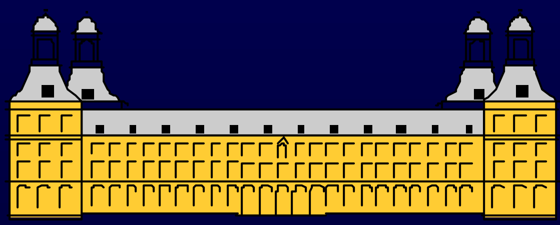
Single Atom wants to meet Single Photon

Controlled Processes with Neutral Atoms

Collège de France

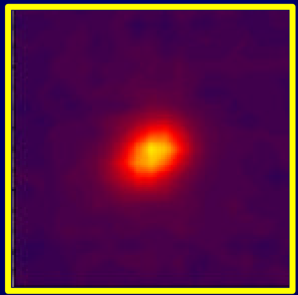
Paris, Fevriér 26, 2002



Universität Bonn

D. Meschede,

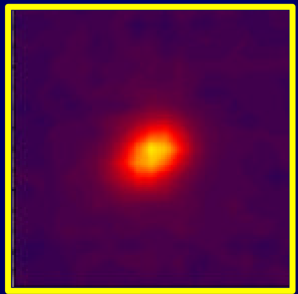
Institut für Angewandte Physik

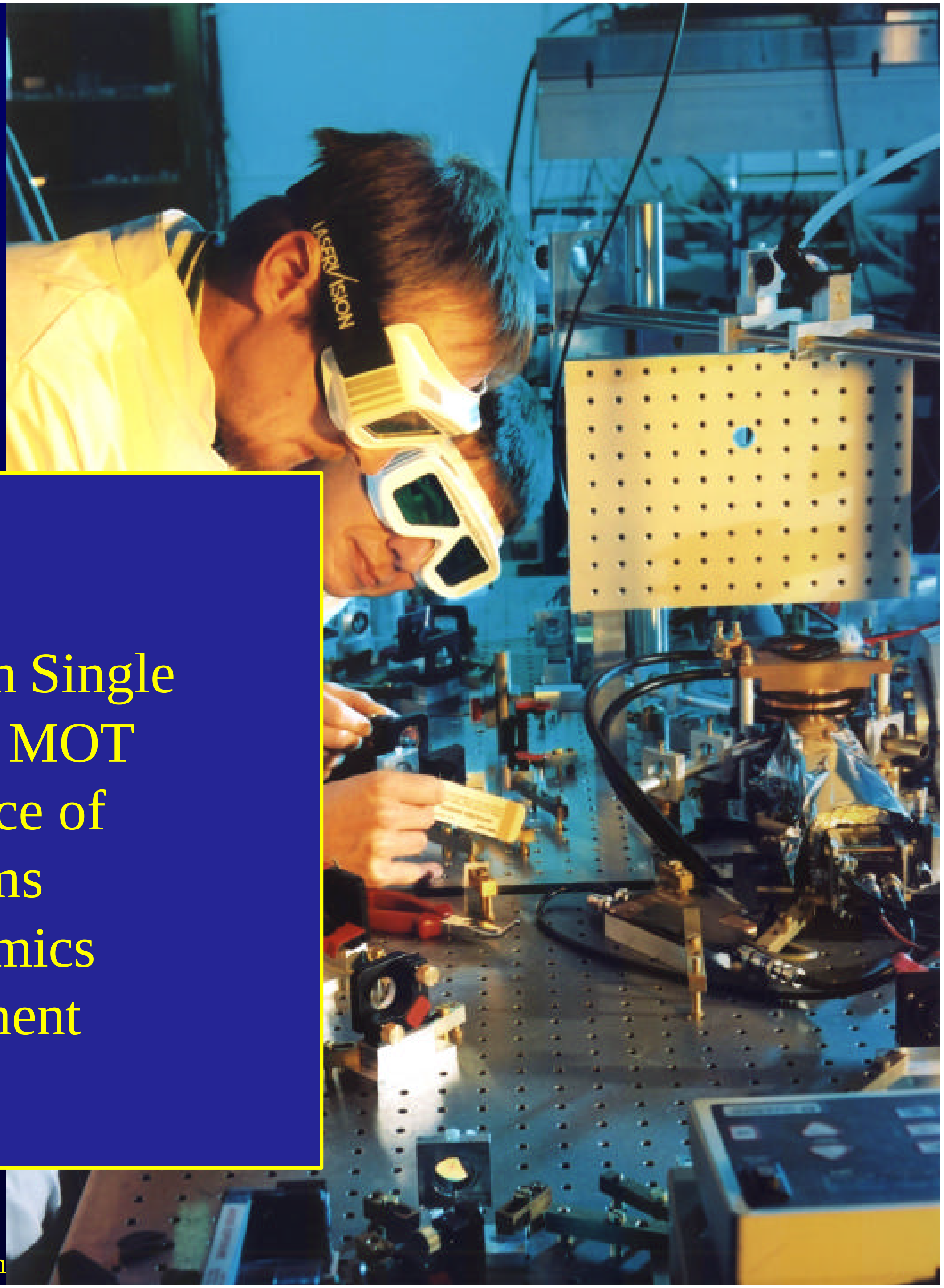


Single Atoms Crew

Dr.Victor Gomer
Stephan Kuhr
Wolfgang Alt
Dominik Schrader
Martin Müller
Yephen Miroshnyshenko

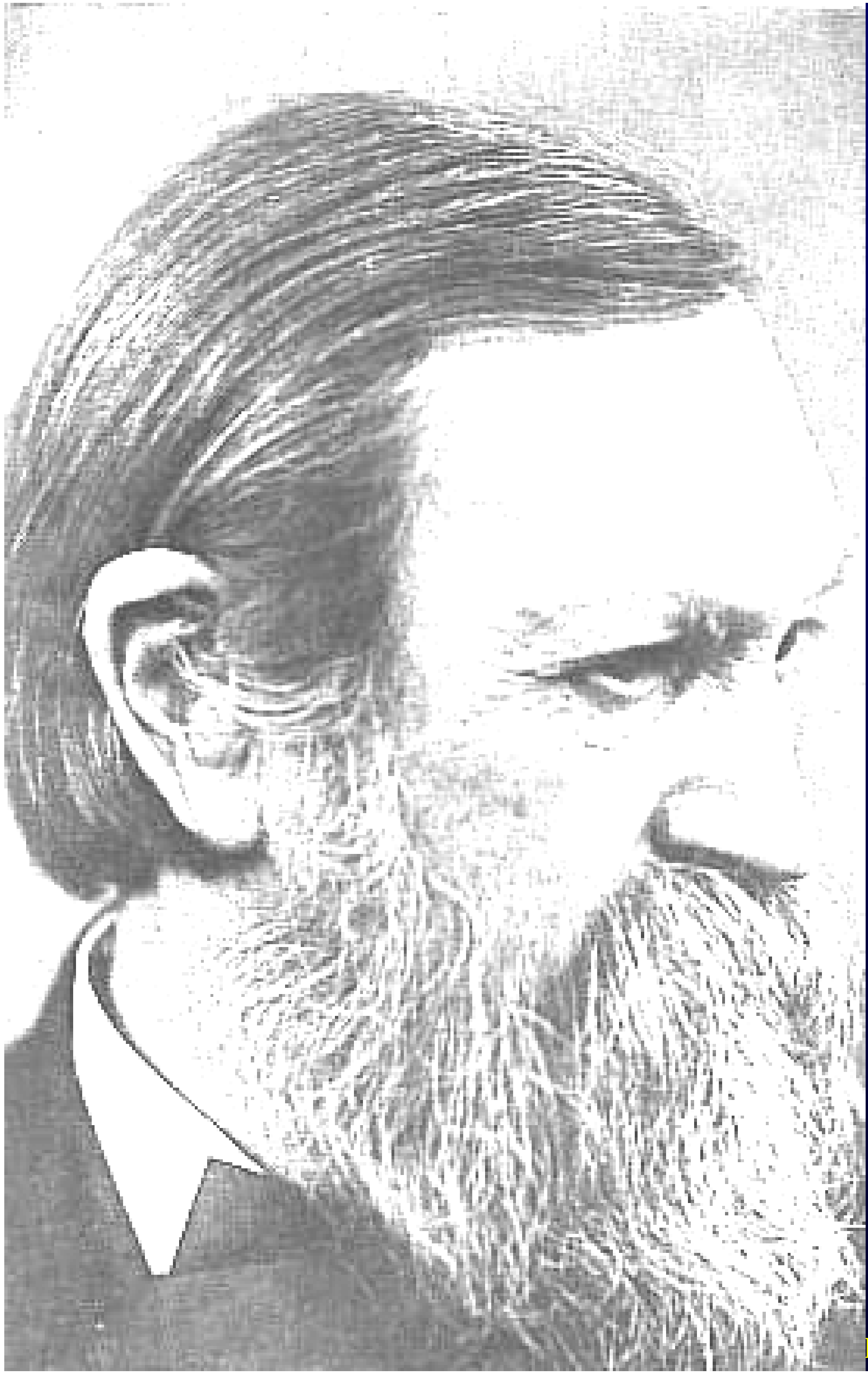
Daniel Frese (`00)
Bernd Ueberholz (`01)





Overview

1. Experimenting with Single Neutral Atoms in a MOT
2. Deterministic Source of Single Neutral atoms
3. Single Atom Dynamics
4. Towards entanglement



„Atome können wir nirgends wahrnehmen, sie sind wie alle Substanzen Gedankendinge.“

(„Atoms themselves cannot be perceived anywhere, like all substances they are abstractions.“ 1912)

Ernst Mach (1838-1916)

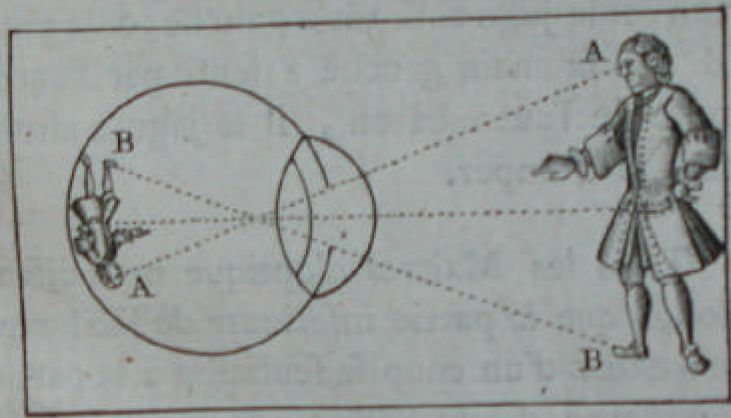
1867 Professor for Experimental Physics Prague
1895 Professor for Philosophy Vienna

ELÉMENS
DE LA
PHILOSOPHIE DE NEUTON,

Mis à la portée de tout le monde.

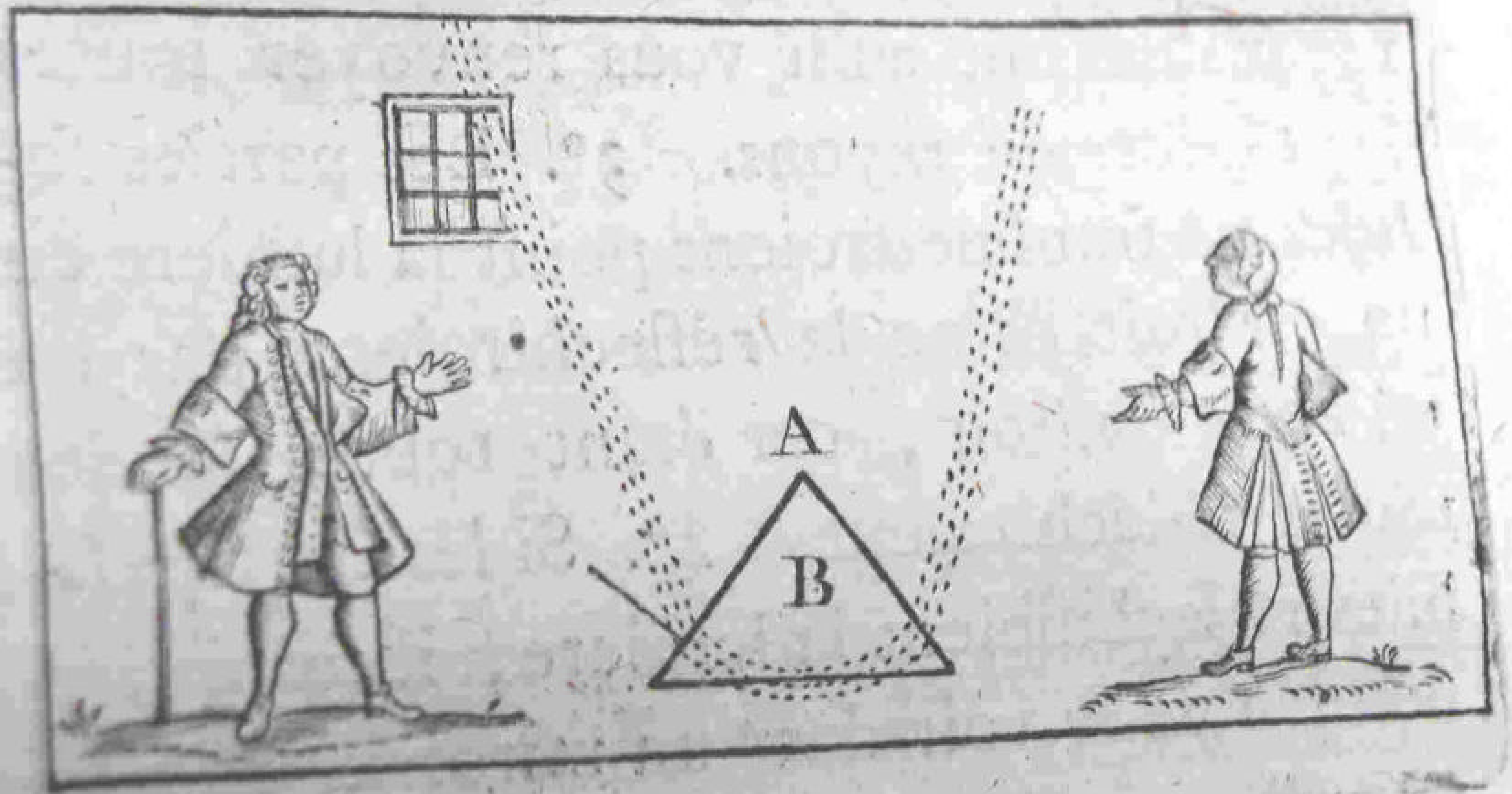
Par Mr. DE VOLTAIRE.

A AMSTERDAM,
Chez ETIENNE LEDET & Compagnie.
M. DCC. XXXVIII.



Pour résoudre cette queſtion, on ſe ſert de la comparaiſon de l'aveugle, qui tient dans ſes mains deux bâtons croiſez avec leſquels il devine très-bien la poſition des objets.

la lumiere eſt réflechie.



2002:
Physics/Quantum Optics is moving towards Quantum Engineering!

Overview

1. **Experimenting with Single Neutral Atoms in a MOT**
2. Deterministic Source of Single Neutral atoms
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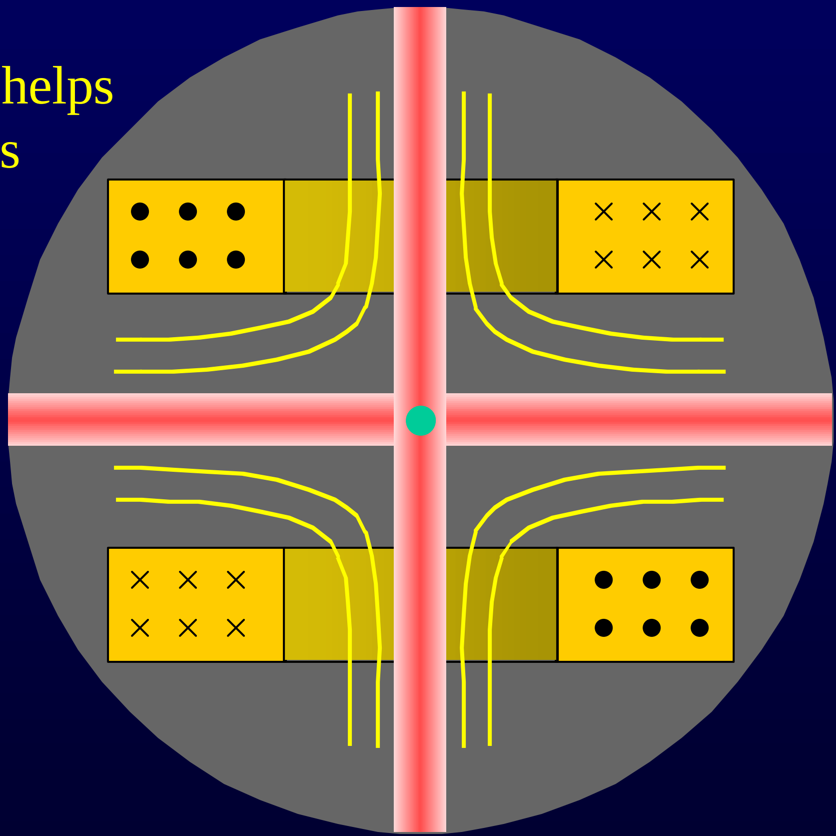
1. Experimenting with Single Neutral Atoms

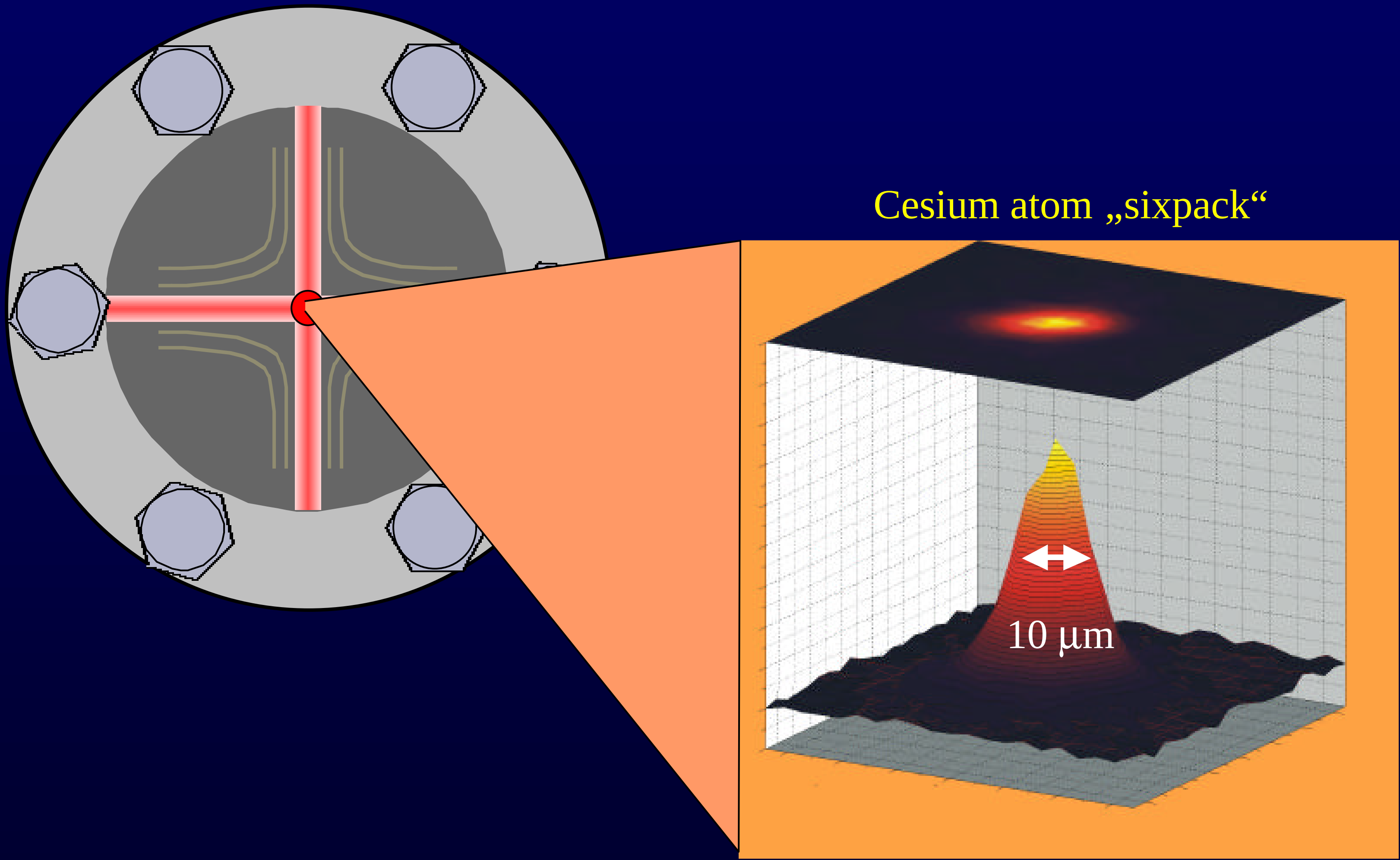
Magneto-optical Trap (MOT)

Strong magnetic field helps
to better localise atoms



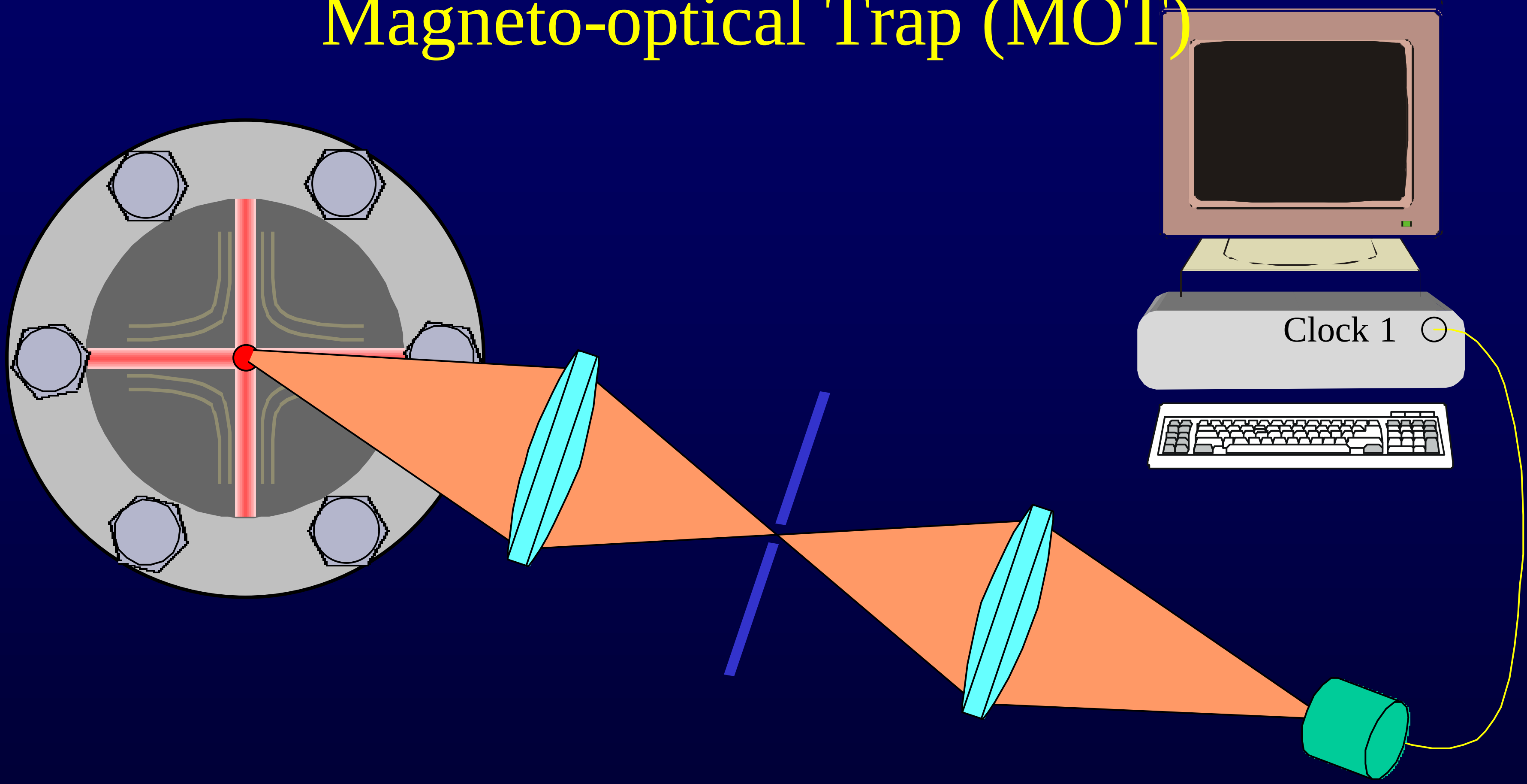
1. Experimenting with Single Neutral Atoms

Magneto-optical Trap (MOT)



1. Experimenting with Single Neutral Atoms

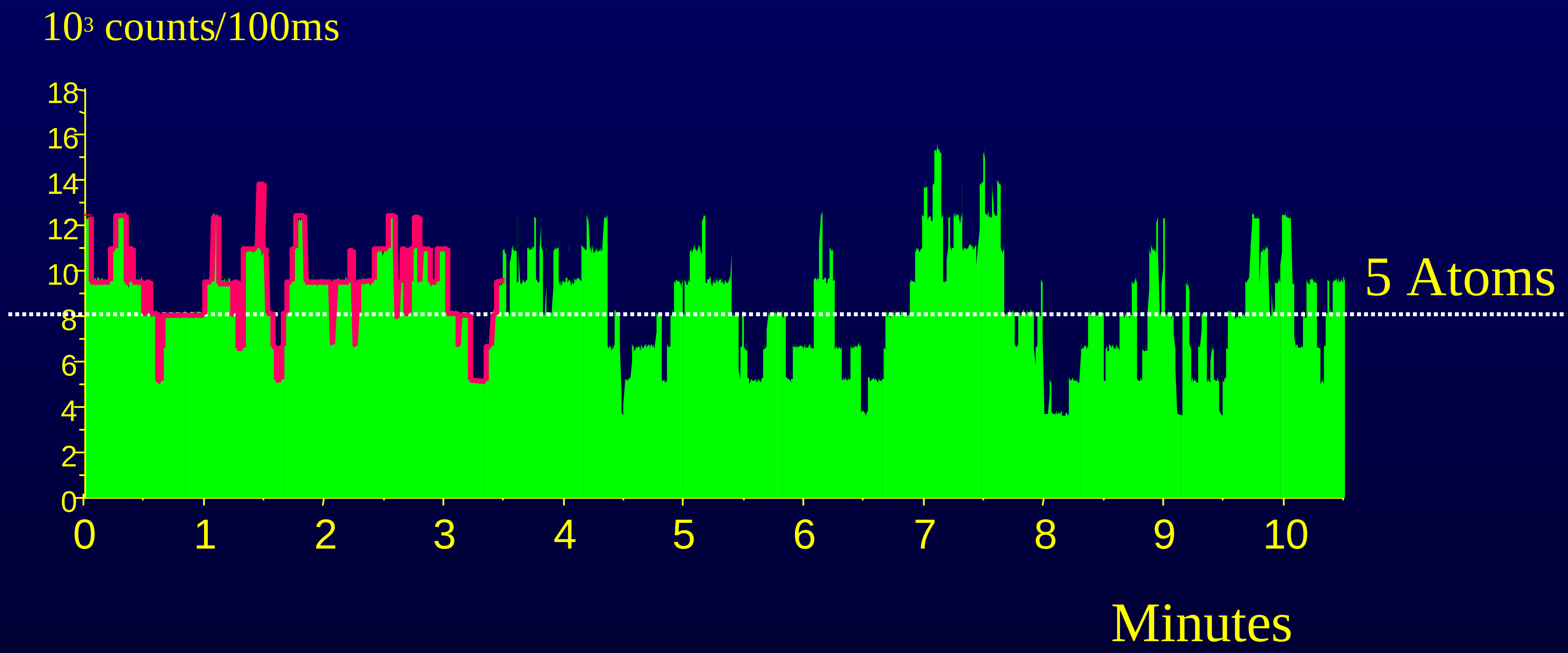
Magneto-optical Trap (MOT)



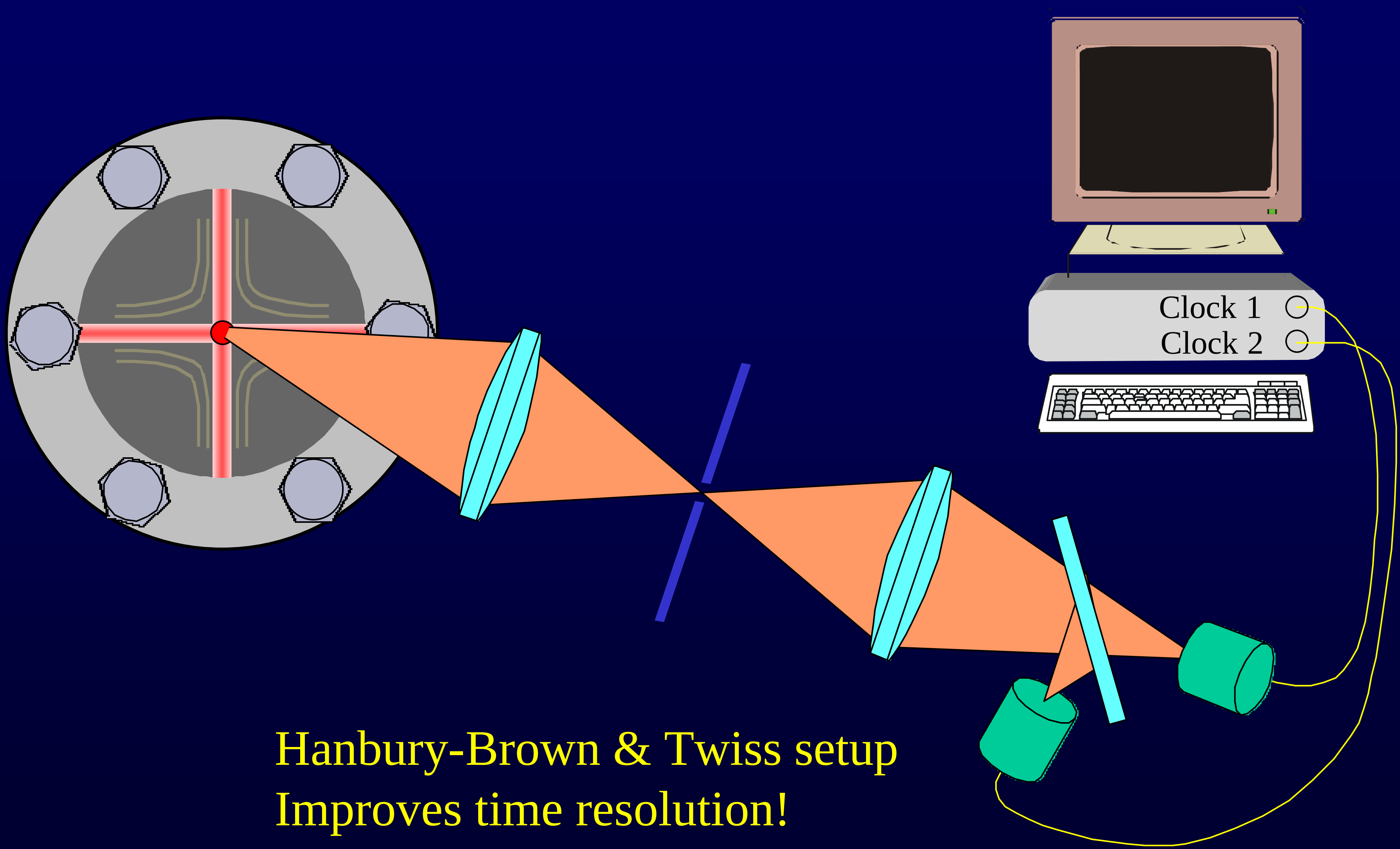
Detectors: APD (EG&G),
200ns dead time, Q.E. > 50%

Clocks: 50 ns resolution, ~ 1 MHz dyn. range

Dynamics of trapped atoms



1. Experimenting with Single Neutral Atoms



Hanbury-Brown & Twiss setup
Improves time resolution!

1. Experimenting with Single Neutral Atoms

Photon correlations
reveal atomic dynamics
at all relevant time scales!

1.	**Presto**	**Internal Dynamics**	**@ nano seconds**
2.	**Allegro**	**Magnetic Bistability**	**@ micro seconds**
3.	Andante	Global trap motion	@ milli seconds
4.	Adagio	Cold collisions	@ seconds/minutes

For a review see: V. Gomer and D. Meschede, Ann.Phys.(Leipzig)10, 9 –18 (2001) and refs. therein

1. Experimenting with Single Neutral Atoms

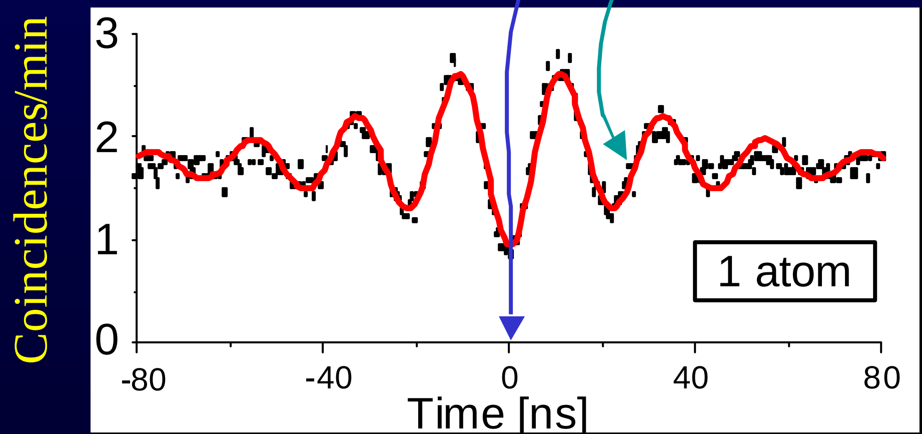
Photon Antibunching – a Classic of Quantum Optics

„Prepares“ atom in ground state

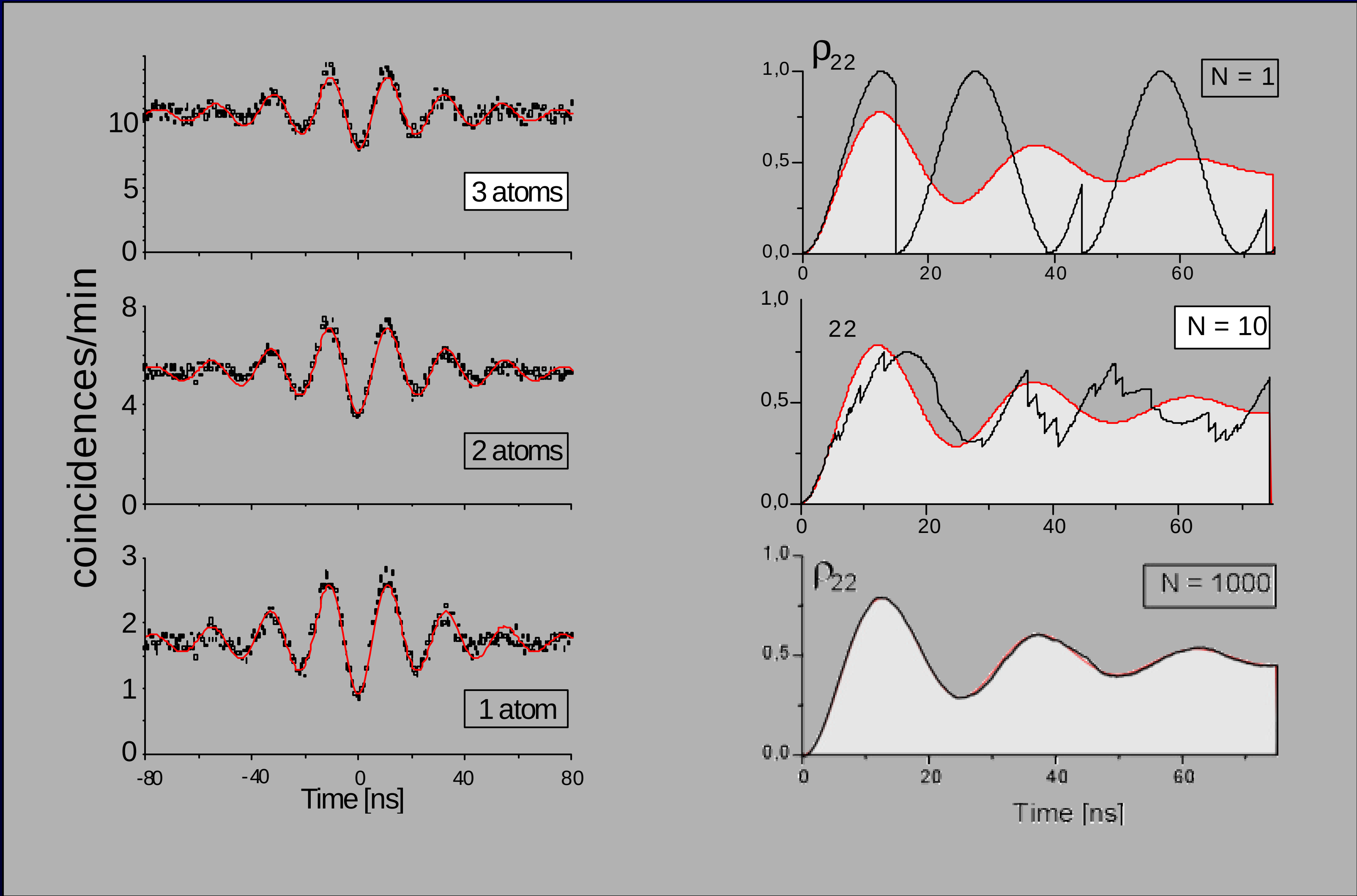
Shows Rabi oscillation

1. Photon

2. Photon

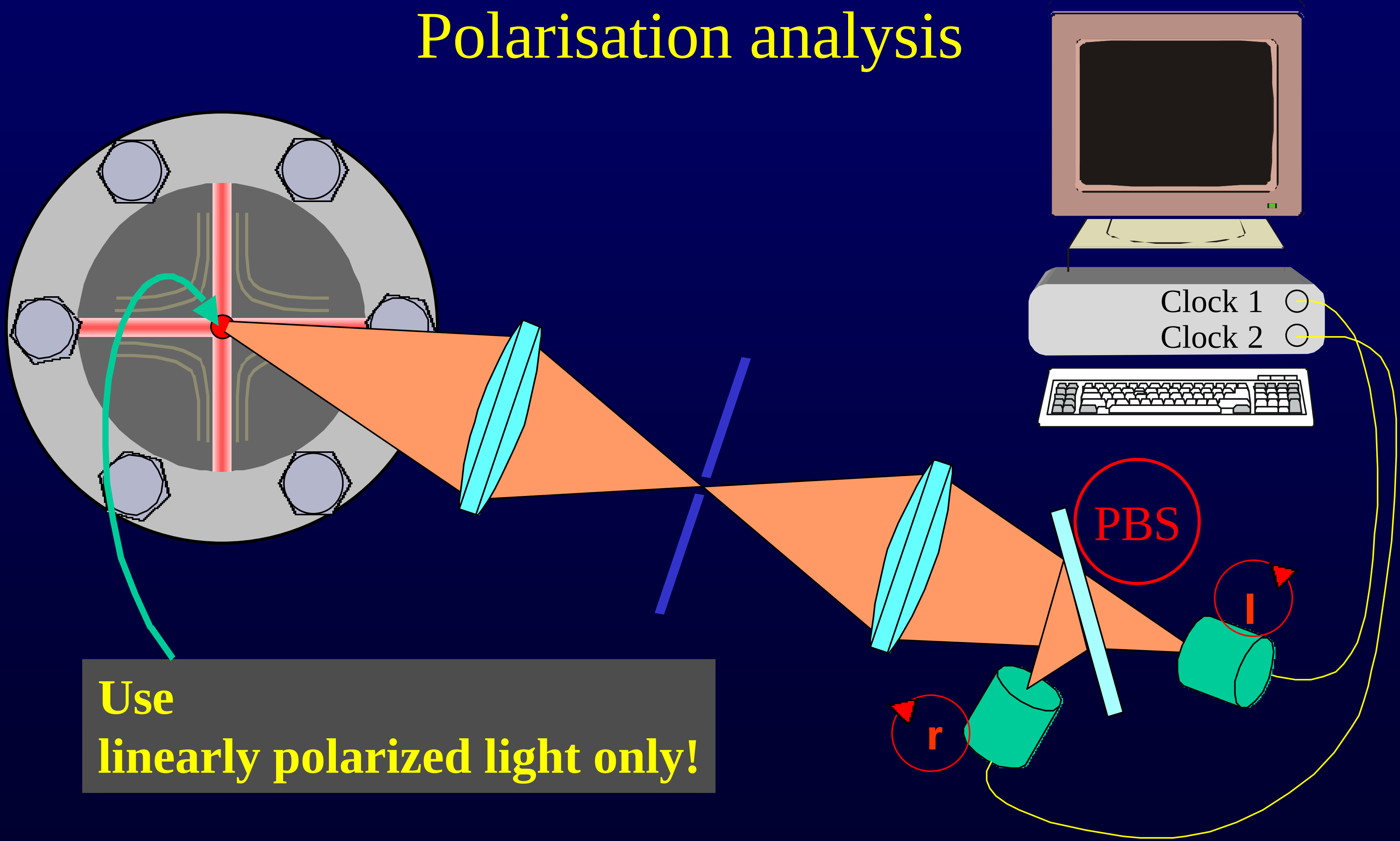


1. Experimenting with Single Neutral Atoms



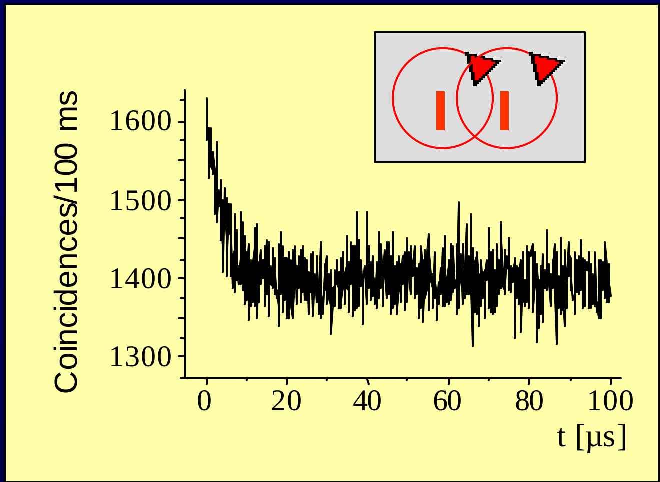
1. Experimenting with Single Neutral Atoms

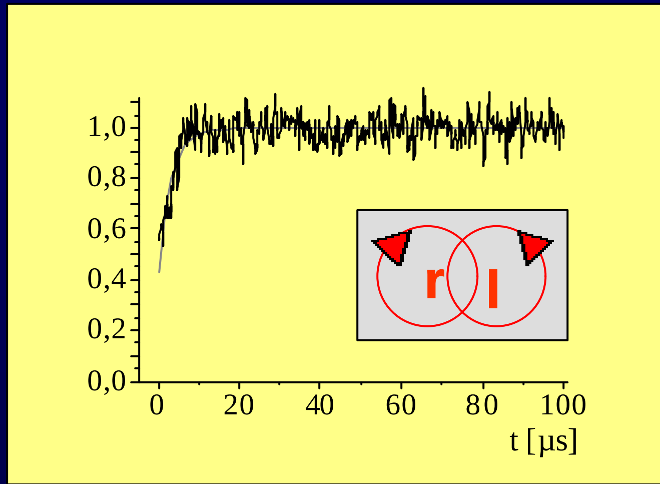
Polarisation analysis



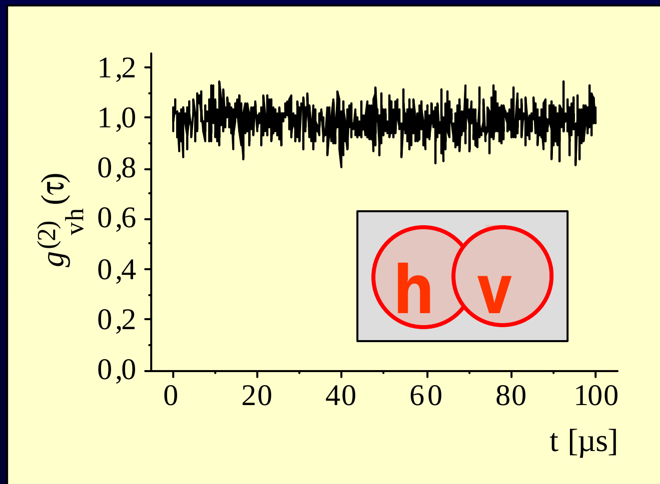
Use
linearly polarized light only!

1. Experimenting with Single Neutral Atoms



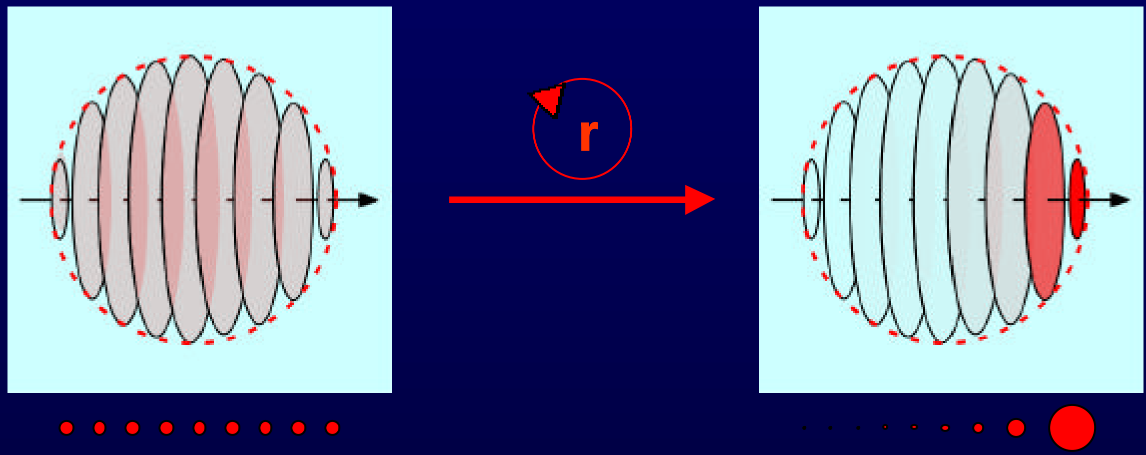


Strong circular correlations!



No linear correlations !

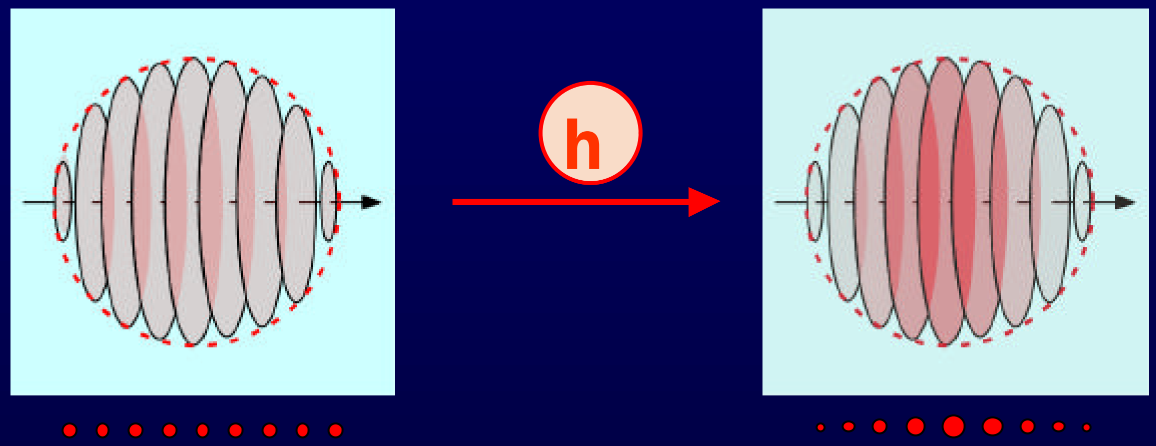
1. Experimenting with Single Neutral Atoms



Magnetic Bistability

(Optical pumping in „real time“, µs time scale)

1. Experimenting with Single Neutral Atoms



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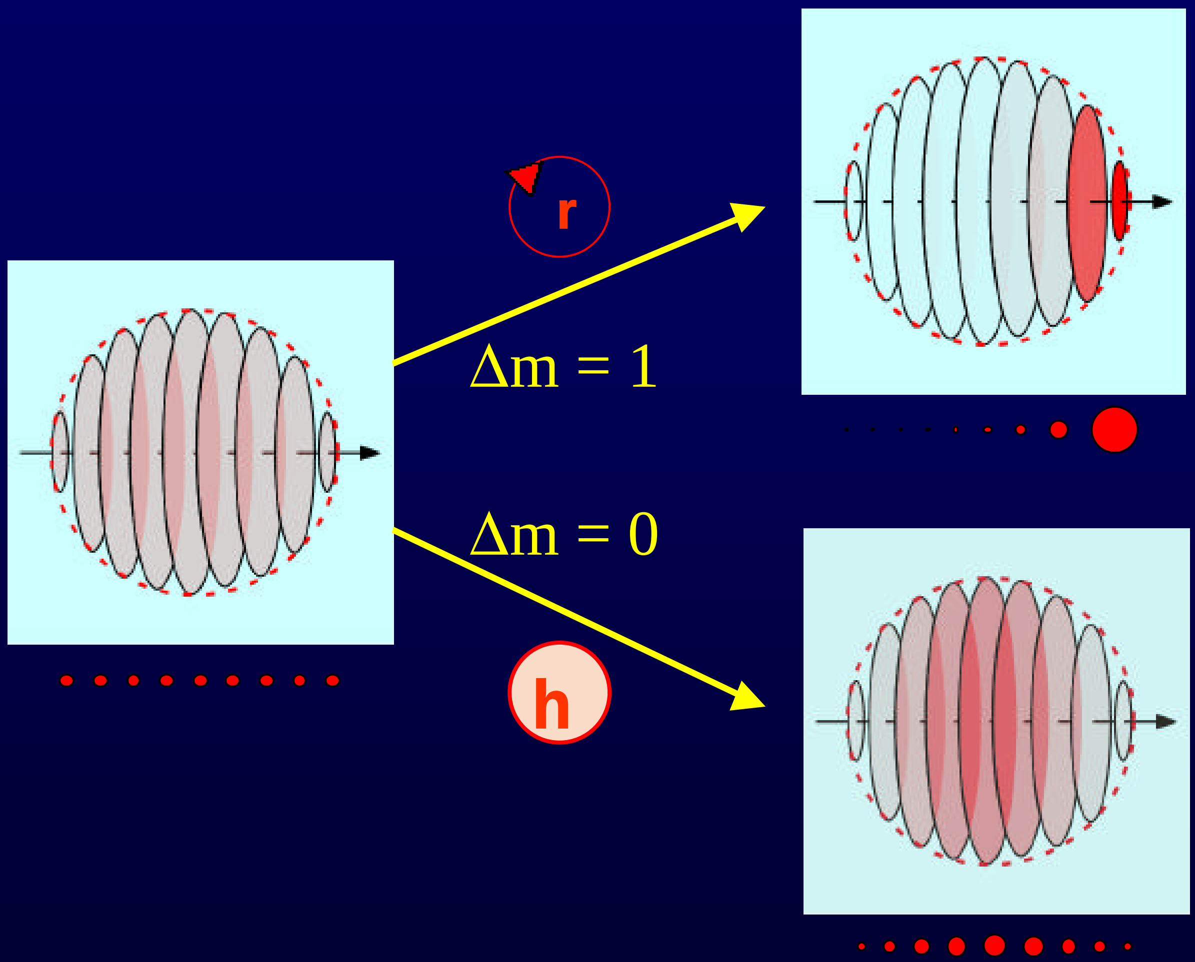


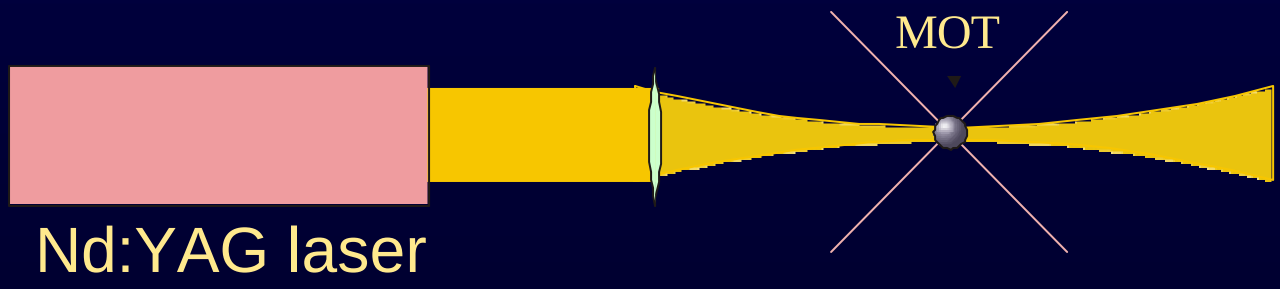
Overview

1. Experimenting with Single Neutral Atoms in a MOT
2. **Deterministic Source of Single Neutral atoms**
3. Single Atom Dynamics
4. Towards entanglement

Controlling atomic dynamics:

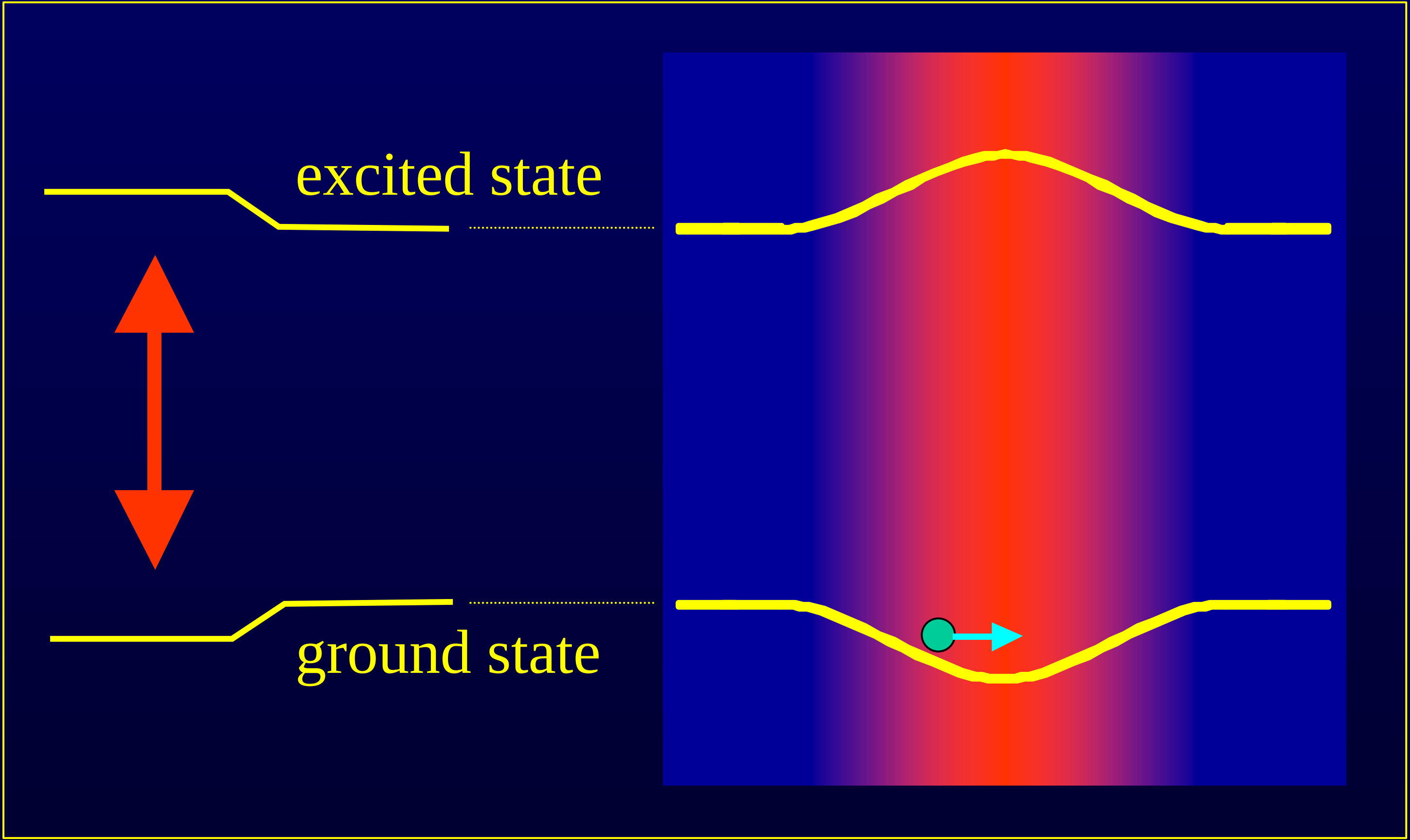
- Impossible in the MOT
- Use off resonant dipole trap!

Setup



2. Deterministic Source of Cold Atoms

Optical dipole potential = AC Stark effect



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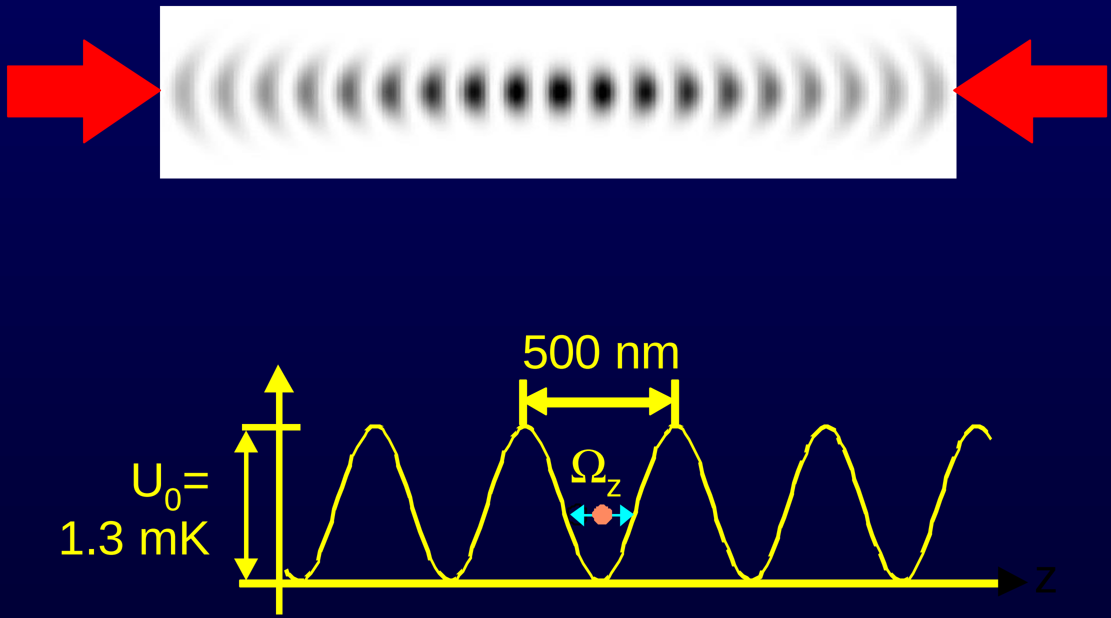

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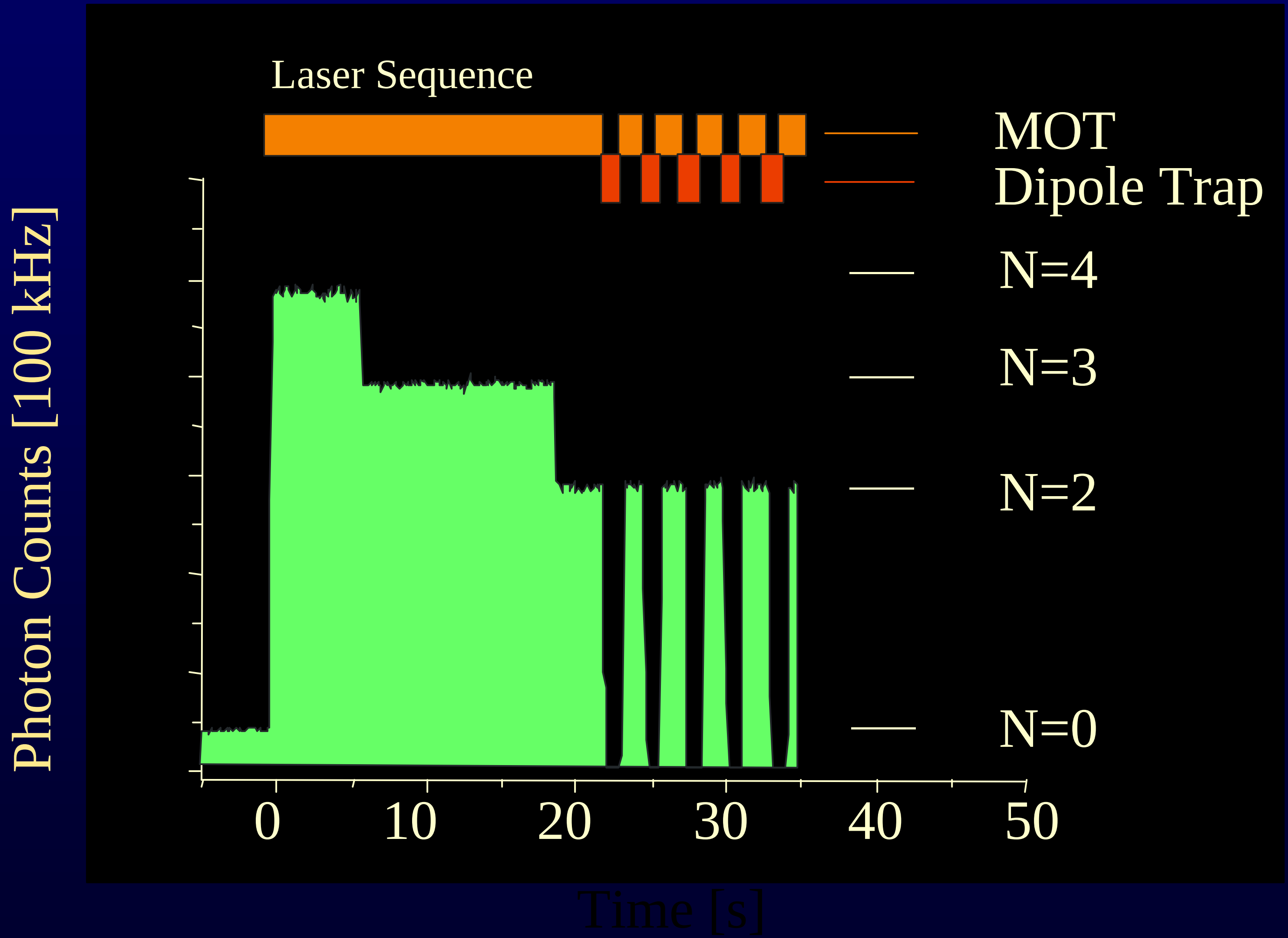
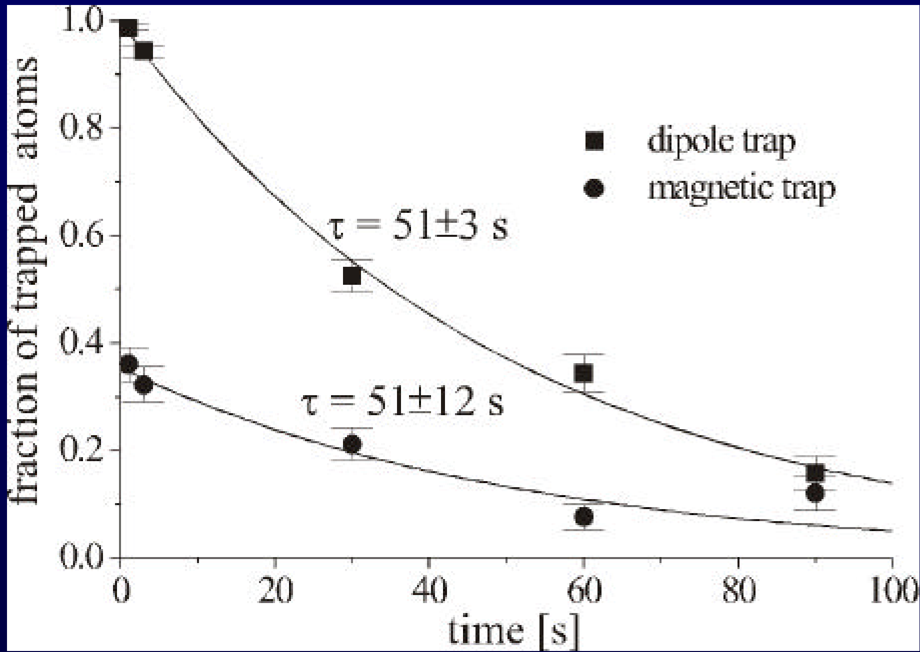
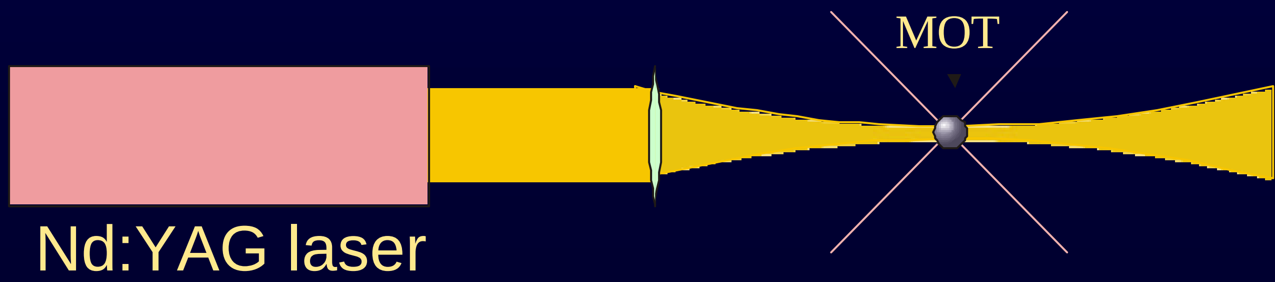


2. Deterministic Source of Cold Atoms

Controlling the **EXACT NUMBER** of atoms !!



Setup



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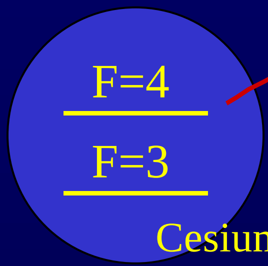
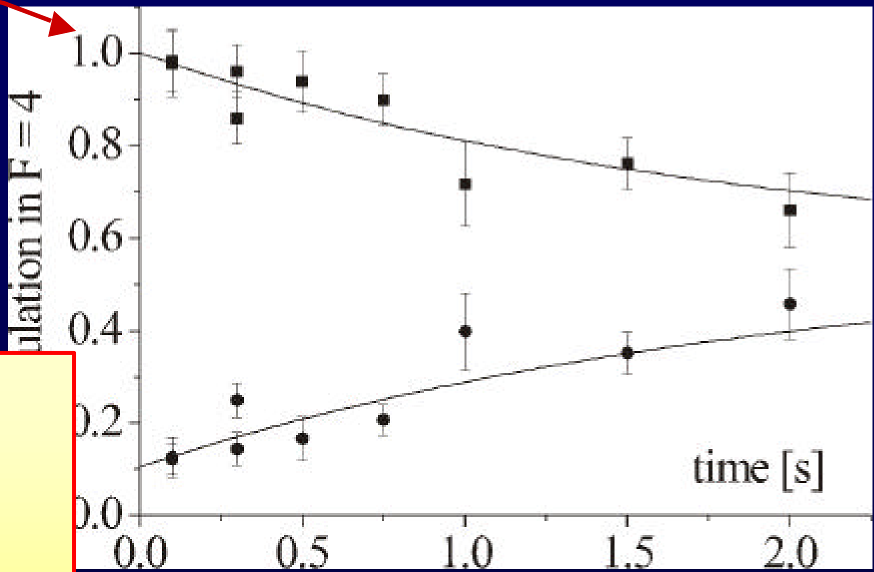
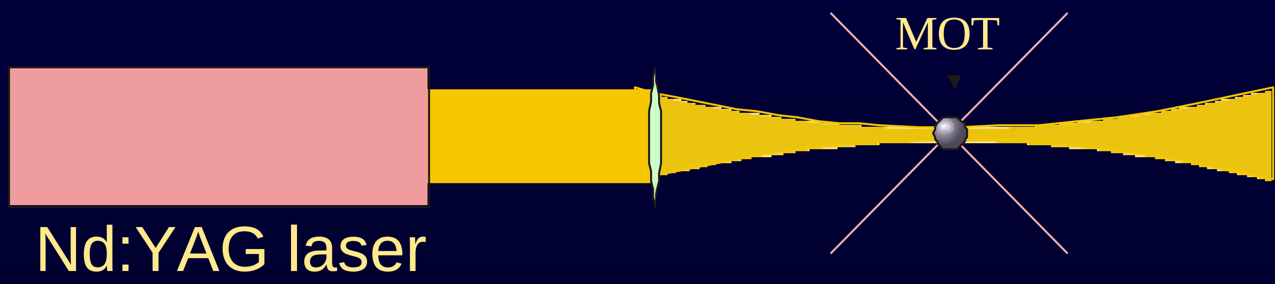


Cesium
Hyperfine structure



Controlling the internal **QUANTUM STATE** of single atoms **!!**

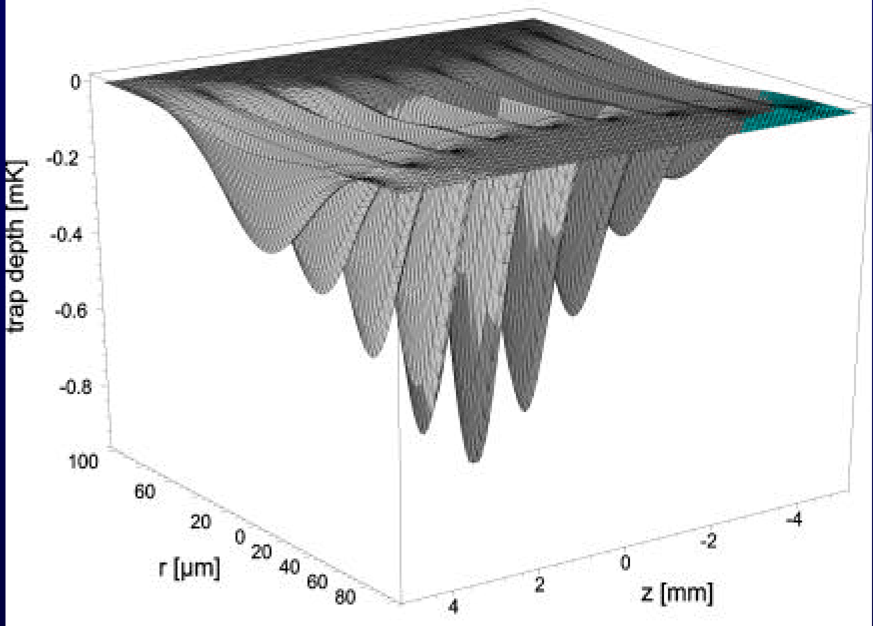
Setup



2. Deterministic Source of Cold Atoms

Towards controlling the **EXACT POSITION** of single atoms **!!**

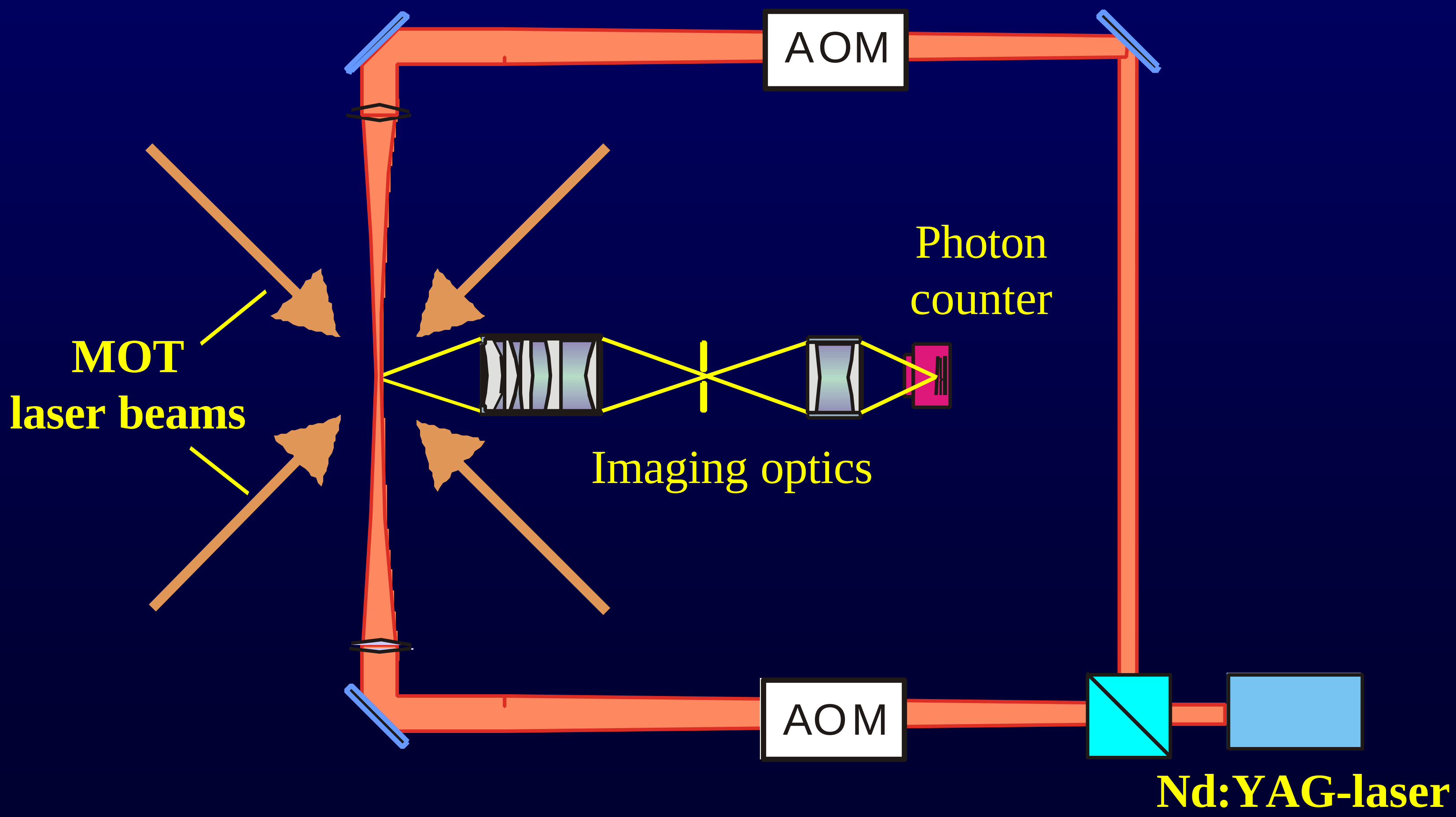
Calculated trapping potential for a red-detuned standing wave



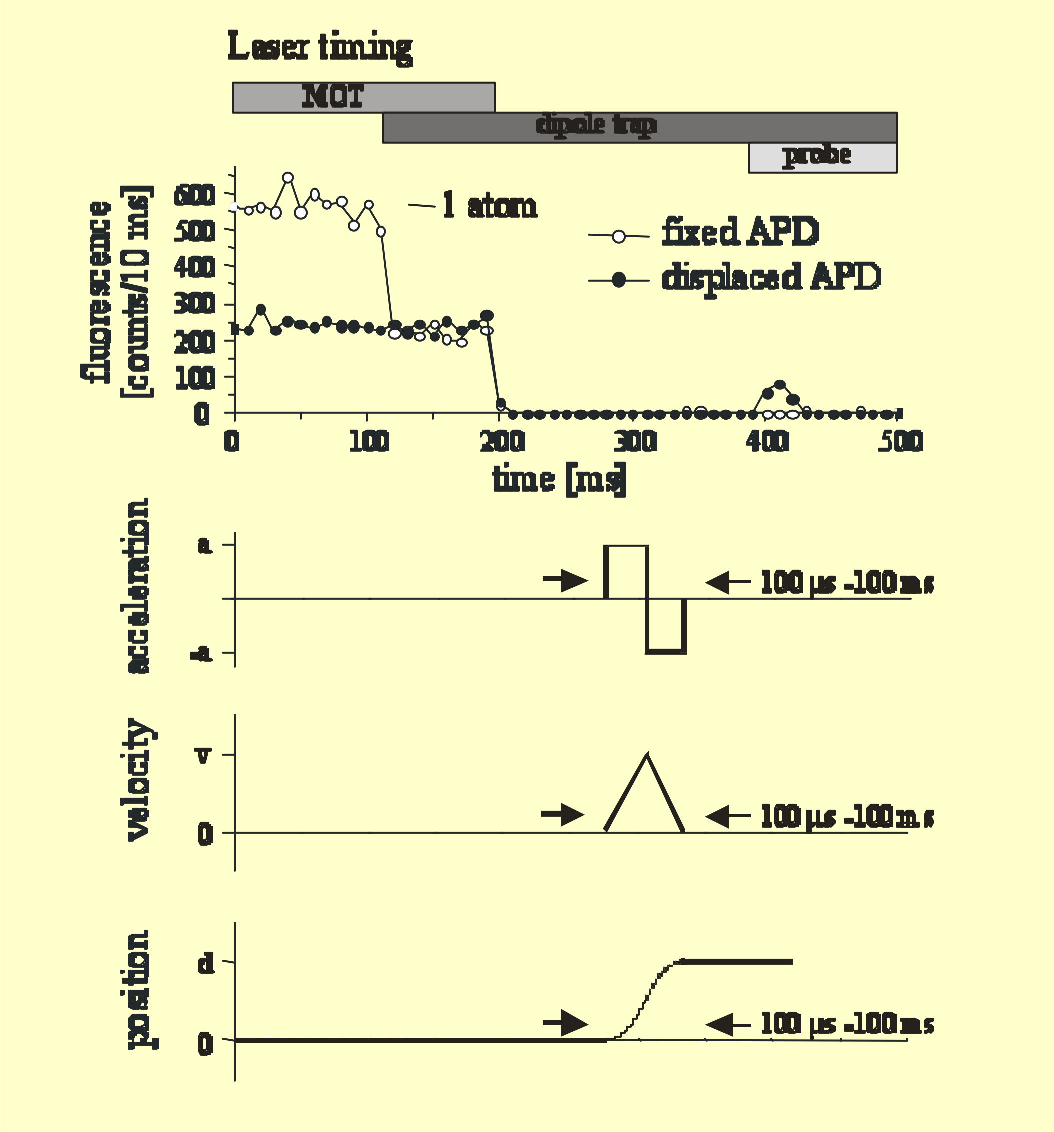
YAG laser power:	3W	
focal beam waist w_0:	32 µm	
potential depth:	1.0 mK	
oscillation frequencies:	327 kHz	longitudinal
	2.5 kHz	transversal
scattering rate:	10 photons/s	

2. Deterministic Source of Cold Atoms

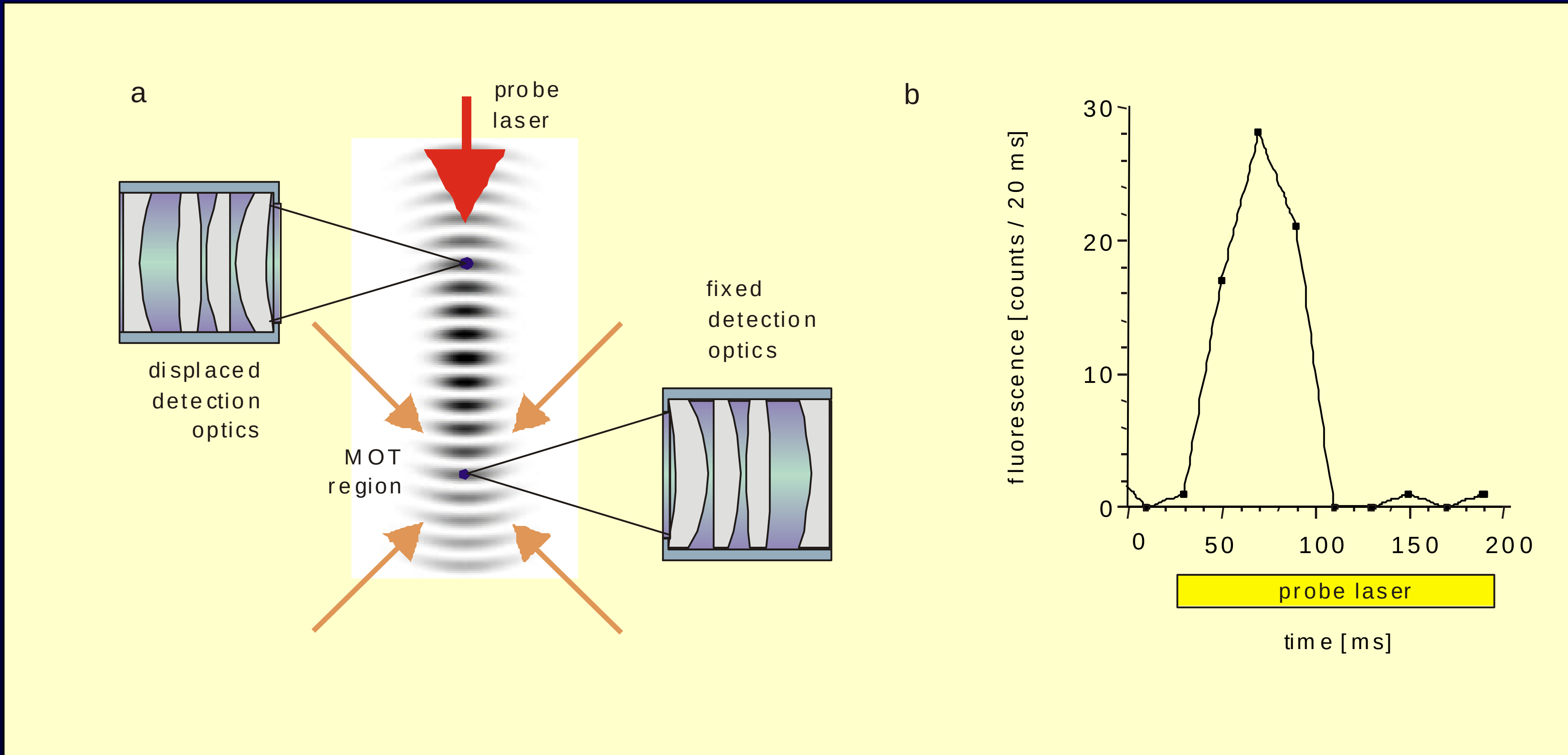
Loading Station for Single Atom Conveyor Belt



2. Deterministic Source of Cold Atoms

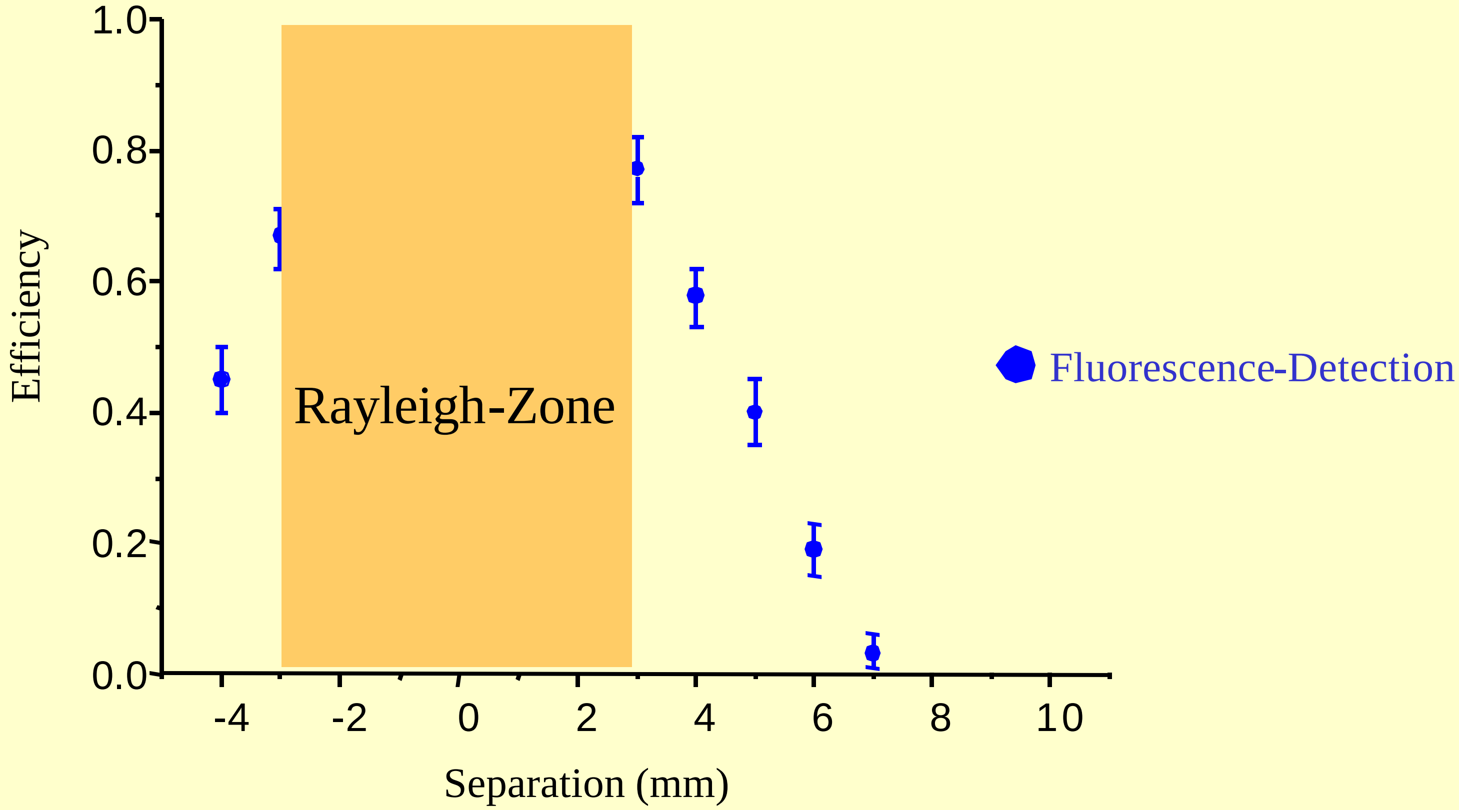


Detection of relocated atoms

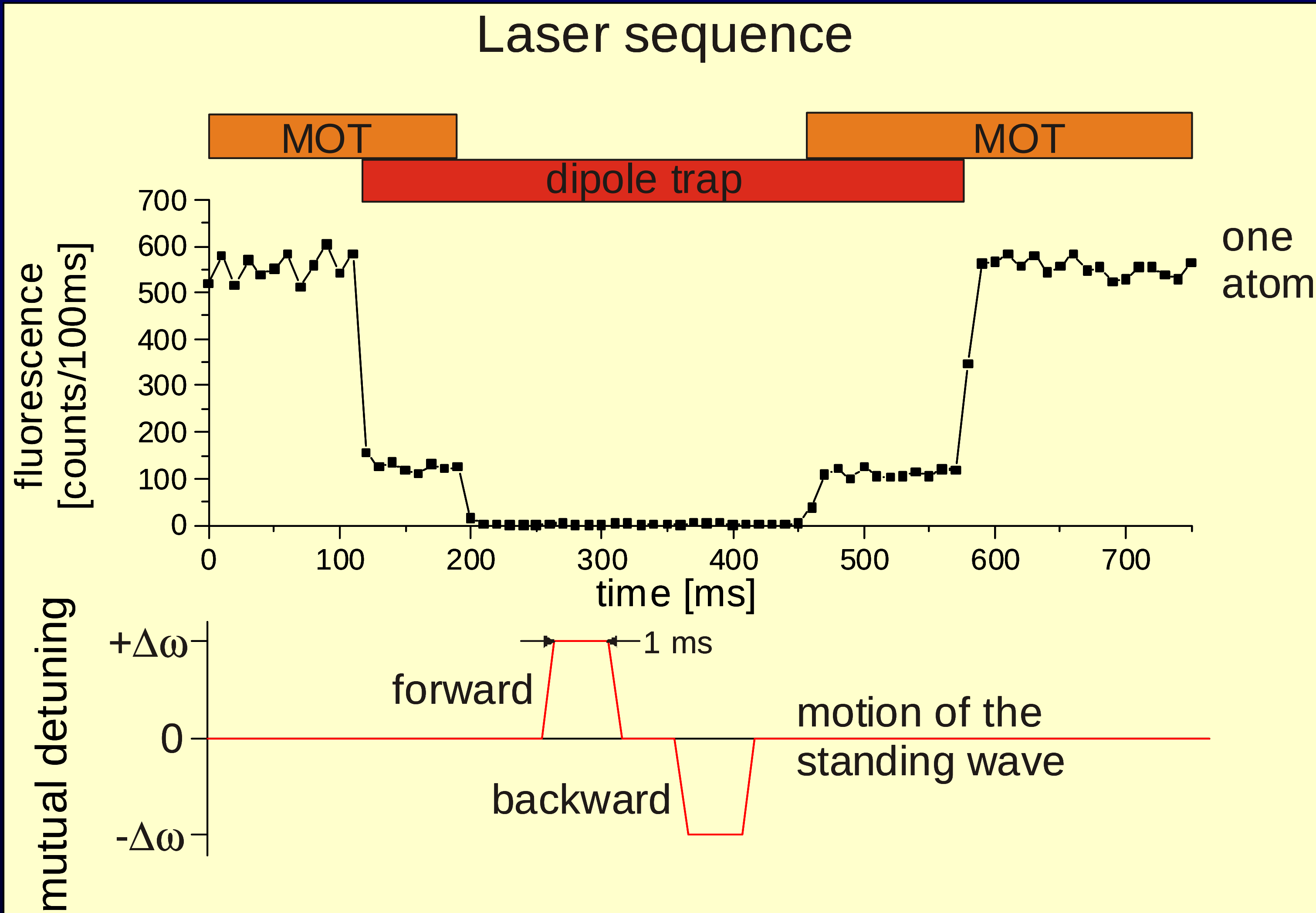


2. Deterministic Source of Cold Atoms

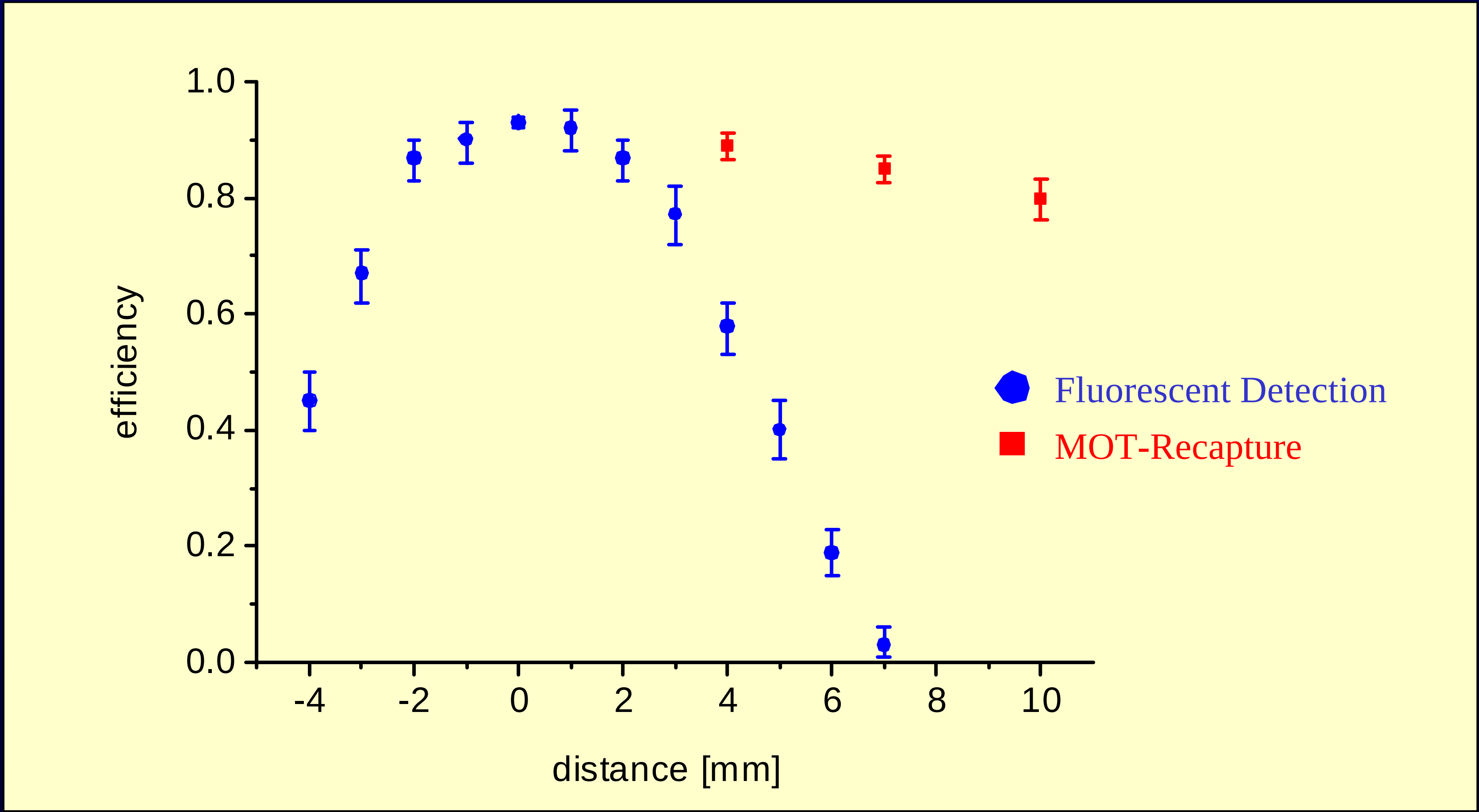
Transport Efficiency of Single Atoms (1)



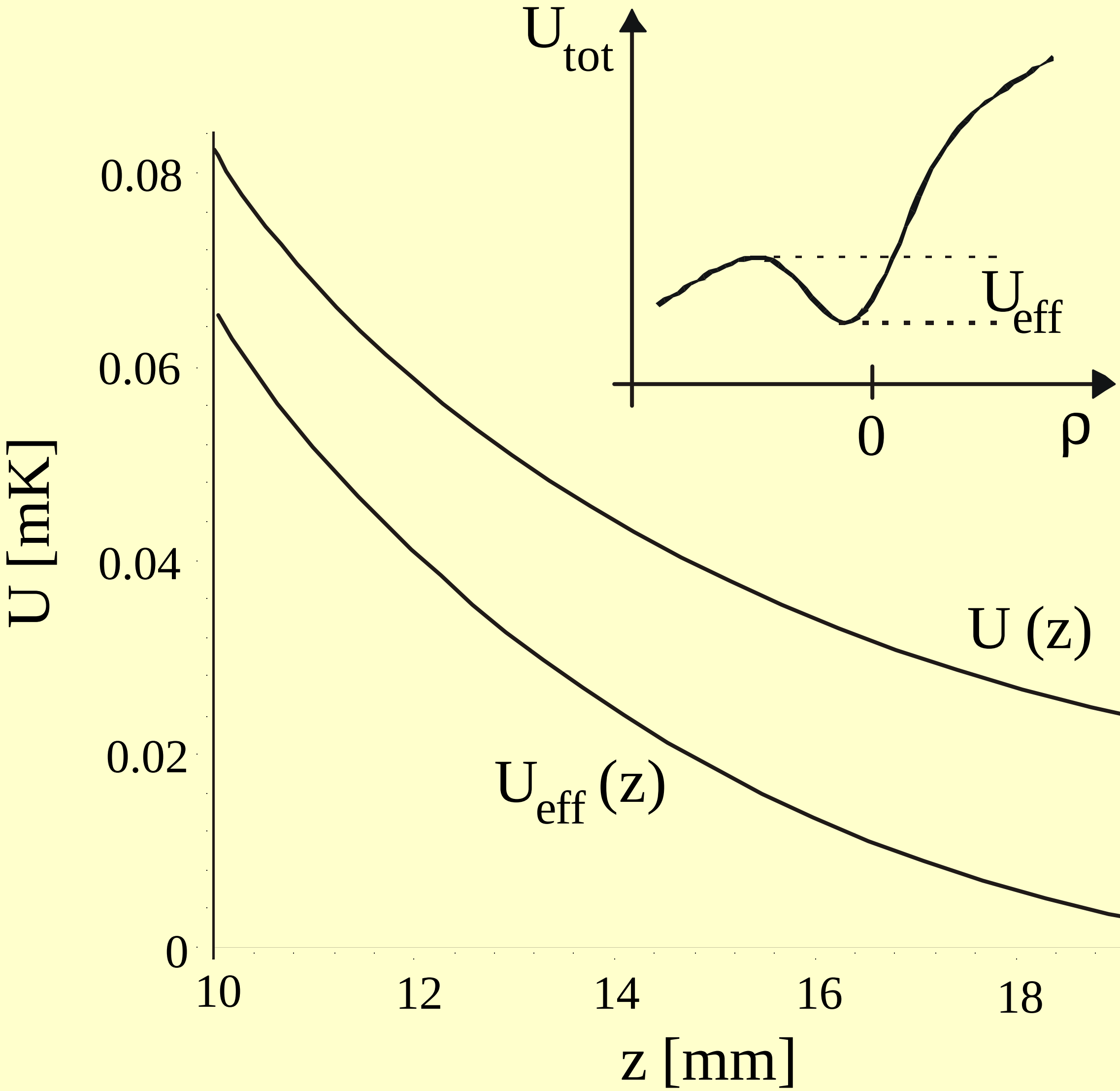
2. Deterministic Source of Cold Atoms



Transport Efficiency of Single Atoms (2)

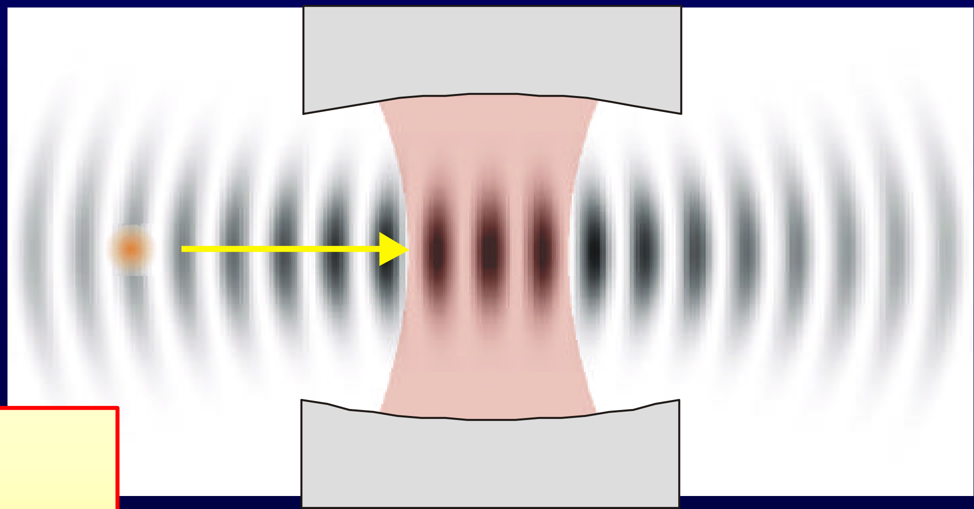


2. Deterministic Source of Cold Atoms



2. Deterministic Source of Cold Atoms

“Moving standing wave”



Delivery of atoms
ON DEMAND !!

1, 2, 3, ... Atoms
0, 1, 2, ... Photons

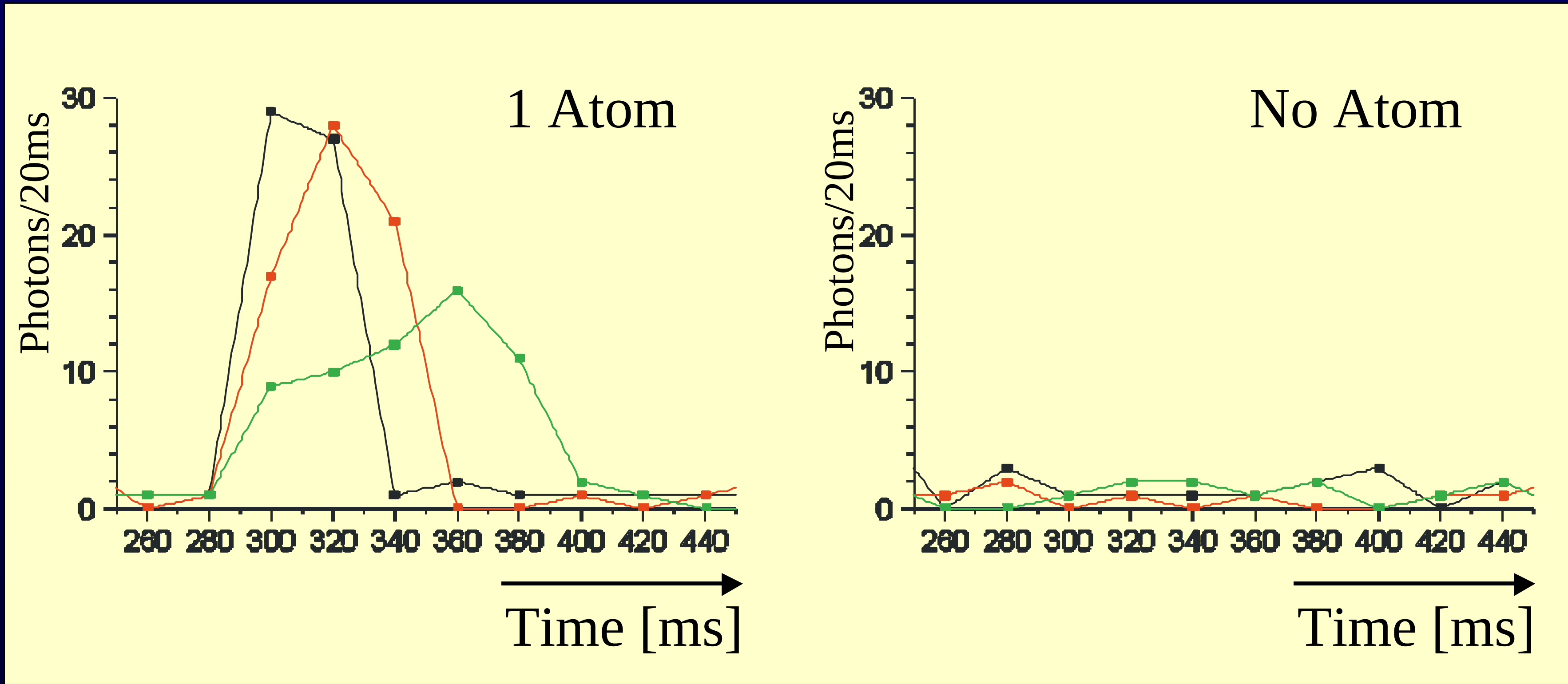
Refs:
D. Frese, B. Ueberholz, S. Kuhr, W. Alt, D. Schrader, V. Gomer, and D. Meschede, Phys. Rev. Lett., 85 3777 (2000)
S. Kuhr, W. Alt, D. Schrader, M. Müller,V. Gomer,D. Meschede, Science 293, p. 278-280, (2001)
D. Schrader, S. Kuhr, W. Alt, M. Mueller, V. Gomer, D. Meschede, Appl Phys B 73 (2001) 8, 819-824

Overview

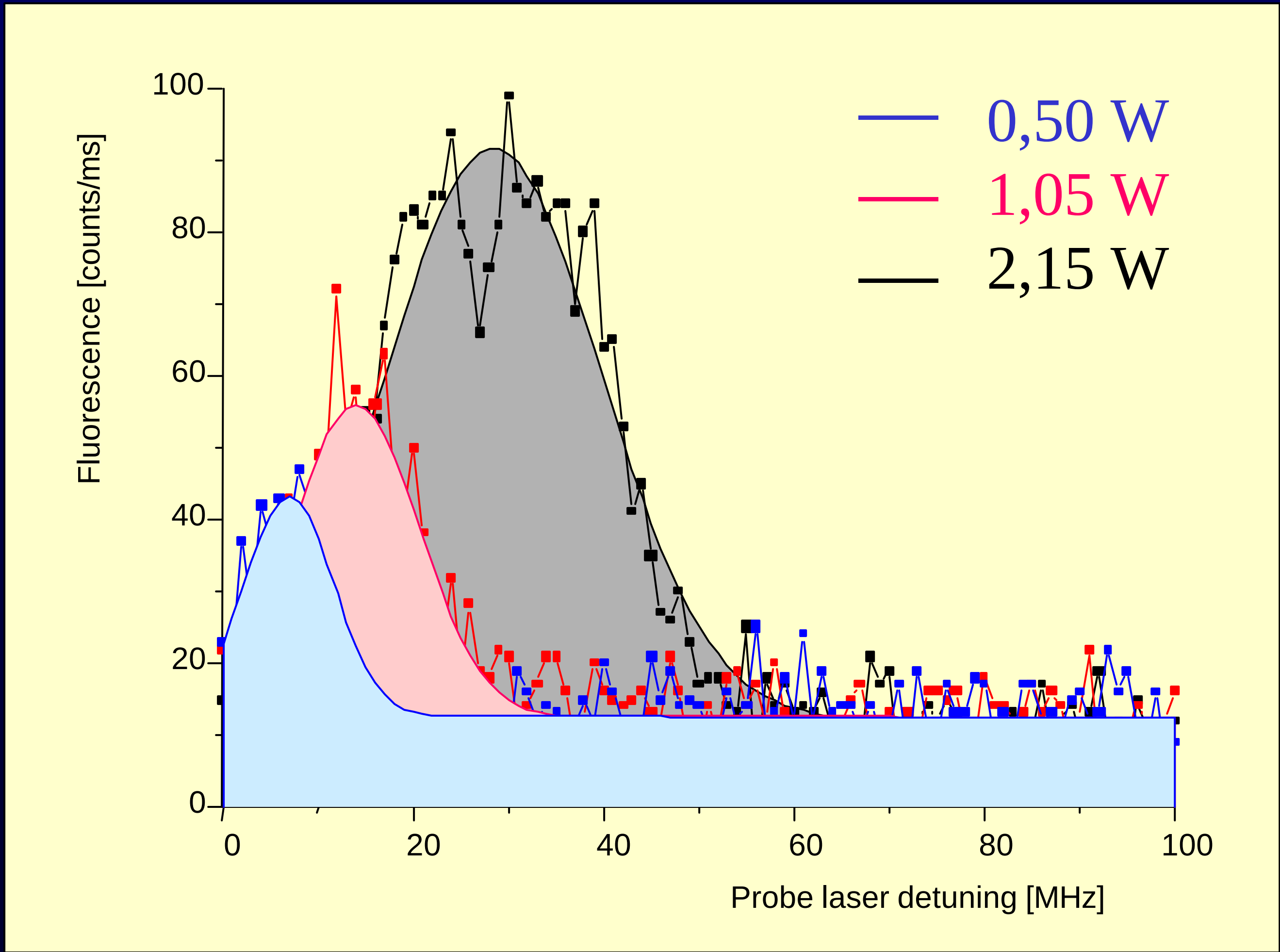
1. Experimenting with Single Neutral Atoms in a MOT
2. Deterministic Source of Single Neutral atoms
3. **Single Atom Dynamics**
4. Towards entanglement

Spectroscopy of a single neutral atom

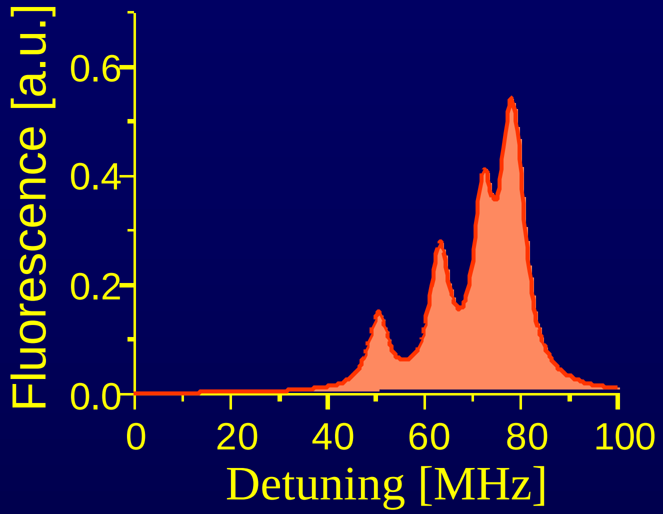
Photon Bursts of Individual Trapped Atoms



Spectroscopy of atoms in dipole trap

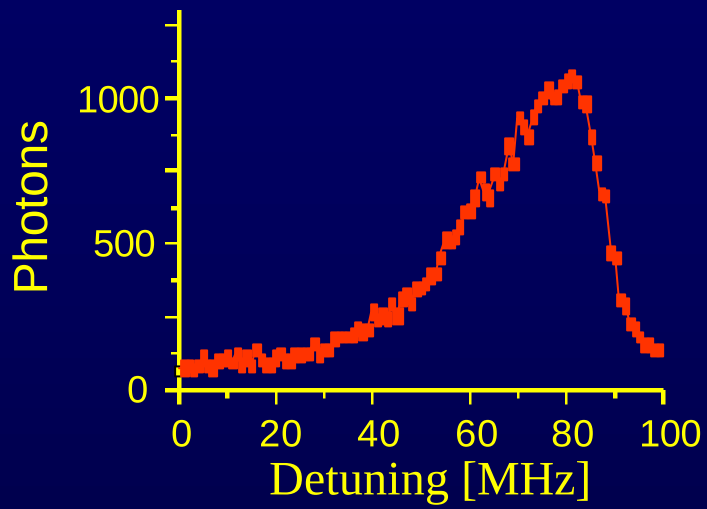


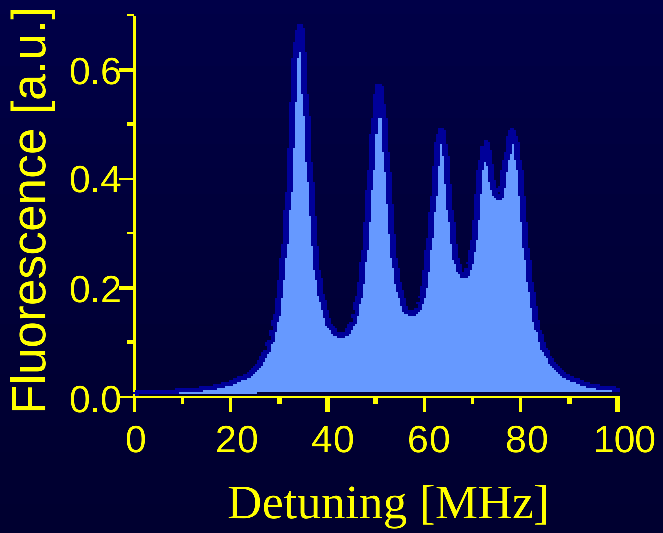
3. Single Atom Dynamics



π-polarisiert

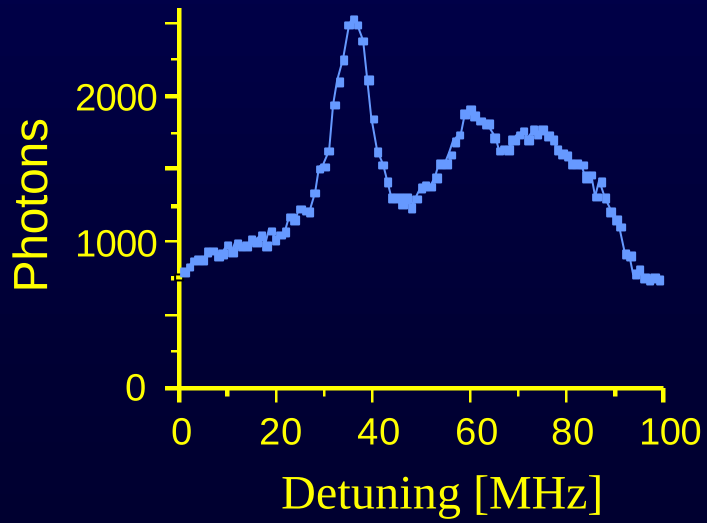
$\Delta m_F=0$



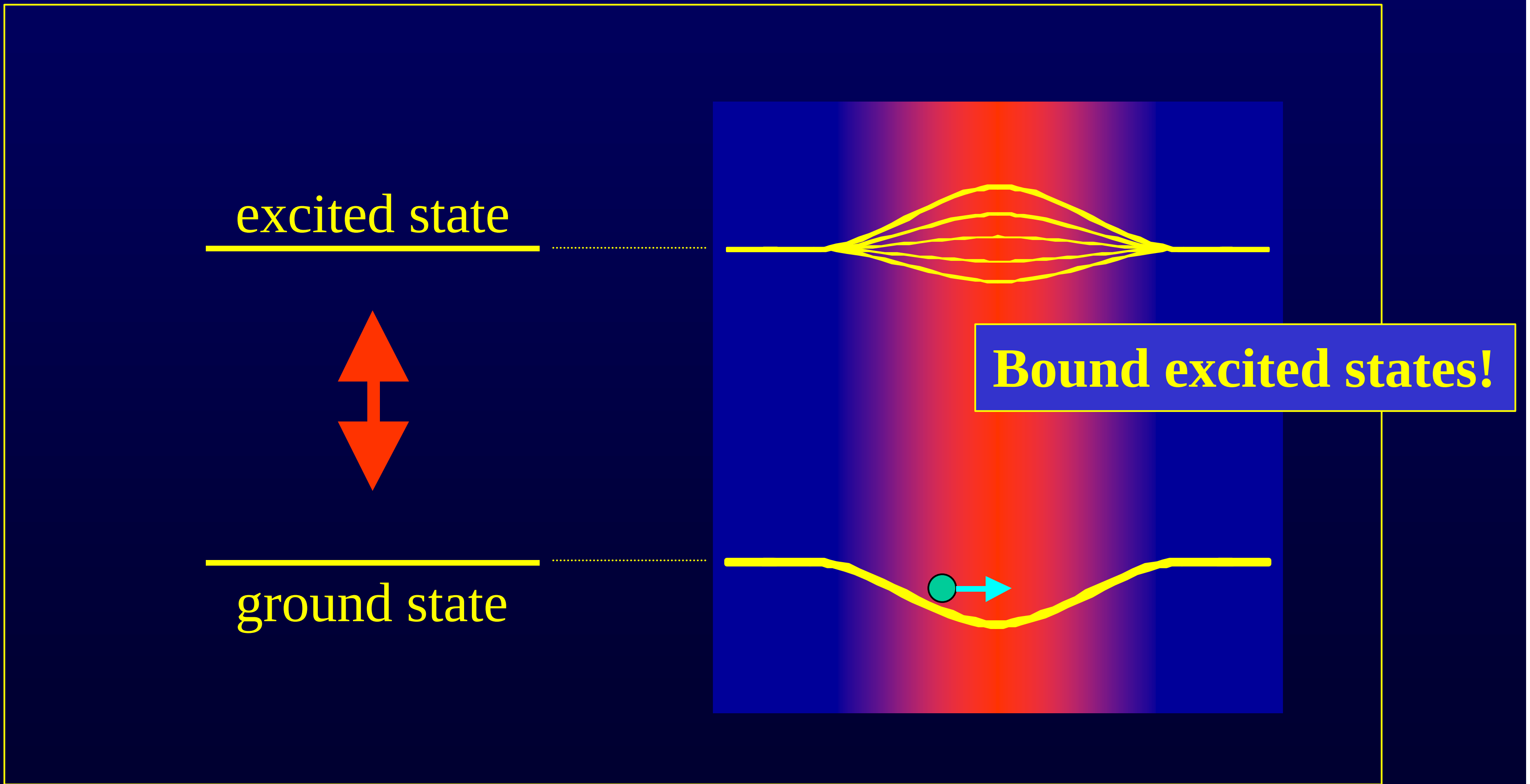


σ-polarisiert

$\Delta m_F=1$

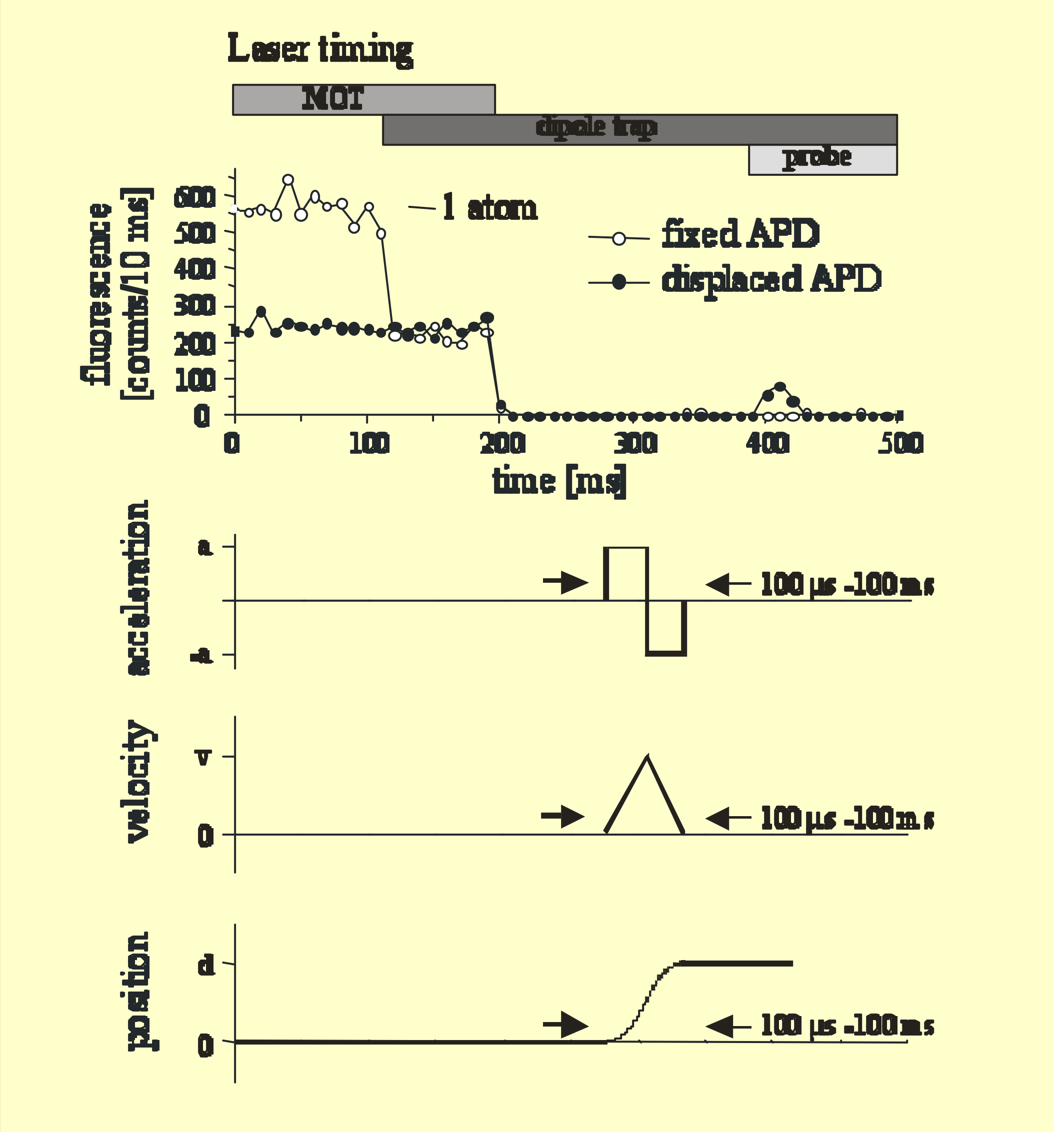


Optical dipole potential = AC Stark effect

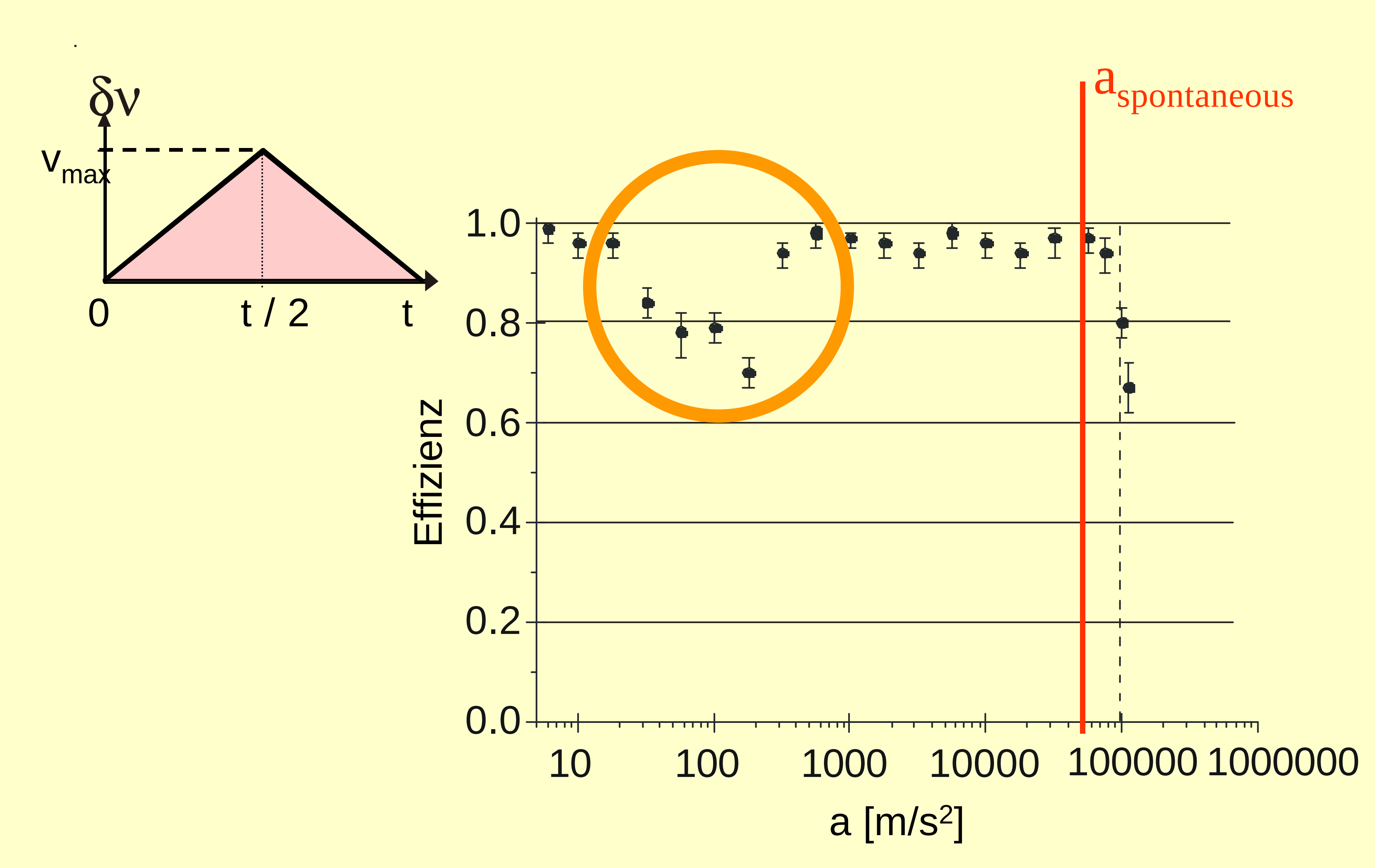


Accelerating
a single neutral atom

3. Single Atom Dynamics

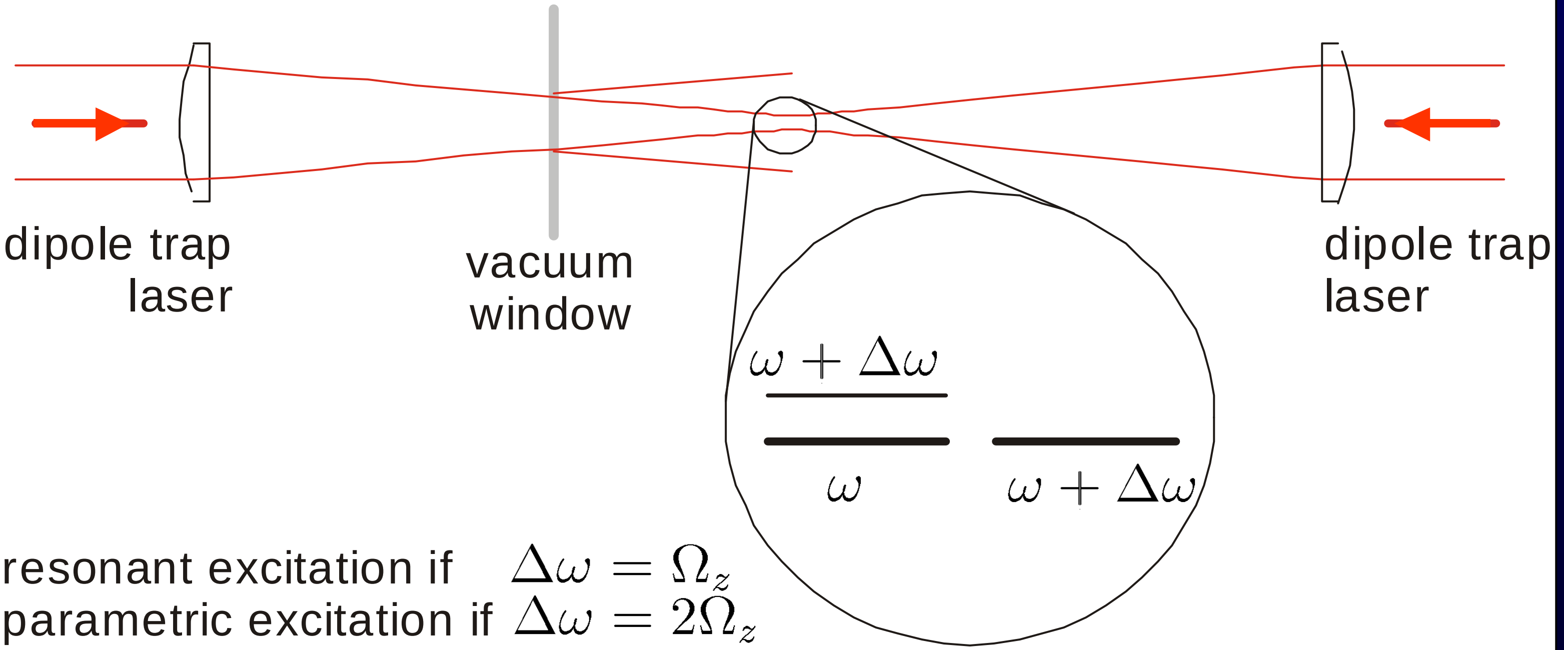


3. Single Atom Dynamics



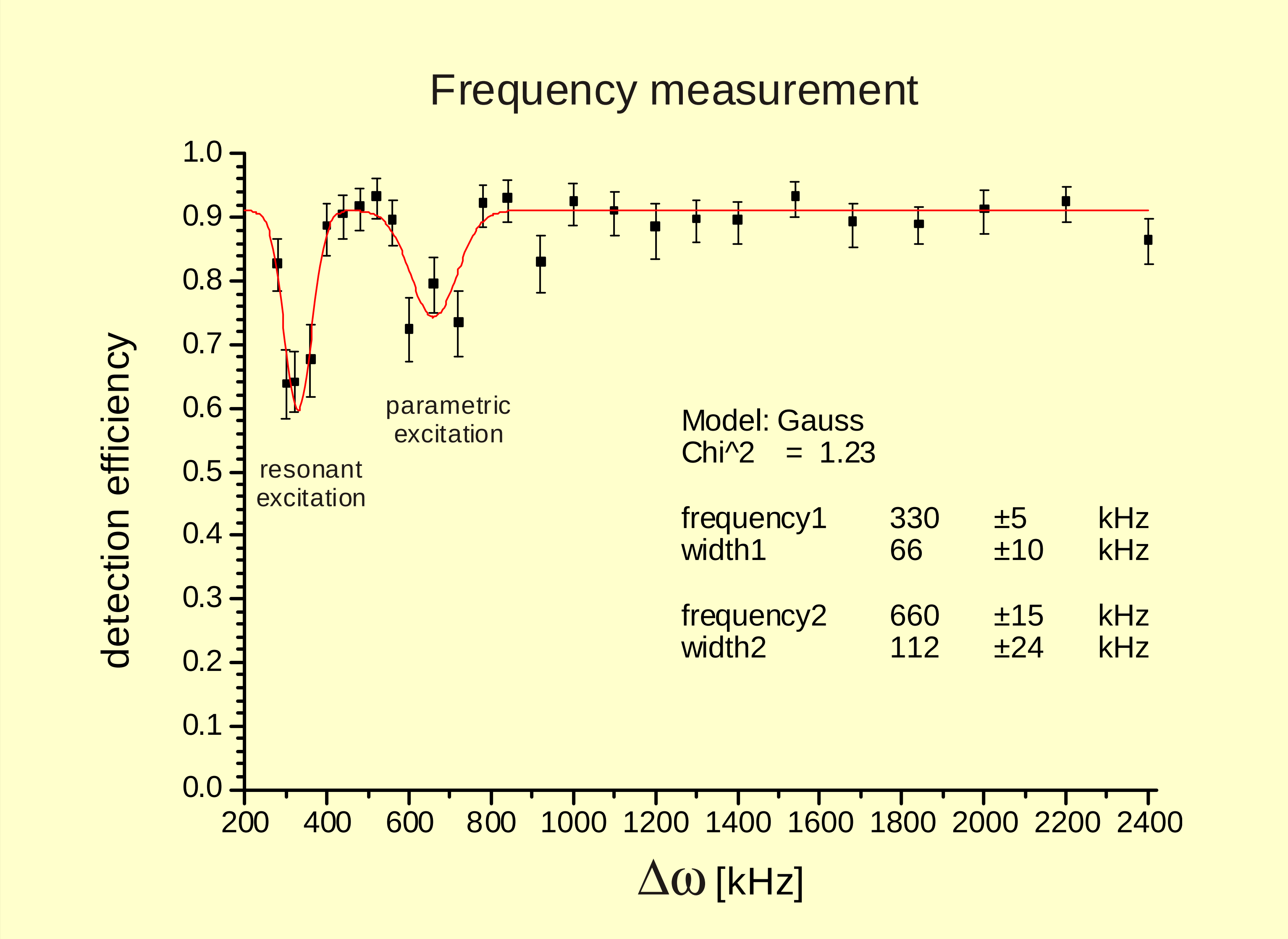
Axial oscillation frequency

Excitation mechanism

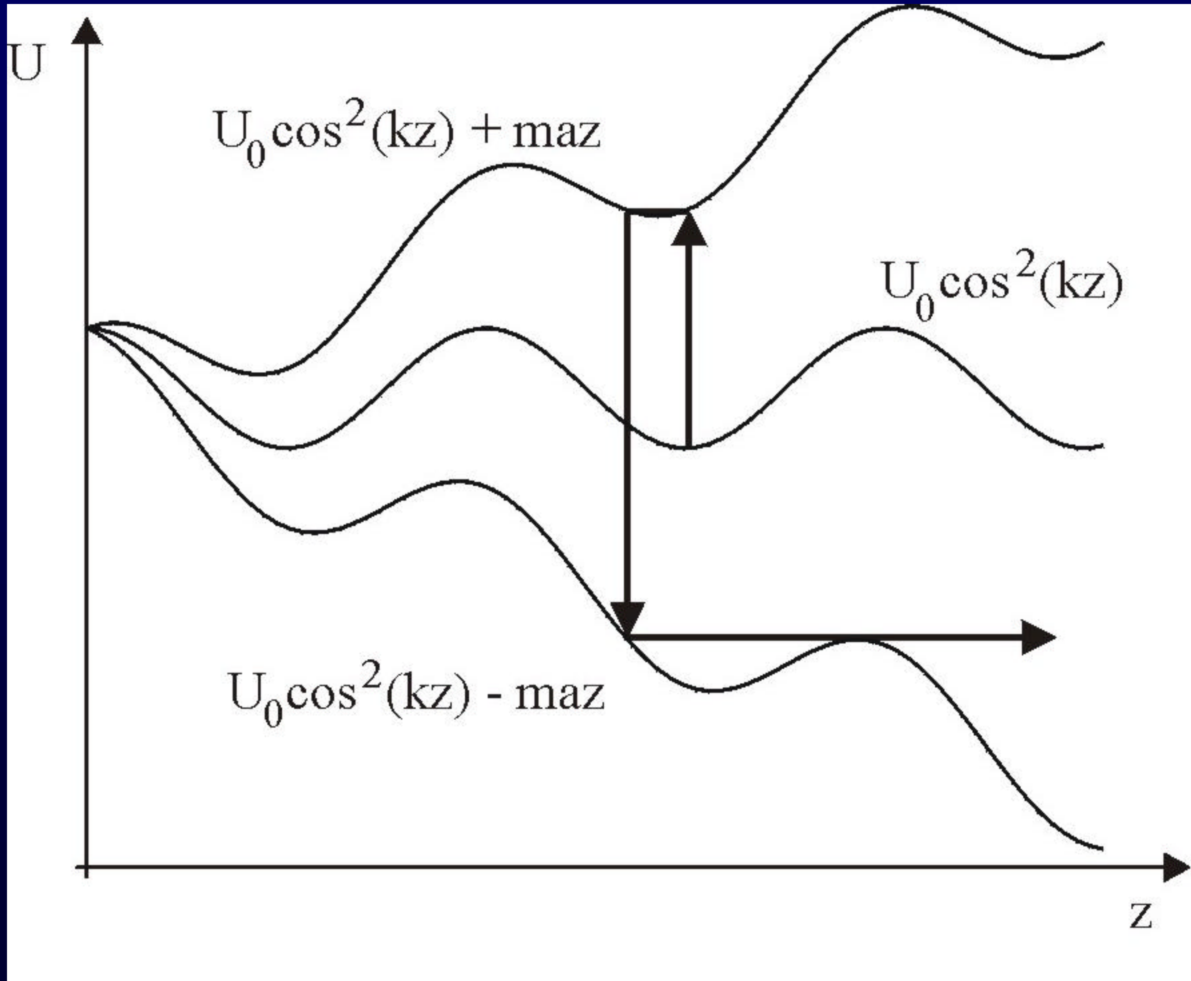


resonant excitation if $\Delta\omega = \Omega_z$
parametric excitation if $\Delta\omega = 2\Omega_z$

3. Single Atom Dynamics

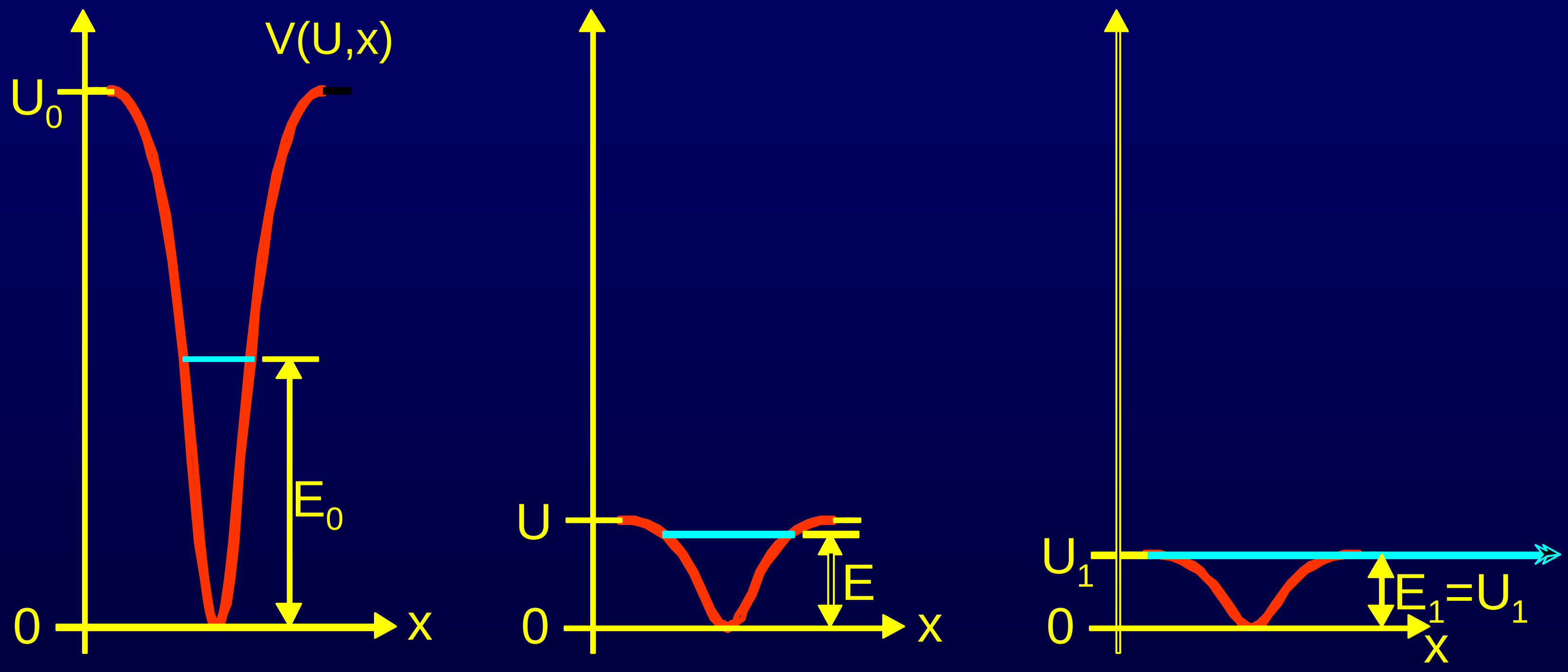


3. Single Atom Dynamics



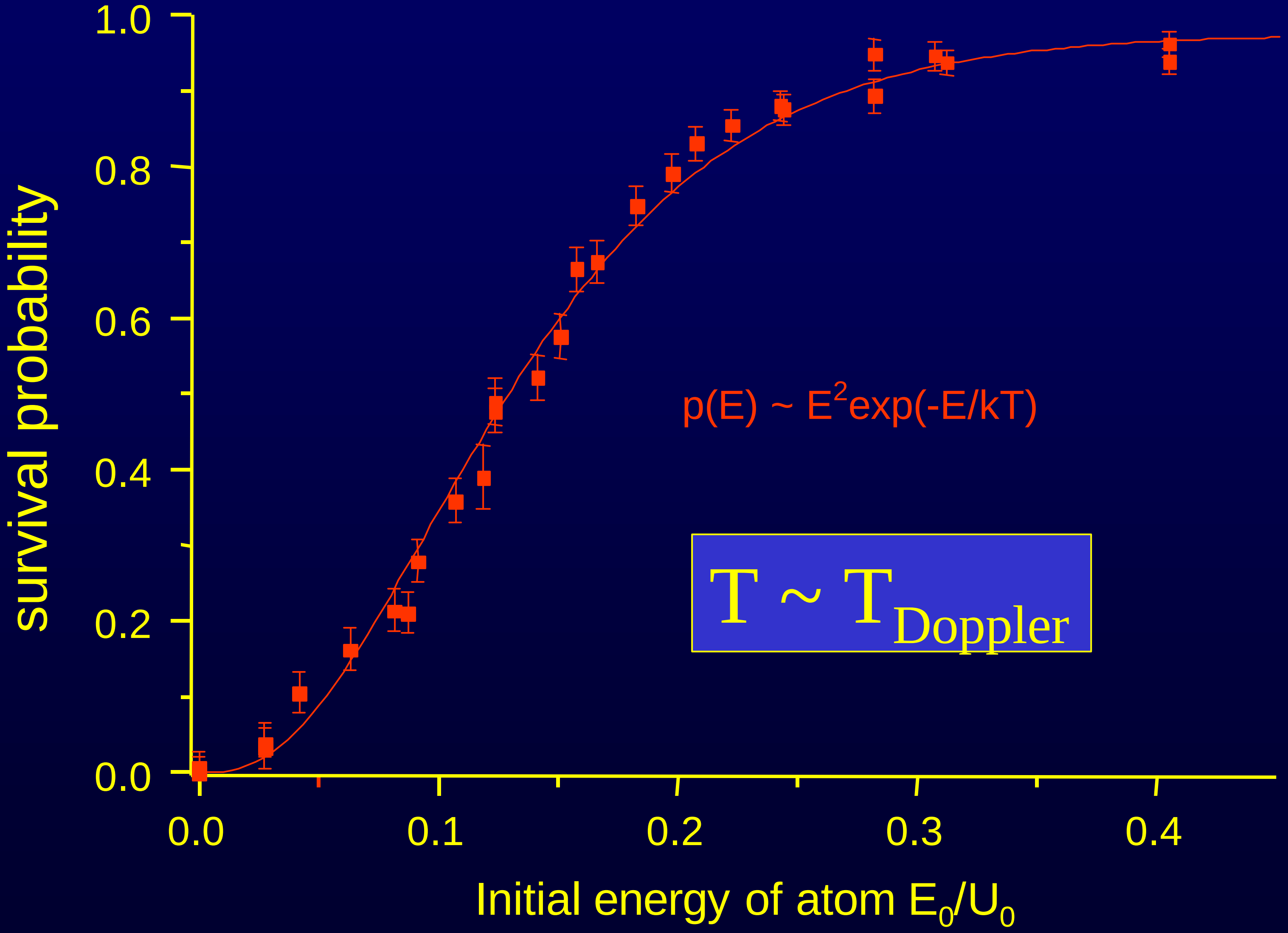
„Temperature“ (E/k_B) of a single neutral atom

3. Single Atom Dynamics



Adiabatic Cooling: $S = \oint p\, dx = \text{const.}$

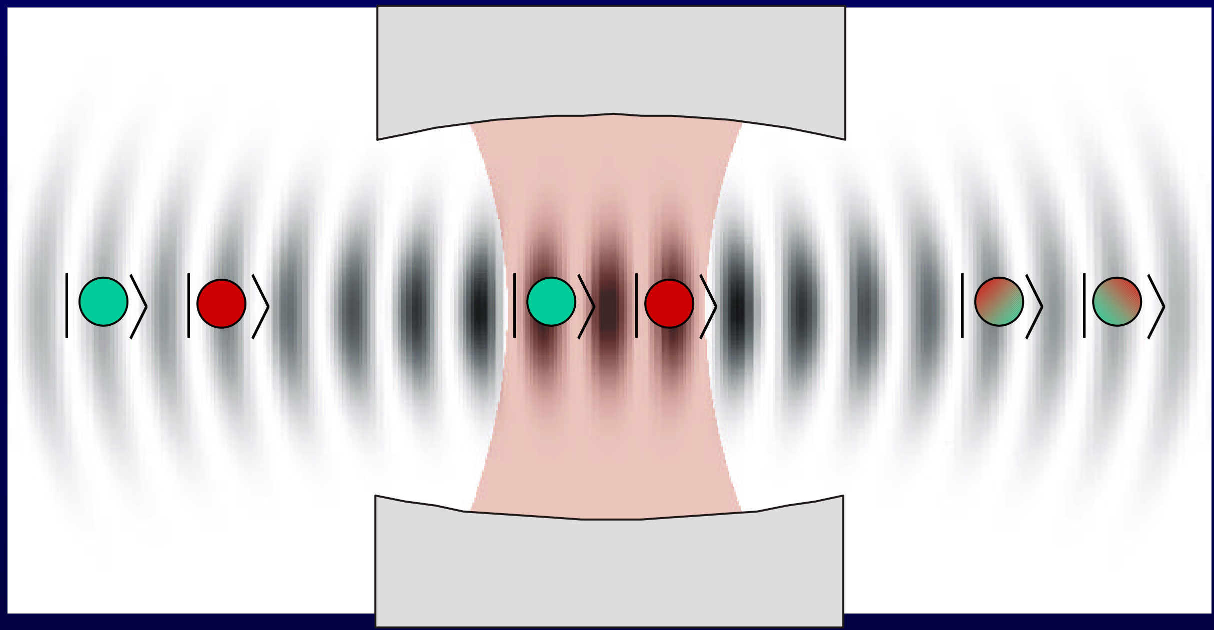
3. Single Atom Dynamics

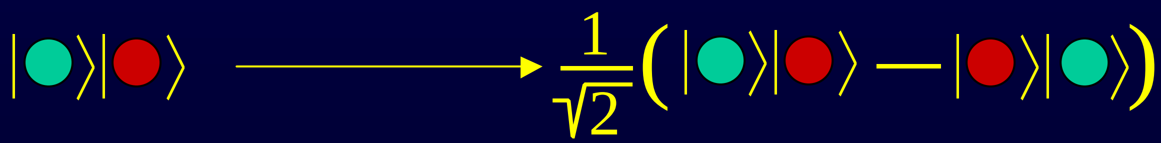


Overview

1. Experimenting with Single Neutral Atoms in a MOT
2. Deterministic Source of Single Neutral atoms
3. Single Atom Dynamics
4. **Towards entanglement**

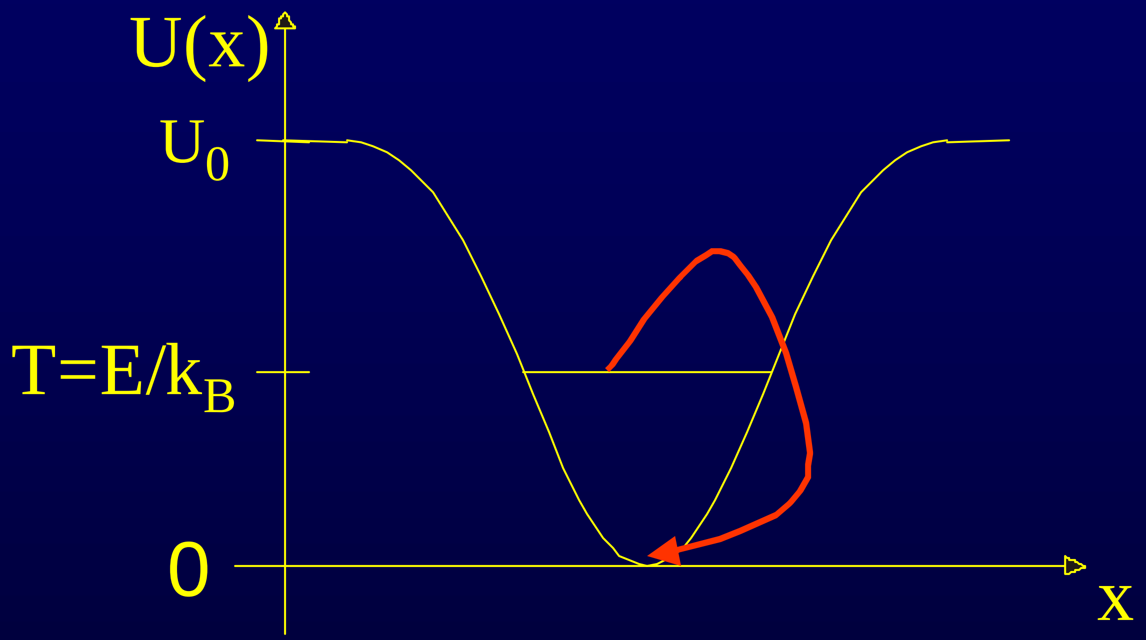
4. Towards Entanglement





Creation of entangled and fully controlled atoms

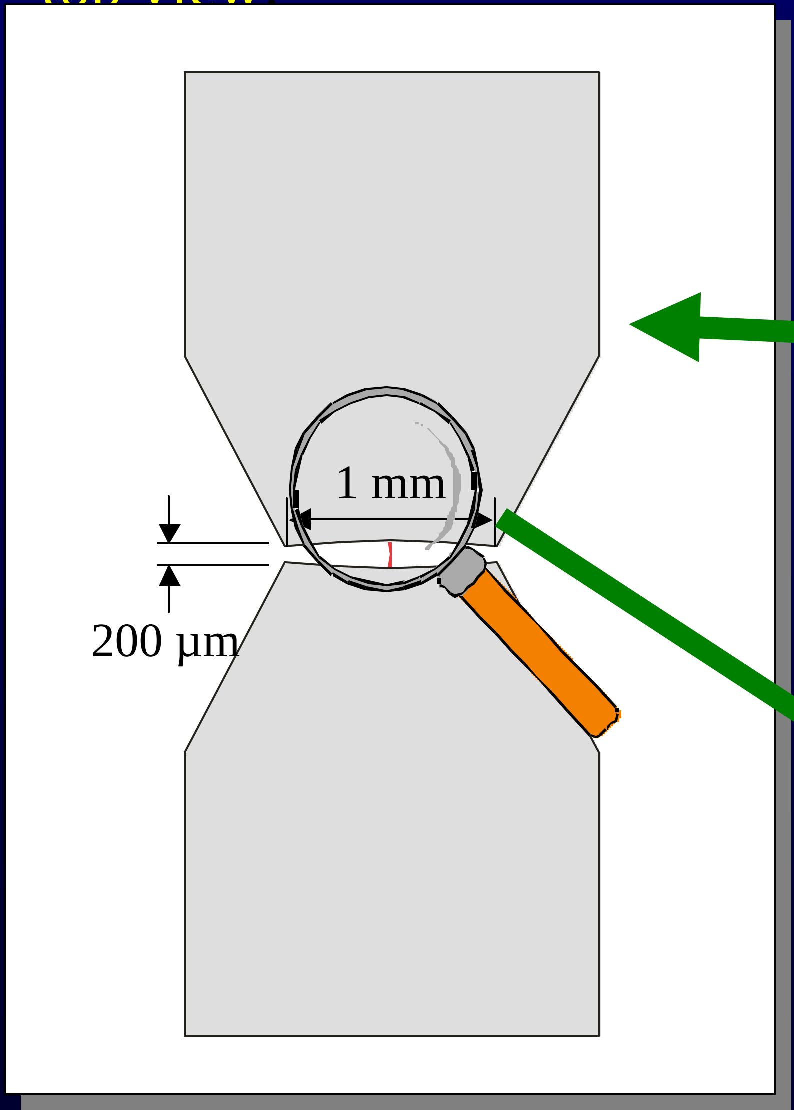
4. Towards Entanglement



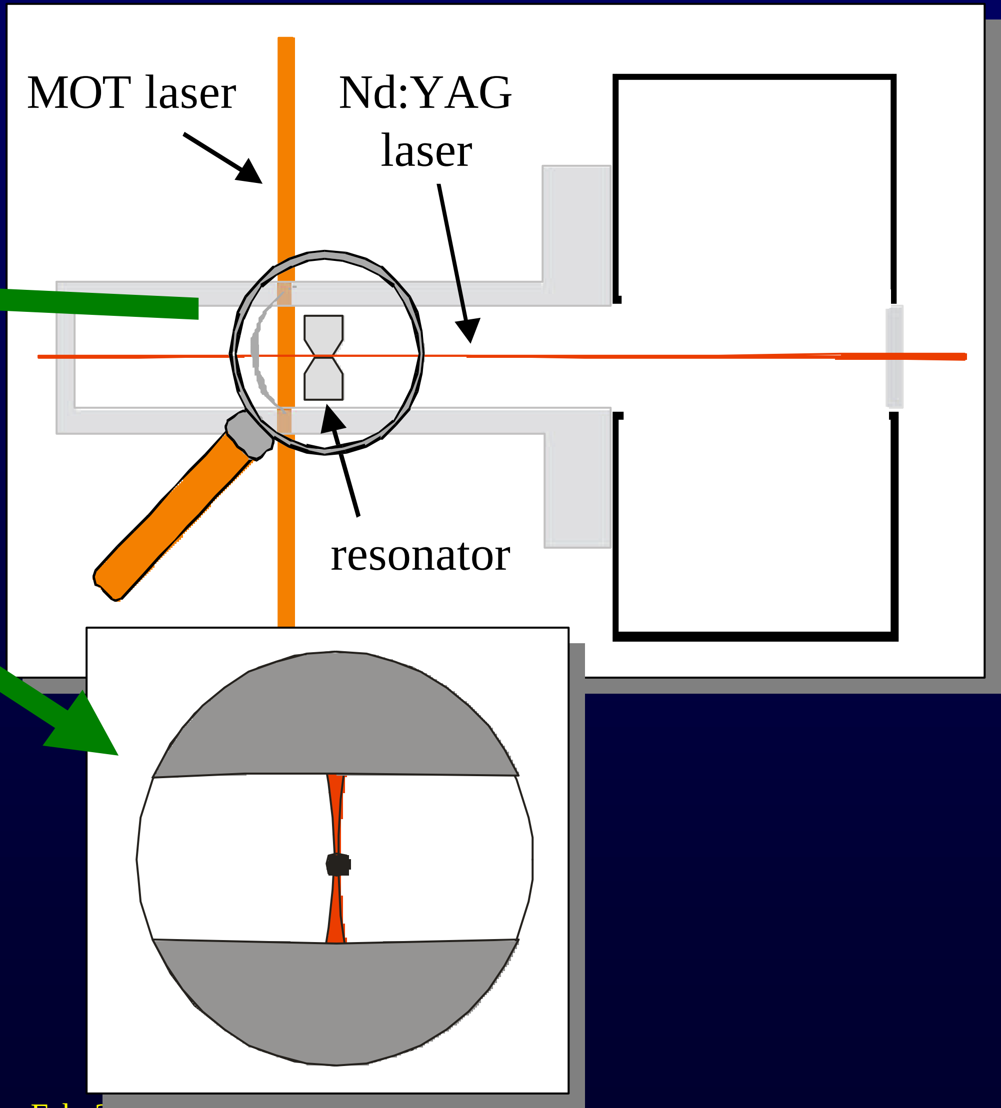
Next technical implementation:
Raman cooling to dipole trap ground state

4. Towards Entanglement

top view:

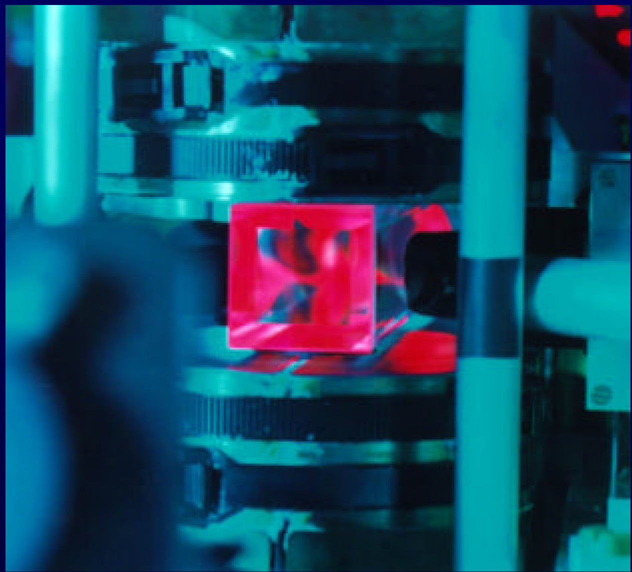


side view:



Conclusion

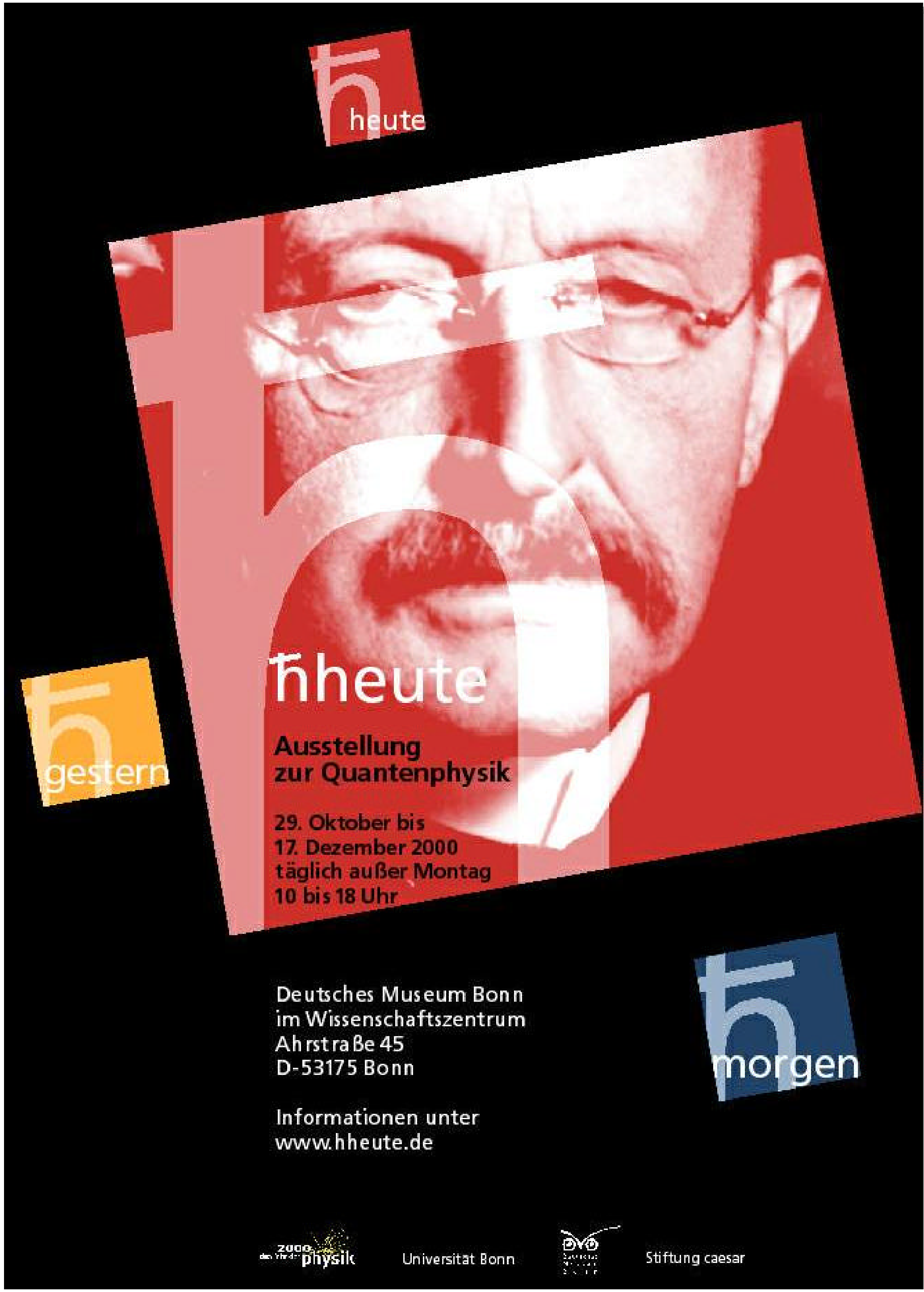
We can or will control neutral atoms:



Exact number U
Quantum state (internal) U
Position (global) U

Trapping oscillator state
Number of photons in cavity
.....

Atoms are excellent quantum memories ...
Photons make good transmitters, switches ...



Merci beaucoup pour votre attention !