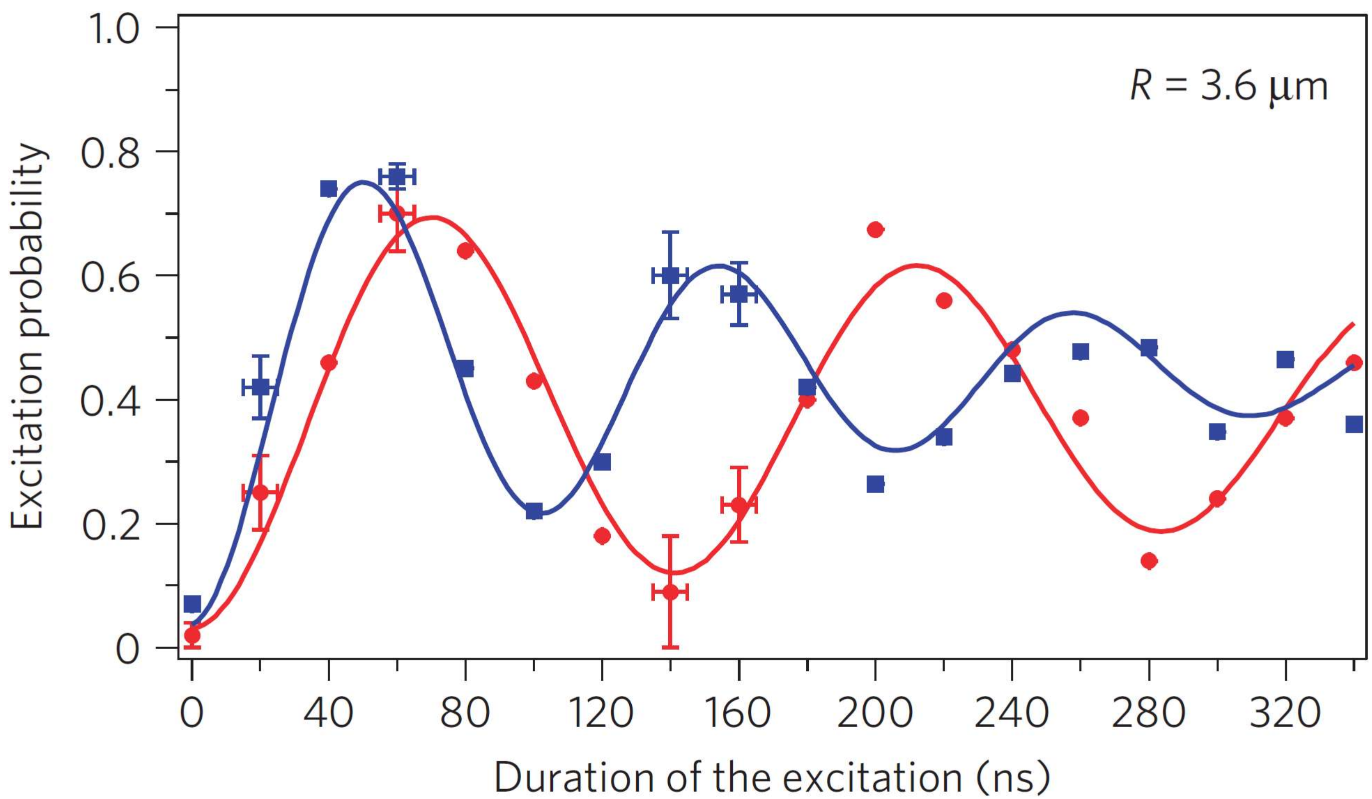
2. Blockade & collective excitation



Red: Single atom excitation (2. trap empty).

Blue: Singel atom excitation (2. atom present).

2. Blockade & collective excitation



$$\Omega' = (1.38 \pm 0.03)\Omega \approx \sqrt{2}\Omega.$$

Indication for entanglement.

2. Blockade & collective excitation

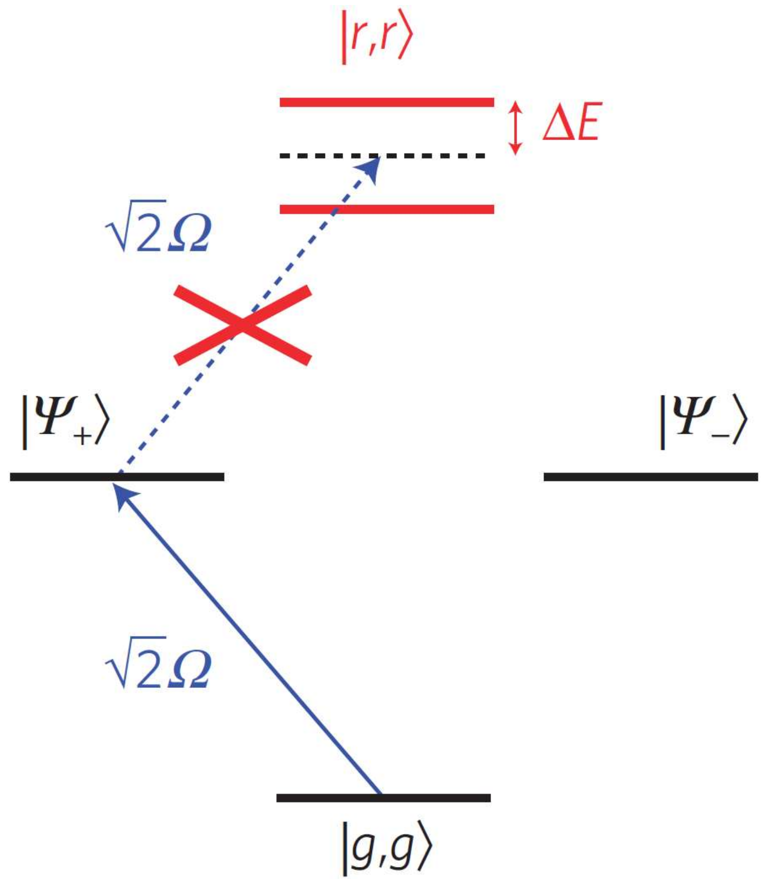
Collective excitation

Atoms excited by same pulses.
$\quad\rightarrow$ Entanglement.

$$|\Psi_\pm\rangle = \frac{1}{\sqrt{2}}\left(|r,g\rangle \pm |g,r\rangle\right).$$

Effective Rabi frequency $\sqrt{2}\Omega$.

$|\Psi_-\rangle$ not coupled (wrong parity).



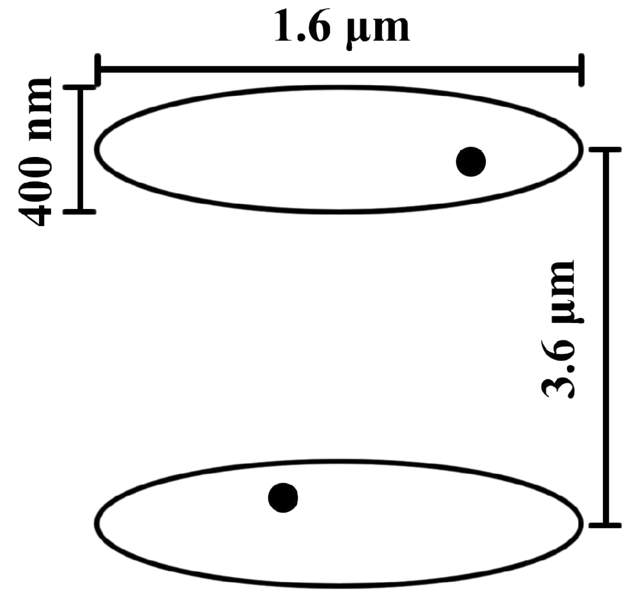
3. Entanglement

Problems measuring entanglement

$$|\Psi_+\rangle = \frac{1}{\sqrt{2}}\left(e^{i\vec{k}\cdot\vec{r}_a}|r,g\rangle + e^{i\vec{k}\cdot\vec{r}_b}|g,r\rangle\right),$$

$$\rightarrow |\Psi_+\rangle = \frac{1}{\sqrt{2}}\left(|r,g\rangle + e^{i\phi}|g,r\rangle\right), \quad \phi = \vec{k}\cdot(\vec{r}_a - \vec{r}_b).$$

$\vec{k} = \vec{k}_R + \vec{k}_B$ wave vectors of the lasers,
$\vec{r}_a,\ \vec{r}_b$ position of the atoms.

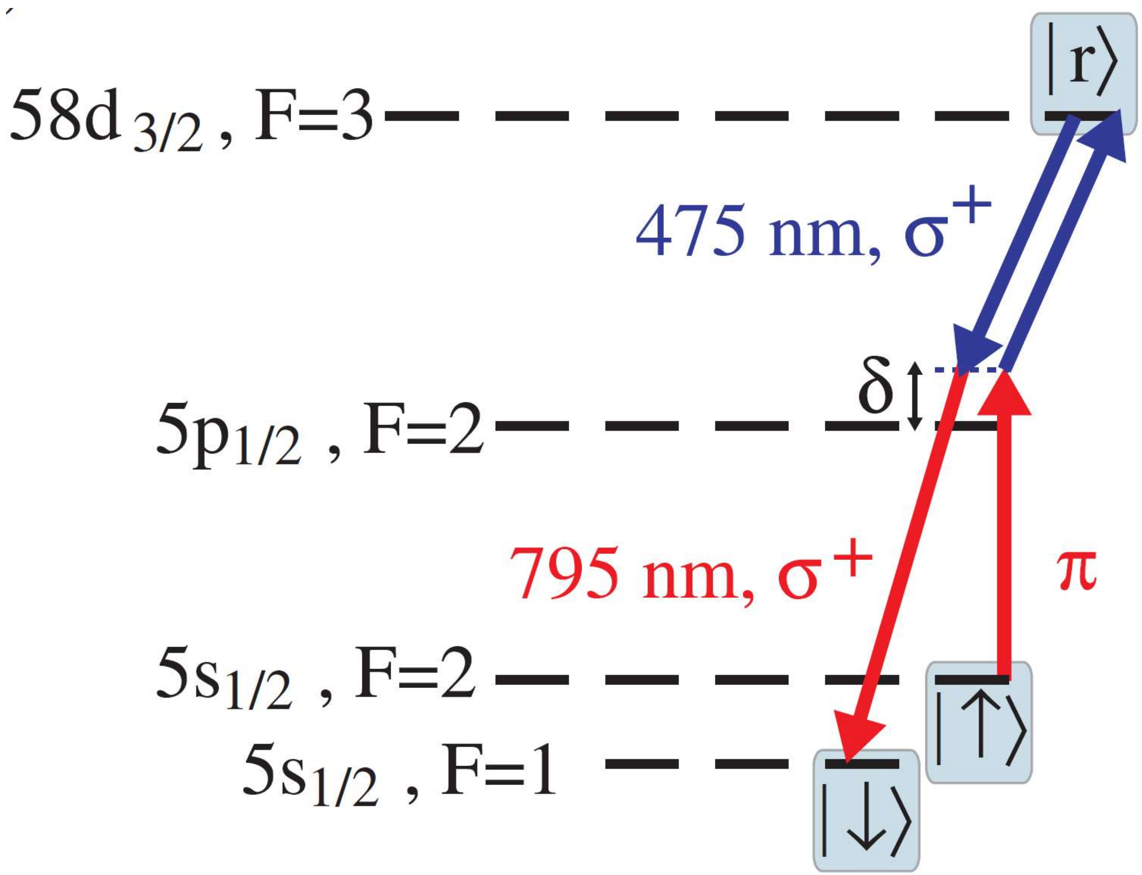


Movement during excitation negligible.

Phase ϕ varies randomly over 2π.
$\rightarrow$ Effecitve decoherence.

3. Entanglement

Solution



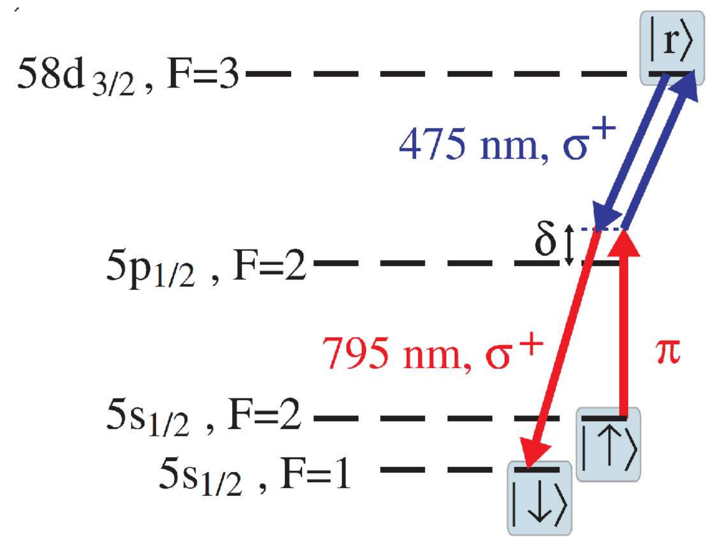
Mapping the Rydberg state to another groundstate $|\downarrow\rangle$.

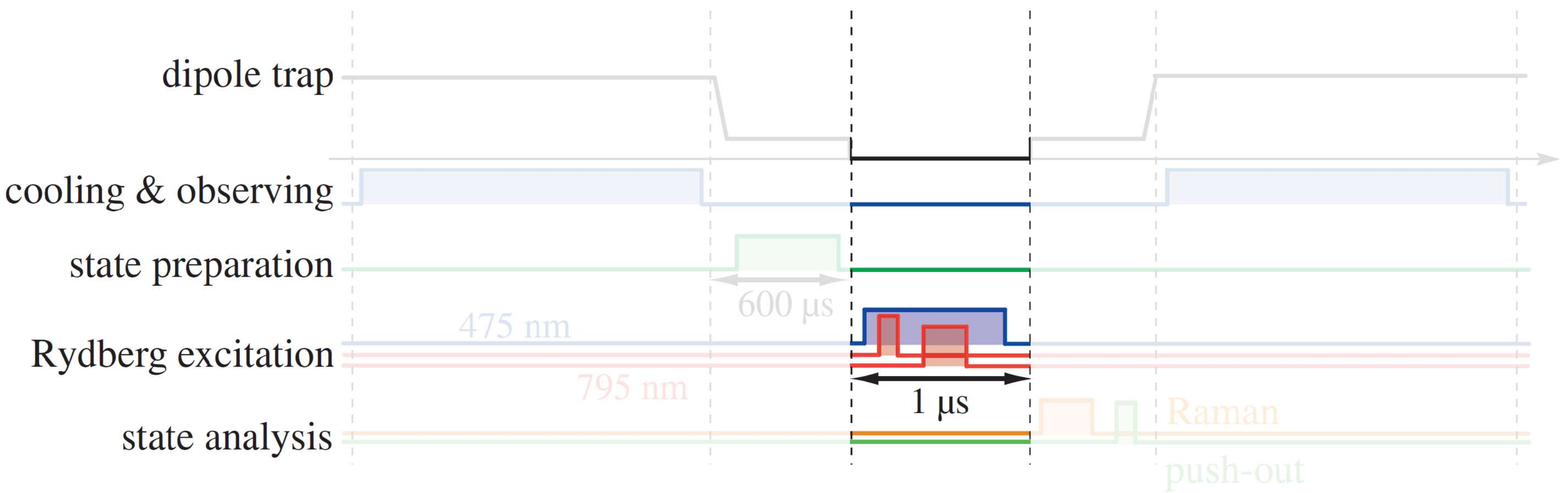
$\vec{k}_{excitation} \approx \vec{k}_{mapping}$ $\rightarrow$ Phase ϕ rewindet during emission.

3. Entanglement

$$|\Psi_+\rangle = \frac{1}{\sqrt{2}}\left(|r,g\rangle + e^{i\phi}|g,r\rangle\right),$$

$$\rightarrow \frac{1}{\sqrt{2}}\left(|\downarrow,\uparrow\rangle + |\uparrow,\downarrow\rangle\right).$$



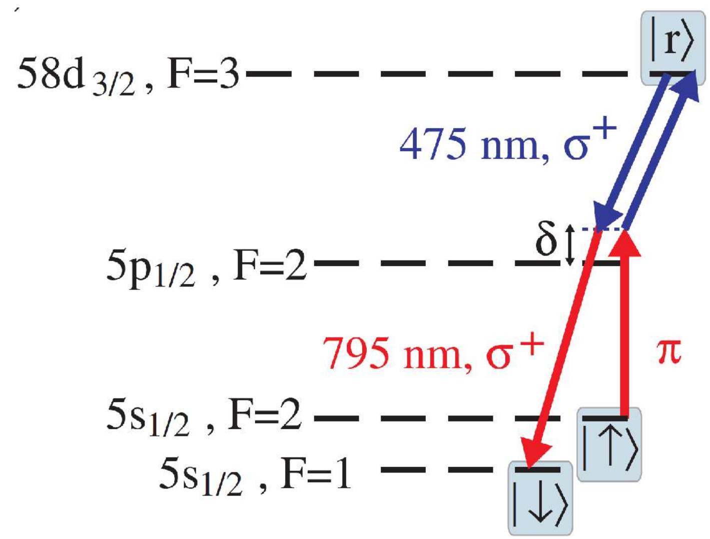


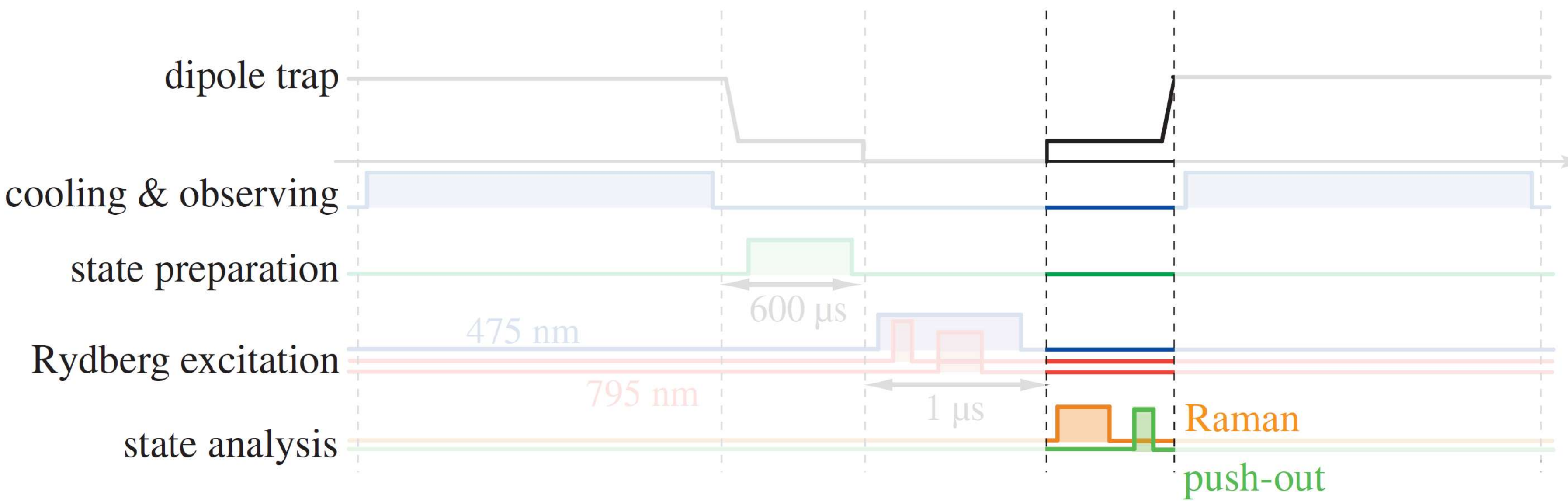
3. Entanglement

Global Raman rotations analyze state.

Push-out laser ejects $|\uparrow\rangle$ states.

$$\begin{aligned} |r\rangle &\rightarrow \text{lost}, \\ |\uparrow\rangle &\rightarrow \text{lost}, \\ |\downarrow\rangle &\rightarrow \text{recaptured}. \end{aligned}$$

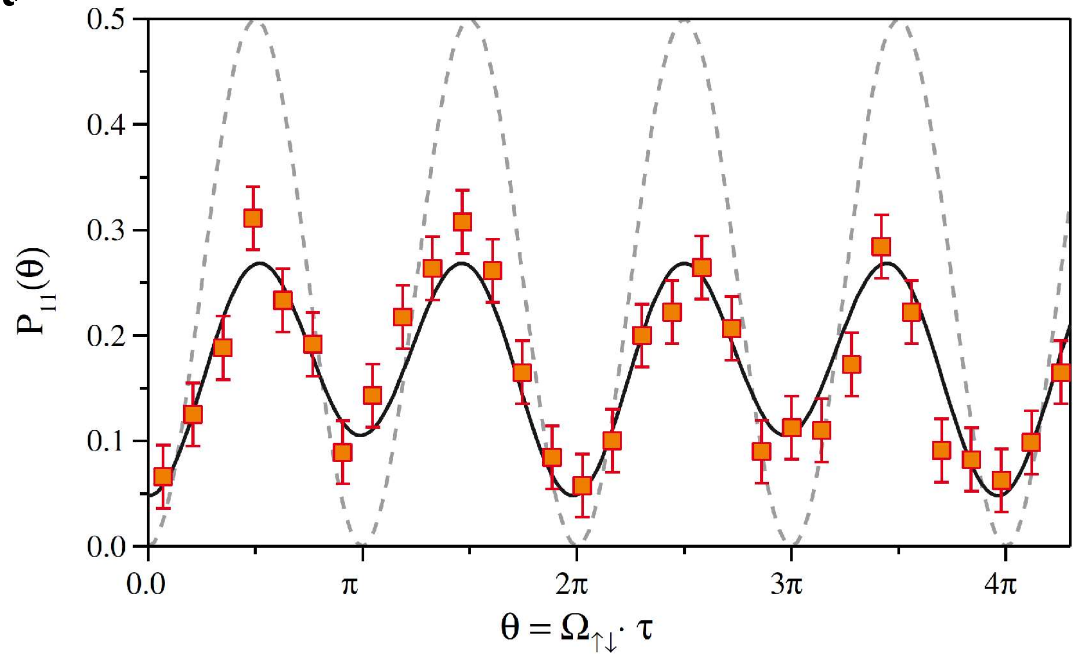




3. Entanglement

Measuring entanglement

$$\frac{1}{\sqrt{2}}\left(|\downarrow,\uparrow\rangle + |\uparrow,\downarrow\rangle\right).$$



Density matrix elements given by global Raman rotations.

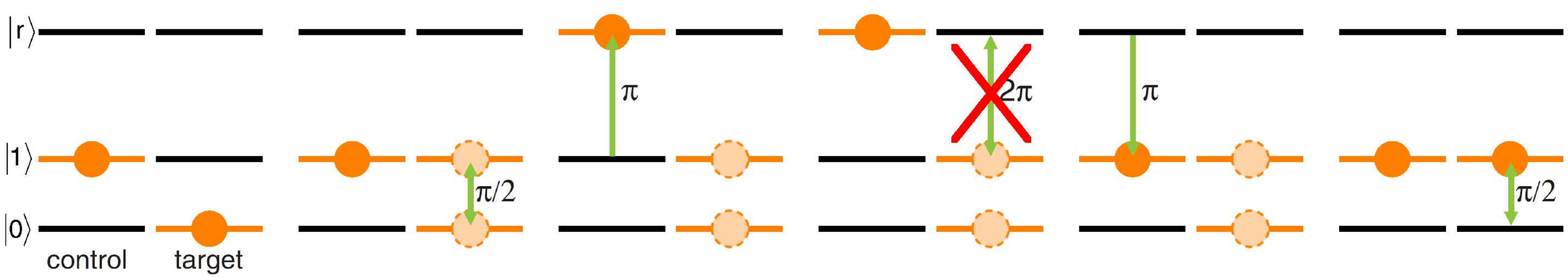
Probability to recapture two atoms: $p = 0.62(3)$.

Fidelity: $F = 0.75(7)$ (theoretical maximum $F = 0.97$).

4. CNOT gate

H-Cz CNOT gate

Atoms controlled separately.

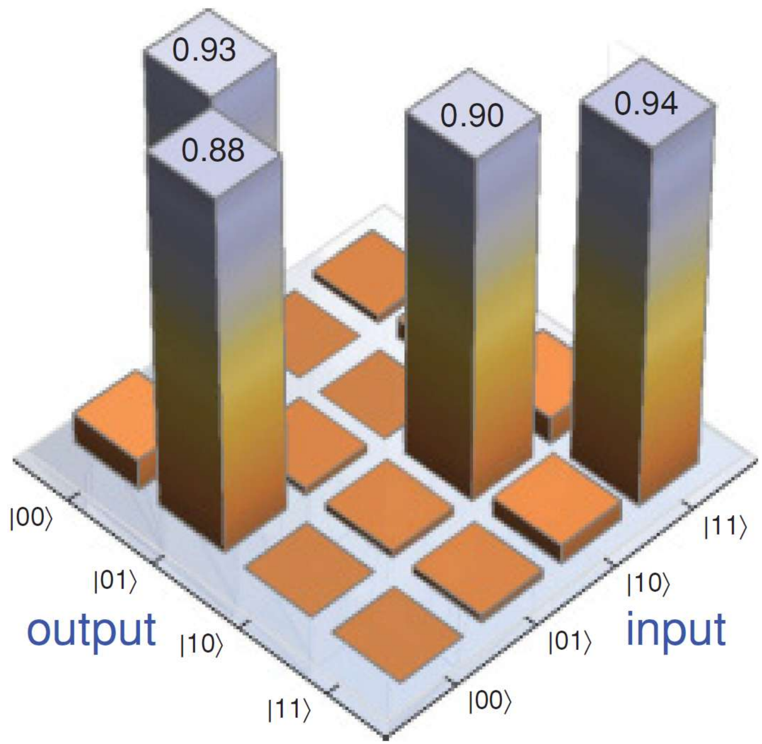


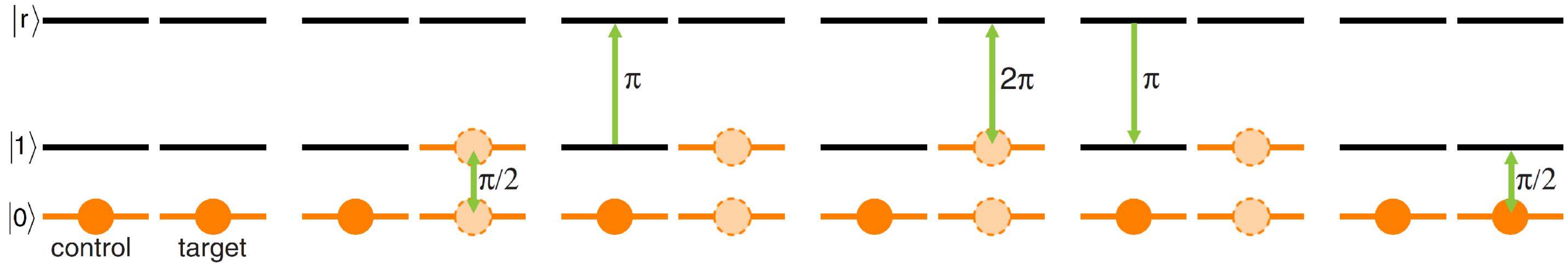
4. CNOT gate

H-Cz CNOT gate

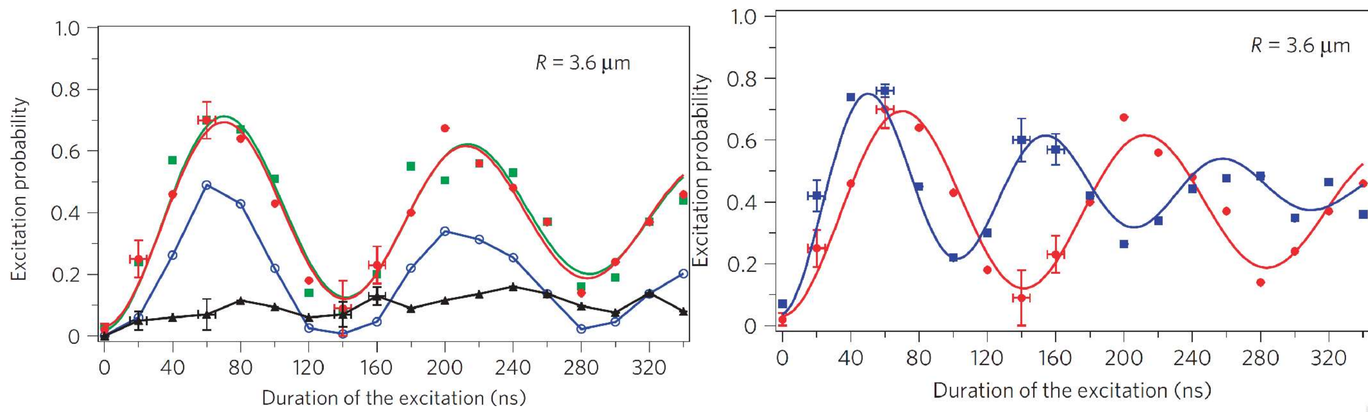
Atoms controlled separately.

2π pulse gives a π phase shift to the target atom.





5. Summary & references



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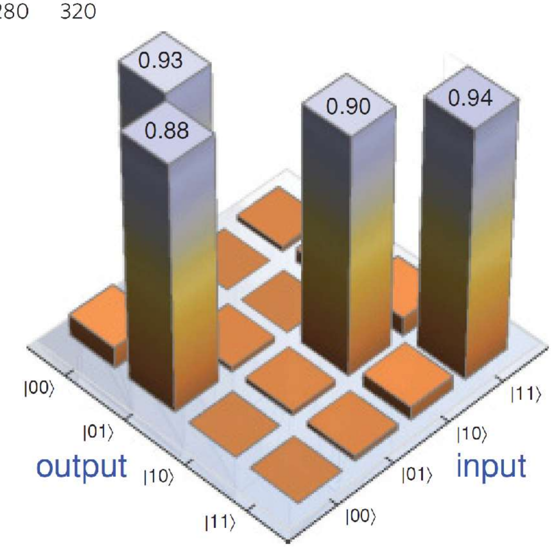

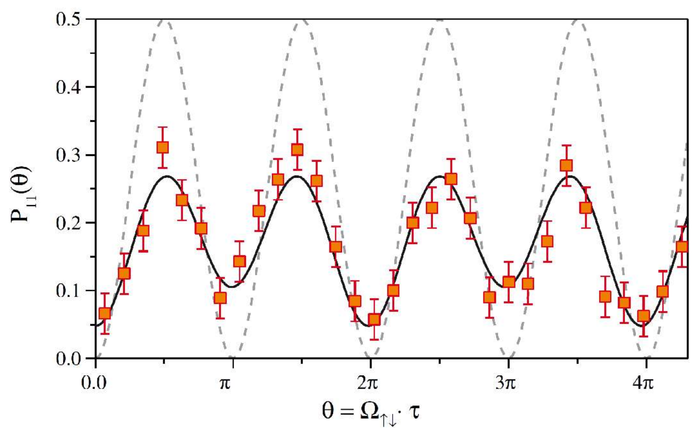

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X. L. Zhang *et al.*, Phys. Rev. A 82, 030306(R) (2010).

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